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MŰSZAKI
KATONAI
KÖZLÖNY

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Application of Natural Water Retention Measures in Flood Management

Természetes vízmegtartó megoldások alkalmazása az árvízvédelemben

Due to climate change, increasingly extreme weather conditions and runoff parameters are leading to the enhancement of flood risk. The increasing probability of fast flowing, high intensity flash floods jeopardize both the residents of small municipalities and the fields of farmers, especially in the downstream areas of mountainous and hilly regions. In many cases the protection of settlements cannot be solved through conventional flood management approaches due to high investment costs and built-in floodplains. The main goal of this article is to analyse the potential of flood risk mitigation with applying natural water retention measures. These additional measures could have a positive effect on the quality and quantity of surface and groundwater. Research results facilitate an even more effective preparation in a way of applying nature based solutions to supplement traditional flood management.

Keywords: *flood management, flood risk, natural water retention, water pollution*

Az éghajlatváltozás következtében egyre szélsőségesebb időjárási körülmények és a lefolyási viszonyok hatására növekszik az árvízkockázat. A hegy- és dombvidékeken megnövekvő valószínűséggel kialakuló gyors lefolyású, nagy intenzitású villámárvizek veszélyeztetik a környékbeli kistelepülések lakóit, illetve a mezőgazdasági termelők földterületeit. Egyes területek védelme a nagy beruházási költségigények és a kistelepülést átszelő vízfolyás beépítettsége miatt sok esetben nem oldható meg a hagyományos árvízvédelmi módszerekkel. A közlemény célja, hogy megvizsgálja az árvízkockázat mérséklésének lehetőségét a természetes vízmegtartó megoldások alkalmazásával. A kiegészítő intézkedések pozitív hatással lehetnek a felszíni és a felszín alatti vizek minőségére és mennyiségére. A kutatás eredményeként a hagyományos árvízvédelem kiegészítése a természetes eredetű megoldásokkal hatékonyabb felkészültséget eredményezhet.

Kulcsszavak: *árvízvédelem, árvízkockázat, természetes vízmegtartás, vízszennyezés*

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Introduction

Due to climate change the probability of occurrence of extreme weather conditions is increasing. The intensification of precipitation events is crucial to society regarding the significant impact through flooding [1]. Research results show that heavy rainfall events are getting more frequent on daily timescales in many regions of Europe [2]. Increasing flood risk can be forecast in the European Union (EU) concerning extreme weather events and inappropriate land use [3]. Prolonged exposure to extremities burdens the economic competitiveness of Hungary. Flash floods might jeopardize the vulnerable stability of the nature–economy–society complex system in the future [4]. The increasing volume of flood-affected areas is in accordance with the affected number of people and even the damages are escalating in parallel. The increasing probability of fast flowing, high intensity flash floods threaten small municipalities, especially in the downstream areas of mountainous and hilly regions [5]. In many cases the protection of settlements cannot be solved through conventional flood management approaches due to high investment costs and built-in floodplains.

The question arises: how the safety, in terms of flash floods, could be enhanced in a cost-efficient way in the case of the aforementioned small municipalities? It is reasonable to assume that natural water retention measures could facilitate the decrease of flood risk concerning small municipalities in the downstream areas of mountainous and hilly regions.

The main objective of this article is to analyse the potential of flood risk mitigation with applying natural water retention measures and facilitate the integration of these methods to the conventional flood management. These additional measures could have a positive effect on the quality and quantity of surface and groundwater. Research results facilitate an even more effective preparation in a way of applying nature based solutions to supplement traditional flood management. Completion of conventional flood management methods, in the system-level designing way, may result in the implementation of cost-efficient, complex solutions, contributing to the increase of safety level.

