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IMPACT OF FLOODS ON CRITICAL INFRASTRUCTURE SYSTEMS

Abstract

Recent decades have seen significant changes in the Earth's climate. This has already been proven by many domestic and international studies and is treated as a clear fact. As a result of these changes, stronger and more frequent rainfall is occurring in many parts of the world, which are becoming more frequent in terms of probability and increasingly significant in terms of their impact, covering the entire catchment area. Urban areas are no exception, where the negative effects are exacerbated, and causing serious problems in the operation of urban infrastructures. Exposure to floods can be expressed in the form of significant and often difficult to repair damage, service outages, increasing vulnerability and increasing risk. Prudent security policy measures to ensure the proper functioning of urban (water) infrastructure need to be prepared for these emergencies while maintaining the resilience of the system. The aim of the present research is to reveal the impact of floods in water infrastructure systems.

Keywords: critical water infrastructure, urban flood, resiliency, risk management, vulnerability, security of supply, operation

AZ ÁRADÁSOK HATÁSA A KRITIKUS INFRASTRUKTÚRA RENDSZEREKRE

Absztrakt

Az elmúlt évtizedekben jelentős mértékű változás figyelhető meg a Föld éghajlatában. Ezt számos hazai és nemzetközi kutatás már bizonyította és egyértelmű tényként kezeli. Ezeknek a változásoknak köszönhetően erősebb és gyakoribb esőzések tapasztalhatók a világ számos részén, amik valószínűségét illetően egyre gyakoribb, hatását tekintve pedig egyre jelentősebb áradásokat indukálnak a vízgyűjtők teljes területére kiterjedve. Nem képeznek kivételt ez alól a városi területek sem, ahol a negatív hatások még inkább felerősödnek súlyos gondokat okozva ezzel a városi infrastruktúrák üzemeltetésében. Az áradásoknak való kitettség jelentős és sokszor nehezen helyreállítható károk, szolgáltatás kimaradás, növekvő sérülékenység és növekvő kockázat formájában fejezhető ki. A városi (víziközmű) infrastruktúrák megfelelő működését garantáló körültekintő biztonságpolitikai intézkedéseknek pedig fel kell készülni ezekre a veszélyhelyzetekre. Jelen kutatás célja az áradások hatásának vizsgálata a vízi infrastruktúra rendszerekben.

Kulcsszavak: kritikus víziközmű infrastruktúra, városi árvíz, reziliencia, kockázatkezelés, sérülékenység, ellátásbiztonság, üzemeltetés

1. INTRODUCTION

Both water surplus and water scarcity are a problem for our future. We are able to deal with multiple problems at once, but we tend to delay them until we find the right solution. Adequate urban water management is the right tool to conserve water resources and the best possible way to exploit a natural resource that we simply cannot afford to throw into the sewer.

Cities are growing faster and faster and this growth is not always planned and controlled enough. This is probably one of the main challenges cities are now facing: rationalizing land use and sustainable development. In this way, the sustainable management of urban flood waters offers a viable alternative to trends in aggravating problems. Restoring the hydrological cycle of urban water management (in space and time) could be the solution to control the problems caused by urban flooding. Hydrology must be implemented that affects the movement of water, the location of roads, buildings and infrastructures. These problems need to be addressed together with controlled monitoring of urban land use and expected urban development.

The concentrated population; the accumulation of huge impenetrable surfaces, increased infrastructure improvements, solid and liquid waste without treatment; clogged water and sewer systems, intensive economic activity; regional changes around cities are most characteristic of today's cities. Today's city is unable to solve the problems that arise from these. There are periodic, bridging solutions but the most important tasks lie ahead: regulating the amount of urban floods, managing their quality by providing infrastructures of the right quality and capacity ("*in order to minimize the risk of floods and water damage"* [1]).

The peculiarities of water supply are determined by the characteristics of the urban environment on both the consumer and service provider side [2]. Information on flood risks is essential to estimate the vulnerability of past, present and future floods to critical infrastructures [3]. A precondition for the preparation of action plans is a long-term survey, a digital utility register, and an efficient exchange of information between planners, operators and institutions. In order to solve the problems of municipal stormwater management, it is also necessary to create a database containing the results of relevant scientific research. Knowing this, we can develop action plans to protect critical infrastructures that can address the problem as effectively as possible. In order to achieve sustainable urban water management (specifically striving for close-to-nature solutions), the basic goal must be the actual strategic management of water resources (water retention, water storage, water utilization) so that the conditions and efficiency of municipal water management do not deteriorate. Water recycling is increasingly being included in policy frameworks and guidelines in order to help mitigate the unsustainable demands for potable water supplies in urban areas. Increased scientific knowledge, concern for the environment and the effects of global climate change has recently altered public opinion in cautious favour of water recycling initiatives. Technological advancements also now make water recycling more economically viable. Urban planning must recognise regional limits to development in order to maintain natural habitats and biodiversity, which is so important to our continued existence.

