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Addressing the different aspects of urban land use and urban flood risk together, and identifying ways to manage them successfully

A városi földhasználat és a városi árvízkockázat különböző szempontjainak együttes kezelése, és az azokkal történő sikeres gazdálkodás lehetőségeinek meghatározása

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Absztrakt:

A földhasználat és az árvízkockázat összefüggéseinek vizsgálata elengedhetetlen a fenntartható városfejlesztés és a hatékony árvízkezelés szempontjából. Az urbanizáció és a klímaváltozás együttes hatása jelentős mértékben növeli a városi árvízkockázatot, mivel a városok sokszor koordinálatlan terjeszkedése a természetes vízgyűjtők és zöldterületek csökkenésével jár, ami csökkenti a talaj vízbefogadó képességét és fokozza a felszíni vízlefolyást. A városok tervezése során figyelembe kell venni a földhasználat azon változásait, amelyek közvetlen hatással vannak a vízgyűjtők hidrológiai viszonyaira. A városi árvízkockázat kezelésének egyik kulcseleme a megfelelő földhasználat tervezés, amely megakadályozza a túlzott arányú beépítést, főleg a magas árvízkockázatú területeken. A kutatások szerint a jövőbeli árvízkockázatok csökkentése érdekében koordinált módon kell megvalósítani az infrastrukturális beruházásokat. A fenntartható árvízkezelés érdekében holisztikus megközelítések alkalmazására lesz szükség, amelyek magukban foglalják a strukturális és nem strukturális intézkedéseket is. Az ilyen intézkedések közé tartozik a közösségi részvétel, a zöld infrastruktúra fejlesztése, valamint a természetes vízgyűjtők védelme és helyreállítása.

Kulcsszavak: földhasználat, árvízkockázat, infrastruktúra, strukturális és nem strukturális intézkedések

Abstract:

Examining the links between land use and flood risk is essential for sustainable urban development and effective flood management. The combined effects of urbanisation and climate change are significantly increasing urban flood risk, as the often-uncoordinated expansion of cities is leading to a loss of natural catchments and green spaces, reducing the soil's capacity to absorb water and increasing surface runoff. Urban planning must take into account land use changes that have a direct impact on the hydrological conditions of watersheds.

A key element in managing urban flood risk is appropriate land use planning to prevent overdevelopment, especially in high flood-risk areas. Research shows that infrastructure investments should be implemented in a coordinated way to reduce future flood risks. Sustainable flood management will require holistic approaches, including structural and non-structural measures. Such measures include community involvement, green infrastructure development and protecting and restoring natural river basins.

Keywords: land use, flood risk, infrastructure, structural and non-structural measures

1. INTRODUCTION

In cities where urbanisation's rapid and impervious surfaces are prevalent, land use patterns worsen stormwater runoff and flood risks due to insufficient infrastructure and planning measures in place [1]. The interaction of land use and flood vulnerability highlights the need for a holistic urban planning approach that combines flood risk management strategies with sustainable land use techniques [2]. Researchers stress the significance of community engagement in flood risk management to improve the impact of interventions by incorporating knowledge and participation effectively. Engaging the public and providing information regarding flood risks are essential for establishing sound practices, in flood risk management in a sustainable manner. Enhancing communication can increase the awareness of planners, decision-makers, and developers. This helps them integrate flood risk factors into planning and development activities [3]. Engaging the community in decision-making helps them feel a sense of responsibility and customises flood risk plans to fit their unique requirements and susceptibilities [4]. However, sustainable urban drainage systems (SuDS) can provide a solution to manage stormwater and reduce the impact of flooding in cities and play a crucial role in reducing surface runoff and improving water quality by filtering pollutants before they reach water bodies [5]. Research has shown that conscious urban planning is needed to manage flood risks in cities that can increase flood resilience [6] [7]. While absorption methods may not work during heavy rainfall, a focused design strategy is essential for improving rainwater retention and reducing pressure on drainage systems. Additionally, it is crucial to protect wetlands and floodplains to preserve harmony and natural flood defence mechanisms [8]. Research studies emphasise the connection between urbanisation and flood vulnerability and stress the importance of land use planning to address shifting water-related conditions. This is why ~~city~~ urban planners must evaluate the effects of land use alterations [9]. In managing flood risks in cities and towns, there is a growing interest in blending old-school water expertise with planning methods as a viable strategy. The aim is to strengthen the ability of urban areas to cope with floods. Besides combining know-how with contemporary scientific approaches, urban planners can craft efficient flood management plans [10]. Furthermore, using tools like Geographic Information Systems (GIS) helps experts and city planners study the distributions of land usage and flooding, making it easier to pinpoint high-risk zones and create specific strategies. The capability to visualise and simulate flood risk situations leads to strong decision-making [11]. In sum, the discussion about managing land use and flood risk effectively entails a comprehensive strategy that enables planners to craft holistic plans that reduce flood vulnerabilities, encourage sustainable growth in cities, and prepare cities for the challenges of flood risks in an ever-changing landscape. This article aims to explore the connections between land usage and the vulnerability to floods and how they affect crucial water infrastructure.

