Integrated Approach to Flood Management

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ABSTRACT **Floods are considered to be the biggest of all natural disasters. Rapid urbanisation, economic and social development, climate change and its variability have all altered the hydrological cycle and, within that process, made our communities more prone to flooding. Flood management implies a set of engineering works and non-structural strategies for protection, prevention and mitigation of risk and damage that floods pose to settlements and human lives. Traditional flood protection measures are more focused on managing the safety of the inhabitants in floodable areas. In urban settlements, they are primarily orientated to water collection and conveyance by using the 'as fast as possible' principle. In the light of increasingly prominent climate change and climate variability, traditional flood protection measures need constant upgrading i.e. higher dykes and deeper channels. The chapter focuses on the concept of Integrated Flood Management (IFM), which combines flood mitigation and risk management by considering several key principles such as: water cycle management; the interrelationship between land use and flood protection; the consideration of the various socio-economic, environmental, and governance hazards; and the engagement of all relevant stakeholders in the decision-making process. The general IFM concept is presented together with the most common structural and non-structural measures and solutions. Flood protection challenges and inputs necessary for a successful IFM implementation are discussed. Recent examples of IFM best practices are reviewed, highlighting the role of spatial planning integration in flood management as a promising process that leads towards a sustainable and resilient built environment.**

KEYWORDS flood, flood protection measures, integrated flood management, urban drainage system

1 Introduction

Floods are some of the greatest challenges for sustainable development. Approximately 70% of global disasters are linked to hydrometeorological events (WMO, 2009b). Of all natural disasters in Europe, such as earthquakes, landslides, epidemics, floods, droughts, etc., 34% come from floods causing 37% of total damages and making over 57% of affected people homeless (CRED, 2017). The Centre for Research on the Epidemiology of Disasters (CRED, 2017) reports that 63% of all floods occurred in the past 16 years (2000-2016), while the remaining 37% happened in the 20th century. A rapid increase in flood occurrence, which may be associated with rapid urbanisation and climate change, started around the 1950s.

By definition, flood is an uncontrolled overflow of water (rivers, lakes, coastal waters, urban waters, etc.) that covers, for a specific period of time, land that is usually dry (Cambridge Dictionary, n.d.). Flood duration may range from several hours to several weeks, depending on flood cause, on the general condition of the flooded area, and the degree of development and urbanisation (Douben & Ratnayake, 2006).

According to their origin, floods are classified as either a natural disaster (caused by unfavourable weather conditions) or an anthropogenic disaster (caused by human activity).

Depending on the place of occurrence, floods can be rural or urban. Urban areas are typically more vulnerable to floods i.e. less able to resist the hazard or to respond when disaster has occurred (UNISDR, 2004) due to the high numbers of people and building density.

Rural (basin) floods are usually provoked by heavy and/or long-lasting rainfall events, snow melting or by slow development of flood flows due to the exceeding of the natural pathways' capacity (riverine flood type). Poor catchment conditions, such as deforestation and/or mining, increase potential of runoff generation and are a common cause of rural flooding. Other causes of rural floods may be the inadequate design or poor maintenance of the flood protection system, dam failures, landslides, obstructions of the flood way such as bridges, culverts, etc.

Urban floods can be induced by prolonged or heavy precipitation events or by snow melting, but also by brief torrential rain that exceeds the capacity of the urban drainage system. Other conditions that can increase flood occurrence in urban areas are inadequate design and poor maintenance of drainage system elements, failure of the city protection dykes or river inflow into the drainage system during river high waters.

In sprawling areas (EEA, 2006) floods can be both rural and urban. This is due to the specificity of these types of settlements, which represent the spread of urbanisation into the rural landscape.

Management of floods should be a legal obligation and every country should have a flood management plan and strategy. Traditional flood

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protection measures address the problem with the focus on safety; to secure a certain area from flooding using probability of flood occurrence as a safety factor.

The chapter presents a different approach that has emerged in recent years, which combines and integrates various aspects (environmental, ecological, social, economic, climatic, technical, and institutional) contributing to the development of a more comprehensive and sustainable flood management strategy.

Integrated Flood Management (IFM) implies a holistic view of the phenomena and adopts the best, optimised combination of structural and non-structural strategies to cover all aspects of flood 'timeline': preparedness; prevention; protection; recovery; and adaptation of strategies in new versions of management plans considering previous flooding experience and the lessons learned. Mitigation and non-structural flood protection measures tend to be very efficient long-term and a more sustainable solution. However, structural measures for flood protection are, and will be, an important element for both existing and new developments. The best management practice for basin and urban flood protection is a wise combination of measures that work along with nature and enhance the landscape functionality, amenity, and provide multi-functional benefits.

Flood management is subjected to a number of challenges that need to be addressed in its process such as securing lives, rapid urbanisation, and climate change. With the IFM approach, each of these challenges is addressed as a multi-objective task. The consequences of rapid urbanisation are mitigated by sustainable flood protection measures mimicking the natural hydrological cycle; the population's safety is increased by raising public awareness and preparedness together with a series of structural measures; resilient flood protection measures can cope with climate change by being able to adapt to variability, etc. These challenges are discussed in Section 2.

The concept of IFM is presented in Section 3, while the most common structural and non-structural measures, traditional and nature-based solutions promoted within IFM are presented in Section 4.

An efficient IFM implementation requires an efficient governance within the several decision-making levels (governmental, public, technical, and managerial). Clear institutional functions and roles, coordination between local, regional, national, and international levels within river basins and a multi-disciplinary approach are important prerequisites for a successful IFM development. Integrating IFM into urban planning and vice versa is especially important. Land-use planning can enhance flood mitigation in flood-prone areas by regulating land utilisation, built areas, and location of infrastructures. The aspects of effective implementation of IFM are presented in Section 5.

The recent flood management examples and best practices are reviewed and discussed in Section 6.

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2 Flood Protection Challenges

2.1 Rapid Urbanisation

Progressive urbanisation considerably increases the risk of flooding due to the impermeability of the expanding soil and territory fragmentation. Urbanised areas interrupt the natural hydrological cycle by changing compartmentalisation of hydrological components. For example, impervious areas obstruct natural groundwater recharge, evaporation and transpiration processes are changed due to decrease of natural (vegetative) land and increase of artificial materials (concrete), and change in land cover increases runoff coefficient that yields more runoff. Beside this, urbanisation leads to poorer ecological conditions, water quality, and habitat.

