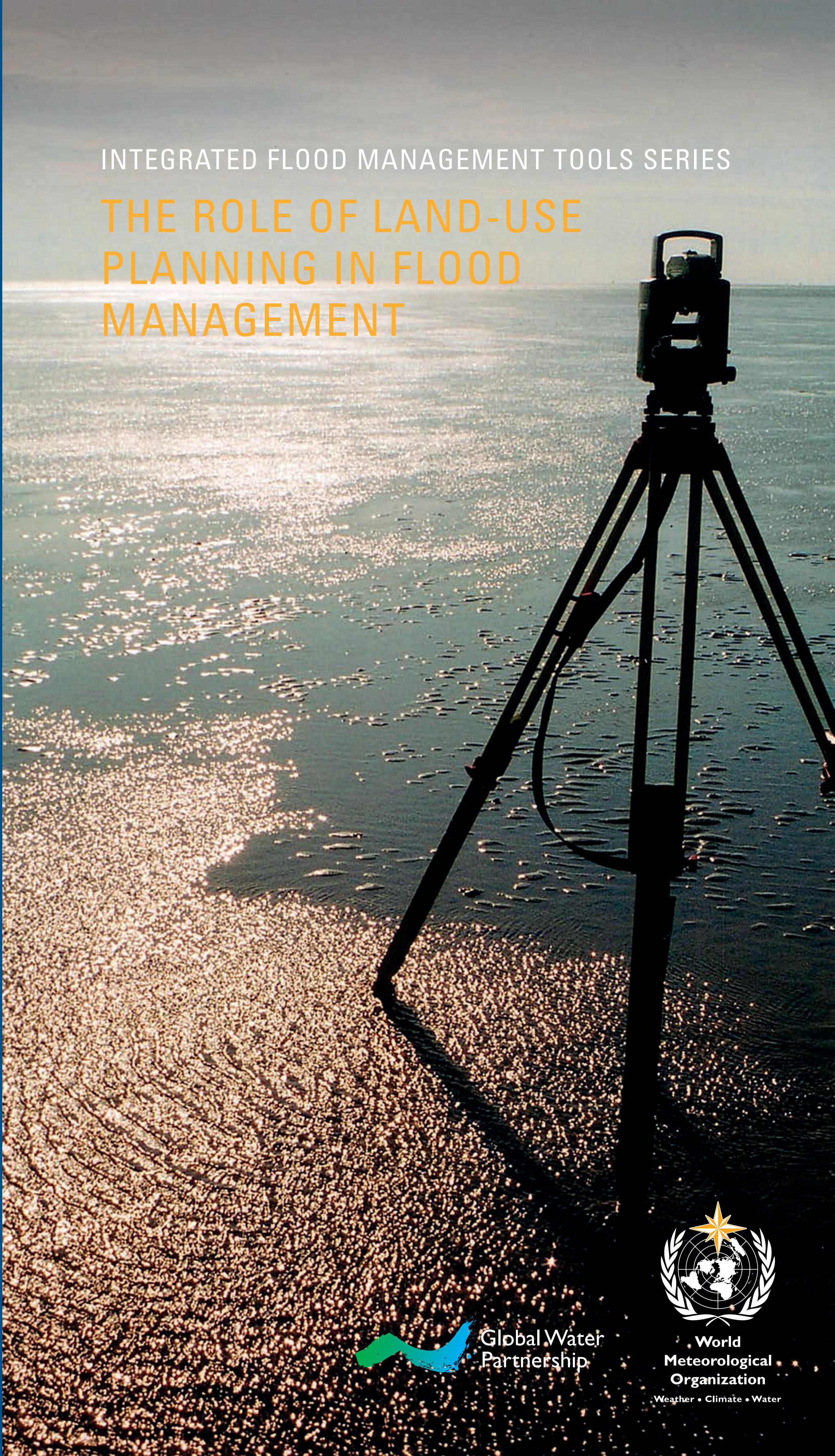
ASSOCIATED PROGRAMME
ON FLOOD MANAGEMENT

INTEGRATED FLOOD MANAGEMENT TOOLS SERIES

THE ROLE OF LAND-USE PLANNING IN FLOOD MANAGEMENT



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Weather • Climate • Water

The **Associated Programme on Flood Management** (APFM) is a joint initiative of the World Meteorological Organization (WMO) and the Global Water Partnership (GWP).

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To the reader

This publication is part of the *"Flood Management Tools Series"* being compiled by the Associated Programme on Flood Management. The *"Role of Land-Use Planning in Flood Management"* Tool is based on available literature, and draws findings from relevant works wherever possible.

This Tool addresses the needs of practitioners and allows them to easily access relevant guidance materials. The Tool is considered as a resource guide/material for practitioners and not an academic paper. References used are mostly available on the Internet and hyperlinks are provided in the *References* section.

This Tool is a *"living document"* and will be updated based on sharing of experiences with its readers. The Associated Programme on Flood Management encourages disaster managers and related experts engaged in in the development of risk maps with regard to floods and other hazards around the globe to participate in the enrichment of the Tool. For this purpose, **comments and other inputs are cordially invited**. Authorship and contributions would be appropriately acknowledged. Please kindly submit your inputs to the following email address: apfm@wmo.int under Subject: "*Role of Land-Use Planning in Flood Management"*.

Acknowledgments

This Tool makes use of the work of many organizations and experts as listed in the references. Special acknowledgements are due to Ms Charlotte Poussin, main author of the second edition of this publication, for her valuable expertise and great dedication under the technical guidance of the APFM Technical Support Unit.

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1 INTRODUCTION

1.1 General Context

1 Global changes over the years, changing social requirements and views necessitate a revision of flood-risk management strategies in the long term (Klijn et al., 2004). Furthermore, climate change and current developments, such as population growth and connected issues of food security and urbanization, are putting land and water resources under considerable pressure: the causes of floods are shifting and theirs impacts on society are accelerating (Jha et al., 2012).

2 The influence of land-use changes on flood risk is now a central feature of flood-management discussions. Indeed, numerous studies have been carried out to understand how land-use changes, in particular deforestation, urbanization and agricultural practices, may increase the occurrence and intensity of floods, together with exposure and vulnerability of people thereto (Ramesh, 2013).

3 There is evidence that land-use changes have altered runoff-generation processes and the flooding regimes of river basins (Bronstert et al., 2002; Ghosh and Dutta, 2011; Ramesh, 2013; Beckers et al., 2013; Santato et al., 2013). Indeed, modern land-use practices have accelerated runoff through reducing the infiltration capacity of soils or obstructing the natural drainage system. Furthermore, man-made land-cover changes have disturbed erosion and sediment dynamics.

4 Looking at the historical development of societies, it becomes evident that floodplain zones have been a privileged area for human settlement as they offer numerous opportunities, in terms of available natural resources, in the economic, social or environmental domains. Although living on floodplains has great advantages, their occupants are exposed to many disturbances, such as floods. This generates a risk for society in terms of flood loss and damage potential. There is a tendency to accumulate economic values on floodplains, in particular in the form of “urban uses” encroaching on the floodplain. In some parts of the world, this has led to a discussion on acceptable levels of flood risk. This increase in exposure and vulnerability has led to considerable changes in national flood-management policies towards limiting flood-damage

potential by land-use planning policies. The increase of flood risk is therefore directly linked to the increase of property values and human occupancy in flood-prone areas, the lack of access to information, and deficiencies in urban planning and governance (UNECE HLM and CERG-C, 2015).

5 Now that land use is recognized as playing an essential role in flood exposure and susceptibility to damage, calls have been made to interlink and harmonize land-use management and flood-risk management. Indeed, through the adoption of planning practices built from the natural sciences and related studies on natural hazards and risks, flood risk may be mitigated or avoided (UNECE HLM and CERG-C, 2015).

6 In its worst form, a traditional and reactive approach would be to build infrastructure on flood-prone land without knowledge of the prevailing flood hazards and providing local flood defences once flooding has occurred. Instead, the approach promoted in this Tool – and largely recognized as the way forward – is to take development decisions based on the knowledge of the prevailing and expected future risks and to adapt development planning according to the degree of risk faced and the risk a particular society is willing and able to accept. Integrated flood management (IFM) as a development policy concept calls for a balance between development needs of society and flood risks oriented towards the maximization of net benefits derived from floodplains to ensure sustainable development (WMO, 2009).

7 Aims and target groups

8 The primary objective of this publication is to introduce the role of land-use planning in flood management. This Tool aims to:

- Identify the link between land use and floods and integrate it as part of the management of the water cycle as a whole (not only the water system);
- Identify processes and policy principles that necessitate a linkage of land-use planning in IFM;
- Identify the impacts of land-use changes on flood risk;
- Provide an overview of land-use planning instruments considered applicable in the flood-management context;
- Identify the challenges and opportunities provided by good flood management and its socioeconomic and environmental consequences in a specific context;
- Provide guidance on how those sectors can work together.

9 This publication focuses in particular on flood hazards in riverine and urban flooding contexts. The issues in the context of other flood hazards, such as coastal flooding, are covered in other Tools available in the APFM Flood Management Tools Series. Other APFM documents providing information and analysis regarding economic, social, environmental and legal aspects of flood management are available from the APFM Helpdesk (www.floodmanagement.info). Information and insights from these publications and other sources will be incorporated or referenced here, with examples.

10 This Tool is written primarily for flood managers at municipal and higher administrative levels to facilitate the necessary dialogue with land-use planners at the local, regional and catchment

levels, urban and agricultural planners, transportation planners, developers of individual land parcels, etc.

11 **Chapter 2** exposes the concept of flood risk through the notion of flood hazard, vulnerability and exposure and how land use interacts with each of those elements. **Chapter 3** subsequently examines the processes of flood management and land-use planning to provide a better understanding of possible points of interaction between those and the prevailing challenges faced in doing so. **Chapter 4** highlights the legal and institutional framework requirements and enforcement aspects to integrate land-use planning strategies in an IFM scheme. **Chapter 5** provides an overview of various paths for government interventions for managing development under flood hazard conditions, as well as a number of major practical issues that need to be considered in the intervention process. Finally, **Chapter 6** emphasizes the important aspects covered throughout this publication to understand the role of land-use planning in flood management and to implement appropriate land-use planning to reduce risks associated with flood hazards.

2 LAND USE AND FLOOD RISK

2.1 Visiting terminology

12 For closer coordination between flood management and land-use management and to understand correctly the role of land-use planning in flood management, it is paramount to have a thorough understanding of these topics.

2.1.1 Land-use planning

2.1.1.1 Land-use

13 Land use is characterized by *"the total of arrangements, activities, and inputs undertaken in a certain land cover type (a set of human actions) to produce, change or maintain it"* (FAO/UNEP, 1999). It is also possible to use the term "land use" in the sense of the social and economic purposes for which land is managed (e.g. grazing, timber extraction and conservation) (IPCC, 2000).

14 This publication mentions several times the concept of land use changes that refers to *"a change in the use or management of land by humans, which may lead to a change in the observed physical and biological cover of the Earth's land, as vegetation or man-made features"* (IPCC, 2000).

2.1.1.2 Land-use planners

15 Land-use planners play various roles in integrating different disciplinary perspectives into planning and plan-making activity. The role of the planner varies according to the context, but in all situations he/she has to provide relevant information and technical expertise to create programmes and plans for land development and usage (Randolph, 2004).

2.1.1.3 Land-use planning

16 In view of land scarcity and global changes such as demographic shift, land-use planning aims to make the most efficient use of limited resources to serve society in achieving its economic, social and environmental goals. Indeed, land-use planning is *"the process undertaken by public authorities to identify, evaluate and decide on different options for the use of land, including consideration of long-term economic, social and environmental objectives and the implications for different communities and interest groups, and the subsequent formulation and promulgation of plans that describe the permitted or acceptable uses"* (UNISDR). *"The driving force in planning is the need for change, the need for improved management or the need for a quite different pattern of land use dictated by changing circumstances"* (FAO, 1993).

17 In other words, it is the land-use planning regulations that establish the basis for the kinds of uses and activities permitted in the floodplain (WMO, 2012b). Depending on the country and the context where this term is used, the meaning varies and can take various designations, such as regional planning, urban planning or spatial planning.

18 Spatial planning is critical for delivering economic, social and environmental benefits by creating more stable and predictable conditions for investment and development, by securing community benefits from development, and by promoting prudent use of land and natural resources for development (UNECE, 2008).

19 **Figure 1** is an example of a land-use planning map, showing the possible land-use allocation beyond 2030 realized by the Ministry of National Development of Singapore.

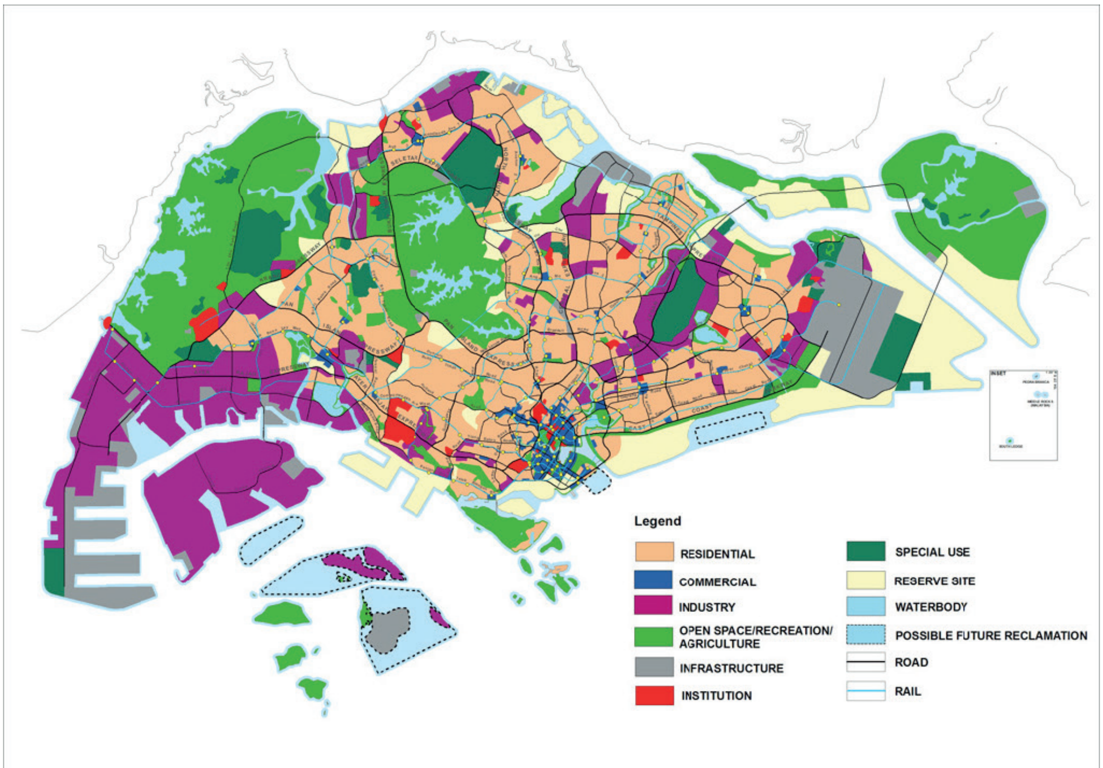


Figure 1 — Land-use plan developed by the Ministry of National Development of Singapore (Ministry of National Development, Singapore, 2013)

2.1.2 Flood management

2.1.2.1 Flood

20 Floods are natural phenomena, related to the natural regime of a river (WMO, 2012b). Floods occur when flows in a river, stream or other body of water surpass their carrying capacity, causing water overflow to the adjacent lands and inundation (WMO, 2006e). More particularly, in the context of land-use changes, *"flooding is generated when landscape runoff delivered to the channel network exceeds its capacity to convey runoff to the catchment outfall, leading to the inundation of rural and/or urban riparian/floodplain areas"* (O'Connell et al., 2007, p. 96).

21 This natural event results from various meteorological, hydrological and human factors, such as excessive rainfall or snowmelt or a reduction in a river's conveyance capacity due to siltation, ice jams or inadequate land-use practices **(Table 1)**. Indeed, as will be discussed in Section 2, land-use changes in the catchment area and floodplains also affect natural frequency, intensity and general characteristics of flooding (WMO, 2006e; Beckers et al., 2013; Ramesh, 2013; Konrad, 2014).