Flood Management In Europe

It is important to clarify the definition of flooding. Flooding in general is a natural phenomenon that only becomes a catastrophic event when human lives or properties are affected [6]. Flood means the temporary covering by water of land not normally covered by water. The general concept shall include floods from rivers, mountain torrents, Mediterranean ephemeral water courses, and floods from the sea in coastal areas, and may exclude floods from sewerage systems [7]. The exact concept of flood may be slightly different from nation to nation. After the evaluation of related Hungarian national legislation, I identified the lack of exact legal definition of flood.

According to new researches, the global sea level rise has been accelerating in the past decades. A new study, based on 25 years of NASA and European satellite data, presents that the sea level rise is not increasing steadily, but accelerating [8]. "If the rate of ocean rise continues to change at this pace, sea level will rise 26 inches (65 centimetres) by 2100 – enough to cause significant problems for coastal cities [9]." I primarily concentrated on the flood management in terms of rivers and mountainous water courses.

Under the leadership of the EU's Joint Research Centre (JRC), scientists implemented multi-model projections of river flood risk in Europe due to climate change. They compared estimates of river flood risk concerning three recent case studies, assuming global warming scenarios of 1.5, 2, and 3 degrees Celsius from pre-industrial levels. The assessment is based on comparing ensemble projections of expected damage and population affected at country level. Figure 1 shows the results of modelling.

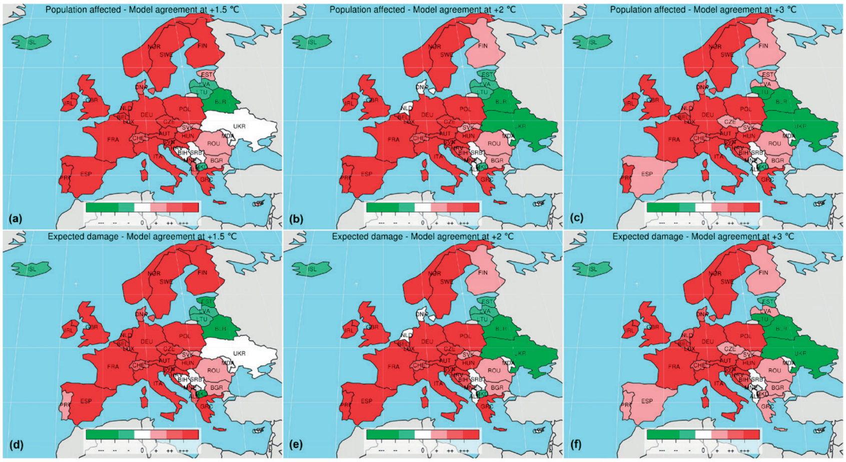

Figure 1. Multi-model agreement of projected changes in affected population (a–c) and expected damage (d–f) at specific warming levels (SWLs): 1.5 °C (a,d), 2 °C (b,e), and 3 °C (c,f). Colors depend on the number of cases predicting a positive or negative change in impacts [3]

"Red colours signify agreement between the models on an increasing flood risk, and green indicates agreement on a reduction of flood risk [3]." In summary, they projected increase in both the number of affected people and damage costs. According to the results, flood risk is expected to increase across Western and Central Europe, so the EU Member States (MS) are deeply affected.

Europe suffered approximately 213 major flood events between 1998 and 2009 [10]. Severe floods reinforced the need for coordinated action that based the implementation of Directive 2007/60/EC on the assessment and management of flood risks. Directive 2007/60/EC is commonly known as the Flood Directive (FD), so in the following I will use the aforementioned abbreviation. The main goal of the FD is to ensure effective flood prevention and mitigation of flood damage. Flood risk is technically the combination of the probability of a flood event and of the potential adverse consequences associated with a flood event [7].

Floods Compared to Flash Floods

Europe is constantly threatened by large-scale floods. In the framework of this scientific article I briefly present typical examples in order to reflect on the relations between floods and flash floods.