Broad landscape conservation is necessary to maintain ecosystem function and biodiversity, but there is also great opportunity for the sensitive redevelopment of many previously developed areas. An empathetic approach in the maintenance and encouragement of natural ecosystems creates a more sustainable relationship with the natural environment.

The aims of the sustainable urban flood management system are to store and purify urban run-offs. The central concept is that the water management can be feasible on the developed areas. The characteristics of the existing sewer systems strive for to minimize the effects due to the development and contribute to the evolution of the optimal hydrological circumstances. The effectiveness of a critical water utility infrastructure system lies in its ability to meet site-specific requirements and end-use preferences.

My overall research goal is to jointly manage different aspects of urban land use and urban flood risk and to identify opportunities for successful management of them in terms of critical water utility infrastructures. Indeed, it has been shown that a change in the nature of urban land use that increases stormwater runoff leads to an increase in urban flood disasters. These changes have a dominant impact on water infrastructure systems and also on associated ecosystem services. With the good land use practices, we are able to promote the implementation and effectiveness of the flood risk reduction strategies preferred also by the Water Framework Directive and we can help eliminate the effects of weather-related water extremes.

2. THE CONCEPT OF CRITICAL INFRASTRUCTURE

Several concepts are known in the scientific literature, to define the infrastructure as a concept, and there are innumerable conceptions of its approach. The nature of the term is mainly technical. According to the broadest interpretation, the concept of infrastructure includes everything that provides the conditions for human life, except for arable land, while narrower interpretations included individual communal services in this category [4].

Aim of the critical infrastructure protection is at first the preparation for disruption or destruction of the critical infrastructure on the other hand proportionate and necessary response and recovery [5] (Figure 1.)

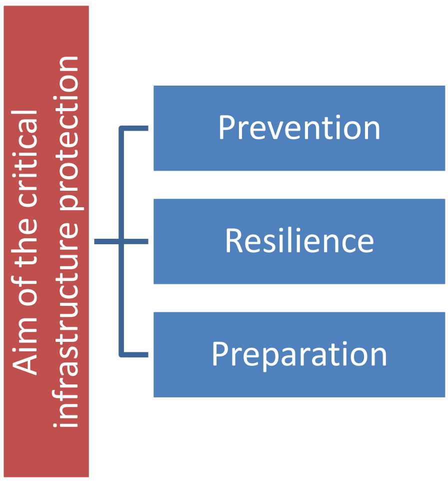

Figure 1.: Aim of the critical infrastructure protection (source: Bonnyai T. [6], edited: Mrekva L. 18//11/2020)

Examining the international definitions of the concept of critical infrastructure, I found the following similarities:

- Critical infrastructure is a set of systems, networks and devices whose continued operation is essential to ensure the security of a given nation, economy and population, and the provision of public health [7].
- Critical infrastructure "*consists of devices, systems, and networks, whether physical or virtual, that are so vital that the obstruction, incapacity, or destruction of any of them would adversely affect state security, the security of the national economy, national public health, or any combination thereof* "(U.S. Department of Homeland Security - according to DHS) [8].
- Critical infrastructure or critical national infrastructure is a term "*used by governments to refer to physical, non-physical and computer resources or tools and systems that are essential for the maintenance of government operations and the minimal functioning of society and the economy*" [9].
- Critical infrastructure refers to processes, systems, facilities, technologies, networks, devices, and services that are essential to health security, public safety, or economic well-being, and to the efficient operation of government. Critical infrastructure may be self-contained, interconnected and interdependent in terms of territorial competence, whether located within or across national borders. Failure of critical infrastructure can cause catastrophic losses that can have adverse economic consequences and have a significant impact on public confidence [10].
- Critical infrastructure that, if lost or compromised, could result in:
    - has a significant detrimental effect on the availability and integrity of basic services, including those services whose breach or loss of security could lead to significant death or illness, taking into account economic or social impacts; and or
    - "*has a significant impact on national security, national defence or the functioning of the state*" [11].
- Critical infrastructure is a device or system that is essential for maintaining vital social functions. Damage, destruction or disruption of critical infrastructure in the event of

natural disasters, terrorism, crime or malicious behaviour can have a significant negative impact on security and the well-being of citizens [12].

