

# Sustainable integrated land-use plan and flood risk management: A review

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**Abstract.** Floods have always been the natural disaster causing the greatest loss of human life and economic damage across the globe, at local and global levels. Several studies suggest that for many river basins, flood risk will further increase during the 21<sup>st</sup> century as a result of not only climate change but also economic development and land-use changes. Land-use changes can influence several surface and near-surface hydrological processes. These processes may include evapotranspiration, interception, infiltration, overland flow, surface and subsurface runoff and surface retention. It is also important to analyse the spatio-temporal dynamics of flood exposure due to urban development along the rivers as well as other areas upstream and downstream. In this paper, we review the impact of land-use change process on flood damage potential and discuss measures to manage flood risk. The main contribution of this paper is to highlight a general evolution of flood prevention policies, from a techno-centred approach towards a preventive integrated sustainable flood and land-use management approach.

**Keywords:** flood risks, flood prevention policies, land-use changes management

## 1 Introduction

In modern times, ongoing urban development put natural resources under considerable pressure. This affects the environmental systems causing an increase in frequency and magnitude of natural disasters from which flooding is the greatest worldwide. About 233 out of the 633 largest cities in the world are threatened by flood, affecting about 663 million inhabitants (UN, 2012).

Widely, floodplain areas have been preferred for economic and residential uses, which increases risks to the urban development process with serious socioeconomic consequences. To this end, flood risk raises remarkable interest in research worldwide (e.g. Ali, Khan, Aslam, & Khan, 2011; Beckers et al., 2013; Bronstert, Niehoff, & Bürger, 2002; Bryant & Rainey, 2002; Dutta, Herath, & Musiaka, 2000; Lee & Lee, 2003; Poelmans, Van Rompaey, & Batelaan, 2010; Pottier, Penning-Rowsell, Tunstall, & Hubert, 2005; Wheeler & Evans, 2009).

Taking a closer look at the issue of flood risk, there are two major aspects that link land-use and flooding: (1) the development of land has consequences on the flow of water by changing water runoff rate through reducing the infiltration capacity of soils; and (2) the location of economic elements on floodplains that provides economic benefits and at the same time creates risks for the society in terms of flood exposure.

Flood risk management strategies have been discussed extensively (e.g. Fleming, 2002; Kellens, Zaalberg, Neutens, Vanneuville, & De Maeyer, 2011; Plate, 2002; Pottier et al., 2005). Flood risk management provides a framework for capturing, weighting, and addressing the flooding risk to minimize its impacts. Under normal circumstances, a clear division exists between water and land. During flooding, the water regime expands to temporarily inundate land. Therefore, in many countries, like The Netherlands and France, flood risk management plan involves both land-use management and water management.

For several decades, structural flood controls, e.g. embankments, were the main measure introduced in flood risk management strategies to reduce flood risk. Recently, these structural controls

have been criticised in many regions due to their impacts on environment and society, e.g. higher dikes means more devastating floods when dikes fail. Therefore, in a modern framework of flood risk management, there is a trend to develop integrated flood risk management strategies covering socio-economic and environmental responses. These modern strategies also consider that the future generations should have a possibility to reconsider their options and set their own priorities according to the prevailing value system of their time. This trend leads to shifting from non-removable flood controls to sustainable flood management process as response to changes in environment and the community. As a result, the integrated strategies covering planning practices in the different sectors and groups dealing with land-use planning on the one hand and flood protection or flood risk management on the other.

This paper provides an overview of the link between land-use and flood risks; and land-use planning instruments that necessitate a linkage of land-use planning in integrated flood management context.

## 2 Effect of land-use changes on flood hazard

The interactions between land-use changes and water regime has severe impacts on the surface water balance. The most common land-use change trend is changing from natural cover into built-up cover. At a catchment scale, the evaluation of land-use changes impact on flooding requires an understanding of the relevant storm runoff generation mechanisms for both catchment characteristics and precipitation conditions (Bronstert et al., 2002). Generally, these impacts could mainly influence fluxes of evapotranspiration, groundwater recharge and surface runoff (Laconte & Haimes, 1982; Poelmans, 2010).