Table 1 — Factors contributing to flooding (WMO, 2006e)

Meteorological factors	Hydrological factors	Human factors
— Rainfall — Cyclonic storms — Small-scale storms — Temperature — Snowfall and snowmelt — Cyclones	— Soil moisture level — Groundwater level prior to storm — Surface infiltration rate affected by vegetation, soil texture, density, structure and soil moisture — Presence of impervious cover such as snow and ice — Channel cross-sectorial shape and roughness — Presence or absence of overbank flow, channel network — Synchronization of runoff from various parts of watershed	— Land-use activities such as urbanization increase runoff volume and rate — Occupation of the floodplain obstructing flows — Structural flood-control measures such as embankments upstream — Greenhouse-gas emissions which may affect climate change and frequency and magnitude of precipitation events. — Decrease in conveyance of the river channels owing to build-up of river debris, restriction of waterways, dumping of minerals, rubbish and other waste — Mining and other industries alter water regimes, pollute water channels and affect ecosystems; can also alter water courses.

2.1.2.2 Flood management

22 The concept of flood management varies depending on the country where it is carried out and the overall aim that is given to flood-management policy. For example, in some countries, the term "flood management" is used synonymously with "flood control", emphasizing the control approach focusing on river engineering and structural flood-management measures. While those structural measures also form part of flood management, the control approach is slowly losing the central position. Societies increasingly recognize that floods can be controlled only to a limited extent and that a residual risk of flooding always exists (see **"Flood risk"** below).

23 This publication focuses more specifically on the IFM approach (the concept of IFM is explained in the Concept Paper (WMO, 2009) and discussed in a variety of APFM documents). IFM is a process promoting an integrated – rather than a fragmented – approach to flood management within the framework of Integrated Water Resources Management **(IWRM)**. It integrates land and water resources management in river basins and coastal areas in order to maximize the efficient use of floodplains while minimizing loss of life and property from flooding (WMO, 2009) **(Figure 2)**. As opposed to traditional flood-management options, IFM is a proactive approach with systematic actions in a cycle of preparedness (to ensure effective response), response (to reduce adverse impacts during flooding) and recovery (to increase the resilience of affected communities).

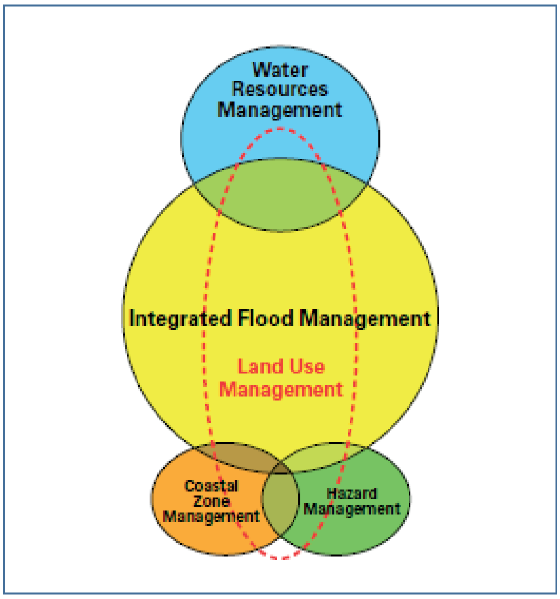
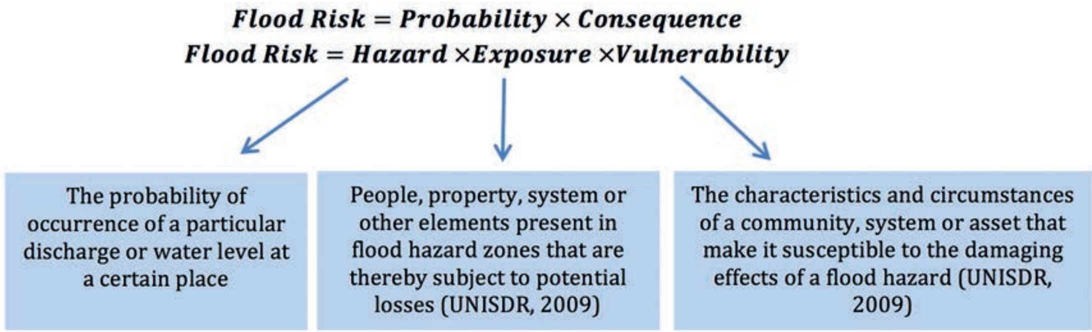


Figure 2 — Representation of the integrated flood management approach (WMO, 2009)

24 Taking a wider view of the interactions between land and water environments within a river basin, and of the broader socioeconomic and environmental implications of floods, the IFM approach provides a sound conceptual basis to bring about a convergence between land-use planning and flood management.

2.1.2.3 Flood risk

25 Flood risk is a function of hazard, vulnerability and exposure as indicated below.



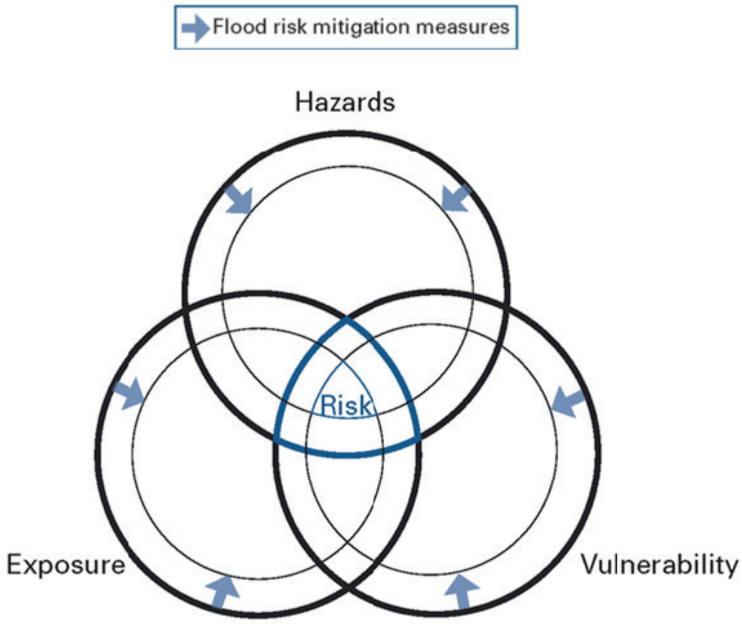


Figure 3 — Concept of flood risk and its reduction (WMO, 2009)

26 As the flood-risk definition indicates, risk mitigation addresses all three components of risk: hazard, exposure and vulnerability. These are linked to many different fields, including purely technical or engineering problems, as well as other environmental, socioeconomic and policy aspects. Therefore, in order to mitigate flood risk, it is essential to consider each component of the risk equation and to identify a best mix of actions comprising both structural and non-structural measures, such as land-use planning regulation and activities involving the general public **(Figure 3)**. Societies have to cope with flood hazard by attempting to reduce risk to an acceptable level. This "acceptable level" varies according to the perception of the risk of a given society and should therefore be adapted to the community concerned by the flood problem. As mentioned earlier, it is important to keep in mind that, despite various mitigation measures, a residual risk cannot be avoided.

2.2 Planning processes

27 As land-use planning has a significant role to play in flood-risk management, in particular by regulating land-use changes in flood-prone areas, both processes have to be interdependent. Flood management should be taken into account at all levels of planning, including flood information in all plans and programmes. Indeed, information-sharing about river flow and how it is affected by land use can help communities and urban planners decrease their current and future risk of floods (Konrad, 2014).

2.2.1 Land-use planning processes

28 Land-use planning processes involve many different stakeholders such as land users, decision-makers and the land-use planning team itself, to work together towards common goals. These planning processes also take place at various levels of government, usually with increasing levels of detail and decreasing administrative scale, as shown in **Figure 4**.

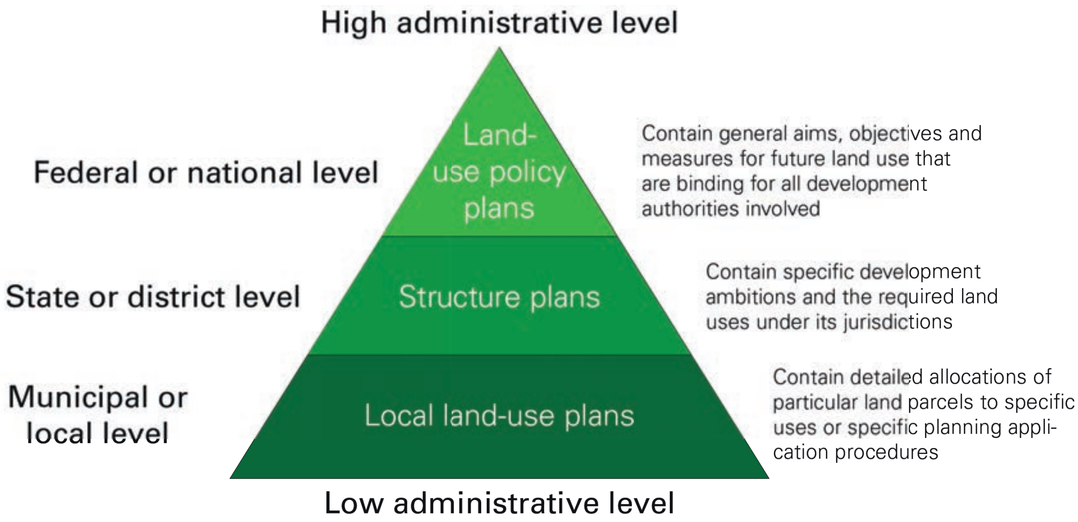


Figure 4 — Administrative levels involved in land-use planning

29 At the local level, plans may be prepared as "comprehensive layout plans" which provide strategies of land-development management in a community (Burby, 2000). Indeed, comprehensive plans have the advantage of *"taking into account wider arrays of community goals for urban development and of discovering the potential for accommodating urban growth in areas outside of the floodplain"* (Burby, 2000). Those plans are usually binding for the landowners or promoters concerned. Such comprehensive local development plans are, for instance, used in various parts of the USA. Even though varying in emphasis in different locations, such plans usually contain information on community infrastructure (schools, hospitals, civil defence, etc.), transportation, housing and neighbourhood development, cultural heritage, environmental assets and conservation sites, and economic development (Burby, 2000). Sometimes they also have a specific component on flood hazards and risks. An example of a comprehensive plan incorporating notions of hazard mitigation is provided in **Annex 1**.

2.2.2 Flood-management planning

30 The development of a flood-management planning process is generally triggered by certain large flood events causing extensive economic, social and environmental consequences (WMO, 2007). Flood-management plan processes, such as land-use planning processes, should involve all organizations, institutions or communities that could affect or be affected by the hydrological processes of the river basin. Also, they are developed at different administrative levels as part of sectoral planning. These include:

- Basin or Catchment Flood Management Strategy;
- Basin or Catchment Flood Management Plan;
- Local Floodplain Management Plan;
- Project Plan.

31 The different plans vary largely according to spatial and temporal scales. The first two are prepared for areas of similar size and with substantial time horizons (up to several decades). For more information about basin- or catchment-management plans, see the Tool Formulating a Basin Flood Management Plan (WMO, 2007). The latter two types of flood-management plans are prepared on rather small spatial scales and timescales of months or a few years. In these local plans, a variety of specific issues can be addressed such as flood-hazard mapping needs, regulatory standards and procedures, areas where repeated flood losses have occurred, local flood-defence requirements, river-bed corrections and adjustments, etc.

2.2.3 Other related planning processes

32 Depending on the context, various other sectoral development plans may be of interest in flood management, in view of their relation to flood risks:

- **Industrial development:** flood risk consideration in industrial development planning is essential for ensuring sustainability of business operation and to control flood-damage potential. Plans also address pollution control and the spread of hazardous substances following the flooding of industrial premises.
- **Agriculture development:** agriculture heavily relies on floodplain areas because of their readily available fertile soil and water resources. At the same time, agricultural practices can influence runoff generation, infiltration processes and sediment yield.
- **Water resources management:** flood risks form a central component of water resources management plans to ensure the effective management of floodwaters and safeguard the functioning of the water system during floods.
- **Transport and communication development:** location and structural design of these infrastructure elements need to be planned in full awareness of flood-prone areas. It is also important to understand the possible impacts of this infrastructure on hydrological processes during a flood event.
- **Disaster management:** this is undertaken with a consideration of all hazards affecting communities, such as landslides and floods. Disaster management offers a good treatment of common risk to life and shows the relations which could exist between various natural phenomena (WMO, 2009).

33 The complex interrelation of various development processes, land-use planning and flood management is illustrated with the example of the planning framework in England in **Figure 5**.

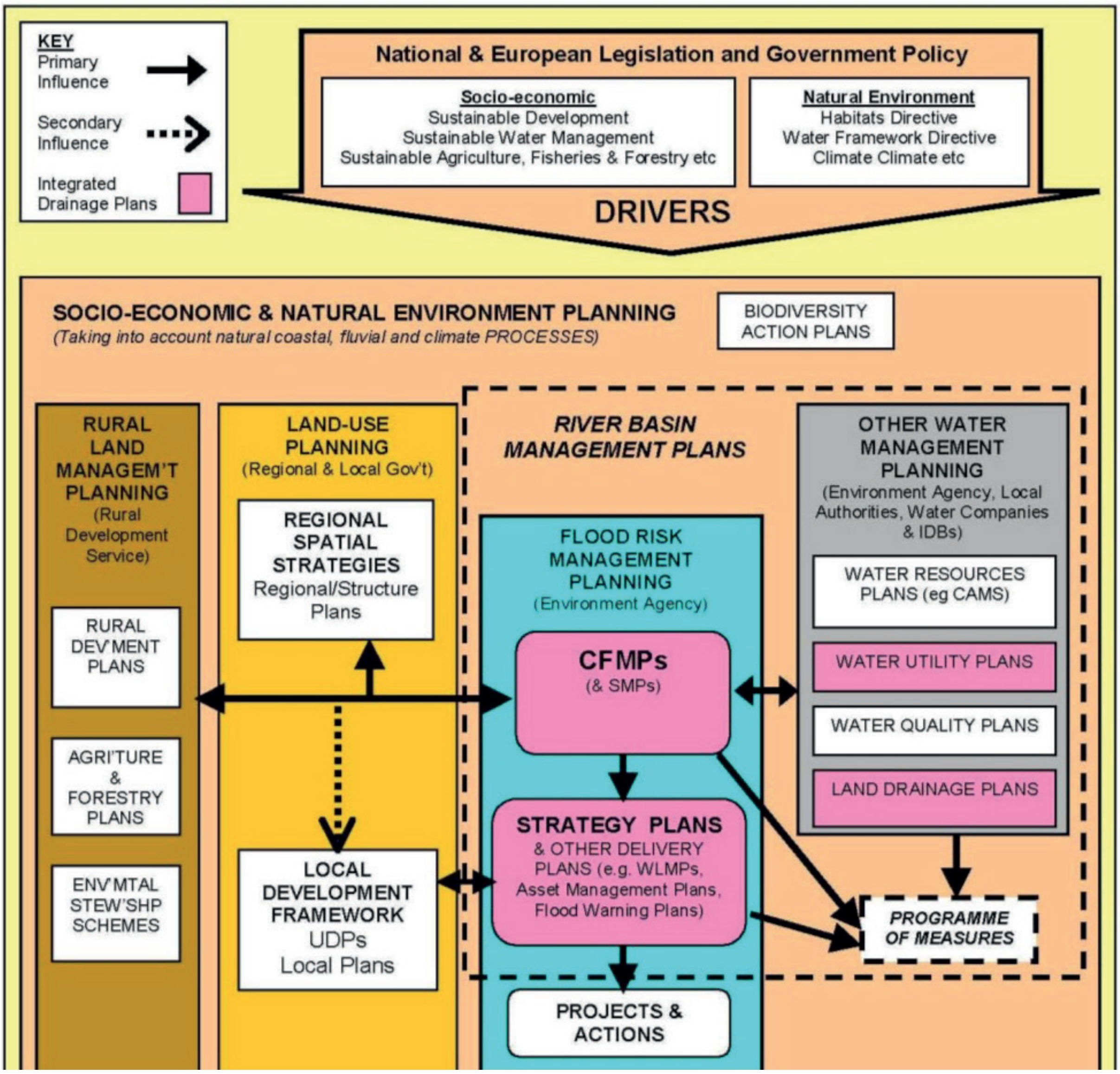


Figure 5 — Links between Flood Risk Management Plans and the wider planning framework in England, United Kingdom (Environment Agency, United Kingdom, 2004)

2.3 Interactions between land and water environments

34 River basins are dynamic systems driven by complex interactions between land and water environments varying over time and space. There are essentially three connected fluxes: water, sediments/nutrients and pollutants. As illustrated in **Figure 6**, surface runoff carries sediments, nutrients and pollutants from the land through the river system. Also, during floods, sediments/pollutants and water will be transported to the floodplains. The deposition of materials has, over the centuries, created highly fertile alluvial soils in floodplains. Depending on factors such as geomorphology and connectivity between the river channel and the adjacent floodplain,

other beneficial effects of floods may be observed, such as recharging water sources and rejuvenation of the river ecosystem. However, pollutants – such as pesticides, fertilizers, pathogens and toxic contaminants – can also be conveyed by surface runoff and affect soil and water quality.