Usually, floodplains are very convenient areas for living due to their favourable location and fertile soil provided by the rivers. On the other hand, vulnerability and risks for people, property, and crops in floodplains are very high and must be properly addressed. The safer solution would be to reserve floodplains for rivers only. However, this is not always possible due to limited space in highly packed urban areas and the fact that the existing developments cannot be simply removed. In this case, various methods of flood relief may be applied, such as early flood warning systems and flood recovery measures.

However, negative impacts of population growth in cities particularly affect less developed countries, where the urbanisation process is poorly planned. The weak economic status of some inhabitants prevents them from moving to less exposed land, leading to the development of unplanned settlements in floodplains, usually occupied by a poor population. Dense urban areas occupying floodplains leave no space for water during flood events (Jha, Bloch, & Lamond, 2012). In addition to other changing conditions, i.e. increased flood risk due to climate change, vulnerability becomes very high.

Flood risks from increasing urbanisation may be reduced by implementing IFM. Some measures within the IFM approach may reduce the peak runoff and improve water quality; for example: incorporating green roofs on top of buildings, using permeable pavements and parking lots, building green infrastructure for collection and conveyance of stormwater, etc.

2.2 Climate Change

Climate change is an ongoing process and should be addressed globally. However, 'local' measures are both desirable and necessary. Various climate models like UKMO-HadCM3, GISS-ER, CGCM3, CNRM-CM3 and many others (Randall et al., 2007) particularly at continental and larger scales. Confidence in these estimates is higher for some climate variables (e.g., temperature try to predict the future change of climate variables, such as precipitation height and temperatures, in order to prepare the population for such a change. However, besides preparedness, prevention is crucial, but it is not always given adequate attention.

According to the Intergovernmental Panel on Climate Change (IPCC, 2014), the future temperature increase is likely to be between 0.3-4.8°C, depending on the climate scenario used. While the change in the amount of precipitation is not uniform globally, even in regions with decreases in precipitation, the expected overall frequency and rainfall intensity is likely to increase. At the same time, IPCC expects the seawater level to rise by 26 cm by 2065 and 50 cm by the end of the 21st century. This increases the potential for lowland inundation and coastal flooding, apart from many other related problems (coastal erosion, altered tidal regime, etc.).

Climate change is a major source of uncertainty in terms of the common assumption that design flows will remain the same in the future, and that the present flood protection engineering works would withstand the future hydrological regime. On the other hand, individual climate projections are uncertain due to various Global Circulation Models (GCM), downscaling techniques, difficulty in predicting future population and socio-economic growth, etc. The World Meteorological Organization (WMO, 2009a) proposes two potential actions to deal with these uncertainties: (1) the adoption of adaptation measures that do not depend on precise projections of e.g. river flow and (2) the adoption of strong management measures. The same document states that waiting for a less uncertain assessment is an 'irresponsible strategy'; adaptation measures should be implemented because climate change is already taking place. For example, design flood calculations that incorporate projected river runoff increase or decrease due to climate change depend on precise runoff projections. Design for floods will show a necessary design runoff change, i.e. an increase by a particular percentage. However, it is highly unlikely that a full range of expected changes would be included due to the unrealistically high costs, which cannot be justified with the benefits of such a solution. The IFM adaptive management, which changes actions and plans according to outcomes from the established knowledge base that deals with scientific uncertainties and optimised best combination of strategies that provides sustainability and resilience to expected changes (WMO, 2009a), may offer a solution to this problem.

2.3 Illusion of the Absolute Flood Safety

Achieving absolute flood protection is an illusion (Kundzewicz, 1999). Kundzewicz & Takeuchi (1999, p. 417) stated that "a more disaster-conscious society needs to be built with better preparedness and safe-fail (safe in failure) rather than unrealistic, fail-safe (safe from failure) design of flood defences". 'Living with floods' implies a more flexible adaptive and realistic approach since absolute protection is not technically feasible or environmentally possible (European Commission, 2010; Kundzewicz & Takeuchi, 1999; Manojlovic & Pasche, 2008)

The traditional flood protection approach assumed constant hydrological variables and fixed design flood value according to corresponding design standards. However, fixed flood protection measures are not always appropriate. An adequate combination of structural and non-structural flood protection measures, together with damage mitigation measures, is included in the IFM approach. For instance, a set of flood control systems might be combined with flood insurance programmes, as well as with actions aimed to raise the public awareness about the risks run by households located in flood-prone areas. However, traditional flood protection structures such as dykes, floodwalls, or bypass channels will be always necessary for the protection of the existing settlements; at least until they are entirely converted into sustainable and resilient 'water sensitive environments' (Anđelković, 2001; WMO, 2009b).

3 Concept of Integrated Flood Management (IFM)

Various definitions of IFM presented in the literature are almost always connected with the concept of sustainability (Kundzewicz, 1999; WMO, 2009a). In order to achieve efficient flood management, the IFM approach ensures the protection and development of natural ecosystems by integrating various aspects of other planning sectors (i.e. land use, environmental, landscape, etc.).

The IFM concept combines water and land resources development at the scale of the river basin. It derives its principles from the Integrated Water Resources Management (IWRM) approach, presented in the Dublin Statement on Water and Sustainable Development (ICWE, 1992) and at the Earth Summit in Rio (UNCED, 1992). At these meetings, the IWRM approach was recognised as a necessity within the concept of sustainability (WMO, 2009b), as well as at many subsequent meetings, of which the most notable is the 2002 World Summit on Sustainable Development held in Johannesburg (WSSD, 2002).

Sustainable development, defined as development that fulfils the needs of present generation without compromising those of future generations (WCED, 1987), should be the goal of all flood management plans.

According to WMO (2009b), there are six key elements to be addressed by an IFM plan:

- managing water cycle as a whole;
- integrating land and water management;
- managing risk and uncertainty;
- adopting the best combination of flood protection measures and options;
- ensuring participatory approach;
- integrating hazard management approach.

Managing water cycle as a whole. The hydrological cycle is a natural process of the cycle of water on the Earth. It comprises a balanced equation of water inputs such as snow, rainfall, dew, hoarfrost, and water outputs like evaporation, transpiration, infiltration, interception, and percolation. An important part of the cycle, infiltration, is mostly disturbed in urbanised areas due to land cover changes (i.e. from permeable natural covers to impermeable surfaces). IFM seeks the best way to manage the land phase of the cycle by restoring groundwater recharges through various nature-based solutions.