Taking land-use change as the process and water regime as the product, changing natural surface into built-up land will reduce the interception of precipitation and the water storage which has a direct effect on the amount of water that is immediately available for evapotranspiration (Bronstert et al., 2002; Poelmans, 2010). This conversion also decreases groundwater recharge rate which may has a strong negative impact on surface runoff.

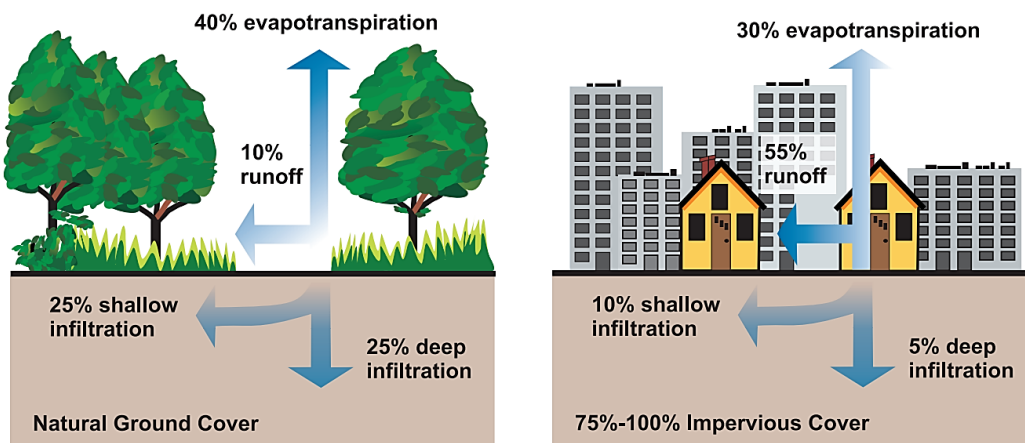


Fig. 1. Relationship between land cover and water run-off (source: US EPA, 2003)

In Europe, the urban development process is strong in dense metropolitan areas like North West Europe (EEA, 2006) due to the concentration of population and economic growth in those areas. For instance, the area of built-up lands increased by 30% between 1980 and 2009 in the Walloon, Belgium (CPDT, 2011). This leads to increased flood risks in many regions in Europe in the years to come.

## 3 Impact of land-use on flood damage potential

Next to land-use induced changes to the characteristics of the flood risk, the way that land-use are occupied has a major influence on the flood damage potential and the degree of vulnerability of local

communities. Urban developments along rivers induce a higher exposure to risk of newly developed areas, with subsequent increases in the value of elements-at-risk.

The overall economic output from floodplain areas can be significantly higher than in other areas. That can be proved from the high population densities within different floodplains over time. Consequently, decision makers seek not only to minimize impacts of floods, but also to maximize the utilization of the areas at the floodplain.

Flood damage potential can be defined as the extent of possible damage in a given flood exposed area. This damage can come in various forms to different elements such as buildings, goods, crops, etc. By taking decisions on land-use and on placing such elements on land liable to flooding, humans can have an influence on the flood damage potential (APFM, 2007). The assessment of flood risk involves three steps: (1) future flood hazard assessment, (2) future exposure assessment and (3) future flood damage assessment (Beckers et al., 2013).

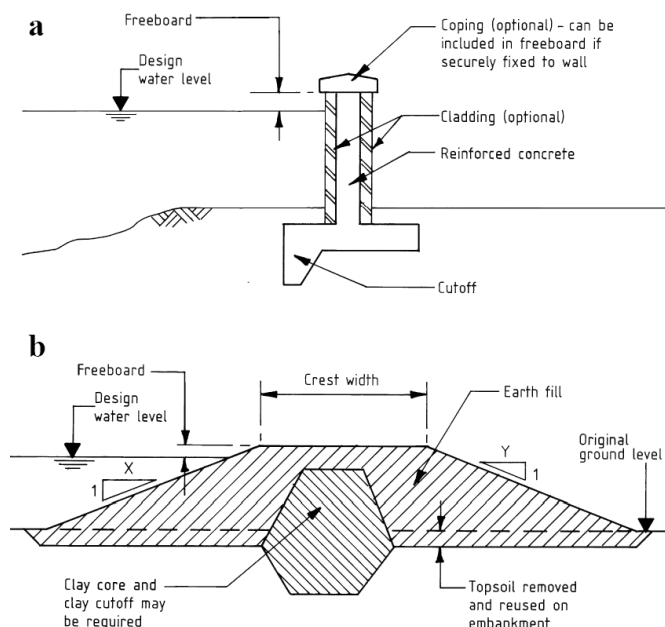
Exposure assessment identifies elements that are affected by a certain flood scenario. These elements are commonly extracted by intersecting land-use data with inundation data by means of operations within a geo information system (Merz, Kreibich, Schwarze, & Thieken, 2010).