2. LINKING URBAN LAND USE AND FLOOD RISK

In urban environments, various land use types can be identified, including residential, commercial, industrial, and recreational areas (residential – where people live; commercial – retail and service establishments providing goods and services; industrial – manufacturing and warehousing facilities; recreational – parks and green spaces crucial for community well-being). Each land use category significantly impacts the character and functionality of urban areas.

Studying how urban land use relates to flood risk is crucial amidst growing urbanisation and climate shifts affecting cities today. Urban development impacts water flow patterns and can increase flood risk in highly populated regions [12]. Additionally, urbanisation frequently results in declining natural flood control systems vital for infiltration of surplus water during heavy rainfall. The disappearance of these raises the risk of flooding and reduces the valuable services they offer to the environment (e.g., biodiversity) [13]. The deteriorating situation is worsened by the reality that numerous cities are located in areas prone to flooding, as demonstrated in the research conducted by Kim and Newman, which examines the relationship between urban expansion strategies and vulnerability to floods in both Amsterdam and Houston [14]. Managing flood risk is essential to develop urban areas that are effectively resilient to challenges. Efficient land use planning plays a role in reducing flood risks by controlling development in areas prone to flooding and encouraging the implementation of eco-friendly infrastructure. To illustrate this point further, Trogvcevic and colleagues suggest integrating spaces as water storage facilities in urban layouts. This method effectively absorbs excess rainfall and significantly reduces surface runoff [13]. Oliveira and colleagues also emphasise the importance of having a flood risk evaluation tool that coordinates land use planning with flood control strategies to improve urban resilience [15]. Modern spatial information tools are crucial for effectively linking urban land use with flood risk management.

These advanced tools enable visualisation and in-depth analysis of geographic data, which is essential for planners and decision-makers. By using these tools, planners can identify specific hazard zones prone to flooding and assess the potential impacts of different land use scenarios. For example, Ya Mei et al. used a GIS-based method to develop a map that classifies flood hazard areas based on their vulnerability to flooding [16]. Data analysis is essential for making informed decisions in urban planning and effective flood risk management.

The social and economic implications of the use of urban areas, which also greatly burden already inadequate infrastructure, should not be underestimated [17]. Research by Hounkpè et al. highlights the impact of social changes on flooding patterns and stresses the importance of holistic planning that considers environmental and social aspects [18]. Climate change is now widely acknowledged as a factor in worsening flood risks alongside socio-economic factors. As climate change leads to more frequent rainfall events in urban areas, the need to adjust land use strategies to mitigate these effects is becoming more apparent. Research shows that planning land use that considers climate forecasts and flood risk evaluations is crucial for improving the resilience of cities. There is a pressing necessity for decision-makers to formulate flood-resistant spatial strategies that consider the escalating hazards linked with climate change and urban development [19]. Integrating flood risk management into urban land use planning poses complex challenges requiring careful consideration and collaboration among stakeholders (local governments, inhabitants, urban planners, emergency services, policymakers, researchers) to develop successful strategies. For example, research emphasises the significance of considering economic and institutional factors in assessing flood resilience. It underscores the importance of various dimensions for efficient flood management [20]. Effective management of the problem requires the cooperation of all the groups involved, such as government agencies, city planners, and local communities, to ensure that flood protection plans are comprehensive and involve everyone in the process.