Integration of land use and water management is a crucial IFM element because the hydrological response to precipitation depends heavily on soil/surface characteristics. Information, knowledge exchange, and teamwork within these two planning activities may yield multiple benefits by integrating successful flood protection measures and creating appealing multifunctional landscapes.

Managing risk and uncertainty is a part of every development and management process. However, this is especially exacerbated in flood management due to climate change and the fact that the scale of future hydrological conditions cannot be predicted with certainty. 'Living with floods' facilitates flood risk management by providing information and research on flood occurrence and by increasing preparedness and flood awareness. As argued in this section, those measures may mitigate flood risk along with post-flood non-structural measures.

A valid IFM strategy/plan seeks to *adopt the best possible combination of flood prevention and protection measures*. This goal is usually achieved through an optimisation process that requires extensive knowledge about climate, the basin characteristics and specific conditions in the region, and previous experience. In this process, building professional capacities in the field of flood management (e.g. in hydrology, hydraulics), as well as in socio-economics, policy development, and regulation, plays an important part in the IFM implementation.

The participatory approach means involvement in the decision-making process of all relevant stakeholders such as residents, planners, and policy makers. However, the coordination between all parties at national, river basin, and local levels is one of the IFM challenges that needs to be addressed in particular.

Flood associated hazards need to be addressed through *integrated flood hazard management.* This means aggregation of measures dealing with all possible hazards such as landslides, storm surges, dam breaks or dykes failure, rather than treating them one at a time. This approach usually demands that IFM is a part of the broader risk management activity.

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4 Flood Protection Measures

Over the centuries, various (usually structural) measures have been undertaken to protect settlements from flooding. Traditional and conventional measures address water quantity and, to some extent, water quality problems. Growing demands and the consequent challenges of rapid development require a more adaptive, sustainable, and resilient approach not only strictly related to water aspects, but also relating to ecology in terms of the quality of the landscape, and to the interaction of all the socio-economic sectors involved (Chocat et al., 2007).

This approach could substantially reduce the exposure and vulnerability of the population, and the built environment, to floods. Flood protection measures can no longer be considered the only interventions applied to a specific territory but need to be integrated into a variety of planning actions.

Traditional flood protection measures are implemented through structural solutions such as conveyance canals or river diversion structures, multifunctional reservoirs, urban drainage systems, dykes along the river, etc.

Nature Based Solutions (NBS) (Božović et al., 2015) combine various structural options for managing urbanisation and climate change problems in a more sustainable way. Depending on the locations in which NBS are planned and realised, this approach is named differently:

- The Centre for Neighborhood Technology (CNT, 2011, p.1) states that *Green Infrastructure (GI)* is "a network of decentralized stormwater management solutions such as green roofs, trees, rain gardens and permeable pavement that can capture and infiltrate rain where it falls, thus reducing stormwater runoff and improving the health of surrounding waterways";

- *Sustainable Drainage Systems (SuDS)* have gradually been designed and developed over the past 20 years in the UK to minimise the impact of urban surface waters on new and existing developments (Woods-Ballard et al., 2015) and maximise benefits (water quality and quantity, facilities and biodiversity) from surface water management;

- *Low Impact Development (LID)* is an approach developed in North America and Canada (US EPA, 2017), similar to GI networks, aiming to preserve, restore, and create green spaces;

- *Best Management Practice (BMP)*, also developed in North America and Canada, is mostly oriented to water pollution control besides other benefits (water quantity control, amenity, etc.) (US EPA, 1993);

- As a broader, macro-scale concept, *Water Sensitive Urban Design (WSUD)* represents a holistic approach to the planning and design of urban development (BMT WBM Pty Ltd, 2009; Moreton Bay

Waterways, Catchments Patrnerships & WBM Oceanics and Ecological Engineering, 2006);

- *Low Impact Urban Design and Development (LIUDD)* is an approach adopted in New Zealand that combines low impact development and water sensitive design (Puddephatt & Heslop, 2007; van Roon & van Roon, 2005). It is a synthesis of a number of approaches: LID; Conservation sub-divisions (CSD); Integrated Catchment Management (ICM); and Sustainable Building/Green Architecture (SB/GA).

All these principles and methods aim to minimise the impact of urbanisation on nature, mimic natural (pre-development) hydrological cycle, improve amenity and urban living conditions, solve flood and water scarcity problems, and provide better adaptability to climate changes and other stresses on natural resources.

4.1 River Engineering and Structural Flood Protection Measures

Traditional flood protection measures entail engineering works on river courses and floodplains to protect settlements from flooding (Ghosh, 1997). As absolute protection is not possible, engineering works are made to decrease the risk of flooding and susceptibility to flood damage as much as possible.

Flood risk assessment is usually calculated using the concept of the 'return period' (T) or 'probability of occurrence' (P). T is a time interval, usually expressed in years, in which a maximum runoff (estimated from the historical flood data sample) is expected to occur at least once. This analysis is based on statistics and probability theory and for the extreme flood events T is equal to the reciprocal value of P.

For flood defence design, a common T value is assigned to each structure, which defines the degree of protection needed for that specific asset. For example, the most used T values are 10, 20, 100, and 1,000 years, depending on the asset (5-10 years for drainage systems, 100 years for dykes, 1,000 years for dam evacuation systems, etc.) (Chow, Maidment, & Mays, 1988). According to the return period assigned, based on the statistical analysis of the observed flood sample data, the design flow is evaluated and further used for that specific design.

The uncertainty of the calculated design flow lies, among other things, in the calculation methodology, i.e. the flood frequency estimation method used; the uncertainty of parameter estimation for a particular method; and the uncertainty of the observed data length and quality (Kjeldsen, Lamb, & Blazkova, 2014), as well as in weather unpredictability. For instance, new extreme events such as floods that occurred in Bosnia and Herzegovina and in Serbia in 2014, significantly changed statistical values of historical flood data (a 100 year return period design flow became 50 years or less). Consequently, in such cases, structural flood protection measures should be redesigned or

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improved to better respond to the changed conditions. This approach often leads to the adoption of expensive and unsustainable measures (Maksimovic et al., 2015).

The various structural flood protection measures can be grouped into five main lines of intervention:

- conveyance systems or measures to decrease capacity;
- flood storage systems for runoff volume attenuation;
- drainage systems for urban runoff management;
- systems that separate water from population;
- emergency measures.