Besides the direct damages caused by the physical contact with water, floods also trigger a chain of indirect economic damages due to the interruption of some activity by the flood, e.g. reduced economic activity or traffic disruption. Contrary to the assessment of direct damages, indirect damages are more difficult to quantify as they may have effects on time scales of months and years (Merz et al., 2010).

## 4 Flood management strategies

Flood risk management puts emphasis on controlling the overall flood disasters in the sense of being prepared for a flood and to minimize its impact as much as possible. This process includes risk analysis and management. In this paper, we limit our attention to the main options for flood protection systems.

Flood structural defense alongside water channels is one of the most common measures available in the light of flood risk controlling. It refers to a massive construction to keep water flow within banks and to pass the problem to downstream areas. It mainly includes floodwalls and embankments.



**Fig. 2.** a. typical floodwall, b. typical flood embankment (source: UK EA, 2010)

One of the main challenges with this kind of flood controls is the poor aesthetic and impact on place-making, accessibility and legibility. These structural defences need to be incorporated into the land-use planning process to safeguard spatial requirements of those measures (APFM, 2007). Be-

sides this, it can be observed than when these technical devices come to fail, because of collapse or lack of capacity, they tend to worsen the impacts of flood. The cost and lack of reversibility of these measures is another major source of concern.

#### **4.1 Towards an integrated and sustainable approach to flood management**

The concept of sustainability is a development process that meets the needs of the present generation without compromising the ability of future generations to meet their needs. It has three main inter-related pillars: economic concerns, social concerns and environmental protections. While constructing a flood protection measures to meet our needs, sustainable concept requires us to consider that future generations may have other needs or knowledge. Therefore, current management measures should not be immutable, such as constructing irremovable structural defences or soils that are permanently degraded (Plate, 2002).

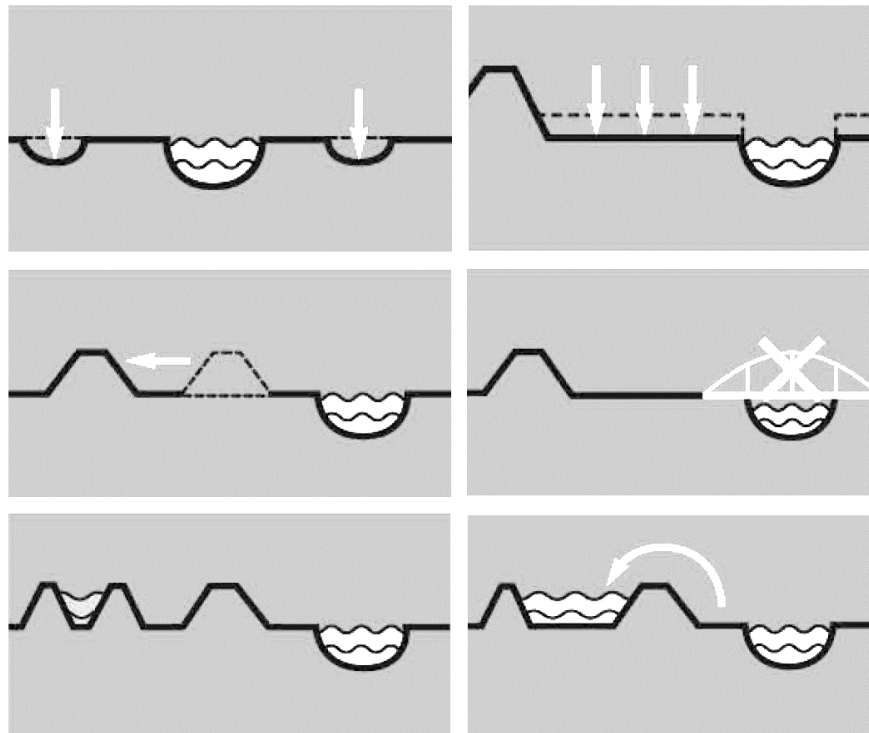
Traditional structural flood measures face serious opposition related to environmental concerns and the vulnerability degree of socio-economic system to the flood risks. The structural measures cut off the natural interaction between water and land. As a result, this reduces wetlands and weakens riparian border fauna and flora in many regions causing great concern of environmentalists (Plate, 2002). On the other hand, these structural protections do not provide the best solution in terms of flood vulnerability. Vulnerability refers to the degree to which a socio-economic system is resilient to cope with the impact of flood risks (APFM, 2007). A resilience shows the ability of the flooding management system to cope with the risks while remaining functional (APFM, 2007; Lu & Stead, 2013).