In 2018, due to prolonged heavy rainfalls, water levels increased on one of France's most emblematic river, the Seine. It is an approximately 780-kilometer-long river that flows through Paris. On 24 January, the Seine at Austerlitz Bridge in Paris stood at 5.22 meters and the water level continuously increased until the day of 29th January. It peaked at 5.88 meters. It was about 4 meters higher than the average river level, which is normally around 1.5 metres. French authorities were enforced to shut down roads, traffic on river and even particular parts of the rail network. According to the official reports, about 1,000 inhabitants were evacuated. They managed to protect the city without any loss of life [11].

In 2013, the flood on the Danube peaked at 891 cm at Budapest (Vigadó square), which was the highest value ever measured. 23% of Hungary is considered to be flood-prone area that means 21,248 km^2 [12]. More than 200 residents were evacuated from their homes. Similarly to the French example, roads and transport systems were affected throughout the country. In summary, more than 1,200 people were evacuated from 26 different municipalities [13]. Like in France, despite all the damages done, there had not been reported deaths related to flooding.

Figure 2. Soldiers and water management professionals are fixing the dike at Győrújfalu
(Source: Krizsán Csaba, MTI)

Hungary is one of the countries most exposed to flooding in the EU and has the highest relative share of people living in such areas (1.8 million people, 18% of the population) [14]. Increasing flood risk is projected in Hungary, therefore it is crucial how – the enforcing and maintaining of dikes, the operating of reservoir systems and the floodplain management – will be implemented and how it could be comprehensively composed. According to the records, in the past decades, serious floods had occurred more frequently in Hungary [15]. Flood management systems – based on dikes, reservoirs and floodplain management – need to be operated cost-efficiently. For proper flood management it is crucial to make decisions that are based on a structured system level operation. Holistic approach and data-based decision making is a must. Existence of conventional infrastructure combined with up-to-date IT network is essential in modern flood management.

Protection against a large flooding event costs an enormous amount of money, and gets a broad media attention. Floods compared to flash floods show a fairly different character. In some cases, flash floods may be even more dangerous. In the following, I examine what "flash flood" means and collect some of the latest typical disasters in Europe. Flash floods usually occur after heavy rainfalls on mountainous terrain. It can be caused by short-duration intense precipitation. The dangerous nature of flash floods is fairly attributed to the characteristics of flash floods i.e. events occurring on small spatial scales with short time scales due to rapid surface runoff. Flash floods can even be caused by dam or levee failure, or collapse of debris and ice jams [16]. In this article, I place emphasis on flash floods caused by intense precipitation under the condition of rapid surface runoff. I collected two different distinctive examples to present the characteristic nature of flash floods.

Extremely intense precipitation caused flooding in the Occitanie region of France in October 2018. The heaviest rainfall was recorded in Trébes. The Meteorology of France had registered 295 mm of precipitation (244 mm of that fell in just a 6-hour period). It is the equivalent of 4 months of rain at this place. River Aude at Trèbes jumped approximately 7 meters over one night and peaked at 7.68 m. At least 13 people died in this sudden disaster [17]. Similarly to the aforementioned French case, some areas of Mallorca were affected by more than 230 mm of rain fallen in less than 4 hours in October 2018. Water courses, around the town of Sant Llorenc des Cardassar overflowed their banks after the intense precipitation. The government confirmed that at least 10 people died in the flooding on the island of Mallorca [18].

Hungary is also among the countries threatened by flash floods. In 2018, it was hit by some small-scale flash floods at several municipalities, for example Bakonycsernye and Szilvásvárad. Due to the climate change, flash floods may presumably become more severe in Hungary. Figure 3 shows the flash flood risks in Hungary [19].