Conveyance systems. River flooding occurs when runoff exceeds riverbed capacity so that the excessive volume is discharged over the banks to the surrounding land. Measures used to increase river capacity are: channel cleaning to decrease flow resistance, channel deepening/ widening, and diversions (bypass channels) for peak volume relief. By changing the river capacity, the natural morphology and ecological river regime are usually disrupted and, over time, may tend to shift the problem downstream or upstream. Among conveyance systems, bypass channels are a good solution for runoff distribution, although these interventions are not always possible due to specific on-site conditions.

Flood storage systems include various types of reservoirs, accumulations and other similar spaces and devices provided to accept and attenuate the flood volume. Different types of dams, embankments and retention basins provide water storage as an integral part of the overall flood protection system. The storage capacity changes the dynamics and quantities of water rising and water outflow by decreasing and postponing the time of peak flow (Fig. 3.1), which is very favourable for the downstream areas.

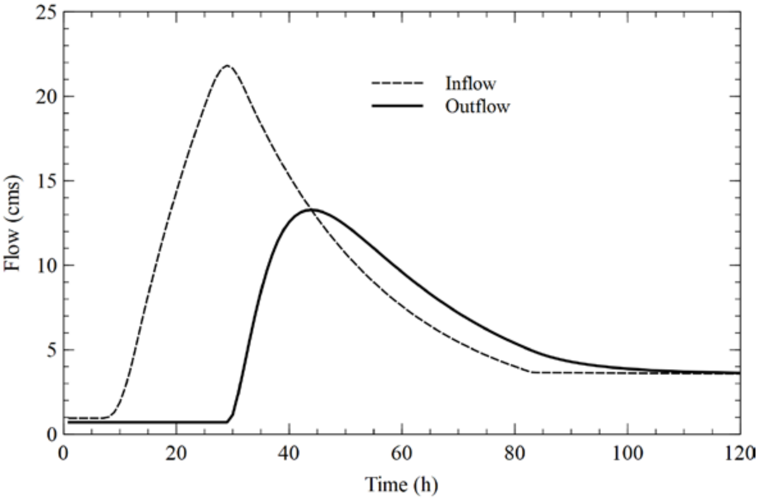

FIG. 4.1 Hydrograph transformation in accumulation *(Image by author)*

Urban *drainage systems* constitute an essential infrastructure of the urban space, often part of the underground utilities. Therefore, their proper functioning is very important. It consists of the inlet devices that accept stormwater close to its origin and direct it to the underground system of pipes. The traditional urban drainage system collects and conveys urban waters as quickly as possible by using primarily structural measures i.e. pipes, gutters, curbs, culverts, etc. Such a system is not easily adaptable in case of extreme events as it is very costly to increase the water capacity that can be safely drained off by the system. Moreover, this type of intervention does not eliminate future flooding issues because it lacks sufficient flexibility to adapt to plausible change (Zhou, 2014).

Separation systems. Dykes are linear constructions, artificial barriers that carry water away from the land and stop the flooding of lower areas. The dimensions of dykes depend on the design flow determined for a specific river (or other water body) and hold only for that specific design flow. Further improvement of this protection system is usually very expensive and requires large construction works. However, if appropriately planned, it remains one of the most effective security measures, especially in urbanised areas. With the same purpose as dykes and embankments, floodwalls are vertical barriers constructed using solid, impermeable materials in the immediate vicinity of the water (river, sea). Floodwalls are usually located on riverbeds and quays (wharfs), preventing excess river flow from reaching urban areas. This flood protection solution may be very useful, especially if it is constructed to be mobile. Appropriate land use and building regulations can also contribute to the protection of the population living in floodable areas (Jha et al., 2012; Tucci, 2007). For example, zoning helps to identify flood-prone areas and their risk of flooding; building regulations in floodplains allow development under special conditions that provide flood resistance (elevated building, buildings without cellars, coating with waterproof building materials inside and out), etc.

Emergency systems. In extraordinary events, flood protection measures may fail. In this case, in order to protect living areas and mitigate damage, emergency measures are necessary. The most common intervention is the deployment of sandbags and temporary/mobile flood barriers that prevent floods from overtopping dykes or retention basins. The evacuation of people usually takes place, along with the strengthening of the existing defence structures (WMO, 2011). In these cases, prevention measures such as the alertness of the population and the availability of information play important roles alongside the implementation of emergency measures (Lendering, Jonkman, & Kok, 2015; Molinari, Ballio, & Menoni, 2013)

4.2 Sustainable and Resilient Flood Protection Measures

The need for an integrated approach to flood protection was recognised a few decades ago (UNCED, 1992, ICWE 1992). The shortcomings of traditionally used protection systems motivated an alternative approach for managing floods that would be more sustainable and resilient. Consequently, nature based solutions started to be developed and

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implemented worldwide, as already discussed in the introduction of this section. A combination of flood protection structural elements and various non-structural prevention measures (i.e. building regulations and appropriate land use planning, relocation of buildings out of flood-prone areas, suitable design of inundation areas, early warning systems, preparedness for and awareness of floods, flood insurance, etc.) provides the optimal flood protection. In the group of alternative, nature-based structural measures, several solutions are described here: excessive runoff management at the source of origin, (i.e. individual object or location), replacement of pipe drainage systems with green solutions, storage and infiltration facilities for collection, attenuation, infiltration and treatment of storm water. Each system described here successfully solves the problem of excess water, while at the same time each represents a part of nature and natural water flows without disturbing hydrological cycle. These flood protection systems, together with non-structural options, briefly discussed at the end of this section, meet the majority of the IFM key principles listed in Section 3.

Source control systems

Source control measures are structural solutions for solving a 'problem' at its source. Some of the measures are green roofs, rainwater harvesting, proprietary infiltration, and treatment systems. These facilities are not typical flood protection elements such as traditional structural measures but may substantially contribute to decreasing peak runoff and peak volumes especially in cases of small rainfall events (Woods-Ballard et al., 2015).

Green roofs or vegetated roofs of buildings have a certain potential to decrease the peak runoff if properly designed and connected on site with other elements of an urban drainage system. According to Beyerlein, Brascher, & White (2005), a typical green roof with 20 cm of topsoil may reduce the runoff and storage by 20%. Besides rainfall volume control, these elements may contribute to the improvement of the urban ecosystem and landscape as well as of the conditions of urban life in general.

Blue roofs are designed to store water during rainfall events. These roofs have a higher storage capacity than the green solution, and hence blue roofs are a more suitable flood control solution.

Rainwater harvesting systems are components that collect water from impermeable surfaces such as roofs, parking, and other paved surfaces and reuse it for various purposes, such as toilet flushing, gardening, etc. and/or for groundwater and river base flow recharge through infiltration.