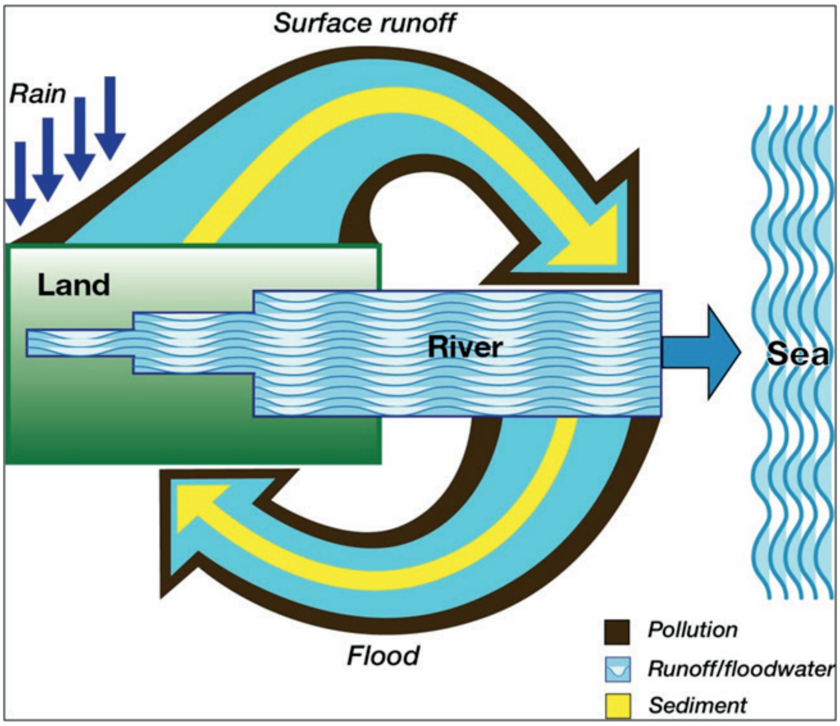


Figure 6 — Interaction between land and water environments (WMO, 2009)

35 Other external processes, such as natural geomorphologic processes, can influence the system to varying degrees. For instance, natural phenomena such as landslides or erosion of the land surface can have a significant influence on sediment loads of adjacent watercourses. Those materials are deposited on the drainage systems, reducing the conveyance capacity of the channel and thus increasing the likelihood of flooding. Human alterations of the catchment area can also significantly contribute to changes in all those processes through large-scale land-use changes and practices.

36 Spatial dimensions of land-use effects on catchment areas are an important aspect to consider. Indeed, observable impacts of land use on river basins vary depending on basin spatial scales (FAO, 2000). For example, the effects of certain land-cover changes on sediment load and peak flows can be established in smaller watersheds but, on basin scales, it is much more difficult to observe the influence of land-cover changes. At the largest scales, some effects are difficult or impossible to identify because of a long time lag between cause and effect, as well as many overlapping factors (FAO, 2000). This makes it difficult to select appropriate measures and actions in order to effectively mitigate flood risk at different scales.

2.4 Impacts of land-use on flood risk

37 Modern land use gradually encroaching on the natural environment has an impact on all three dimensions of flood risk, namely hazard, vulnerability and exposure. Indeed, demographic

growth and economic development in flood-prone areas, accompanied by poor design of land-use plans, lead to increased flood risk of the communities living on floodplains. As illustrated in **Figure 7**, the number of reported flood events has grown significantly, particularly in the past 20 years. Moreover, their impact on social, economic and environmental domains has increased, not only because of hazard increase but also exposure and vulnerability of the society at risk (Jha et al., 2012). Flood risk over a specific area depends on the natural catchment characteristics (topography, soils, etc.) as well as on land-use management practices and vulnerability to economic damage (O'Connell et al., 2007). Nowadays, the link between environmental degradation, land-use practices and flood risk is well accepted.

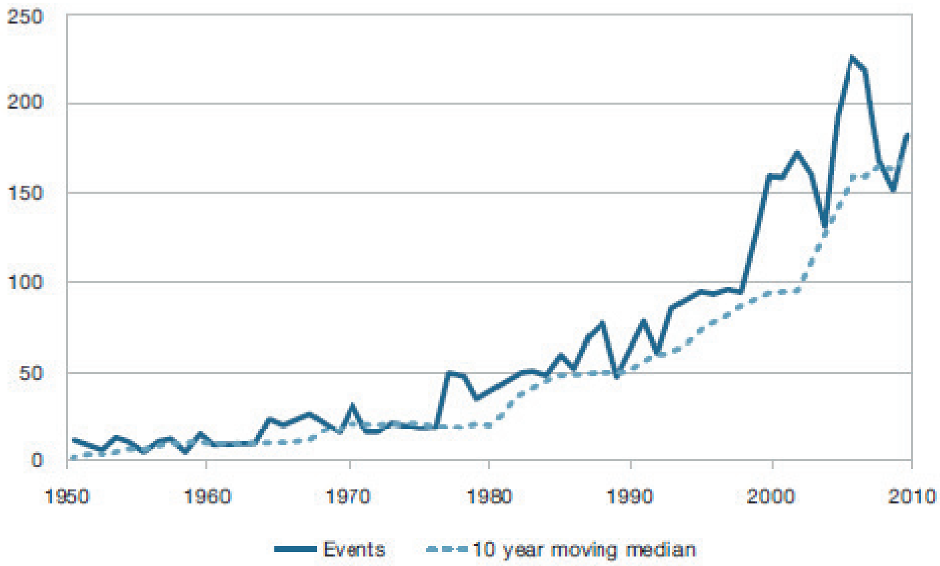


Figure 7 — Number of reported flood events
(Jha et al. 2012, based on Centre for Research on the Epidemiology of Disasters Emergency Events Database (EM-DAT/CRED))

2.4.1 Impacts of land-use on flood hazards

Changes in land use and the river systems in recent years – such as urbanization and deforestation – have modified the hydrological regime and the annual water balance, increasing flood frequency and severity (see **Annex 2**). Through modifications of soil cover, these types of land-use changes decrease the infiltration capacity of the land surface and thus increase runoff. Indeed, soil-structure degradation due to compaction or soil-sealing plays a key role in runoff parameters by reducing storage and infiltration capacity. A variety of factors, including the type of land use and soil in a watershed, therefore have an influence on the rate of runoff generation as shown in **Figure 8**.

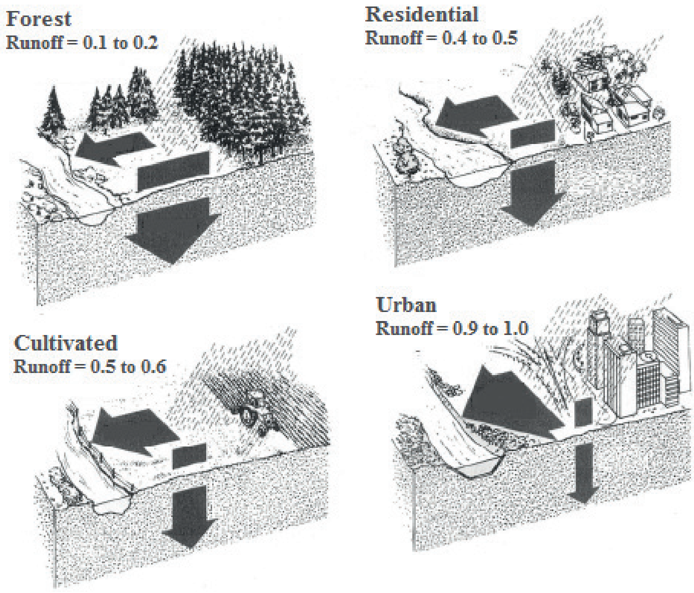


Figure 8 — Modification of runoff generation, depending on land use (CERG, 2015)

39 This additional runoff increases the delivery rate to the channel network, thereby leading to the modification of flood regimes. As a result, the peak discharge, volume and frequency of flood increase in nearby rivers.

40 As shown on **Figure 9**, when urbanization and forest disease increase, flood conditions worsen by increasing the peak discharge.

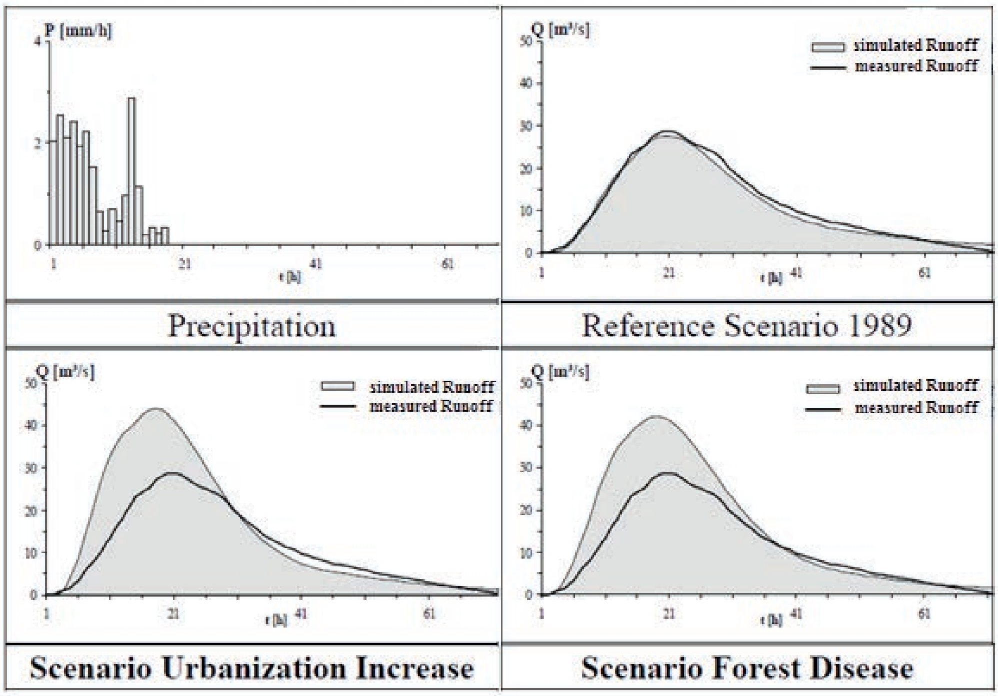


Figure 9 — Observed and simulated flood hydrographs: The flood event of June 1984 in the Nims catchment (Germany) combined with conditions of the 1989 urbanization scenario (built-up areas increase from 5.8% to 23.6%) and forest-disease scenario (forested areas decrease from over 30% to 8.6%) (Schultz, 1995)

41 Hydrological responses to rainfall depend strongly on local characteristics of the soil, such as water storage capacity and infiltration rates. The type and density of vegetation cover and land-use characteristics have an impact on the responsiveness of an area to a given rainfall event. Saturated conditions – or conditions quickly becoming saturated during the rainfall event – inhibit the infiltration of rainwater. The consequences are more abrupt for high-intensity rainfall over small, steep basins.

42 Environmental degradation coupled with uncontrolled land-use changes in watershed areas, such as urbanization or deforestation, leads to an increase of flood frequency and severity. This hazard can be avoided or mitigated, however, through a better approach to land-use planning management. Topography, basin size, geology and storm patterns also play a role in streamflow. Indeed, the flood-formation process is influenced by various other factors: for large-scale floods, especially, the geomorphology of the catchment area and preceding rainfall conditions. These parameters should then be taken into account during the development of land-use plans.

2.4.1.1 Effect of land-use change processes on flood hazards

43 This part of the publication focuses on three specific land-use change processes, namely urbanization, agricultural practices and deforestation. Indeed, these represent the majority of land-use changes and play a key role in flood hazards.

Urbanization

44 In recent years, the planet has experienced profound changes in population size and spatial distribution. Indeed, the world has undergone a process of rapid urbanization over the past six decades (United Nations, 2014). Interestingly, it is estimated that, around the year 2010, the proportion of the world's population living in urban areas outnumbered the population living in rural areas and will reach 66% by 2050, according to estimation models (United Nations, 2014). The extent of current and expected urbanization in terms of total population in urban areas is illustrated in Figure 10. Unfortunately, this rapid urban expansion is often carried out in an unplanned or inadequate way, leading to social, economic and environmental deterioration. In particular, it was shown that urbanization affects flood hazards in many ways.

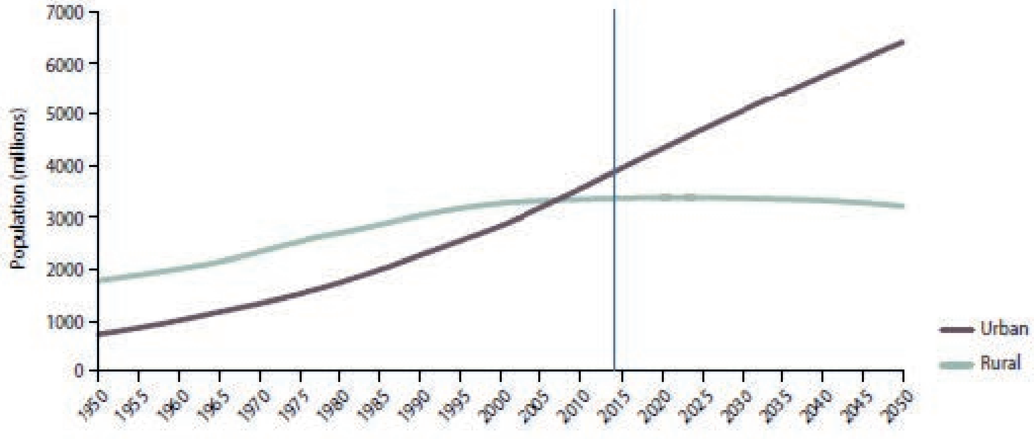


Figure 10 — Urban and rural global population, 1950–2050 (United Nations, 2014)

45 Removing vegetation and soil, grading land surface and constructing drainage networks disrupts natural drainage patterns and natural watercourses. By changing pervious natural surfaces to less- or non-pervious artificial surfaces, stormwater runoff rate and total runoff volume increase as a result of declining natural land water storage capacity. Indeed, in undeveloped areas, such as forests and grasslands, rainfall water is collected and stored by vegetation in the soil column and in surface depressions. When the system reaches its saturation point, runoff flows slowly through soil as a subsurface flow. In contrast, urban areas, where most of the land surface is covered by roads and infrastructure, have less storage capacity (Konrad, 2014). For instance, on the east branch of the Brandywine Creek Watershed (USA), a considerable urban development between 1992 and 2000 increased surface runoff up to about 12% of rainfall water **(Figure 11)** (Coutu and Vega, 2007).

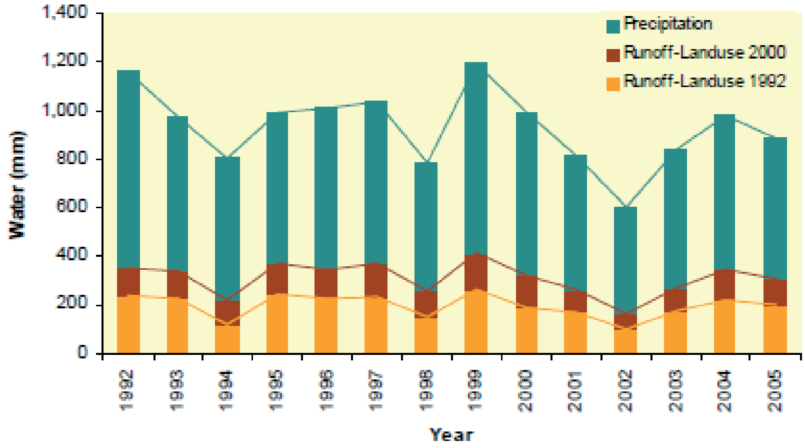


Figure 11 — Surface runoff generated per year in the Creek watershed (near Philadelphia, USA) between 1992 and 2005 (Coutu and Vega, 2007)

46 The total volume of water discharged during a flood event tends to be superior for an urban river than a rural river, as shown in **Figure 12** (example of the streamflow in Mercer Creek, an urban stream in western Washington) (Konrad, 2014).