2.1 Land use types and their characteristics

Knowing the different types of land use and their distinct features is essential for planning and flood risk management. Categorising land use patterns helps assess their effect on water runoff, infiltration rates and vulnerability to flooding events.

Various studies show how zoning maps of urban areas can be used to identify the impacts and hydrological consequences of changing land use types on flood risk [21][22][23]. For example, the use of multi-faceted decision-making approaches can help identify potential flood risk zones by assessing different factors such as land cover, drainage capacity and socio-economic vulnerability. Other studies have shown that changes in land use patterns can result in more runoff and less water retention, altering flood patterns, particularly in regions subject to rapid urban growth [24]. In urban areas susceptible to flooding, it is essential to maintain undeveloped spaces to support ecological balance and improve flood resilience. Shen's research highlights how mixing land uses like recreational areas in city planning can maximise water-related advantages [25]. The characteristics of land use categories are also influenced by social and economic factors, which significantly impact the rate and nature of urban growth and development. Twum and Abubakari point out that these areas are highly vulnerable to flooding due to inadequate infrastructure and lack of urban planning [26]. Utilising land unlawfully for unsanctioned purposes creates challenges in flood management, since such locations frequently lack the essential drainage infrastructure to handle excessive rainwater efficiently.

Integrating land use planning with flood risk management is essential for creating urban areas that can withstand challenges over time. Neuvel and Knaap's research on spatial planning emphasises the importance of considering different spatial aspects and values, such as flood risk, to build resilient urban landscapes [27]. This overall strategic approach ensures that land use planning decisions are made considering the consequences of flooding. It encourages the development of infrastructure capable of withstanding severe weather conditions.

In addition to existing strategies, technological advances help urban planners visualise and assess the relationships between land use categories and flood risk levels. They represent a significant advance in categorising land use patterns, tracking changes over time, and assessing flood risk [28]. These data are essential for guiding decisions on the best land use and planning strategies for flood management.

2.2 Flood risk factors in the urban environment

Urban areas subject to heavy rainfall and river flooding face an elevated risk of inundation. Urban development, sprawl, and the importance of green spaces are crucial factors in influencing flood risk in urban environments. Urban planners must recognise the need for adequate flood risk reduction plans that minimise the consequences of urban flooding. In a changing climate, it is essential to adopt a strategy that combines effective flood risk management with sustainable urban planning to strengthen the resilience of cities.

Because of the rapid expansion, the types of urban surfaces are frequently changed. This disrupts the natural hydrologic cycle, resulting in a greater chance of flooding. Kim and Newman pointed out that urban growth in Houston has led to an increase in surface runoff, contributing to the expansion of flood-prone areas while increasing flood risk [29]. Inadequate drainage systems exacerbate these problems in areas that have expanded rapidly without sufficient infrastructure to cope with the increased drainage caused by rapid development trends.

Lack of adequate drainage can cause these systems to become overloaded during heavy rainfall events and lead to local flooding. In their research, Idris and Dharmasiri stress the importance of linking flood risk management and urban planning to address drainage problems [30] effectively. The impact of urbanisation on flood risk is exacerbated by the expected increase in the frequency and intensity of extreme weather events due to climate change, as pointed out by Kaspersen et al., who highlight that climate change and growth together increase the risk of pluvial flooding [31]. With further urban sprawl and an increase in impervious surfaces, changing rainfall patterns are expected to cause frequent and intense flood events in the future. Studies have shown that increasing green spaces in cities can significantly reduce the risk of flooding events.

Moreover, green spaces provide ecosystem services that help reduce the impacts of urban flooding by absorbing water and reducing runoff while improving water quality by filtering pollutants in stormwater. Agustine's research also highlights the benefits of these green spaces for stormwater retention [32]. Hyo-Min and colleagues have discovered that incorporating green spaces can potentially reduce flood risk by more than 50%, which varies depending on the size and location of these spaces [33]. This finding highlights the importance of consciously incorporating infrastructure into urban planning as a preventative measure to address flooding problems.

In addition, urban green spaces play a role in increasing the resilience of cities, as they have several benefits in managing floods. They help to clean the air and promote biodiversity and the physical health of city dwellers [34]. Despite these advantages, urban planning often favours developed, infrastructural areas. Silva and Costa stress the importance of integrating flood protection strategies into urban planning, promoting a holistic approach that respects man-made structures and the natural environment [35].