By combining the described facilities, a significant decrease of flood peak and runoff can be achieved.

Green infrastructures as drainage systems

Traditional urban drainage systems work on the principle of collecting rainwater and conveying it in the shortest amount of time. Green

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infrastructure can represent a multi-functional and more sustainable alternative. Sustainable urban drainage options as alternatives to traditional conveyance elements (i.e. pipes) comprise filter strips, filter drains, and swales (Woods Ballard et al., 2015).

Filter strips are vegetated, mildly sloped elements used to slow down the runoff and provide settling and filtering of the suspended solids it carries, as well as eventually infiltrating one part of its volume depending on site conditions. As a pre-treatment, they are normally used in combination with other elements, such as infiltration or storage systems. Filter strips are usually inserted along streets and highways.

Filter drains are linear shallow trenches filled with porous material for faster drainage. A perforated drainage pipe is placed onto the base of the trench to collect and convey stormwater to the downstream drainage system. This system is usually placed along the edges of highways to enable the sub-base layer drainage (Ellis, Chocat, Fujita, Rauch, & Marsalek, 2004).

Swales are vegetated channels that, similar to filter strips, slow down, store, attenuate, and convey stormwater. As swales have the capability of trapping sediment and silt, they have a certain degree of pre-treatment potential.

These elements can reduce runoff peaks and volumes by over 50%, depending on specific site conditions and event size (Ashley, Nowell, Gersonius, & Walker, 2011; Garcia-Serrana, Gulliver, & Nieber, 2016; Topalović, 2009).

Storage facilities

Storage facilities are active protection measures suitable for rainwater and riverine floods (Urbonas & Stahre, 1993). Their general purpose is to collect peak flood volume and attenuate it for a period of time. The collected water is released slowly and is infiltrated or treated and then used for different purposes (water reuse systems). Some sustainable storage facilities are bio-retention swales; rain gardens; pervious pavements and parking lots equipped with underlying storage devices; attenuation storage tanks; detention basins; and wetlands and ponds. The storage effect of vegetation and soil in these facilities, ground depressions, and wetlands, has an important mitigating effect, especially in minor and medium-scale floods.

Besides controlling water runoff peaks and volumes, *bioretention systems,* shallow depressions vegetated with certain grass and plants species, act as primary purifiers of polluted water. Moreover, these elements may contribute to the improvement of the environmental microclimate conditions, increase the biodiversity and attractiveness of the urban landscape.

Rain gardens are downsized bioretention systems for storing and treating only small portions of the stormwater from a single site, such as roof or parking lot. Due to their size, they are less engineered than bioretention swales (Woods Ballard et al., 2015), but the possibility for their installation is generally bigger.

Pervious pavements and parking lots are constructed with underground storage/retention tanks where collected runoff can be slowly released to a drainage system or downstream element. Storage capacity is designed according to the specific probability of the occurrence of runoff (e.g. once in 10 years). There are different types of pervious pavements and parking areas, such as concrete elements with small openings for percolation or concrete elements combined with grass.

Attenuation storage tanks cannot be considered as parts of a green infrastructure. Rather, they are a component of highly engineered systems constructed with various types of pipes or geocellular storage blocks. Each element in these modular systems can store a certain amount of water which, when exceeded, will travel to the next element. The number of elements and overall tank capacity depends on the runoff that needs to be stored to effectively reduce the risk of flooding. The main advantage is the ease of assembly. Expanding, or shrinking, the storage capacity by adding or removing individual elements generally does not affect the built environment, nor the activities taking place on the surface.

In these underground structures, stored water is released in a controlled manner, infiltrates the surrounding soil, or is reused.

Detention basins are vegetated depressions designed for storage and attenuation of the excess water during the flood events. Between one event and another, they are dry and serve for other purposes (parks, playgrounds, etc.). For that reason, special attention should be paid to their adequate design. Detention basins are usually used in locations where infiltration is not recommended for some reason (i.e. groundwater pollution). Apart from the stormwater quantity control, water quality control is provided through the settling of sediment, silt, and some pollutants.

Wetlands and ponds are storage systems permanently filled with water but with additional free volume to accept a certain amount of stormwater. The biological removal of pollutants and suspended solids is provided through the selection of vegetation planted in these pools. Therefore, both wetlands and ponds attenuate and treat stormwater, thus providing great ecological benefit, wild habitat, and amenity.

Infiltration systems

Infiltration systems are specially constructed to enable groundwater and river baseflow recharge by infiltrating collected water. They are soakaways, infiltration trenches, infiltration blankets, or basins (Woods Ballard et al., 2015). Each of these elements uses the same principle of infiltration, whereas differences lie in the shape of the elements, which can be linear (trenches and soakaways) and flat surfaces (blankets), or curved for water retention.

Soakaways are manhole-like pits filled with porous material for temporary water storage, before its infiltration into the adjacent soil. Depending on the on-site situation, a pre-treatment facility to improve water quality before it infiltrates the ground is usually installed prior the construction of soakaways.

Infiltration trenches are linear elements usually aligned along roads or parking lots. Their water collection principle is similar to that of a conventional culvert system, but with a significant difference: instead of conveying all the stormwater to the closed drainage system, from where it goes to the recipient (usually rivers, lakes etc.), the collected water infiltrates the lower layers specifically designed for soakage and groundwater recharge.

Infiltration blankets are shallow infiltration surfaces usually placed beneath larger urban flat surfaces such as parking lots, playgrounds, sport fields, etc. Stormwater disperses within the blanket through a perforated pipe system connected to a drainage system. The main advantage of these systems is unhindered land use above blankets.

Infiltration basins are specially shaped and usually vegetated depressions in which stormwater is released from a drainage system and stored for the period needed to infiltrate the adjacent soil. Therefore, it is very important to determine the basin location according to the soil infiltration capability. Similarly to detention basins, infiltration basins can host parks, playgrounds and other recreational facilities. For this reason, it is important that the water can flow away as fast as possible.

Non-structural options

Non-structural options mainly tackle the processes of flood mitigation and flood recovery. Flood preparedness combines a series of plans and strategies for raising public awareness of flood risk, its consequences, and actions to be performed before and during the event. Various forms of training, exercises, and public information measures may also be conducted (Anđelković, 2001).

Emergency response measures are a part of the public information and regulatory (policy and organisational) management based on a mobilisation and disaster plan, including coordinated flood fighting units during the event.