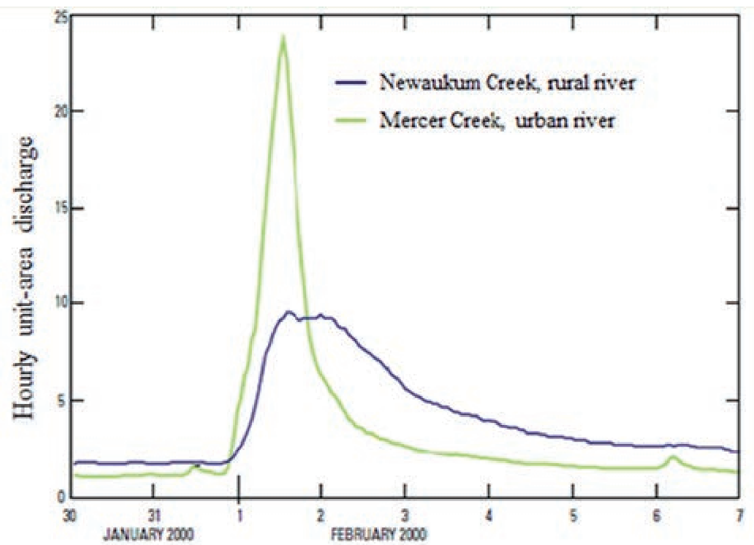


Figure 12 — Comparison between an urban stream (green) and a nearby rural stream (purple) (Konrad, 2014)

47 The relative increase in peak discharge due to urbanization is greater for frequent floods than for rare events characterized by large floods (see **Table 2**). Nonetheless, even a small intensification of the peak discharge of a large flood event can increase flood risks.

Table 2 — Relative increase in flood peak discharge in Salt Creek, Illinois, USA, due to urbanization (Konrad, 2014)

Flood frequency	Chance that flood's peak discharge will be exceeded in any year	Increase in flood peak discharge because of urban area
2-year	50 %	100–600 %
10-year	10 %	20–300 %
100-year	1 %	10–250 %

48 Change of natural water storage as a consequence of urbanization also causes significant changes to temporal characteristics of runoff, such as the shortening of runoff travel time and giving a flashing appearance to the event. Erosion of urban rivers is another consequence of urbanization. Indeed, frequent flooding in urban streams increases channel and bank erosion. Furthermore, a channel straightened in order to give more space to urban development can increase streamflow velocity, allowing a river to transport more sediment, which, in turn, increases erosion.

Agricultural practices

49 Agricultural practices also have an influence on the runoff/infiltration process. It has been argued that modern agricultural practices and their related soil-drainage system, choice of crops and cropping patterns can reduce soil macroporosity. Those changes in soil structure can contribute to increasing the runoff parameter in agricultural areas as illustrated in **Figure 13**. In other words, modern agricultural management increases soil compaction and thus affects runoff generation and can contribute to flooding.

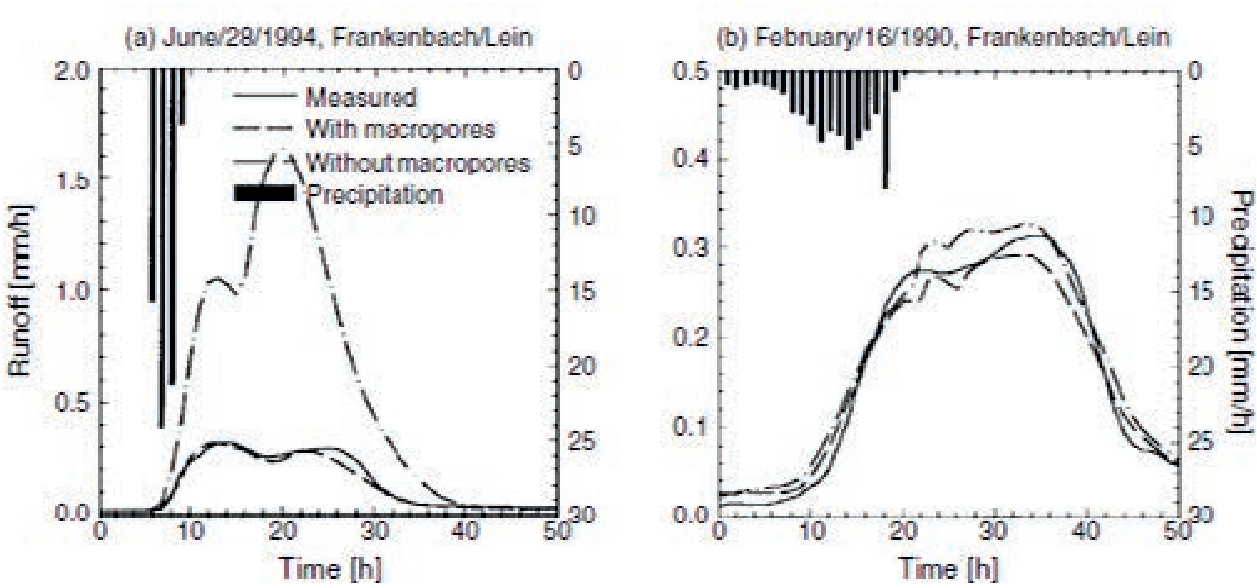


Figure 13 — Simulation of two flood events in the Lein catchment (Rhine basin, Germany) with a return period of three years as a response to (a) a convective and (b) an advective storm event, showing the impact of macropores on runoff generation (Bronstert et al., 2002)

Box 1 — Impact of land-use changes on flood hazard

The impact of land-use changes on runoff generation has been investigated with a model for the Lein catchment of the Rhine basin in south-western Germany. It has been shown that urbanization consisting of asphaltic and paved surfaces decreases soil infiltration capacity. Indeed, as illustrated in Figure 13, surface runoff increases when urbanization grows. This figure also highlights the fact that floods caused by convective rainstorms (high rainfall intensities and previous low soil moisture) are more strongly influenced by land-surface conditions than floods caused by advective rainfall (lower intensities but previous high soil moisture) (Bronstert et al., 2002).

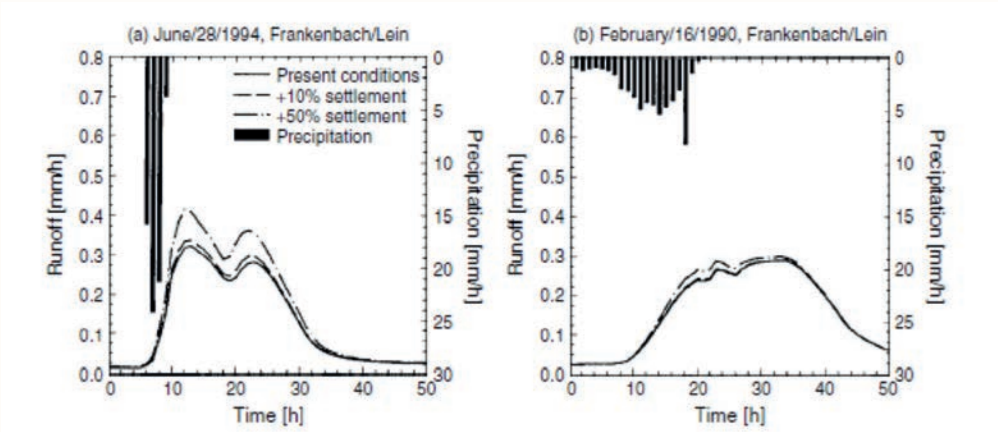


Figure 14 — Simulation of two flood events in the Lein catchment (Rhine basin, Germany) with a return period of about three years for current conditions and two urbanization scenarios (namely, an increase in settlement and industrial areas of 10% and 50% respectively) for (a) a convective storm event and (b) an advective storm event

For further information see:
www.researchgate.net/profile/Axel_Bronstert/publication/227497362_Effects_of_climate_and_landuse_change_on_storm_runoff_generation_present_knowledge_and_modelling_capabilities/links/0fcfd5123429fc62d2000000.pdf

Box 2 — Impact of agricultural practices on flood hazards in the United Kingdom

In recent years, large floods have occurred in the United Kingdom and several observations in the field have shown that the degradation of soil structure is a possible causal mechanism. Indeed, since World War II, the United Kingdom landscape has undergone considerable changes with an increase of larger fields and an accelerated loss of natural vegetation as illustrated in the figure below. These land-use modifications induced "changes in runoff generation and its delivery to the channel network, such as the extent of soil compaction, the efficiency of land drains, and the connectivity of flows paths" (O'Connell et al., 2007). Different measures focusing on improvements in agricultural practices were also undertaken to mitigate the impact of modern land use. For example, for maize cropping, particularly in free-drainage loamy, silty and sandy soils, ploughing during autumn and spring can reduce field-runoff generation between 30% and 100% compared to conventional management (O'Connell et al., 2007).

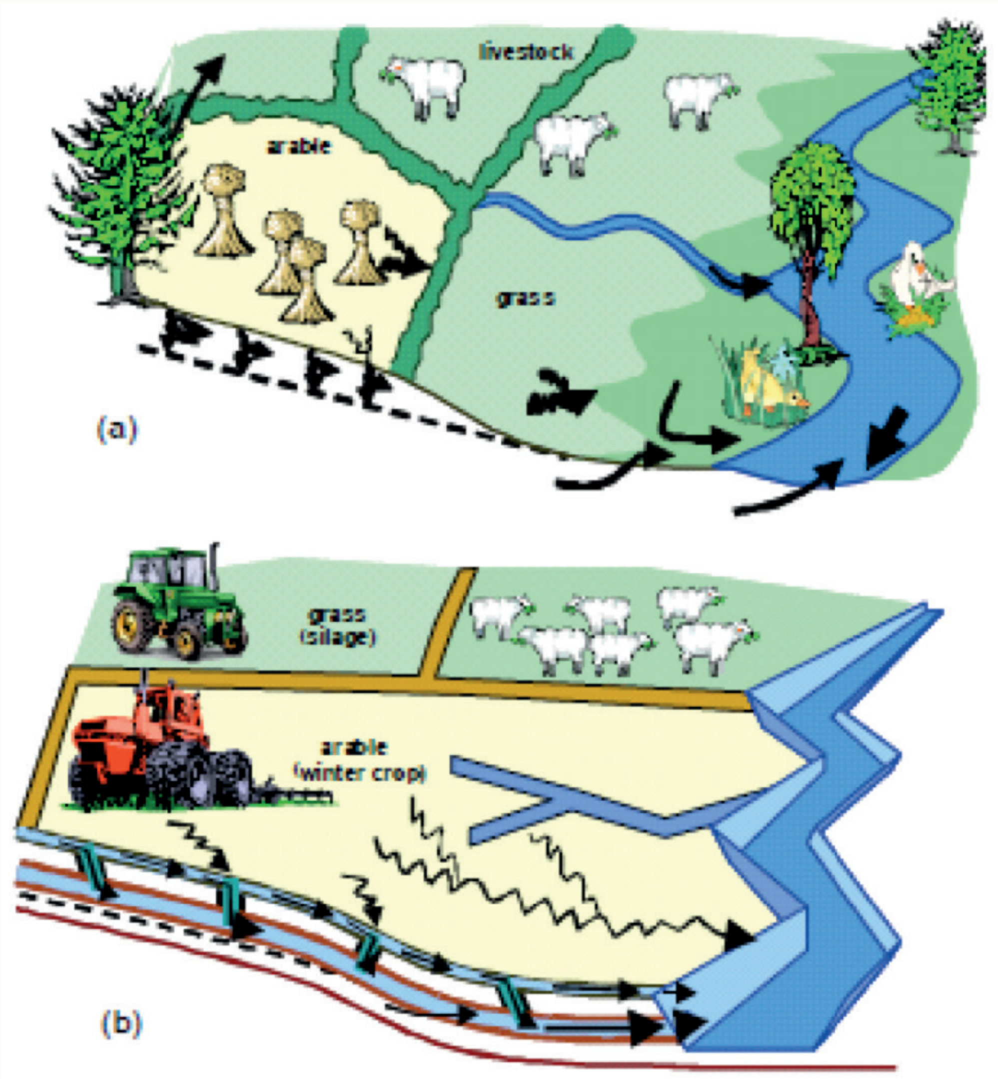


Figure 15 — (a) Pre-World War II and (b) recent agricultural landscape at the hillslope scale in the United Kingdom

For further information, see:
www.hydrol-earth-syst-sci.net/11/96/2007/hess-11-96-2007.pdf

Forest cover

50 Forests located in catchment areas provide a connection between soil and aquatic systems. In addition to environmental, social and economic aspects, forests play an important role in hydrological processes within the basin (WMO, 2006b). Various parameters, such as forest density, canopy and soil cover, impact runoff generation and erosion. Loss of vegetation and forest clearing increase runoff and erosion by decreasing soil water-retention capacity and indirectly reduces evapotranspiration. For example, significant changes to those parameters, such as excessive logging, conversion of forested areas to other land-use types and conversion of land through forest fires, have an impact on the runoff generation, erosion and sediment processes, in particular at smaller spatial scales (FAO, 2005). As shown in **Figure 16**, there is a relative difference of infiltration rate and annual runoff volume according to soil-cover type, with an increase of runoff when land cover moves from trees to grazed plots (CIRIA, 2013).

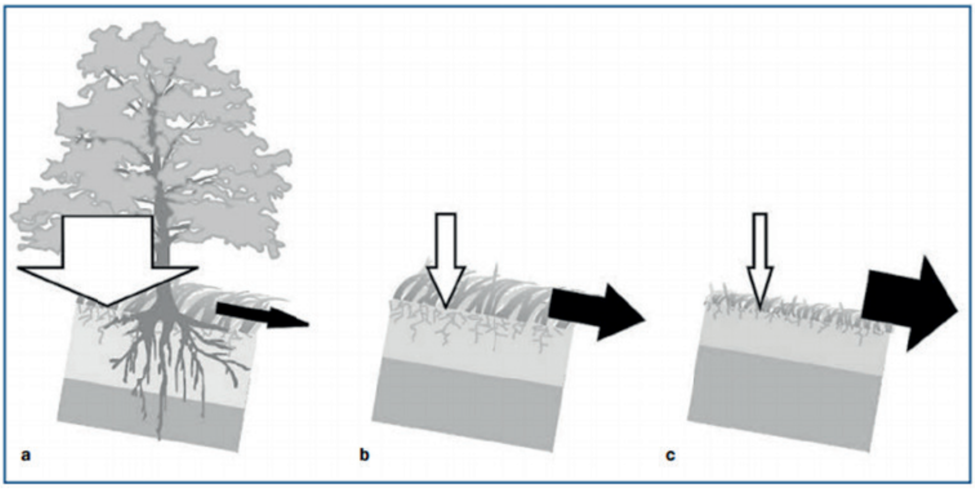


Figure 16 — Schematic diagram showing the relative difference of infiltration rates (white arrows) and annual runoff volumes (black arrows) for: (a) ungrazed and tree-planted; (b) ungrazed; and (c) grazed plots

51 Deforestation can, therefore, also influence streamflow patterns, such as annual discharge. For instance, for a tropical watershed, deforestation of about 30% in the basin induces an increase of 24% in annual mean discharge (Costa et al., 2003).

52 Forest-cover changes can have a significant effect on flooding, influencing frequency and severity. Despite the fact that vegetation presence in the basin stabilizes river flows through infiltration and evaporation, forests' regulative effects have certain limitations and depend mostly on structural complexity, forest size and type, in combination with depth and structure of soil cover and previous soil-moisture conditions in the catchment (WMO, 2006b; Ashagrie et al., 2006).

2.4.1.2 Effect of specific infrastructures on flood hazards

Large-scale diversions/earthworks

53 Many urbanization projects involve specific construction interventions or infrastructure on flood-prone areas. Beyond their positive contribution to urban development, human interventions,

such as earthworks or channelization, can have adverse effects on the water environment. For instance, large-scale earthworks within the floodplain, particularly the active part, can result in flood-flow obstruction. Moreover, channelization induces changes in stream channels, which can limit their capacity to convey floodwaters, modify the peak flows downstream and destroy natural environments (Randolph, 2004; Konrad, 2014). Furthermore, water diversions, as well as engineering structures, such as dams or reservoirs, can alter stream-discharge rates and modify the hydrological systems of adjacent channels. This may also result in hazard transfer by increasing flood hazard in other areas of the catchment.

Construction of transport infrastructure

54 Floodplains offer many advantages to develop transport infrastructures such as highways and railroads. Indeed, the construction of such infrastructure requires flat and open corridors of stable land. The development of infrastructure along the river or on other parts of the floodplain can, however, alter the capacity of a channel to convey water and increase water level for a given discharge. Furthermore, under flood conditions, those works can serve as dams, i.e. by obstructing waterflow, and therefore increase flood hazards on adjacent lands. Similarly, structures (e.g. bridges) that encroach on the floodplain tend to narrow the channel, increasing upstream flooding of such artificial "bottlenecks" (Konrad, 2014).