3. URBAN FLOOD RISKS AND WATER UTILITY INFRASTRUCTURE

Managing flood risk poses severe obstacles to vital water supply systems, significantly affecting their operation and reliability. The relationship between flood risk and water infrastructure is complex and requires a thorough understanding of the interrelationships. In this article, I examine the impacts of urban flood risk on water utility infrastructures to highlight the need for adequate flood risk mitigation tactics.

Urban flooding affects water supply systems by causing disruptions that lead to pollution and interruption of services. Drinking water sources can be contaminated with harmful pollutants and pathogens. (It should be be noted that flooding can significantly degrade groundwater quality by raising the water table and increasing groundwater pressure, which promotes the infiltration of pollutants into aquifers. This issue is particularly severe in alluvial and karst aquifers, where the interaction between surface water and groundwater is complex, leading to substantial contamination. Moreover, flooding poses a substantial threat to piped drinking water distribution systems by causing physical damage to the infrastructure, such as pipe ruptures and joint failures. These impairments can exacerbate the risks of contamination. During flooding events, various contaminants from the surrounding environment, including heavy metals and organic compounds, may infiltrate the water supply, particularly when the pipes are corroded. This also has significant implications for the security of supply.) This risk is particularly evident in environments where floods can overload treatment plants [36]. Deteriorating water quality not only threatens human health but also generates additional costs for water companies.

Increasing hydrological threats make urban water management and infrastructure development more complex [37]. During floods, when water supply systems fail, such failures can cause problems for public health and safety, as clean water is essential for proper hygiene and sanitation.

Urban drainage systems often struggle to handle the runoff caused by urban growth and heavy rainstorms, as noted by Davis and Naumann in their study on how traditional drainage systems are unable to keep up with urban expansion and changing weather patterns. This results in more runoff and a greater likelihood of urban flooding [38]. When drainage systems become overloaded with water flow exceeding capacity limits, flooding worsens significantly in cities and low-lying areas and affects water utility infrastructure.

During flood events, drainage systems fail to function correctly, causing significant financial losses and disruption to infrastructure services [39]. By integrating sustainable drainage systems (SuDS) into urban planning, we can improve the drainage capacity and reduce the likelihood of flood events, ultimately protecting essential water utility infrastructure.

The interconnectedness of infrastructure systems during floods leads to a crisis that is difficult to manage [40]. This highlights the need to assess and control the risks associated with managing such situations, as emphasised by Koks et al., stressing the importance of increasing the resilience of vulnerable infrastructure to minimise flood-related consequences [41]. Achieving resilience involves taking steps and investing in upgrading infrastructure to prepare for future potential flood risks. In such cases, the economic impacts of flood risk on water utility infrastructure are significant in nature and scale. Therefore, conscious and rational infrastructure investments can have a significant impact on future flood vulnerability [42]. Hence, it is crucial to have strategies to manage flood risks to safeguard infrastructure and encourage steady economic progress in cities.

Implementing Sustainable Urban Drainage Systems (SuDS) as effective stormwater management practices is essential to preserve water quality and prevent pollution in flood situations [43]. The importance of wastewater treatment systems cannot be overstated. The research of Hummel et al. emphasises the vulnerability of these facilities to flooding events, as they play a role in treating wastewater and protecting the environment from the risk of contamination [44]. Practical handling approaches must be in place to safeguard wastewater treatment facilities from floods and guarantee their operation.

Under normal circumstances, urban drainage systems are adequately managed to control water run-off. In times of heavy rainfall, these systems can make matters worse, as all the water is discharged into receptors without treatment. Incorporating infrastructure such as permeable pavements and detention basins can improve the efficiency of stormwater drainage systems and help reduce flood impacts [45][46]. The link between infrastructure systems means that problems in one place can affect other areas. Therefore, a comprehensive strategy for urban water management is key to addressing flooding problems [47]. These combined effects can lead to the collapse of the entire infrastructure system, underlining its vulnerability to extreme situations [48]. The impact of flood damage on infrastructure systems is significant. The cascade of failures can disrupt services over time and cause permanent damage to the entire infrastructure system [49][50]. The combined effect of these setbacks can hinder the revitalisation and expansion of communities, especially in regions highly dependent on water utility services [51]. Moreover, service deficits in infrastructure systems can severely affect populations, exacerbate existing inequalities (economic, social, and societal) and cause difficulties in post-disaster recovery efforts [52][53]. Sustainable stormwater drainage systems are designed to control run-off and prevent flooding but can become bottlenecks in extreme weather situations. Increased impervious surfaces due to unwarranted urban development exacerbate the problem by causing more runoff, which drainage systems may not be equipped to handle [54][55]. In short, the damage caused by floods often results in costly repairs and longer service outages that strain local budgets and divert resources from essential services [56][57], further exacerbating existing societal inequalities.