Flood recovery measures also include non-structural flood protection options, i.e. flood insurance that allows property owners to be compensated for the losses incurred during floods.

Rehabilitation measures aim to restore life conditions before a flood event takes place. They can be prepared and organised in advance (having a prepared plan in order to speed up the process of recovery).

A combination of the above measures with a proper set of area-specific and tailor-made structural measures coordinated over all relevant sectors provides a good integral flood management practice.

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5 Integrated Flood Management Implementation

A successful IFM implementation requires several inputs at governmental, public, technical and management levels. Clear institutional roles and functions are necessary to provide objective and straightforward policies together with accompanying regulations and legislation based on the IFM practice strategies. An efficient flood risk management policy should consider both low and high probability flood events and include the participation of stakeholders and residents in the decision-making process.

According to Ran & Nedovic-Budic (2016), including flood protection in spatial planning requires the integration of (i) territory (consistency across boundaries and integration of relevant information from different sectors), (ii) governmental policy (consolidation of information from different stakeholders and tools for decision support and analysis) and (iii) institutions (joint platform for the exchange of information, knowledge and interest). Land use planning in flood-prone areas contributes to flood mitigation by allocating spaces and facilities that can withstand floods (The World Bank, 2017). However, in order to secure the successful integration of an adopted flood strategy into spatial planning, clear policy, regulations, and legislation must be defined.

A river basin is a dynamic complex system that involves water, soil, sediment, pollutants, and nutrients (WMO, 2009b). In hydrological science, it is well known that uncontrolled deforestation alters natural surface runoff regime due to change in land cover resistance (runoff coefficient). This change increases not only the river runoff but also sediment deposits, which directly influence hydraulic regime i.e. decreases river flow capacity (McCuen, 1998). Urbanised areas with their increased impermeable surfaces could drastically alter even relatively small parts of catchment conditions in the basin. Road networks could function as dams by blocking and diverting natural waterways. Therefore, since the response of a basin to rainfall (rainfall-runoff relationship) can be affected by human activity, an integrated approach, harmonised on the basin level and coordinated at local, regional, national and international levels is a crucial requirement for efficient IFM implementation.

According to WMO (2009b), 90% of the world's population live in countries whose river basins are transnational. This is common because rivers have always been natural boundaries between states and regions. Therefore, the coordination between countries at a basin scale is necessary. In practice, international commissions are formed to coordinate policy, strategy, and the implementation of IFM at the basin level. For example, the International Sava River Basin Commission aims to establish the international regime of navigation, sustainable water management, and prevention or limitation of hazards (droughts, floods) within the Sava River Basin. The International Commission for the Protection of the Danube River is a transnational body that aims to safeguard Danube River resources for the future generations, establish and maintain a healthy (unpolluted) and sustainable river system, and establish damage-free floods.

Another practical example of coordination at a basin scale is the establishment of the River Contracts (RC); i.e. inter-institutional agreements that allow the adoption of a shared set of regulations within an integrated strategy for water resources management and river basin recovery (Guerra, 2013). These contracts support concerted initiatives and active participation of all local/territorial actors (Scaduto, 2016). They are voluntary strategic and negotiated planning instruments that pursue the protection, correct management of water resources, and enhancement of the river territories, together with the safeguard from the hydraulic risk, contributing to local development. The first river contract was signed in France for the river Thur in 1983. The importance of this instrument for river basin management and for spatial/urban planning was globally recognised in the Second World Water Forum held in The Hague in 2000.

For integration and coordination across different sectors, the full participation of community-based institutions is necessary. In such a process, it is very important to develop a shared IFM strategy at the basin level with full participation, decision making, and implementation by local institutions. On the other hand, local and community capacity building is necessary to meet the IFM requirements.

The sharing and management of information is also a precondition for an efficient IFM approach (WMO, 2009a). For example, the transboundary exchange of flood data is necessary for the implementation of a flood preparedness plan for downstream regions.

An efficient IFM strategy can be achieved if various sectors are involved in the decision-making process. A multi-disciplinary approach entails the collaboration of all interested parties, with a focus on obtaining multi-dimensional results (i.e. results that satisfy all participants) of the decision process. This would firstly integrate spatial planning, landscape design and flood management (European Commission, 2010; Jackish, Zehe, Samaniego, & Singh, 2014; McBain, Wilkes, & Retter, 2010; Ran & Nedović-Budić, 2016; Sayers et al., 2013; Tucci, 2007; The World Bank, 2017)

During the implementation of adopted IFM measures, monitoring, evaluation, and incorporation of the acquired knowledge is a very important part of the process. Decisions based on knowledge and experience will serve as an instrument for dealing with uncertainties involved in flood management and risk assessment. This 'adaptive management' enhances the current practice whenever new knowledge and data are obtained. Learning from the differences between the expected and real outcomes changes plans and actions accordingly (WMO, 2009b).

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6 Best Practices on Flood Prevention and Protection

6.1 German Approach

In Germany, following flood disasters in the Elbe River Basin in 2002, the existing flood management model shifted towards IFM. Analysis of the flood management system in light of the later floods showed that incomplete or missing flood warning systems, poor maintenance of flood structures, lack of risk awareness, and inadequate response were the main weaknesses (DKKV, 2004). In the same document, the German Committee for Disaster Reduction (DKKV) highlighted three key elements of flood management:

- emergency response that should limit adverse effects of the flooding;
- recovery actions taken after the event for repairing damage and re-establishing the pre-event living standard;
- risk reduction through flood control measures to prevent inundation and adapted use of flood-prone areas.

Following those key findings, several preventive measures for the future IFM were proposed. The most effective measure for decreasing flood damage is the preservation of flood-prone areas that have not yet been built on. Alternatively, in flood-prone, largely built up areas, several preventive building design and management measures may be applied (elevated building configuration, buildings without cellars, permanent or mobile barriers, building usage adopted to flooding i.e. low value of utilisation in the endangered floors, coating with waterproof building material inside and out, etc.).

Other risk reduction measures examples are through financial instruments, such as insurance of the assets or flood fund, as well as non-financial tools such as establishment of the basis of common measures to minimise damage before the next event.

For the purpose of reduction of flooding volumes, several measures are envisaged. In the floodplains, more space for water is necessary in order to provide natural retention. Reforestation of arable land is conducted for the improvement of water retention capability and decrease of the runoff coefficient. Where appropriate, adaptive agricultural practices (i.e. growing particular crops that decrease runoff or are capable of retaining more water) on flood plains is planned in order to diminish flood hazards. All these measures can help during small to middle-size flood events, while for large events additional solutions must be applied, i.e. dams as a technical (traditional) measure for controlled water retention.