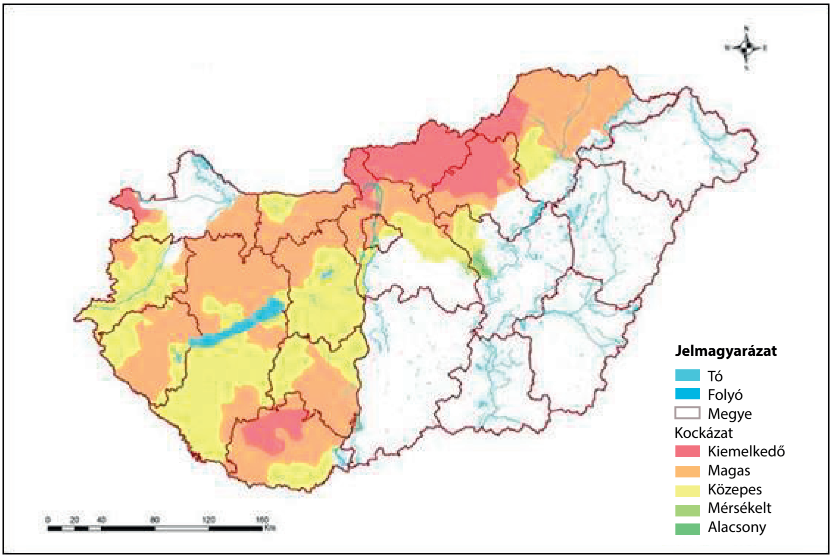

Figure 3. Flash flood risk in Hungary [19]

The most endangered areas are evidently the mountainous parts of the country i.e. Bükk, Mátra and the Mecsek Mountains. If we compare floods to flash floods, it can be stated that in cases of floods on the Danube, the Seine or other major rivers, there are some days to prepare. It is relatively a lot of time compared to the case of flash floods. Examining the aforementioned examples, I stated that flash floods can mean a higher threat to human lives than great floods. In Trébes and Mallorca, flash floods caused the death of 23 people in total, partly because of the lack of time to prepare. Flash floods have a deadly nature compared to floods on the downstream of big rivers. According to statistics in the United States, most flood-related deaths are associated with flash floods i.e. 80% of all flood-related deaths are attributed to flash floods [20]. Floods affect large-scale areas and flood protection activity has high costs. In contrast, flash floods hit small areas (for example just one village), and has relative high costs in terms of cost per capita. Time and per capita values are key factors in flood management. In some cases, flash floods may affect only one or two small villages and they would not catch the attention of media at all or only for a couple of days at most. In Hungary, according to Government Regulation No. 232 of 1996 on protection against water damages, in certain cases, the local mayor is in charge of leading protection [21]. It can be challenging, when the mayor, who is responsible for the defence works owned by the local municipality, is not a flood management expert. Flash floods may occur so fast that there is no time to wait for the national authorities. The lack of statistics may pose a problem regarding flood management.

In cases of small mountainous municipalities, where the implementation of simple conventional flood management practices are not cost-efficient and the role of time is crucial, there is a need for other effective solutions. In order to facilitate a better protection of these municipalities I examined the opportunities offered by natural flood management through natural water retention measures.

Natural Water Retention Measures

Partly due to climate change, the number and the intensity of extreme weather events are increasing, and thus water retention tends to get more attention. Governments, residents and water managers have to face the challenge of managing flooding and droughts. Both water surplus and water shortage may occur in a short period of time at the same place. Water retention can be a useful tool to face the challenges and meet the needs of the residents. What do natural water retention measures (NWRM) mean?

Natural water retention measures are technically adaptation measures that use nature based solutions to regulate the flow of water courses in order to safeguard and enhance the water storage potential of landscape, soil, and aquifers and to smooth flood peaks [22]. Natural water retention measures as a part of sustainable water management may effectively moderate extreme events, such as floods and droughts. Carefully planned preventive measures are always more cost-efficient than the follow-up damage compensation.
Table 1 shows the classification of NWRM measures.