Box 3 — The role of transport infrastructure in the high water level near Khabarovsk, Russian Federation

Human activities, such as the construction of flood embankments, polders, bridges and other protective structures, increased floodwater levels along some stretches of the Amur River during the catastrophic flood of 2013. This flood had unprecedented magnitude at the lower part of the Amur's transboundary stretch, but most of the increase in maximum water levels near urban centres was considered to be human-induced. It is likely that the total contribution of Russian hydraulic facilities amounted to an increase of the peak water level near Khabarovsk by one metre or more (Bolgov, 2014).

Near Khabarovsk City, the water level was higher than expected because of the trans-Siberian railway bridge embankment (shown in the figure below) in the Amur floodplain. The embankment had no culverts and the whole floodplain was blocked, creating a back-up which contributed to the further rise in the water level near the city. As a result, the water level rose up to 40–50 cm in the Khabarovsk area. A nearby agricultural polder (71 km^2) located on Bolshoy Ussuriyskiy Island also contributed to the excessively high water levels (Makhinov, 2014).

Figure 17 — Trans-Siberian railway bridge embankment across the Amur River (Simonov et al., 2015)

Flood embankments

55 Flood embankments (levees, dykes) that do not leave sufficient space for the watercourse to safely convey flood flows can induce a bottleneck effect. This applies to ring levees around cities and industrial parks but also to agricultural levees along watercourses.

56 It is important, therefore, before the construction of such infrastructure, to consider, not only the benefits it may create for directly protected areas, but also the unintended negative impacts of such infrastructure beyond the target area. The notion of flood propagation or flood transfer due to specific intervention is illustrated in **Figure 18**. Under flood conditions, such as those in situation B, the bridge acts as a dam, causing a flood hazard in the upper village. In response, the upper village builds some embankments on both sides of the river for protection. During the next flood episode, therefore, the hazard is downstream, flooding the other village (shown in C). When planning embankments, both benefits for the protected area and potential negative effects should be evaluated. In fact, such an intervention can have impacts far beyond its target area. For example, are upstream areas prepared to deal with backwater effects? Are downstream areas prepared to convey or store parts of the enhanced flood flows? Are opposing banks of the river prepared with the same safety standards in the case of different jurisdiction?

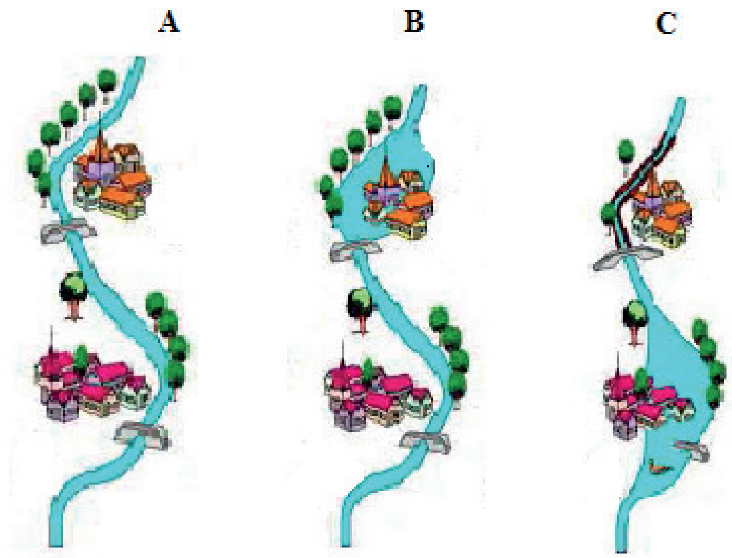


Figure 18 — Flood propagation downstream (CERG, 2015)

57 Active development of floodplains must therefore consider the river basin as a whole. In fact, the way a specific infrastructure is operated in one location may have an impact on flood characteristics of other parts of the basin, transferring flood risk.

Box 4 — Flood embankments on the transboundary Amur River

For several decades, China invested billions of yuan "to protect the motherland's banks with dykes" along the Amur, Argun and Ussuri transboundary rivers between China and the Russian Federation. During the 2013 flood, disastrous dyke failures (see **Figure 19**) occurred in Jiayin, Luobei and Tongjiang counties, resulting in the flooding of large populated areas along the riverbanks in China (marked in red).

Multiple dam failures along the Amur in 2013 prompted the emergence of new engineering projects. In June 2014, the Heilongjiang Province Water Department announced that 24.6 billion yuan (about US$ 4 billion) would be invested in the construction and reinforcement of dykes (2,722 km total planned length) on the major rivers of the Heilongjiang (Amur) River basin. By the summer of 2014, the work was already under way along the Amur and Ussuri rivers **(Figure 20)**: old dykes had been raised by 2–5 m, with the objective of providing protection from floods occurring every 50–100 years. Once such an embankment is built it is expected that up to 25 km^3 of the floodplains' natural flood retention capacity will be lost along the Chinese bank of the transboundary river.

According to recent modelling by the Water Problems Institute of the Russian Academy of Sciences, such embankments on the Amur River may increase maximum flood levels by at least 20–30 cm (Bolgov, 2014).

Figure 19 — Three disastrous dyke failures in China along the Amur River in August 2013

Figure 20 — Construction of a new dyke along the transboundary Ussuri River in 2014

2.4.2 Impacts of land use on exposure and flood-damage potential

58 The location of economic values on floodplains or the investment in floodplain areas has played a major role in the development history of most countries. The overall economic benefits from floodplain areas can be significantly higher than in other areas. This is also evident from the high population densities that floodplains have attracted. In India, for example, the majority of

economic activities and livelihoods are concentrated around the floodplains of the Brahmaputra River basin (Ghosh and Dutta, 2011).

59 With demographic growth and urbanization trends, human occupancy of floodplains is becoming more intensive. Indeed, over time, population and accumulation of assets have increased in most flood-prone areas, thus increasing flood exposure, as explained in **Section 2.1.2** (see **Figure 21**).

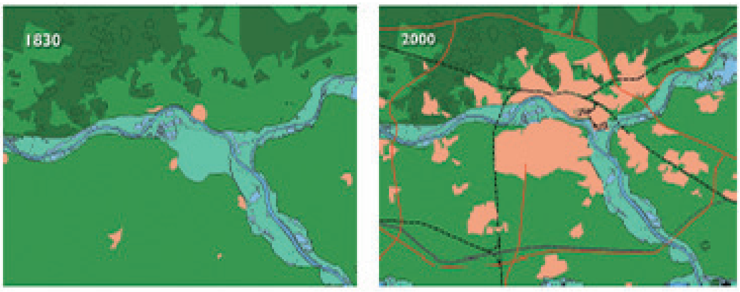


Figure 21 — Increase of land-use intensity around Arnhem, Netherlands, between 1830 (A) and 2000 (B) (Klijn et al., 2004)

60 In the process of urbanization with massive influx of rural populations, spatial requirements for housing become too large to be accommodated in low-risk zones. Uncontrolled development of informal settlements often takes place therefore in high-risk floodplain areas. This is due to multiple reasons, such as the lack of public awareness that leads floodplain occupants to rate poverty risk far higher than flood risk. Also, there might be a lack of alternatives for relocation because of insufficient funds for local housing. On the other hand, the land-use regulatory framework in those areas might be inappropriate or the enforcement capacities of local authorities might be lacking. Informal settlements, as the term implies, are not planned nor are they generally subject to land-use regulations or to enforcement of building or drainage codes (WMO, 2012b).

61 Land-use management therefore has a crucial role in the management of infrastructure, assets and population density located in flood-prone areas. Equilibrium needs to be found between the reduction of exposure to flood by avoiding any socioeconomic development of flood-prone areas and the operation of activities relying on benefits provided by floodplain characteristics. When exposure cannot be avoided, flood protection should be more focused on reducing hazard and vulnerability.

Box 5 — Definition of flood damage and flood losses

In order to understand correctly the conceptual framework, it is important to define and note the difference between flood damage and flood losses.

– **Damage:** Total or partial destruction of physical assets existing in the affected area. Damage occurs during and immediately after the natural phenomenon that causes the disaster and is measured in physical units (i.e. square metres of housing, kilometres of roads, etc.). Its monetary value is expressed in terms of replacement costs prevailing just prior to the event (UNESCAP, 1972).

– **Losses:** Temporary changes in the economic flows arising from the flood disaster. Losses occur from the time of the disaster until full economic recovery and reconstruction have been achieved, in some cases over several years. Typical losses include the temporary decline in output and higher production costs in the productive sectors of agriculture, livestock, fishery, industry, trade and tourism; lower revenues and higher cost of operation in services (education, health, electricity, water supply and sanitation, transport and communications), as well as the unexpected expenditure to meet humanitarian assistance needs in the emergency phase. Losses are expressed in current values (UNESCAP, 1972).

In other terms, "flood damage" refers to the physical damage caused to public and private assets such as infrastructure, houses and vehicles as a result of contact with floodwaters. The term "flood losses", on the other hand, refers to temporary changes in economic flows from the time of the flood disaster until full economic recovery and reconstruction.

For further information see: www.floodmanagement.info/publications/tools/APFM_Tool_02.pdf

62 With growing economies and the emergence of wealthier societies, the damage potential of flooding is constantly rising, as illustrated in **Figure 22**. The more people, property, systems or other elements that are located in high flood-hazard zones, the more they are exposed to potential losses. In other words, the more a society has, the more it has to lose. Floods can damage buildings, goods, crops, infrastructures or the environment (WMO, 2007). Urbanization in flood-prone areas brings a higher density of population and economic activities and assets, causing increased amounts of loss and damage related to flood events.

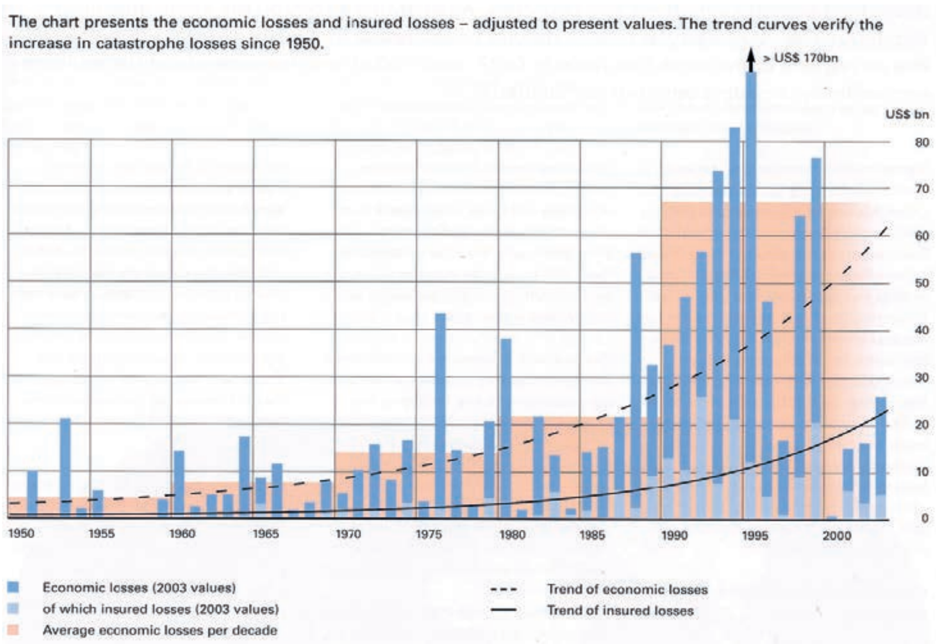


Figure 22 — Economic losses and insured losses adjusted to present values: the trend curves verify the increase in catastrophic losses since 1950 (Munich Re, 2013)

63 For example, estimated economic loss due to flooding of the largest dyke-ring in the Rhine River in the Netherlands increased by almost 30%, from less than 7 million euros in 1990 to over 10 million euros in 2000 as a consequence of economic development in flood-prone areas (Klijn et al., 2004).

64 Flood-damage potential is a function of hazard, exposure and vulnerability (Barredo et al., 2008): if any parameter of the equation increases, damage also increases (Barredo et al., 2008). Flood-damage potential can be defined as the maximum extent of possible damage in a given flood-hazard area (Loat and Meier, 2003). This means that benefits derived from floodplains are provided at the risk of having to bear flood damage. An example of flood damage potential in Europe is provided in **Annex 3**.

65 Land use planning and placing a value on land liable to flooding have an influence on losses and damage due to flooding. In modern flood-management approaches, land-use planning and regulation play a vital role in bringing flood-damage potential to acceptable levels by increasing socioeconomic resilience to floods.

66 In this context, it seems important to consider that society, through political processes and individual choice, has to make decisions on the level of flood risk it is willing to accept. Those choices are sometimes explicitly formulated in policy documents, laws or similar instruments. In most cases, the choice is implicit, e.g. by deciding on the location of a particular infrastructure or by providing insurance cover to certain constructions in flood-prone areas. It is argued here that those implicit choices are made too often without awareness of the prevailing flood risks. This leads to unreasonable increases in damage potential and exposure, especially where reasonable and less risk-prone alternatives may exist. Awareness-raising should therefore be a priority in the overall flood-management policy to ensure that sound choices are made in the decision-making process.

67 A feature of popular debate about flood risk is the calculation of total flood-damage potential in river basins. While employing such statistics in order to raise flood-risk awareness can be beneficial, they tend to oversimplify the issue if employed as a “stand-alone” argument. When using such figures, several aspects are often not taken into account such as:

- The benefits that floodplain areas provide to society;
- The possible lack of less risk-prone alternatives;
- The level of protection that existing flood defences and flood-proofing measures provide.

68 It is therefore essential to take a broader view of risk-benefit relationships in devising a flood-management policy. On the other hand, flood-loss assessments should include all damage dimensions such as adverse social, psychological, political and environmental consequences, in order to gain a complete picture of the damage (WMO, 2013a). Further information about economic analysis is available from the APFM Helpdesk and presented in the *Integrated Flood Management Tools Series No.2: Conducting Flood Loss Assessments*.

Box 6 — Flood damage in the Rhine catchment, Germany

Two large floods with a return period of 30–40 years caused significant damage in the Rhine catchment in 1993 and 1995. These floods were severe, but not extreme. Nonetheless, the damage they caused was extremely high and higher than that observed in the past. These two events raised the question of the role of land-use changes in the increase of flood risk. During the last decades, the Rhine valleys have experienced intensive socioeconomic activity development, including the set-up of infrastructure in areas that had been reserved as floodplains. This urban development exposed more valuable infrastructure to flood damage, although flood hazard had not risen (Schultz, 1995).

For further information see: www.engr.colostate.edu/ce/facultystaff/salas/us-italy/papers/31schultz.pdf

2.4.3 Impacts of land use on vulnerability

69 Apart from the increase of property values and human occupancy in floodplains, the degree of vulnerability of various human activities to flooding plays a crucial role in determining overall flood risk. As mentioned earlier **(Section 2.1.2)**, vulnerability can be defined as the degree to which a socioeconomic system is susceptible or resilient to the impact of flood hazards. Flood vulnerability depends on many parameters, such as physical and material assets located in flood-prone areas (WMO, 2009). When local income depends on infrastructure at risk, it is difficult to restart economic activity after flood events.

70 Social conditions, such as poverty and livelihood, are also major factors influencing vulnerability in a given region (WMO, 2006e). Wealthier populations tend to be less susceptible and more resilient to flood events: they have economic means to better prepare for disasters and can usually more easily afford the recovery and reconstruction of affected infrastructure. Informal settlements and shantytowns are generally built with light materials, such as bamboo, tin, cardboard or scrap metal, that do not withstand floodwaters (WMO, 2012b). With regard to the social structure of communities, it becomes apparent that, in the process of urban growth, land subject to flooding is increasingly used with higher-risk uses. The areas of the floodplain regularly affected by flooding are in many countries used by the economically weaker parts of society because land is under less competition in those areas, resulting in lower land prices.

71 Land-use management is a useful tool to organize the territory in order to increase socioeconomic resilience to floods. One approach to this is through flood-vulnerability classifications of different types of developments and uses as shown in **Table 3**.