Early flood warning systems are recognised as important instruments for risk reduction. The prompt information that the proper functioning of this system can provide, ensures the successful application of emergency measures such as population evacuation and the heightening of floodwalls.

Despite the implementation of many of these measures, the biggest flood in hydrological terms for the last 60 years occurred in Germany in 2013. Even though flood damage was considerably lower (around €7 billion in comparison to €11 billion in 2002), the 2013 flood was more severe than the 2002 event (Thieken et al., 2016). This event constituted a further benchmark for post-evaluation of flood management changes implemented after the 2002 flood, revealing substantial flaws and required improvements, for example, the necessity to better connect flood hazards to spatial planning and urban development policies; to promote more comprehensive preparedness and mitigation measures within the properties and to adopt a more effective emergency system.

6.2 Making Room for the Rivers – Dutch Approach

The implementation of the *Room for the River Programme* (Ruimte voor de rivier, n.d.) started in 2007 and ended in 2015 by restoring the riverine natural floodplain in order to protect inhabited areas at risk.

Due to the fact that more than the 55% of Netherlands, one of the most densely populated countries on Earth, lies on floodplains, huge dykes prevent flooding by the major rivers. In addition, a complicated system of drainage ditches, canals, and pumping stations keep the lower parts dry for settlements and agriculture.

A growing awareness of the challenges posed by climate change influenced the Netherlands authorities to change the flood control strategy by giving more space to the river flooding rather than continuing to raise the level of dams. According to the *Room for the River Programme,* dozens of dykes have been moved back inland. The idea is to lower and broaden floodplains, build diversion channels, and provide temporary water storage areas while creating biodiversity, aesthetic, and recreational values.

'Making room for river' includes several actions that aim to provide more retention for increasing flood volumes (Zevenbergen et al., 2013). Floodplains are excavated to make new parallel channels for collection and conveyance of excess water. Temporary storage facilities are built where site conditions allow. Dykes are relocated inland, or strengthened where provision of room for rivers was not possible. To increase runoff capacity, riverbeds are deepened and all obstacles/objects along rivers are removed.

Room for the River is considered an exceptional programme because it brings together water management, spatial planning, and landscape design.

The evaluation of this integral approach showed that five main items are essential for its effective implementation (Zevenbergen et al., 2013):

- a clear vision for integrated flood protection;

- the accounting for multiple interests within the flood management process;
- a multi-level governance;
- design freedom in planning process;
- and adaptive management principles.

The programme's main goals are (a) flood protection – the reduction of the probability of flooding; (b) creation of the new or restoration of the old landscapes to increase their environmental value, (c) establishment of a multi-level governance aimed at strengthening the collaboration between national, regional, and local administrations.

6.3 Making Space for Water – UK Approach

In 2004, the UK Government published the *Making Space for Water* consultation document (DEFRA, 2004) as an answer to the severe flood events that occurred in 1998 and 2000.

In the context of increasing flood events and the need for adaptation to climate change, *Making Space for Water* aims to minimise the threat to people and properties from floods and to provide better and more sustainable environmental, social, and economic conditions through a comprehensive, integrated, and forward-looking approach.

The main principles within the new strategy (DEFRA, 2005) concern the integration of adaptive measures to climate change in the entire flood management process; the promotion of education, information, and flooding awareness-raising activities; and the integration of flood risk management in land use planning.

Concrete improvement solutions concern both rural (e.g. improving wetlands), urban (e.g. improving drainage system), and coastal (e.g. reshaping the coastal line) environments, aiming to increase or restore their ecological services and, at the same time, to deal with floods, coastal erosion, and other threats.

The possibilities for the restoration of natural defences aimed at decreasing and slowing down the flood runoff have been tested on various areas in different years. Encouraging results (Pilkington, Walker, Maskill, Allott, & Evans, 2012) anchored this idea within the *Making Space for Water* programme so that nature harnessing for flood defence, along with the exposure to floods reduction measures and living with floods principle form the main pillars of this approach.

6.4 Integral Urban Drainage Management – Blue Green Dream

The increase of impermeable surfaces in urban areas has a great impact on the natural environment and leads to a series of consequences. Waterproofing reduces the runoff to the subsoil layers that decreases the natural water table and generally alters the hydrological cycle. As the surface runoff increases, it generates a larger load on urban drainage systems causing floods during increased precipitation. This load often exceeds the maximum amount of stormwater that can be accepted by existing urban drainage systems, thus demanding costly interventions to increase its capacity.

This problem cannot be easily handled by conventional urban drainage systems. The *Blue Green Dream* project (BGD) developed by Imperial College London and funded by Climate-KIC (EIT) combines the best of the Nature Based Solutions (NBS) to achieve urban sustainability and climate change resilience (Božović et al., 2015). The BGD endeavours to develop a new planning system to increase urban resilience and decrease vulnerability to the negative effects of climate change and extreme weather conditions. The focus is on interactions between urban water infrastructures (i.e. urban drainage systems) and green infrastructures, additionally combined with other relevant urban ecosystems.

Dealing with this challenge implies achieving three main objectives:

- strategic spatial and urban planning;
- unification of communal services in the area of urban water systems, green areas and other urban ecosystems (water, food, energy, heat islands, air quality);
- efficiency of resource usage.

The achievement of those goals entails the abandoning of individual solutions and embracing integral, multidisciplinary planning and design with optimisation of interactions between urban ecosystems (urban solutions, green infrastructure, renewable energy, water cycle, pollution, building solutions). With this approach, multiple benefits may be obtained such as increased urban resilience to droughts and floods; reduced water and air pollution and reduced risk of heat waves; better health and comfort in cities; increased building energy efficiency; increased biodiversity and urban agriculture and improved general quality of life. Many BGD solutions serve the above goals: retentions/ accumulations; detention basins; constructed wetlands and biofilters; green areas that decrease the surface runoff; infiltration systems with treatment possibility; green roofs and green walls; water reuse systems; green streets for cooling and water retention and treatment; permeable parking lots and pedestrian areas; systems for increasing the energy efficiency of buildings (shading) and systems for decreasing air pollution and noise levels with vegetated panels.

In 2015, the United Nations Development Programme Bosnia and Herzegovina (UNDP BiH) started the project *Interactions of Flood Management and Innovative Spatial Planning* as a strategy for mitigation of climate change impact.