Table 1. Classification of NWRM measures [22]

TYPE	CLASS	NWRM MEASURE
Direct modification in ecosystems	Rivers and connected wetlands	Restoration and maintenance of rivers, basins, ponds, and wetlands; floodplain reconnection and restoration, reconnection of hydraulic annexes, elimination of riverbank protection…
	Lakes and connected wetlands	Restoration of lakes
	Aquifers	Aquifer restoration
Change & adaptation in land-use & water management practices	Agriculture	Restoring and maintaining meadows and pastures, buffer strips and shelter belts, soil conservation practices (crop rotation, intercropping, conservation tillage…), green cover, mulching…
	Forestry and pastures	Afforestation of headwater areas/mountainous areas/reservoir catchments, targeted planting for "catching" precipitation, land-use conversion for water quality improvements, continuous cover forestry, maintenance of riparian buffers, appropriate design of roads and stream crossing urban forests…
	Urban development	Green Roofs, rainwater harvesting, permeable saying, Sustainable Drainage System; swales, soakaways, infiltration trenches, rain gardens, detention basins, retention ponds, urban channel restoration…

NWRMs are being implemented in various river basins throughout Europe. More information is available from NRWM under the link: http://nwrm.eu. This online platform helps the potential designers and residents to get information from detailed description of case studies.

Hungary launched a LIFE project (https://vizmegtartomegoldasok.bm.hu/en) in 2017, based on NWRM solutions. In the frame of the project, different NWRM prototypes will be designed and tested. One of the requested results is the improvement of climate resilience of involved vulnerable Hungarian municipalities.

NWRM measures have numerous positive effects. But beside the aforementioned benefits we have to take into consideration the costs. On the financial side, NWRMs (considered as soft engineering) have low investment costs compared to hard engineering, but the key factor will be the operational costs. Crucial elements of the needed cost–benefit analysis are the social benefits and ecosystem services that are still challenging to estimate [22]. Better understanding of costs and benefits is essential.

After all, can NWRM be a powerful tool to improve climate resilience or not? Apart from planning, the key is monitoring. Monitoring measures must be a part of planning. Designing has to be based on GIS. River basin models need to be regularly recalibrated in order to get the full picture of reality. Monitoring and data management is important in evaluation of the processes related to these measures.

Speaking of NWRM, we tend to emphasise the benefits and forget about the hazards. If we discuss NWRM, I recommend that we put it into context, and manage it at system-level. If we use this approach, the role of NWRM will be more transparent. NWRM, as an additional measure, can be an efficient part of a complex flood management, but the real benefit of it prevails when we combine it with hard engineering. We need to define a clear goal to find the best solution. There is no exact method or right combination ration of hard and soft engineering, we need to manage the different kinds of situations on a case-by-case basis.

Technical aspects of natural flood management can largely be solved, but the lack of public acceptance can ruin the implementation, thus good practices should be made available to the public.

Flood Risk Mitigation by Natural Flood Management

Natural Flood Management (NFM) is based on NWRM. NFM means the implementation of natural processes to reduce flood risk [23]. I assume that, if we accept and manage it as part of a complex system, it can be a reasonable method to decrease flood risk.

During the planning process, besides the technical aspects like what will the proper design life be, we have to face several legal challenges. Questions arise such as who the competent authority is and how to implement the requested permitting process? Who will be responsible for the operation of the facilities? Who should finance the project? How to proceed in case of transboundary catchments?

I collected and analysed two already implemented NFM projects from the UK in order to find answers. Figure 4 shows the implemented natural flood prevention measures in the catchment area of Belford Burn.