4. MANAGING FLOOD RISK AND LAND USE STRATEGIES

Effectively managing flood risk and land use together is essential to creating an urban environment that can withstand the consequences of flooding and support sustainable growth objectives. Linking flood risk management and planning is key to reducing vulnerability and increasing community resilience. This section brings together the methods and structures that can be used to achieve this integration:

1. Incorporating Flood Risk Assessment into Land Use Planning
2. Implementing Integrated Water Management
3. Utilizing Green Infrastructure
4. Engaging Communities in Flood Risk Management
5. Adopting Risk-Based Land Use Policies
6. Continuous Monitoring and Adaptation

To reduce flood risks and manage land use effectively, it's essential to integrate flood risk evaluations into the planning phase of development projects. Accurate land coverage and zoning data are vital for informed decision-making in urban and rural areas [58]. This strategic thinking aids in averting the construction of sensitive infrastructure in high-risk zones and ultimately mitigating the potential damage caused by floods [59]. Managing water resources and addressing flood risks while considering land use requires an Integrated Water Management (IWM) approach. This framework emphasises collaboration among stakeholders, including government entities, city planners, and residents, to develop strategies considering the interactions between water resources, land use, and flood vulnerability [60][61]. Green infrastructure is essential for managing flood risk and improving land use [62]. Urban planners can create multifunctional areas that serve flood protection and community needs by promoting such initiatives.

Community engagement also plays a role in ensuring the effective and sustainable implementation of successful flood risk management strategies [63], enhancing the effectiveness of flood management plans and building local confidence. To manage flood risk, it is essential to implement land use policies that protect vulnerable populations and critical infrastructure by regulating development in flood-prone areas. Conscious land use planning can limit high-density development while promoting safer development aimed at reducing the impacts of flooding and reconciling urban sprawl with risk-reduction goals [64]. Effective flood risk management requires strategic coordination, using tools such as flood protection maps, zoning of flood risk areas, and this monitoring is essential and necessary to ensure that policies remain relevant [65]. Tools such as Geographic Information Systems (GIS) and hydrological models help produce detailed flood risk maps highlighting areas at risk, providing a basis for spatial planning regulations.

Seher and Löschner stress that the water retention capacity of floodplains must be maintained through strategic land use planning. By complying with zoning laws, local governments can prevent inappropriate construction in flood-prone areas, thereby reducing the overall impact of floods [66]. Flood risk mapping is crucial for raising awareness and facilitating informed infrastructure decisions. This proactive strategy enhances resilience and encourages community involvement in managing flood risks. Establishing land use regulations, such as zoning laws and flood-resistant building standards, is essential for reducing vulnerability in flood-prone areas. Cillier emphasises that integrating flood risk assessments into urban planning is vital for preventing disaster damage and promoting safety and environmental awareness [67].

Moreover, land-use regulations can encourage the adoption of eco-infrastructural features like porous surfaces and green rooftops, which aid in controlling stormwater and lessen the risk of flooding. Girbaciu et al. emphasise that taking an approach to managing land permits strategic coordination of spatial relationships among diverse land uses and promote cooperation across various sectors to tackle flood risks efficiently [68]. Working in this manner ensures that land use choices match flood risk management goals, effectively improving urban resilience in the long run.

Managing flood risk and land use effectively requires a management strategy that evolves to keep pace with the impacts of climate change and urban development trends [69]. This proactive strategy empowers local governments to address challenges. Increasingly, strategies to manage flood risk include nature-based solutions (NbS). Green infrastructure effectively manages stormwater and reduces flood risk by absorbing rainfall on-site. According to Fryirs et al., natural flood management measures increase resilience and promote faster recovery [70].