- Physical assets, supply chains, information technology, and communication networks whose destruction, degradation, or unavailability for an extended period of time significantly affect a nation's social or economic well-being, or affect a nation's defences capability, nation's security [13].

After the international outlook, I examined the European Union's regulations, and then the Hungarian ones as well. The first major milestone in the EU legal framework for critical infrastructure protection is the *European Council's document adopted in December 2004, a proposal for a European Program for Critical Infrastructure Protection* (EPCIP). Subsequently, in November 2005, the European Commission issued the so-called *Green Paper on a European Program for Critical Infrastructure Protection, which set out the basic definitions, findings, processes and procedures* that could be considered as a basis for future legislation. This was followed by EU legislation on the identification and designation of European critical infrastructures and the assessment of the need to improve their protection (*COUNCIL DIRECTIVE 2008/114/EC of 8 December 2008*) [14]. According to this directive:

- "*critical infrastructure means an asset, system or part thereof located in Member States which is essential for the maintenance of vital societal functions, health, safety, security, economic or social well-being of people, and the disruption or destruction of which would have a significant impact in a Member State as a result of the failure to maintain those functions;*
- *'European critical infrastructure' or 'ECI' means critical infrastructure located in Member States the disruption or destruction of which would have a significant impact on at least two Member States. The significance of the impact shall be assessed in terms of cross-cutting criteria. This includes effects resulting from cross-sector dependencies on other types of infrastructure;*" [15].

In order to implement the EU regulations in Hungary, the sectoral and horizontal tasks to be performed have been defined, which include the operation of international and domestic cooperation forums of public administration bodies and critical infrastructure management organizations, and the identification and planning tasks of critical systems and facilities. Sectors affected by critical infrastructure protection regulation: energy, transport, communications and info-communicational infrastructure, water utilities and hydrological facilities, health, food production and supply, finance, industry, government and administration [16]. Similar to the international practice, the regulation concerning the protection of critical infrastructures in Hungary is aimed at responding to a threat covering all threats (natural and civilizational disasters) and a risk analysis approach [17].

The first step in the development of the critical infrastructure protection system in Hungary was the *Government Decision 2080/2008 (VI. 30.)* on the National Program for Critical Infrastructure Protection, which includes water utility services (drinking water services, sewage disposal and treatment) as critical infrastructures [18]. According to *Government Decree 234/2011 (XI. 10) on disaster protection and on the implementation of the law of CXXVIII of 2011 and amendments to certain related laws*, 1 § 25 in Hungary similar to international definitions clearly define the concept of critical infrastructure:

devices, systems or parts thereof which are essential for the performance of vital social tasks, health, safety, human economic and social well-being, and the disruption or destruction of which would have significant consequences due to the lack of continuous performance of these tasks.

Subsequently, the purpose of the *Act CLXVI of 2012 on the identification, designation and protection of critical systems and facilities* was to identify the critical system elements on the one hand and to provide protection after the designation [18], and pursuant to section 15 (3) of this Act extended the scope of protection to the water sector as a critical infrastructure element from 1 January 2014.

The term of public utility is a collective term intended to satisfy the needs of the residents of settlements for public services. Similar to the international interpretation “the concept and characteristics of utilities show significant parallels and identities in defining critical infrastructures at several points [19]”.

Once again, reviewing the definitions of critical infrastructure, the requirements for water utility infrastructures as public services can be summarized in the same figure (Figure 2.).

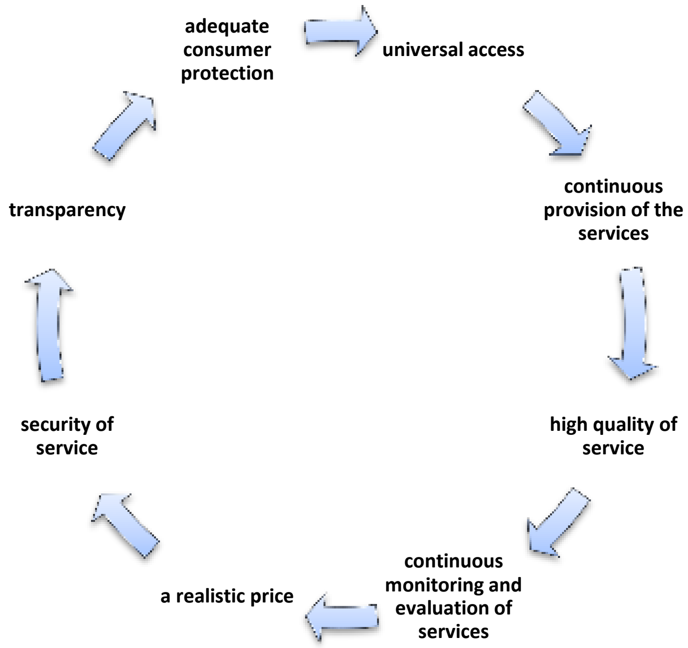

Figure 2.: Public service requirements (source: [20], edited: Mrekva L. 16/11/2020)