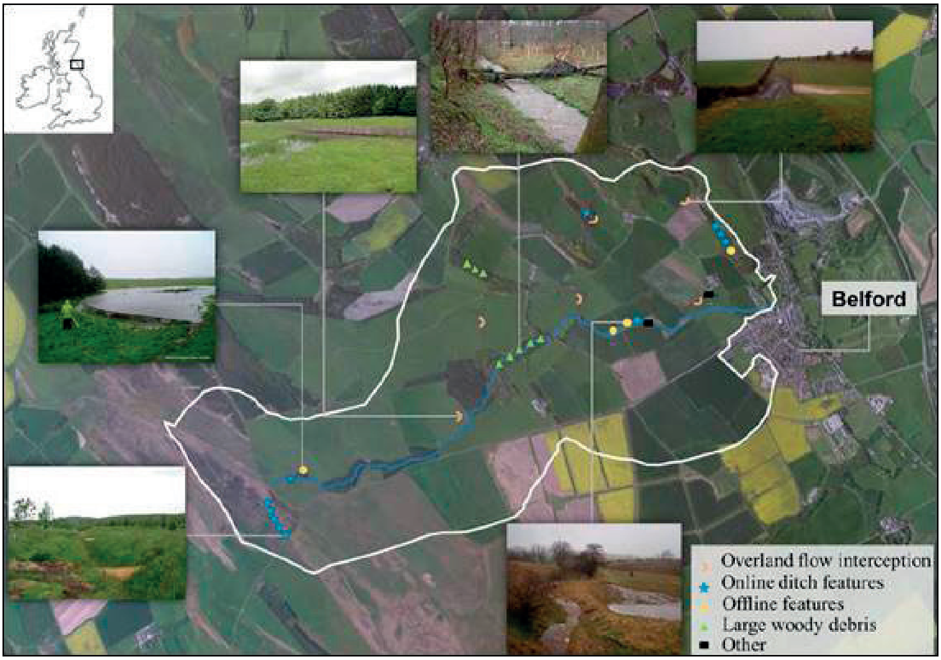

Figure 4. Natural flood prevention measures in Belford [24]

The river basin area of Belford Burn (just outside Belford) is approximately 6 km^2. In 2007, the flash flood occurred in Belford (~1,200 residents) became widely known in the UK, when the local press interviewed the mayor of the village, and released with the headline "Sick of sand-bags and sympathy" [25]. Prior to this event, Belford had been hit by five flash floods occurring over two years, threatening about 30 properties. According to governmental estimations, the building of conventional flood defence would have been £2.5 million. Due to lack of space and cost–benefit anomalies, there was a need to find an alternative solution [24]. The University of Newcastle in partnership with Environmental Agency (EA) launched the Belford Catchment Solutions Project (www.theflowpartnership.org/belford). The main principle of the project was: intercept, store, slow, filter [26]. The design of the implemented measures was based on a catchment area surface model. The model was built on light detection and ranging (LIDAR) measurements. In the project, 35 runoff attenuation features (RAFs) were implemented [24]. Figure 5 shows one of the RAFs.

Figure 5. Offline wood barrier at a hilly pasture of Belford
(Source: Tóth Tamás, NUPS)

The combined value of storage capacity is ca. 10,000 m^3, that has an important delaying effect and results a 30% flood peak reduction [24]. The EA is responsible for maintaining the structures. The design life of RAFs is variable, and even depends on flood frequency. For example, in case of the offline wood barrier (Figure 5) it is about 15 years and we have to calculate with the sedimentation in case of barriers, ponds. The RAFs were implemented in close cooperation with the affected farmers. RAFs were built without land purchase but the farmers got compensations. The project was funded by EA (actual cost of project: approx. £200,000) [26].

Efficiency of the applied NFM methods and features can also depend on the scale of catchment areas therefore I even examined a larger scale pilot project funded by Defra, named "Slowing the Flow at Pickering (2009–2015)". (More information is available at the link: www.forestresearch.gov.uk/research/slowing-the-flow-at-pickering).

Pickering, UK (population: ~6,800) is situated at the downstream area of Pickering Beck catchment (~69 km^2) and has a long history of flooding. Flash flood, in 2007, caused an estimated £7 million damage [27]. Environmental Agency had prepared a conventional project but the cost–benefit analysis showed the proposal to be unaffordable so Pickering, like Belford was in need of an alternative solution. Having regard to the scale of the catchment and the size of the municipality, a much broader partnership was needed than in the case of Belford. The partnership in this case included the Forest Research, Defra, Forestry Commission, EA, Natural England, Durham University and the Pickering Civic Society.