Incorporating green infrastructure into urban planning can effectively reduce run-off and improve water quality while addressing flooding challenges. Developing resilient infrastructure is essential to mitigate flood risk. Flood-resilient modular water supply systems can withstand flooding and provide reliable service in adverse weather conditions. They also help alleviate drainage system pressure during flooding, while supporting environmental objectives such as biodiversity conservation and climate change adaptation.

5. MANAGING CRITICAL WATER UTILITY INFRASTRUCTURE EFFECTIVELY

Managing water infrastructure requires a strategy prioritising affordability, sustainability, and risk assessment. Cooperation between stakeholders is essential to stimulate innovation and create resilient systems that can withstand floods while maintaining essential services.

5.1 Cost-Effectiveness and Sustainability

Introducing environmentally friendly approaches to water utility management can lead to long-term savings. Flood resilient infrastructure systems can reduce the impact of flooding, repair, and restoration costs. Efficiency and environmental sustainability are essential to maintain water utility structures. Nature-based solutions offer a cost-effective alternative to conventional flood protection, support biodiversity, and improve the well-being of residents. By prioritising such infrastructure investments, local decision-makers can ensure water efficiency in the face of climate change and increased flood risk.

5.2 Risk Analysis and Risk Management for Water Utility Operators

Water utility operators must conduct risk analysis and management to address flooding challenges effectively. In Hungary, for example, the management of stormwater is a legally mandated obligation of local governments. However, numerous municipalities face challenges due to insufficient expertise and financial resources for the effective construction, operation, and maintenance of the requisite infrastructure. Currently, stormwater drainage management does not fall under the purview of water utilities. Despite this, the condition and efficiency of stormwater drainage systems substantially impact the quantity and quality of wastewater and the overall operational integrity of water utilities. Consequently, it is imperative to support local authorities in fulfilling this responsibility competently. To facilitate this process, it is essential to establish appropriate legislative frameworks, clearly define the operational parameters for service providers, provide comprehensive training and education for water utility operators, procure the necessary equipment, and enhance the capacity of the human resources involved in stormwater management. Chudziński et al. highlighted the need for utilities to prepare for risks during crises. Utilities can identify weaknesses in their infrastructure by implementing risk assessment frameworks and developing mitigation plans [71]. Additionally, Luis and colleagues emphasised that combining scenario analysis with predictive modelling enhances flood preparedness [72]. Effective risk management is crucial for utility operations, enabling better resource allocation to improve infrastructure and respond to flooding effectively.

5.3 Multi-Stakeholder Cooperation

Collaborating with stakeholders is vital for managing flood risks and ensuring the sustainable operation of water utilities. Working with the government, utility companies, and residents fosters a shared understanding of flood risks, leading to joint solutions. Seher and Löschner emphasise the need to consider downstream effects in flood risk management, especially in land use planning [73]. Involving various groups in the decision-making process helps create strategies that address the community's diverse needs. By encouraging teamwork, communities can build well-functioning water utility systems to manage flooding effectively. Successful flood risk management relies on adequate financing and innovation, with research and development driving technological advancements.

6. CONCLUSION

Urban land use change has a significant impact on flood risk. Floods pose a substantial risk to water utility infrastructures, leading to pollution, disruption, and public health crises. Effectively managing these infrastructures requires a multi-faceted approach, which includes cost-effectiveness, sustainability and the integration of nature-based solutions. The research highlights the complex relationship between urban land use and flood risk. It defines the importance of integrating flood risk management strategies with sustainable land use practices to increase urban resilience. It argues for adaptive land use planning that takes climate change impacts into account. Integration is essential for addressing the interconnectedness of land use, flood risk, and water resources, promoting collaboration among stakeholders to develop comprehensive strategies. Implementing sustainable urban drainage systems can enhance drainage capacity and mitigate flooding impacts, thereby protecting critical water utility infrastructure. In the future, decision-makers should prioritise the integration of flood risk management into urban planning to enhance resilience against flooding. Flood protection mapping and spatial planning will guide future land use decisions, which helps in preventing inappropriate development in high-risk areas. Developing modular, flood-resistant water utility systems is crucial for maintaining functionality during extreme weather events, ensuring essential services remain operational. Continuous monitoring and adaptive management of flood risks and land use patterns are necessary to keep strategies relevant and effective.

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