The presence or absence of infrastructure is a determining factor, a qualifier for the development of an area, anticipates its future development opportunities and designates a toolkit for spatial planning [21]. According to Hirschman (a representative of an American school) infrastructure includes all the basic services: all public services, from the maintenance of public order and legislation, through public health and public education to communications, transport, energy and water supply, and irrigation and sewerage systems [21A]. The focus should be on the consumer demand to be met by the public service.

Water utility infrastructure from the point of view of human existence is considered to be one of the most important critical infrastructures in the world [22].

Utilities face significant challenges and problems with declining utilization of built-in systems, whether it is the uninterrupted provision of clean water, wastewater treatment, or preparedness for floods or water scarcity, so much is certain that good water management in a big city requires good planning and foresight [23]. During the infrastructure design, the primary task of engineers is the examination of the exceedance probability, the return times associated with each flood event, and the frequency of occurrence. And because there is no flood above which should not occur another one the exceedance probability is also at the same time the taken risk [24]. Society perceives the effects of climate change primarily through extreme weather and climatic phenomena such as heat waves and droughts, heavy rains, associated floods and extremely strong windstorms [25]. The existence of water, precipitation and sewerage, and flood protection infrastructure is a basic necessity for the successful operation of any city. Through these systems, we can gain insight into the process by which cities relate to their natural environment. Future urban water systems embody the ideas and dependencies associated with the urban landscape of which we are a part. Meanwhile, cities' hydrological processes are also changing. Winters will be wetter and summers will be drier, which will have a significant impact on the operation of water supply and drainage systems ("*designed for relatively stable and constant monthly rainfall*") will increase flood risk while our current flood protection systems reach the end of their actual life [26]. Therefore, long-term and high-cost infrastructure projects need to be designed to be able to withstand the effects of climate change that are observed today and are expected in the future [27].

3. IMPACT OF FLOODS ON WATER UTILITY INFRASTRUCTURES

The accumulation of weather events often leads to natural disasters such as prolonged rains and floods. In addition to temperature, precipitation is the other most important weather element. Excess rainfall can cause recurring floods, inland waters, local flooding, other damage, and even disasters. The causes of the disaster situations where there is inadequacy of the rainwater drainage system; human irresponsibility; unauthorized construction and the maintenance of the watercourses [28]. Water treatment and water supply infrastructures are vulnerable to the effects of floods caused by climate change. This is because even a small increase in extreme events due to climate change can cause serious damage to infrastructure [29] hence we have to reduce the vulnerability of infrastructure caused by floods [30], which further complicates the work of planners and water professionals.

Extreme climate change in this direction will lead to an increase in the number of *"fluvial and pluvial floods"* in urban areas [26]. Floods in urban areas affect drinking water supply, sewage and stormwater drainage as a public utility service, precisely because they can induce significant disruptions and service outages if we do not adequately protect against them. Therefore, it is very important to understand this risk, to determine the factors influencing quality, to ensure a high degree of protection against potential hazards and disasters.

Flood damage is one of the most significant examples of disaster risk in the world and its impact on infrastructure is still one of the most costly economic factors [31]. Damage to infrastructure by floods, in particular damage to roads, rail networks and key transport hubs, clean water supply, sewage treatment, electricity supply, communication, disruption of health care, together lead to disruption of normal life and a significant impact in the long run can be for the national economy [32]. Due to urban floods, especially during floods, damage to critical urban infrastructure assets can have significant secondary consequences that can be as severe as the immediate consequences. For example, power outages can hamper health services for the entire urban community. This is why it is essential to understand these incremental effects and the relationships between the organizations and systems involved in providing services [33]. In their research, Chiara Arrighi et al. [34] also concluded that floods cause direct losses in water distribution systems due to system failures, such as equipment damage and pipeline contamination, as well as indirect effects, as this can lead to service disruptions and thus it can affect populations far from the event through the functional dependencies of the network.

Urban floods can be dangerous to people, destroy houses, including water and wastewater infrastructure, either due to the power of flooding or other adverse effects [35], and increase the risk of contamination of drinking water supplies during floods [36].