"The overall aim of the project was to demonstrate how the integrated application of a range of land management interventions can help reduce flood risk at the catchment scale [27]." The project was designed to protect Pickering from a 1 in 25 years flood. Like in Belford, they used a complex surface model to locate the RAFs. Modelling software, like HEC-RAS or

HEC-HMS developed by US Corps of Engineers is publicly available (www.hec.usace.army.mil), so it is possible to create models to Hungarian catchments as well, in order to examine runoff and locate RAFs. Threatened municipalities could try to contact universities dealing with modelling to start building hydrological models to make it possible to find solutions, for example in frame of a doctoral thesis.

In total, 129 large woody debris (LWD) dams and 187 heather bale check dams were constructed. They had planted 19 ha of riparian woodland and a large flood storage bund with storage capacity of 120,000 m^3 (Figure 6).

Figure 6. Woody debris dam (left side) and the flood storage bund (right side)
(Source: Tóth Tamás NUPS)

Some measures may make an instant contribution following implementation, while others take a number of years to fully reach their potential (e.g. afforestation). A monitoring system had been established but the analysis of data proved inconclusive. Probably a longer data time series is required. "Quantifying a change in flood response is an extremely difficult task, especially at the catchment scale. This is partly due to the relatively rare nature of flood events, the difficulty of precisely measuring these and the fact that their frequency and nature are thought to be changing due to climate warming [27]".

Over the technical aspects, I identified five inevitable legal questions (criteria) that are crucial to clarify in order to ensure the success of implementation:

- Who is responsible for the flood management of the municipality?
- Who is the competent authority of permitting process?
- How detailed is a plan to be to get a permit?
- Who is responsible to register interventions in property records with easement?
- Who is in charge of operation?

Act LVII of 1995 on Water Management (Water Law) regulates the process of intervention related to water bodies in Hungary. According to the Water Law, the local municipality is responsible to build and maintain flood defence facilities, if the scope of facilities affects no more than two municipalities. Water right permit is required to build, modify or abolish any facilities that may affect the given waterbody in terms of run off, flow, quantity, quality or buffer zone [28]. If we accept that the municipality is responsible for investments, then the question arises: How could a small municipality finance a relatively big investment? In most cases, this situation could spoil an investment, therefore I would deem government intervention necessary.

All interventions need to be registered in property records with easement. If a facility is not implemented in a property of the given municipality, the affected landowner is eligible for compensation. NWRM solutions should be part of the national funding system in order to motivate landowners.

Permitting happens on a case-by-case basis, i.e. separate licence is required in every case of interventions. This could be a significant burden having regard to time and costs. RAFs need to be managed on catchment scale because it is a complex system. What would happen if some RAFs did not get a permit? It could seriously jeopardize the efficiency of the whole system. I recommend analysing the possibility of aggregated permitting.

Having regard to the complexity of natural flood management (both technically and legally), a practical guidance document would be required.

Conclusions

In Hungary, the lack of statistics may be a problem in flash flood management.

NWRM, as an additional measure, can be an efficient part of a complex flood management, but the real benefit of it prevails when we combine it with hard engineering.

Technical aspects of natural flood management can largely be solved, but the lack of public acceptance can ruin the implementation, thus good practices should be made available to public.

Municipalities at risk of flash flood should contact universities with knowledge of modelling.

I identified five legal criteria that are crucial to clarify.

Small municipalities could be unable to finance flood management investments that makes governmental intervention necessary.

Separate licencing could be a significant burden regarding the time and cost factor.

RAFs need to be managed on catchment scale as a system. Total system efficiency is jeopardized, if particular RAFs do not receive a permit. I recommend analysing the possibility of collective permitting.

Having regard to the complexity of natural flood management, a practical guidance document would be required.

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