Recently, a sustainable development perspective has been brought into the flood management domain through developing integrated flood risk management plans, covering prevention, protection and preparation. In the European Floods Directive, such integrated plans are introduced (EEA, 2015). This directive was an initiative of The Netherlands and France (IENM, 2012). Both countries have successful flood risk management plans.

Land-use planning controls the flood risks through several measures including prohibiting constructing buildings in flood prone areas, multifunctional land-use, building codes, etc. Regulating land-use could imply that only open space land-uses would be possible in high risk areas. For instance, since 1996 all constructions in the flood prone areas in The Netherlands have been prohibited for the Rhine and the Meuse rivers up to the Estuary and the city of Dordrecht. In 2009, the Zwarte Water, Zwarte Lake and the enclosed estuaries of the Rhine and Meuse rivers were included as well (IENM, 2012). In France, a specific planning system to control the existing and future land-use and buildings in areas liable to natural hazards, including flooding, has been launched and constantly improved. These plans including predictable natural hazards plans (1984–1995) and the prevention of predictable natural hazards plan, since 1995. Both plans centrally set measures that applied to prohibit or authorize the development within the hazard zones at the local level of the municipalities (Pottier et al., 2005).

After the 1995 floods in The Netherlands, the Dutch government evaluated the overall flood management strategy. All flood structural defences along the Rhine and Meuse rivers, were assessed and restored, if necessary, so they met The Netherlands's safety standards. They also concluded that the discharge rate in the hydraulic boundary conditions in the Rhine and Meuse rivers had remarkably decreased. To compensate for this decrease in discharge rate, a paradigm shift was introduced. The Dutch government launched new strategies that mainly integrated land-use in flood management plan. One of these strategies is 'Room for the River' project established in 2001. It has a national budget of about 2.2 billion Euros (IENM, 2012). The main purpose of the project is lowering the design water levels and improving the natural landscape along the rivers. In this project, instead of raising the structural defences, a range of measures are implemented to create more space for the rivers and reduce high water levels, such as lowering the floodplains, relocating structural defences further inland, lowering groynes in the rivers and deepening the summer beds (figure 3). They decided that the reinforcement of structural defences is a measure that will be implemented only when the alternatives are too expensive or inadequate (EEA, 2015; IENM, 2012). One of the widespread alternatives measures in this project is storing water on farmland. Water storage on farmland refers to overflow polders and retention areas, where the land remains property of the farmer and is used for temporary water storage in extreme flooding. Retention areas are meant to receive the peak discharge of rivers to prevent flooding on other areas. The compensation to farmers for water storage on their own farms may consist in an annual compensation for damage to crops (EEA, 2015). Another measure that in-