Table 3 — Flood risk vulnerability classification in the United Kingdom

Essential infrastructure	Highly vulnerable	More vulnerable	Less vulnerable
– Essential transport infrastructure (including mass evacuation routes) which has to cross the area at risk – Essential utility infrastructure which has to be located in a flood-risk area for operational reasons, including electricity-generating power stations and grid and primary substations; and water treatment works that need to remain operational in times of flood – Wind turbines	– Police, ambulance and fire stations, command centres and telecommunication installations required to be operational during flooding – Emergency dispersal points – Basement dwellings – Caravans, mobile homes and park homes intended for permanent residential use – Installations requiring authorization for hazardous substances (where there is a demonstrable need to locate such installations for bulk storage of materials with port or other similar facilities or such installations with energy infrastructure or carbon capture and storage installations that require coastal or water-side locations or need to be located in other high flood risk areas, the facilities should be classified as "essential infrastructure")	– Hospitals – Residential institutions such as residential care homes, children's homes, social services homes, prisons and hostels – Buildings used for dwelling houses, student halls of residence, drinking establishments, nightclubs and hotels – Non-residential uses for health services, nurseries and educational establishments – Landfill and sites used as waste-management facilities for hazardous waste – Sites used for holiday or short-let caravans and camping, subject to a specific warning and evacuation plan	– Police, ambulance and fire stations which are not required to be operational during flooding – Buildings used for shops, financial, professional and other services, restaurants and cafes, hot food takeaways, offices, general industry, storage and distribution, non-residential institutions not included in "more vulnerable", and assembly and leisure – Land and buildings used for agriculture and forestry – Waste treatment (except landfill and hazardous waste facilities) – Mineral working and processing (except for sand and gravel working) – Water-treatment works which do not need to remain operational during times of flood – Sewage treatment works (if adequate measures to control pollution and manage sewage during flooding events are in place)

Source: Department for Communities and Local Government, United Kingdom, 2012

73 Each class of infrastructure can be regulated differently, according to the following principle: the higher the vulnerability of construction or use, or potential disaster impact on socioeconomic activities, the lower should be the flood hazard in the area where it is located **(Figure 23)**. For

example, vulnerable infrastructure, such as hospitals and schools, should be built in low flood-risk areas. On the other hand, agricultural fields, although vulnerable to floods, could remain in flood-prone areas due to their resilience and the benefits they derive from the enhanced soil fertility occasioned by the floods. These choices should be made on a case-by-case basis, relying on thorough flood-risk studies. Indeed, some elements may be classified differently in different socioeconomic conditions. For example, in the case of subsistence agricultural fields, the destruction of crops would present a major blow to food security and should therefore be located in low flood-risk zones.

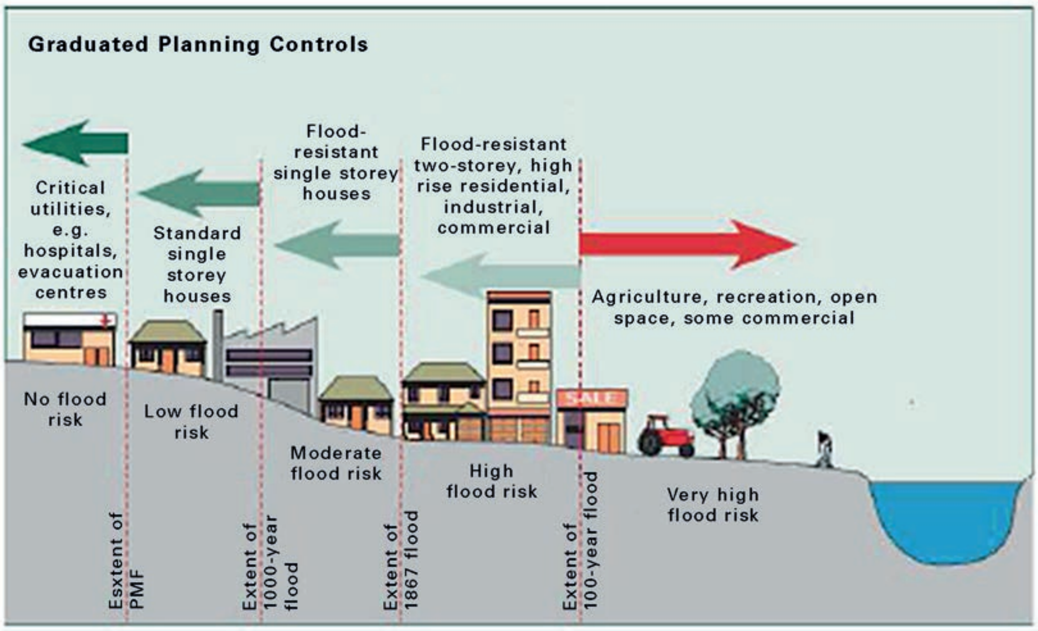


Figure 23 — Graduated land-use planning controls to reduce flood risk
(Hawkesbury City Council's Floodplain Risk Management Advisory Committee, 2012)

3 LAND-USE PLANNING AND FLOOD MANAGEMENT

74 While the need for a closer integration or coordination between flood-management plans and land-use plans has long been recognized, many countries are struggling to devise appropriate policies and administrative mechanisms that would facilitate such integration. Fundamental characteristics and the aims of those planning processes and policies have been driven and implemented by different stakeholders and decision-makers and a mutual understanding of the two processes must be sought.

3.1 Roles of land-use planning in flood-management strategies

75 As discussed in Section 2, land-use planning has an impact both on flood hazard by changing the water-balance system and on flood exposure and vulnerability. The impacts of a particular flood event depend on the kind of infrastructural development choices that were made previously (UNDP, 2004). Land-use management therefore plays a key role in flood-management strategies to mitigate flood risk. This calls for a change of policy strategies of both integrated flood-risk management and land-use planning (Klijn et al., 2004). Indeed, authorities responsable for planning have to consider natural hazards and risks for the development and implementation of land-use planning strategies and policies.

> *"Spatial planning is critical for delivering economic, social and environmental benefits by creating more stable and predictable conditions for investment and development, by securing community benefits from development, and by promoting prudent use of land and natural resources for development".*
> (UNECE, 2008)

76 **Table 4** gives an overview of the possible structural and non-structural measures that land-use planning management should consider to reduce flood risk. It needs to be stressed that only a best mix of strategies adjusted to the particular circumstances of each river basin can serve

the aims of IFM. Indeed, compared to traditional approaches to flood management, usually focusing on structural measures, IFM promotes the use of technical, economic, social and administrative actions in order to address the complexity of each context. Considering a flood-management strategy that would focus only on reducing damage potential would lead to the development potential of floodplains being largely ignored. Taking a closer look at the strategies and options for flood management, it becomes apparent that land-use planning plays a central role in reducing flood risk, as discussed in the following sections.

Table 4 — Structural and non-structural measures to reduce flood risk

Strategy	Options
Reducing flood hazard	— Source control to reduce runoff (permeable pavement, afforestation, artificial recharge, etc.) — Increase drainage system (rooftops or parking to store water — Storage of runoff (wetlands, retention basins and reservoirs, etc.) — Capacity enhancement of rivers (bypass channels, channel deepening or widening) — Dams, dykes, levees and flood embankments — High-flow diversions — Catchment management — Etc.
Reducing flood vulnerability and exposure	— Floodplain regulation (floodplain zoning, etc.) — Separation of rivers and populations (land-use control, dykes, flood-proofing, zoning, house-raising, etc.) — Development and redevelopment of land-use policies — Insurance — Information-sharing (distribution of risk maps, informal training, etc.) — Design and location of facilities (emergency shelters and evacuation plans and facilities) — Housing and building codes — Etc.
Preserving the natural resources of floodplains	— Floodplain zoning and regulation — Enlarge river space — Soil pollution regulation — Etc.

Source: adapted from (WMO, 2009)

3.1.1 Reducing flood hazard

78 Spatial planning can use both structural and non-structural instruments to reduce flood hazard by decreasing flood volume and frequency.

79 Infrastructure planning and implementation of constructions, such as dykes, levees or dams, can contribute to mitigate some flood events by reducing flood probability. These structural measures can, however, induce a false sense of security among the inhabitants of floodplains and can lead to catastrophic events when they fail. In addition, structural measures, besides being very expensive, may remove the positive aspects of floods and transfer flood risk to an unprotected area.

80 Structural flood-management interventions need to be incorporated in the land-use planning process to safeguard spatial requirements of those measures now and in the future. This is a challenging task, since spatial requirements can be substantial with limited available land resources for a dam or reservoir, for example, but also for levees and diversion channels. In addition, our knowledge about the future is inherently limited, particularly concerning future economic drivers, rainfall patterns and other climatic factors.

81 Non-structural measures such as runoff control or capacity enhancement of rivers can be included in land-use planning programmes to reduce flood hazard. For instance, to decrease the runoff-generation process, emphasis must be on techniques that promote infiltration and storage of water in the soil column, such as infiltration trenches and permeable pavement (Konrad, 2014). Indeed, as shown in **Figure 24**, permeable paving creates surfaces that enhance infiltration in urban areas due to specific opening and porous surfaces.

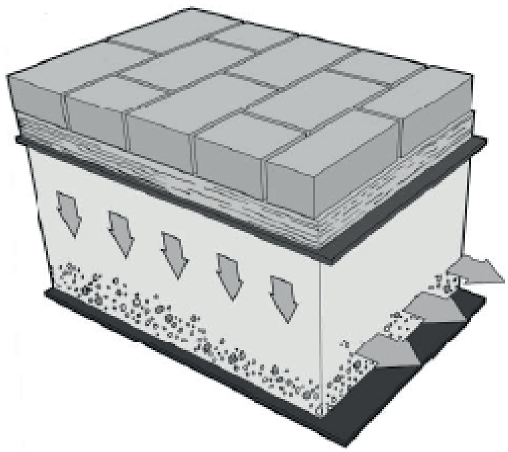


Figure 24 — Permeable pavement increasing infiltration (Jha et al., 2012)

82 A neighbourhood in Seattle (Washington, USA) reduced wet-season runoff by 98% by incorporating vegetated swales and native plants on the sides of streets (Konrad, 2014). In many cases, a change in land use can offer a great number of benefits to ecosystems. For example, replacing intensive by extensive agriculture can improve soil-infiltration rate and water quality and increase the level of aquifer recharge, as well as enhancing biodiversity and landscape quality (Environment Agency, 2009b).

83 Furthermore, by encouraging appropriate land uses, such as forest maintenance and expansion, in a river basin, discharge of excess water in the stream can be significantly reduced. Indeed, *"naturally vegetated riparian areas reduce downstream flooding, which helps in preventing thousands of dollars in property damage and reduces the need of installing costly flood control measures"* (Conservation Reserve Enhancement Program (CREP, 2014)).

84 Measures taken over the whole catchment area are referred to as "catchment management" and deal with a variety of aspects, far beyond the water system, in order to optimize the catchment's functioning. This can entail a source-control approach that seeks to keep as much rainwater retained where it falls so that flood peaks can be attenuated. Another goal of catchment management is to identify where flooding causes least harm – and where it might occur – to protect other crucial areas, such as cities and industrial centres, with high damage potential. These high-risk areas need to be identified and included in the land-use planning and regulation process, in order to be kept free from high-risk uses.

3.1.2 Reducing susceptibility to damage

85 Land-use planning is also a useful tool to organize the territory in order to increase socioeconomic resilience to floods. For instance, policies on the design and location of public services and critical facilities have to be redeveloped to take the flood-risk situation into account. For instance, flood shelters should be included in land-use plans. Similarly, information-sharing about flood risk and how an area is affected by floods can increase the awareness of communities, thereby reducing their current and future vulnerability thereto.

86 One of the strategies of IFM within land-use planning is floodplain regulation, for example, by the implementation of zoning codes to steer human development away from high-risk areas. Some regulation issues, such as floodplain zoning or building codes, will be further discussed in Section 5. Furthermore, appropriate land-use planning should give more space to riverine systems in order to preserve natural open space.

3.1.3 Preserving the natural resources of floodplains

87 Floodplains are subject to competing uses. Societies have an interest in making use of their vast natural resources which, in certain cases, leads to an overexploitation by converting large parts of natural habitats to other land uses with repercussions, not only on biodiversity and the functioning of floodplain and riverine ecosystems, but also on associated livelihoods and economy. Land-use planning and regulation play a key role in balancing the development requirements and the preservation of the natural resources on floodplains.

3.2 Tools and mechanism for interaction

88 The need for closer coordination between flood management and land-use management has long been recognized, but many countries are struggling to devise appropriate policies and administrative mechanisms that would facilitate such integration. Interactions between these planning processes can take place at various levels and through a number of instruments, which are subsequently discussed. It should be noted that the application of those instruments depends on the importance of flood risks on the prevailing political agenda. Generally, land-use

development planning plays a much more important role politically and local and regional land-use development agencies usually hold more powers than flood-management agencies. It is usually after exceptionally large floods or flood disasters that flood-management issues acquire importance on the political agenda.

3.2.1 Flood-hazard maps

89 Provided by qualified scientific technical institutions on appropriate scales, flood-hazard maps are the central instrument to facilitate interaction between different sectoral planning agencies. Flood-hazard maps show the probability of the occurrence of flood within a specific period of time. In other words, hazard maps prescribe which land uses are possible and under which conditions. These maps are visual tools that illustrate flood hazards. As shown in **Figure 25**, areas subject to floods are indicated with simple designs such as shades, colours or lines around affected areas. Flood-hazard maps are good instruments to assess risk, as well as to educate and raise awareness of the general public and stakeholders (WMO, 2012b; Santato et al., 2013).

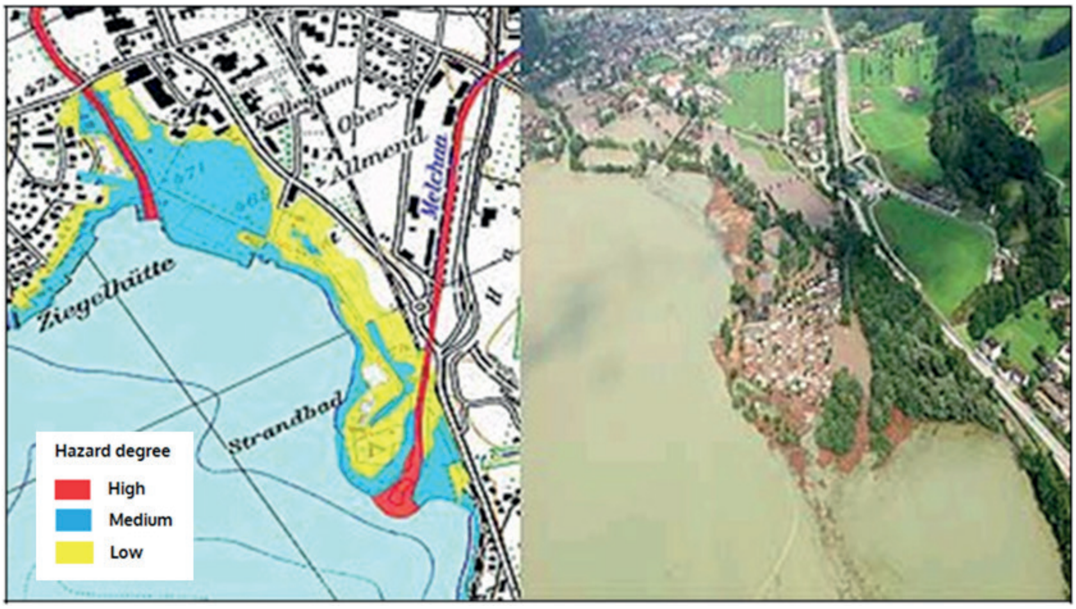


Figure 25 — Comparison between a flood-hazard map and a flood situation during flood events in Sarnen, Switzerland, in 2005 (FOEN, 2012)

90 Indeed, these visual tools are useful in encouraging people living and working in flood-prone areas to find out more about the risk they incur and take appropriate action. It helps governments in the identification of communities vulnerable to flooding and shows the locations of both hazards and opportunities, supporting new infrastructure development or regulations enforcement (WMO, 2012b). It is, therefore, important to make this information available to the general public, community leaders and government bodies. Likewise, potential users of flood maps, such as land-use planners and communities, should be involved in the mapping process. This hazard analysis can be complemented by other flood maps, such as exposure and/or vulnerability maps, in order to assess flood risk in particular regions.

91 Lastly, in designing mapping programmes, it is essential to understand all natural hazards and how they affect a particular area of study of these mapping programmes. Local or regional

land-use maps present an essential opportunity to incorporate information on various hazards in the planning process.

3.2.2 Flood-risk assessment

92 Assessment of flood risk is essential not only to take effective measures but also to know how to deal with an emergency situation (WMO, 2006e). It can also be used to evaluate the net benefits of a flood-mitigation project (WMO, 2006e). Indeed, flood-risk assessment is a tool to quantify hazards in the light of information about areas and structures at risk, estimation of risk parameters, hazard-related damage, availability of mitigation measures, etc. (WMO, 2012b). Risk assessment includes both qualitative and quantitative notions. Multiple scenarios are also used: for example, expected losses during a flood event would be calculated by comparing a situation with and without a dam in a given river basin. Thus, flood-risk assessments increase the understanding of the sources and impacts of flooding and enable the identification of high-risk areas.