It affects "*homes, communities and businesses directly, and also disrupts vital services, resource flows and transport networks along with many cultural heritage assets"*. Floods can cause "*not only major economic losses, but also disruption and misery to those affected by them"*. In addition to climate, a "*number of factors influence flood risk, such as planning and land use"* (placing communities, property, roads and utilities below flood levels in vulnerable areas). "*Planning plays a critical role"* in ensuring that specific infrastructure developments take place in flood-free areas. "*Flood risk management can be seen as a hierarchical process"*. In general, prevention or avoidance ("*the use of flood hazard mapping and flood risk assessments to ensure that new developments are sited in areas of low flood risk wherever possible"*) is preferable to control or mitigation measures. However, prevention or avoidance is not always possible, so an adaptation strategy can be applied at any stage of the inundation a in the hierarchy of risk management. In this process "*protection and preparation means the use of flood management and flood protection measures, including flood defences, and the use of measures such as flood warning systems and emergency planning"* [37]. "*The risk environment for critical infrastructure has increased significantly in recent times"*, due to for example by *"increasing the frequency and severity of hydro-meteorological threats posed by climate change"*. Emergencies such as floods may have justified the prioritization of critical infrastructure [38].

Impacts on infrastructure "*can be divided into direct and indirect categories. Direct (tangible) damage includes physical damage to both the residential* and non-residential sectors, *as well as damage to infrastructure through direct contact with floods"*. People living in urban areas are served by a variety of infrastructures "*that provide the services of modern life* (*e.g. telecommunications, transport services, electricity, water and sanitation, healthcare,* etc.).

The effects of floods on infrastructure are particularly difficult to estimate". Damage to infrastructure elements is extremely "*varied primarily because of these elements because they are extremely specialized. In addition, infrastructures are highly interdependent; power outages can lead to disruptions to water and telecommunications networks. It is particularly difficult to identify these relationships and estimate the costs associated with them"*. There are very elusive effects that can include effects on health as well as damage to the environment.

"*Understanding of vulnerabilities in critical infrastructure networks is limited. Information is often missing"* e.g., the duration of the outage of the infrastructure service, the duration of the flooding of the assets, the time needed to repair and restore the services. "*It is important to emphasize that no impact assessment can cover the full range of impacts, and the analyst must choose what to include and exclude"* [39].

4. SUMMARY

Many industries are experiencing the health effects of environmental damage (air pollution, pollution of surface and groundwater) and the consequences of natural phenomena caused by global warming (centuries of floods). Among the extreme weather conditions, floods due to heavy rainfall are a major source of danger [40]. In cities, their geographical extent is a determining factor in the operation of critical infrastructures. From an operational point of view, their exposure to extreme flood events presents the greatest risk. Over the past few decades, interest in urban flood risk has been steadily increasing, as has the frequency of floods and the damage caused by urban floods.

The proper functioning of the water utility as an infrastructure sector is essential for sustainable economic growth and increased social well-being. The importance of protecting critical infrastructure from flooding is clear [41].

International examinations found that the Earth's surface temperature has risen, making it likely that such climate change has led to, among other things, intensifying storm activity and increased rainfall intensity, increasing flood risk and associated flood damage. Water management is a very important factor in regional development. In order to ensure the long-term development of the area, a balance must be maintained between water resources, water quality conditions and water supply capacity, as well as water needs, if necessary. At the same time, efforts should be made to mitigate and, where possible, avoid water damage. Improving the water management situation always arises as a matter of urgency in the event of an extreme situation. However, the demands made at such times are often exaggerated. A number of examples can be used to prove that such campaign-like developments were not based on real social and economic needs. However taking the effects of climate change into account when making investment and planning decisions, can increase our resilience to today's floods and avoid land use decisions that jeopardize major infrastructure developments. Therefore, the management of urban infrastructure must be managed in an integrated way with land use aimed at preserving natural functions. Due to the problems that have already arisen in the past and the further deterioration that is still taking place, there is an increasing urgency to change the responsible causes and the role of human interventions. These are all regulatory practices that are among the possible flood risk mitigation alternatives.

Information on the real risk of flooding should always be the basis for decision-making. Therefore, we need to know the realistic land use constraints and identify potential societal needs. We need to know what irreversible changes are and which are regenerable. There is a need for continuous analysis, monitoring and management of all human factors affecting the state of water resources.

Pant et al. in their research reveal that this information is important because of the ranking of flood protection measures; it helps water management professionals, city planners to narrow down the plans in the development of resilient flood management strategic plans [42].

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