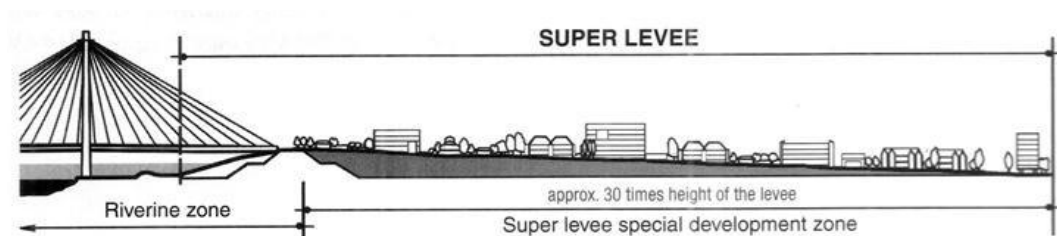
roduced is relocating of the most sensitive land-use types, e.g. residential uses, to the areas with the lower flood risk. The adaptation of land-use allocation policies will gradually cause an increase of the urban and economic development in lower risk areas. Subsequently, higher risk exposed areas may become subject to more natural hydrological regimes with time and may thus restart to function in a natural way as water storage areas that can relieve the pressure of inundation threats elsewhere (EEA, 2015).



**Fig. 3.** Different measures to create more room for the river; side channels, lowering of the floodplain, dike relocation, removing obstacles, a bypass, an emergency flood storage area (source: (IENM, 2012))

The integrated approach, however, is not restricted to the Netherlands and its measures apply in several countries. For instance, France recently starts giving explicit priority to integrated non-structural flood protection measures over structural measures and the two main measures in this respect are more rigorous land-use regulation and a compulsory flood insurance (Pottier et al., 2005).

Another measure in this context is a multifunctional land-use. Figure below shows an example of the multi-functional land-uses include the use of water storage areas for recreational purposes under normal circumstances, such as parks, nature reserves and outdoor sports facilities.



**Fig. 4.** Super levees in Japan (source: Watson & Adams, 2010)

From economic point of view, it becomes apparent that in the land subject to flooding is increasingly used with higher risk uses. In such a case, constructing flood resistant buildings provides a successful solution, such as wet-proofing, constructing based on elevated ground, orientation of the building to minimize flood obstruction or built on stilt. Recent technological advances also provide other options such as demountable flood defences that could be applied in very sensitive urban loca-

tion, e.g. historical centres. This type of temporary defence will only be erected in case of flood warning (Fleming, 2002).



**Fig. 5.** Pile House, designed to be safe and dry under the highest anticipated water level (source: water studio, The Netherlands)



**Fig. 6.** A typical air or water filled tube (demountable flood defence)

## 5 Conclusions

This paper has introduced a brief review of the links between flood management and land-use planning. Table 1 shows the main roles of land-use planning in different flood management strategies.

**Table 1.** Strategies and Options for Flood Management (source: APFM, 2007)

Strategy	Measures
Minimizing hazard	Saving the spatial requirements of structural measures Catchment management
Minimizing vulnerability to damage	Controlling development within floodplain Location of facilities Building codes Flood-proofing
Preserving the natural environmental system of floodplains	Balancing the development requirements

It was found useful to consider an integrated land-use and flood risk management strategy. This integrated strategy was found to minimize flood hazard through mainly reducing peak discharge due to lower runoff rates caused by higher infiltration capacities. In such integrated strategies, particular concerns regarding protecting environmental system, economic and social interests have been involved. Therefore, these strategies are considered as a sustainable flood management plan. It needs to be stressed that only a best mix of the measures is applicable to a specific floodplain based on its own

characteristics. It is also important to note that with integrating changes in flooding magnitudes and frequency with a specific land-use change plan, it is hard for all other possible factors that might influence flood generation to be constant. However, we limited this paper to the integration between land-use and flood management plans without considering other factors.

In our research project named 'land-use change and future flood risk: influence of micro-scale spatial patterns' we model the future flood risks for a long time horizon up to 2100 considering the complete risk chain, from climate impact, via hydrological and hydraulic modelling, to land-use changes and damage estimation. The analysis is performed at two spatial levels: catchment level and building level. We also consider that our knowledge of the future is inherently limited. Consequently, we put a strong focus on modelling uncertainty in each components of the project. For land-use change modelling component, we consider two main scenarios for the future changes (1) business-as-usual scenario and (2) sustainable land-use changes scenario.

**Acknowledgments.** The research was funded through the ARC grant for Concerted Research Actions, financed by the Wallonia-Brussels Federation.

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