Within the framework of this project, the BGD principles have been used in the feasibility studies for two towns that were severely exposed to floods in the last decade: Srbac and Jajce. The BGD concept application was developed by Professor Čedo Maksimović from the Imperial College London. In the pilot project (Maksimović et al., 2015) for Srbac, a sports hall was renovated using EPA's Storm Water Management Model (US EPA, n.d.). The renovation, which was based on BGD, includes a green roof, rain harvesting system, and porous pavement for the existing car park (occupying only 20% of the overall asphalted area around the building), with the addition of vegetated infiltration trenches on the downstream side and routing the runoff from impermeable to permeable areas. The renovation substantially changed the appearance of the building and its surroundings (Fig. 3.1), while the stormwater runoff from this site, directed to a conventional drainage system, decreased by 88%.

FIG. 6.1 BGD reconstruction of the sports hall in Srbac *(Image by UNDP, 2015)*

In the municipality of Jajce, which was affected by severe flooding events from the Rika River, there is a plan to provide a multifunctional accumulation system for storing flood volume while simultaneously providing recreational and tourist facilities. Depending on the accumulation technical solution (dam height), the downstream runoff may be decreased by up to 65% and thereby will provide safer living conditions in the downstream settlement of Rika.

6.5 Best Practices Comparison and Discussion

The aforementioned flood management programmes represent good examples of the shift from traditional flood protection towards more flood resilient solutions. Generally, this approach can be called 'risk-based approach' or 'risk management' since the used strategies aim to reduce overall flood risk (de Moel, van Alphen, & Aerts, 2009) the EU has adopted a new Directive (2007/60/EC. However, these programmes reflect the IFM approach and cover some (or all) of the five flood management goals: prevention, protection, mitigation, preparation, and recovery.

The four programmes consider the integration between spatial/urban planning, ecological/landscape design, and flood prevention/protection measures as a prerequisite for their implementation. While in the German approach this is mainly oriented toward 'clearing' floodplains to reduce flood risk by reducing exposure, the Dutch approach envisages recreational, touristic, amenity, and other services within spaces anticipated for excess water.

In the UK's and BGD's approaches, the integration between spatial planning and flood defence measures, includes not only floodplains but the whole region, involving infrastructures and upper parts of the basin where substantial flood defence/prevention measures can be placed (e.g. accumulations, reforestation, etc.).

The BGD strategy deals with all consequences of climate change (such as heat or cold waves, extreme winds, etc.).

Non-structural measures are the least represented in the Dutch approach. The flood management still relies mainly on engineering works with one of the highest design return periods in the world (from 1/2500 to 1/10000) (Bubeck et al., 2015). The *Room for the Rivers* programme introduces the integration of the engineering works (expanding floodplains) with nature conservation and the provision for other uses of floodplains in dry periods (e.g. recreational, touristic, aesthetic). The underuse of non-structural measures is probably because of the high structural protection level developed over the last 800 years and the fact that flood probability is usually low (Klijn, Asselman, & Van Der Most, 2010), contrary to the level of awareness of the hydraulic risk by the population, which is very high.

Conversely, the German approach potentiates non-structural measures, especially for flood preparedness and recovery (early warning system, insurance). However, for large events, flood management still relies on structural works such as high dykes and large accumulation basins. In this regard, the UK approach is very similar to the German one.

The main difference is that usual flood protection measures are replaced with strategies to restore urbanised areas in order to mimic the natural runoff condition (i.e. natural hydrological cycle) and maximise natural flood protection systems. The *Making Space for Water* approach relies less on traditional structural measures and more on their sustainable alternatives, which are described in section 4.2. Similarly, the BDG approach comprises additional multifunctional elements leading to more sustainable solutions (e.g. by reusing excess floodwater to deal with other urban system problems).

7 Conclusions

Flooding is one of the greatest natural hazards that affect the global population. In the last 16 years, flood occurrence in Europe has doubled due to rapid urbanisation and climate change.

Floods are usually caused by heavy rainfall and torrential storms. Some of them occur due to anthropogenic causes such as dams or a dyke failure. Urban floods may be a result of poor drainage system design, maintenance, or lack of adaptability to changes.

Traditional flood protection measures mainly deal with the safety of people and protection of resources. The reliability of engineering works for flood protection started to be challenged by climate change and the consequences of human activities in areas that are considered as well-protected. This led to the reconsideration of the existing flood management approach in many countries (Bubeck et al., 2015) in favour of more sustainable and resilient solutions. While still necessary, traditional measures cannot provide absolute protection and need to be amended to achieve more flexible flood protection and mitigation solutions, water quality improvement, amenity, and improvement of overall living conditions.

Integrated Flood Management (IFM) provides a holistic approach that combine structural and non-structural strategies and, therefore, covers all aspects on the flood 'timeline': preparedness; prevention; protection; mitigation; recovery; and post-flood updating. Mitigation and non-structural flood protection measures tend to be more efficient and long-term sustainable solutions. However, structural solutions for flood protection remain very useful, especially for existing settlements.

Several important key actions define a successful IFM programme: managing the hydrological cycle; integrating spatial planning and flood management; managing risks and uncertainties; adopting the best combination of flood protection strategies and measures; ensuring a participatory and multi-hazard approach.

Land use planning can enhance flood mitigation in flood-prone areas by regulating locations, uses, and structural measures. This plays a central role in flood management due to several important reasons: land use type has a significant effect in runoff generation that defines flood magnitude; the implementation of flood protection structural measures has to be incorporated into land use planning process for current and future developments; susceptibility to damage can be reduced through land use regulations (e.g. land use in floodplains). Moreover, the integration of flood protection measures in urban plans should provide multi-functionality along with amenity and appealing landscapes.

The successful implementation of IFM programmes requires clear institutional roles and functions, coordination at all levels of authority within the basin, coordination between sectors, a multi-disciplinary approach, information sharing and management, upgrading of IFM according to knowledge base development, and changing conditions within river basins.

Flooding is a natural component of the hydrological cycle. However, the frequency of their occurrence increased significantly due to

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changes of climate and land use. The problem is further enlarged with the poor management of territories and resources located in risk zones. Unfortunately, in many cases, it is only after large floods and associated hazards that flood management is prioritised in the political agenda of governments and local administrations. However, risks and consequences of floods can be diminished through good flood management that follows the principles of IFM presented in this paper, which will no doubt continue to be improved and developed in the future.

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