93 Strategic plans can be used in the framework of flood-risk assessment procedures, in particular for higher administrative levels or by different administrative domains not specialized in flood management. They help to gauge in advance the likely impacts of a particular plan or strategy. They could also be included in the administrative process of infrastructure permit release, whenever it is located on an area classified as a "high-hazard area".

94 In some cases, it is difficult to undertake flood-risk assessments because they require a large amount of hydrometeorological and socioeconomic data that are sometimes difficult to acquire. In this case, community-based data management is a possibility to explore.

3.2.3 Environmental assessment

95 Environmental assessment is an important input for project and strategic planning. It can be applied to plans or projects that are likely to cause adverse impacts on the environment and may help avoid, reduce or mitigate such impacts (WMO, 2013b). This instrument helps to document, identify, evaluate and mitigate environmental impacts of flood-management measures, from early planning to project implementation stage. Integrated flood management is a multidisciplinary approach and it is therefore important to collaborate with various planning agencies, specialized technical agencies and local governments to integrate the complexity of all processes in the assessment.

96 Two kinds of environmental assessment procedures can also incorporate elements of flood risk. One is strategic environmental assessment, representing environmental assessment at the planning stage. More specifically, it is used to assess and predict the impact of different policies, plans and programmes on the environment in order to prevent and avoid environmental damage (WMO, 2013b). This assessment provides an opportunity to consider environmental, social and economic aspects in strategic decision-making. It can be applied in the field of land-use planning, for example for transport plans. The other, environmental impact assessment evaluates the impacts of a proposed project on human and ecosystem well-being (WMO, 2013b). The APFM publications *Environmental Aspects of Integrated Flood Management* (WMO, 2006b) and *Applying Environmental Assessment for Flood Management* (WMO, 2013b) give a more detailed description of the application of those two environmental assessment procedures.

Box 7 — Principles for spatial planning and natural hazards in Switzerland

While different countries may have developed a specific and detailed approach for devising the appropriate role of land-use planning in flood management, a number of central policy elements are derived here from the example of Switzerland. They are built on four pillars, namely: recognize hazards; avoid hazards where possible; cope with risks; and review safety periodically.

Switzerland has to deal with scarce land resources that are affected by multiple hazards, combined with a strong and diverse economy that has made use of the floodplains for centuries. On the other hand, Switzerland has already gained substantive experience in employing land-use planning as a tool to deal with flood hazards and risks on the technical, as well as legislative and regulatory, frameworks.

For a detailed description of Switzerland's approach, see: *Recommendation of the Swiss Government on Spatial Planning and Natural Hazards*

4 LEGAL AND INSTITUTIONAL FRAMEWORK

4.1 Rights, powers and responsibilities

97 Since flood management is an interdisciplinary field involved by a wide range of bodies, IFM should be based on a well-defined legal framework that supports institutional activities. As shown in **Figure 26**, law has an important role in the implementation of flood-management policies.

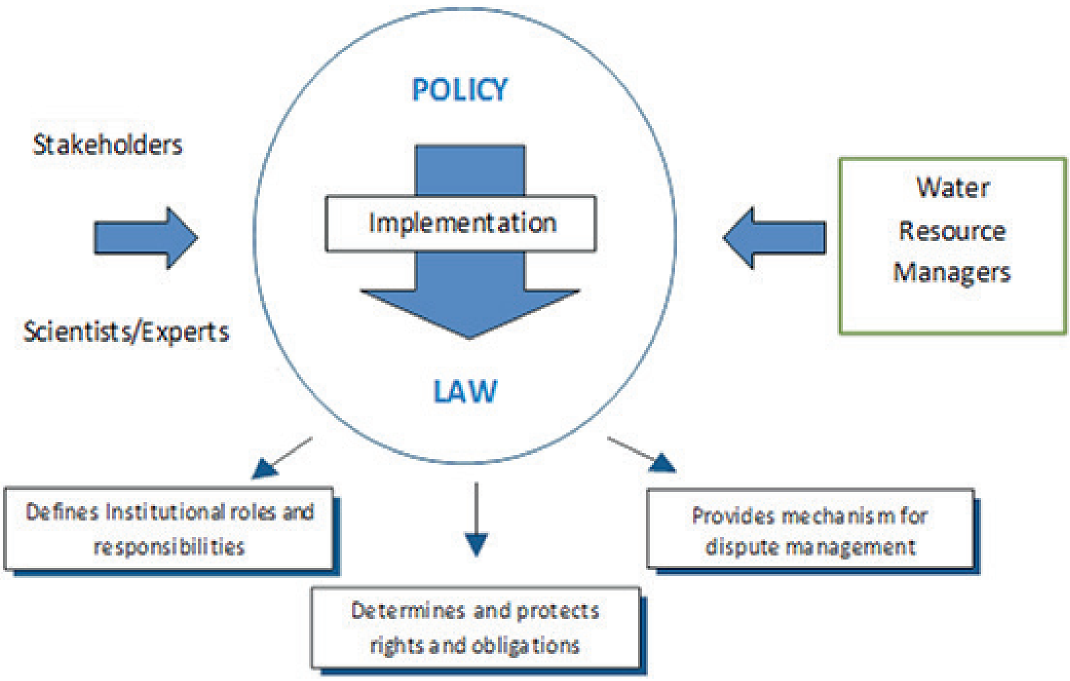


Figure 26 — Role of law in integrated flood management (WMO 2006c)

98 Based on the political and administrative system of a country, direct responsibility for flood management may be attributed to federal or local government. The primary responsibility of national policy, guidelines and framework legislation may rest with the central or federal government, while detailed regulation, implementation, operation and maintenance of flood-management measures may be assumed by subnational administrative entities (WMO, 2006c). For instance, the role of the Swiss Federal Government concerning flood management is to provide financial, technical and scientific support (WMO, 2006d). The law on spatial planning (LAT, RS 700) obliges the cantons (Swiss administrative subdivisions) to identify areas affected by natural hazards such as floods, even when such status implies some impacts on the economic growth of these zones. The responsibility of flood control is assigned to the cantons, which, depending on the case, can transfer the responsibilities to the municipality or landowners.

99 France has developed a specific planning system to regulate existing and future land use in areas liable to natural hazards. Local authorities have to take into consideration these hazard-specific arrangements and directives in the planning process. Thus, both floodplain storage areas and developed areas should be considered and delimited (Pottier et al., 2005).

> *Governments may discourage encroachment, but local developers and community leaders will often have different interests; floodplain development brings rewards in the form of private profit for individuals through increased land values and as higher levels of property-based community taxes for local government, derived from increased employment, regeneration and other local economic change.*
> (Pottier et al., 2005)

Responsibilities of the State to provide flood hazard or risk maps as the basis of planning

100 The very basis of incorporating flood risk in development planning is the availability of accurate information on flood hazards in the form of flood maps. In order to keep technical and scientific standards harmonized and in view of the highly specialized nature of the subject, it seems reasonable to argue that the development of these maps should be coordinated on a large scale and high administrative level, i.e. at river-basin or federal level. The law should enforce relevant agencies to prepare such maps, supported by the required resources, to make them publicly available and update them in adequate intervals. A recent example is the European Union Directive on the Assessment and Management of Flood Risks, which mandates Member States of the European Union, among others, to prepare flood-hazard and flood-risk maps, at the most appropriate scales (WMO, 2006d); Directive 2007/60/EC).

101 In England and Wales, the United Kingdom Environment Agency represents the principal flood-risk management authority and is therefore responsible for a range of activities related to flood issues, such as flood-risk mapping, forecasting and building and maintaining defences (Environment Agency, 2009a).

Provisions that natural hazards must be taken into account in the land-use planning process

102 Once adequate information is made available, provisions should be incorporated in the relevant laws and regulations to ensure that flood-risk information is taken into account as part of the land-use planning process. Any decision that influences the hydrological cycle of the basin or other flood-risk components has to consider flood-related risk issues (WMO, 2006c). The agency

responsible for flood-mapping should be positioned such that it needs to be consulted on strategic plans and on specific development plans of specific areas as required. This is, for example, the case in England, where the Environment Agency has a leading role in providing advice in those cases (Environment Agency, 2009a).

Obligation to disclose hazard information in the context of land transactions

103 Given that adequate flood hazard and risk maps are available, property sellers can be obliged by law to disclose information about prevailing hazards to buyers. Failure to comply can result in legal claims for compensation.

Box 8 — Mapping process in Switzerland

Swiss cantons (administrative subdivisions) are required by law to identify high -risk areas through hazard maps and risk inventories. The database ShowMe (FOEN) gives an overview of the progress in the mapping process. As shown in **Figure 27** below (FOEN, 2015a), almost all the inhabited areas in Switzerland have been mapped. Two-thirds of the territory have already integrated their hazard maps into land-use (FOEN, 2015b).

Figure 27 — The status of flood-hazard mapping in January 2015 (FOEN, 2015a)

4.2 Clear definition of roles and responsibilities

104 Relevant bodies must be aware of their role and responsibilities in flood management. The general public must also be conscious of their accountability, rights and powers concerning flood-management issues (WMO, 2006c). The roles of different actors in planning and flood management vary widely from country to country, between sectors and administrative scales and between the private and public domain. In one country, provision for flood defences may rest exclusively with regional catchment authorities or similar bodies, while, in others, those responsibilities are shared between actors on different scales, from federal government down to individual property owners. The delineation of functions, rights and powers of the

various stakeholders involved must be set out in law (WMO, 2006c). This is essential to minimize conflicting or overlapping responsibilities and to give clear mandates to specific organizations to undertake certain duties. Furthermore, the law has to provide appropriate instruments for the settlement of disputes at different levels. Indeed, flood management involves a wide range of stakeholders with different interests and visions, which may lead to conflicts of interest. The WMO publication Legal and Institutional Aspects of Integrated Flood Management (WMO, 2006c) provides assistance in undertaking an initial assessment of the prevailing legal system and the roles of different actors and provides guidance as to how gaps can be identified for the flood-management sector.

4.3 Institutional coordination mechanism

105 For land-use planning to fully utilize its potential in flood management, there is need for adequate coordination mechanisms between different sectoral planning agencies at all institutional levels **(Figure 28)**. Even though this requirement for horizontal and vertical integration in the flood-risk management context has been voiced over decades, there are indications that, in practice, the coordination between land-use planning and flood-risk management should be improved in many cases.

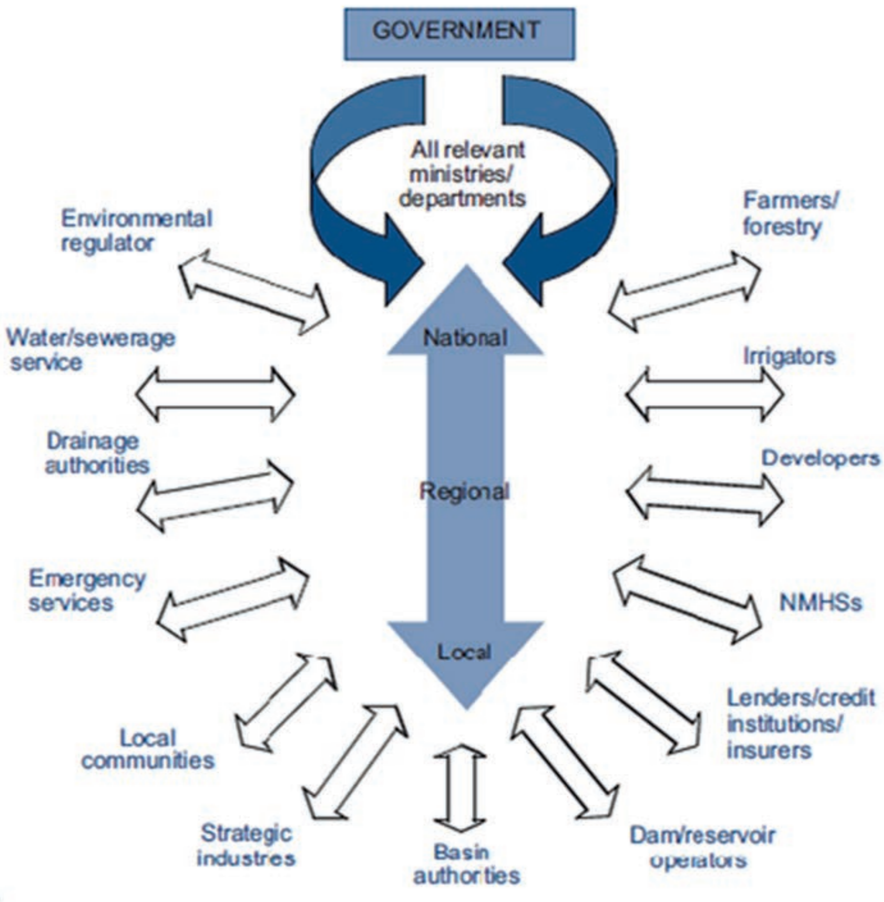


Figure 28 — Institutional coordination and integration in flood management (WMO 2006c)

4.4 Compliance and enforcement

106 In order to enforce existing land-use regulations, the administrator of a floodplain or local authority requires a series of legal powers. Land-use regulations or zoning ordinances usually provide such powers to administrators using various actions of enforcement. Depending on the applicable laws and regulations, an administrator may obtain legal powers, for instance:

- To take remedial action as necessary to prevent damage to property or danger to life;
- To negotiate a schedule for the completion of constructions, repairs or other activity necessary to abate law violation;
- To initiate a civil or criminal complaint against the violator;
- To contract work forces to perform required remedial actions and submit an invoice to the person who is not complying with the law;
- To initiate a procedure resulting in denial of flood insurance due to the violation of existing laws and regulations.

107 All these processes can be justified only when stakeholder awareness is high enough and flood-risk information is openly available, to help the public make well-informed choices.

5 DEVELOPMENT-MANAGEMENT TECHNIQUES IN THE FLOOD-HAZARD CONTEXT

5.1 Paths of government intervention

108 To implement an integrated land-use management plan incorporating flood-related risk notions, governmental action can use various activities and measures. The first and perhaps most applied is land-use regulation, which, in practice, is usually combined with other measures, such as the provision of incentives, knowledge enhancement and redirecting or rearranging public investment. Land-use regulations establish the basis for the kind of uses allowed in the floodplain and under what conditions (WMO, 2012b). The typology provided in **Table 5** illustrates the form of these regulatory mechanisms in more detail in the context of flood-risk management. The detailed selection of actions to be utilized will depend on the local context in terms of the prevailing socioeconomic, legal, political and cultural conditions. However, as stated above, a mixture of elements from the aforementioned strategies is more likely to be successful, rather than focusing on only one of the columns of **Table 5**.

Table 5 — Typology of land-use plan implementation in the flood-management context

Mitigation targets	Strategy of government action: Restrictive regulation	Incentive	Knowledge enhancement	Public investment
Land use	— Prohibit constructions — Limit density — Exclude hazardous/ critical land uses	— Density transfer/density bonus — Preferential taxation	— Public awareness campaign	— Locate public facilities outside floodplains — Purchase property
Design of building site/landscape design	— Elevate site with landfill — Elevate roads and other infrastructure — Set back from hazard — Cluster on least hazardous zones — Impervious surface regulation — On-site flood detention/ retention requirements — Impact assessment	— Availability of flood insurance	— Technical assistance publications — Workshops for site planner/civil engineers — Technical assistance of retrofitting provided at disaster assistance centres after floods	
Design of buildings	— Elevation to or above base flood (e.g. 100-year flood) — Flood-proofing — Retrofits of existing infrastructure	— Availability of flood insurance — Low-interest loans — Tax deferral	— Technical assistance provision with publications — Capacity-building for architects/home builders — Technical assistance on retrofitting	— Design public buildings as leading by example

	Strategy of government action			
Mitigation targets	Restrictive regulation	Incentive	Knowledge enhancement	Public investment
Knowledge of hazard/mitigation	– Mandatory disclosure in real-estate transaction – Mandatory delineation of floodplain areas – Mandatory requirement of flood insurance	– Free or low-cost technical assistance	– Public awareness campaigns – Posting of warning signs – Provision of information in public libraries/ internet – Participatory planning processes – Availability of flood-risk maps to the general public	
Area-wide control of flood hazard	– Peak discharge standards – Storm-drainage requirements – Impact fees for flood control			– Flood-control structures – Channel improvements – Watershed treatment
Resilience of public facilities	– Subdivision of design standards – Vulnerability assessment			– Design standards of public buildings – Retrofits

Source: adapted from Burby, 2000

110 Regulating land use could imply that only open-space land uses would be possible in high-risk areas or certain adaptations would be required to building design. But, as mentioned before, restrictive floodplain regulations should be accompanied by other less intrusive measures, such as public awareness campaigns on the risks of development in specific areas, as well as the provision of reasonable alternative options to pursue local development aspirations. Similarly, to avoid social exclusion or aggravation of poverty, land-use regulatory processes have to integrate social housing programmes.

111 Enforcement capacity of the authorities concerned has an impact on the choice of instruments applied. Depending on the prevailing system of property rights regulations, enforcing land-use regulations can be a lengthy, complex and resource-demanding task. The National Flood Insurance Programme (NFIP) is a USA federal programme enabling property owners in participating communities to purchase insurance as a protection against flood losses in order to help in adapting to state and community floodplain regulations that are designed to reduce

future flood damage (FEMA, 2002). Therefore, if a community adopts a floodplain management ordinance to reduce flood risk of new constructions in flood-prone areas, the federal Government makes flood insurance available within the community as a financial protection against flood losses and damage (FEMA, 2002). Through state compensation, insurance or some other instrument, human uses of floodplains are improved (Pottier et al., 2005).

112 Other possible measures mentioned in **Table 5** include taxes and fees as a tool of land-use regulation. Various models of taxation and fees on land and infrastructure are also applied to provide incentives to preferential land uses and development options, or provide disincentive to undesirable uses (Anderson, 2005).

113 Another key aspect of the approach selected relates to the existing assets and investments in floodplain areas. Sometimes, land-use regulation may be perceived locally as unreasonable or inequitable and/or a devaluation of property.

114 The willingness and capacity of the local/municipal government to develop and enforce these regulation mechanisms can be a limiting factor in the application of these regulations. To implement some existing land-use regulations, the administrating authority of a floodplain requires a number of legal powers through ordinances. If local ordinances and regulation processes are ignored or not enforced because economic development receives preferential treatment at the expense of flood management, however, then both adaptation and flood management will suffer (WMO, 2012b).

115 Zones where land-use changes can significantly increase flood risk downstream can also be regulated to strengthen water retention in upstream areas. This, in turn, requires an elaborate assessment of flood risk both of the areas directly at risk and those receiving higher peak flows due to upstream land-use changes. During the planning process, it is important to think globally, because local land-use changes can generate an increase of flood risk elsewhere in the watershed.

5.2 Floodplain-zoning and risk-sensitive approach

116 Flood zoning is defined by national regulations or ordinances of local governments as a basis for safe and appropriate land-use management (WMO, 2012a). Indeed, land use needs to be matched carefully to flood hazard both to maximize the benefits of using the floodplain and to minimize the risks and consequences of flooding (CSIRO, 2000). A risk-sensitive approach would increase regulative intervention with increasing levels of risk, based on different hazard zones and the projected or existing types of development within each zone. Compared to the simplicity of that statement in theory, the successful practical application is highly complex.

117 Floodplain-zoning ordinances constitute an important tool in operationalizing a risk-sensitive approach. A flood-zone classification can be undertaken on the basis of average annual flood exceedance probabilities. The one most commonly used for land-use planning purposes is the 100-year-flood representing 1% average annual exceedance probability. Based on this zone classification, specific regulatory mechanisms can be introduced. For example, high-risk areas can be put under strict provisions that regulate land use and/or infrastructure (buildings, etc). Therefore, according to the degree of flood hazard, desirable land use is selected. For instance,

as shown in **Table 6**, open-space or rural areas can be located in the high-risk zone, while residential buildings or public facilities should be placed in low risk areas.

> **100-year flood:** *The term "100-year flood" is misleading. It is not the flood that will occur once every 100 years. Rather, it is the flood elevation that has a 1% probability of being equalled or exceeded each year. Thus, the 100-year flood could occur more than once in a relatively short period of time.*
> CSIRO, 2000

Table 6 — Appropriate land uses across the floodplain according to the degree of hazard in Australia

Degree of hazard			
Extreme	High	Medium	Low
— Rural — Recreation — Open-space environment	— Rural — Recreation — Open-space environment — Commercial + — Industrial + — Clubs + + with special controls	— Rural — Recreation — Open-space — environment Residential + — Commercial + — Industrial + — Clubs + — Schools + — Public institutions — Caravan parks — Council — Police + with special controls	— Rural — Recreation — Open-space environment — Residential + — Commercial + — Industrial + — Clubs + — Schools + — Public institutions — Caravan parks — Council — Police — Telephone exchanges — Hospitals — Homes for the elderly — Museums/libraries + with special controls

Source: (CSIRO, 2000)

119 Rules relating to "no construction" or even removal of existing infrastructure can be introduced, especially after flood damage has occurred and the cost and sustainability of reconstruction in a particular area are considered undesirable. The latter is usually viewed as politically controversial, since the social and legal repercussions of such interventions are difficult to gauge in advance.

120 In the USA, for instance, a further distinction in floodplain-zoning ordinances is made between the "floodway" and the "flood fringe", where the reference value is a 1% exceedance probability. As illustrated in **Figure 29**, the floodway in this context is referring to the high-risk area that is kept free from any construction to allow floodwater to pass through this corridor. The level of risk to determine floodway areas can be based on factors such as the depth and velocity of floodwater, duration of flooding, available flood storage capacity or the rate of rise

of floodwater. In the flood-fringe zone, some constructions or modifications are allowed under certain conditions and with a specific permit.

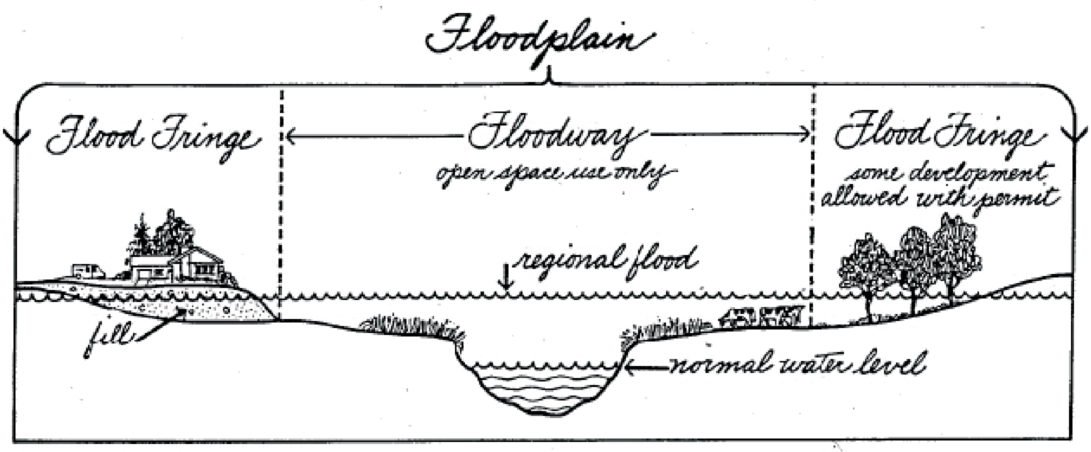


Figure 29 — Floodplain zone classification in the USA (Wisconsin Department of Natural Resources)

121 Another distinction applied in zoning is based on the probable maximum flood (PMF), illustrated in **Figure 30**. This is the largest flood that could conceivably occur in a particular location. This determination can be based on historical records and specific flood studies. In general, it is not practically or economically viable to provide complete flood defences up to that level or to regulate their use on all flood-prone land associated with the PMF. It is essential, however, to consider PMF specifically in locating strategic installations or for emergency response and evacuation planning. A lesser flood standard – the design flood event – represents a compromise between the level of protection that can be afforded and the flood risk. In Victoria, Australia, for land-use planning and buildings purposes, it is based on the 100-year average recurrence interval (ARI).

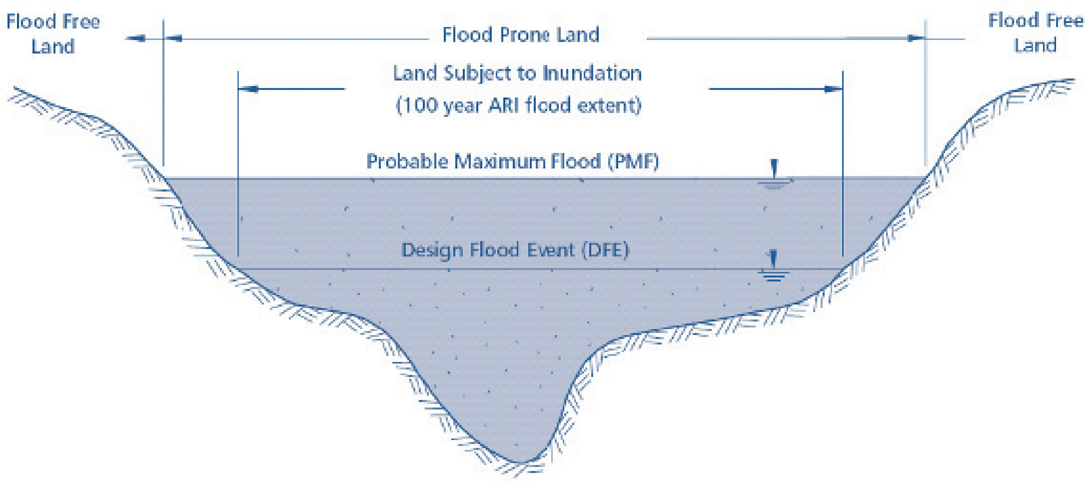


Figure 30 — Defining flood-prone land (Agriculture and Resource Management Council of Australia and New Zealand, 2000)

122 Different zones can also be identified based on the type of floods, such as riverine (or fluvial) floods, coastal floods, flash floods or stormwater floods and groundwater floods. While the riverine and flash floods are relevant for rural and urban areas, stormwater floods are particularly

associated with urban areas where overland flow develops from heavy precipitation when the discharge capacity of the stormwater drainage system is exceeded.

123 It should not be assumed that regulations must always become tighter. If development options are evaluated in conjunction with flood risk, floodplain regulations may also allow more flexible approaches (Stephenson, 2002). The zoning approach needs to be adapted to local circumstances based on data availability. If data are missing or are inadequate, some alternative approaches have to be employed, such as the maximum observed floods in living or historic memory, or the geomorphology of an area.

5.3 Planning permits

124 The process of planning permits is applied to ensure compliance of planned infrastructure or land-use changes with the regulatory regime in order to limit or minimize flood risk. Various activities on the floodplain or activities that have an influence on flood risk can be subject to permission, such as:

- Changes of land-use type or intensification of land use;
- Buildings and structural works (dwellings, commercial and industrial buildings, levees, fences, roads, embankments, etc.);
- Earthworks (land-forming, lanes, tracks, aqueducts, laser grading, surface and subsurface drains, etc.).

125 Depending on the type of activity, the use of low-risk areas such as the flood fringe may be acceptable under certain conditions and enforced during the application process for a planning permit. Certain developments may be permitted under certain conditions, relating, for example, to the:

- Location and extent of building and works;
- Incorporation of various flood-proofing measures into the design of the construction;
- Restriction on storage and goods and materials that may create pollution or become a floating hazard during floods;
- Land drainage and effluent disposal requirements;
- Requirements for access roads or tracks;
- Maximum height and extent of landfill and earthworks, including levees;
- Availability of emergency preparedness plans (for example for tourist sites, camping sites, hotels etc.);
- Provision of adequate water retention or drainage facilities.

126 In Switzerland, based on the intensity and probability of flooding, different regulations are implemented in flood-prone areas **(Figure 31 and Table 7)**. In many administrative subdivisions, laws forbid the approval of construction plans in hazardous areas or only under certain conditions (FESP, FOWG and SAEFL, 2005). For instance, in high-risk areas, no new constructions are allowed (**Figure 31**, red zone). However, in the medium-risk area (**Figure 31**, blue zone), new constructions are allowed with special permits and restrictions. Indeed, depending on the situation and if

the risk can be reduced to a justifiable degree by suitable preventive measures, the conditions required for the implementation are set in the building permit (FESP, FOWG and SAEFL, 2005). If the residual risk is too high, however, the permit should be denied.

127 In constructed areas protected by levees, a strip behind the levee must be kept free of development. This is necessary to allow access in case of flood-fighting or maintenance, but also in the light of future levee-heightening.

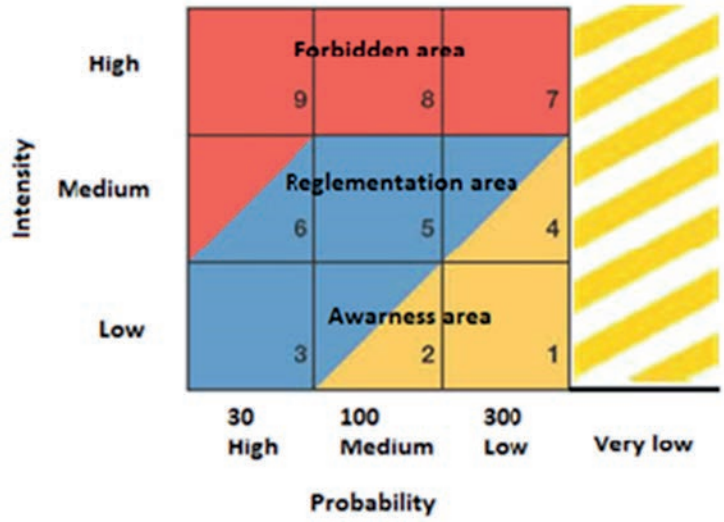


Figure 31 — Hazard levels in Switzerland (FESP, FOWG and SAEFL, 2005)

Table 7 — Land-use consequences of various hazard levels of zoning regulation in Switzerland

Hazard zone	Zone identification	Building and zoning regulation	Other measures
Ban zone (major hazard, red)	– No identification of new building zones – Preclude zoning for undeveloped building zones	– No building or expansion of structures and facilities – Decree necessary use restrictions for existing structures – Rebuilding and functional changes only with conditions to reduce hazards – Rebuilding of destroyed structures only as exceptions with conditions noted	– Prompt information to land and property owners about existing hazard and necessary preventive measures – Note use restrictions in land register if applicable – Rapid planning and implementation of necessary technical and organizational protective measures.

Hazard zone	Zone identification	Building and zoning regulation	Other measures
Conditional zone (moderate hazard, blue)	– Identify new building zones only with conditions and after reviewing alternatives and weighing interests	– No building of sensitive objects – Building permit only with conditions – Decree necessary use restrictions for existing structures – Fix requirements for spatial arrangement, use and design, possibly also development of accessibility to buildings and facilities – Depending on type of hazard and intensity, detailed rules must take account of various protective measures.	
Index zone (low hazard, yellow; residual hazard, yellow/white)	– Avoid zones in which facilities with high potential for damage could be built – Reference to the hazard situation	– Recommendations for existing buildings – Weigh conditions according to risk in case of sensitive uses or major developments	– Information for landowners on existing hazard – Advice on measures to prevent potential damage in cooperation with insurance industry – Special technical and organizational measures for sensitive objects with safety conditions

Box 9 — Tools for regional planning: England

In England, flood zones have been defined through a planning policy document, together with general policy principles and objectives. Several tools are provided for regional planning bodies and local planning authorities to steer development towards zones with lower probability of flooding. This approach is characterized by two principal tools: the Sequential Test **(Annex 4)** and the Exception Test.

The Sequential Test ensures that a sequential approach is followed to steer new development to areas with the lowest probability of flooding. It determines the suitability of land for development in areas liable to flooding. If there are no available sites with low probability of flooding, the local planning authorities have to consider reasonably available sites in areas with a medium probability of flooding applying the Exception Test. The Exception test provides a method of managing flood risk, while allowing necessary development to occur in situations where suitable sites at lower risk of flooding are not available. The latter may only be applied under specific conditions outlined in the policy document.

Interestingly, the zoning does not take into account flood defences with the argument that those may be breached, overtopped or that the lifetime of developments on the floodplain may be longer than the one of the flood defence.

For further information see: planningguidance.communities.gov.uk/blog/guidance/flood-risk-and-coastal-change/planning-and-flood-risk/ and planningguidance.communities.gov.uk/blog/guidance/flood-risk-and-coastal-change/the-exception-test/

5.4 Building standards and codes

129 Building standards and codes can play a strategic role in the reduction of potential flood damage. Based on the delineation of risk zones, this restrictive regulation provides mandatory construction guidance to enhance the flood resilience of infrastructure facilities and buildings (WMO, 2008). In other words, building codes and standards are adopted and enforced to regulate construction in areas at risk (FEMA, 2015). Based on the type of construction material and other features, they deliver building specifications for design, operation and maintenance (WMO, 2012b). There are various measures to reinforce buildings, ranging from simple and low-cost to sophisticated and technical. Basic approaches to flood-resistant design and codes for existing or new buildings are given in **Figure 32**. More information about flood-proofing is available from the APFM Helpdesk in *Tool No.15 – Flood Proofing* (WMO, 2012a).

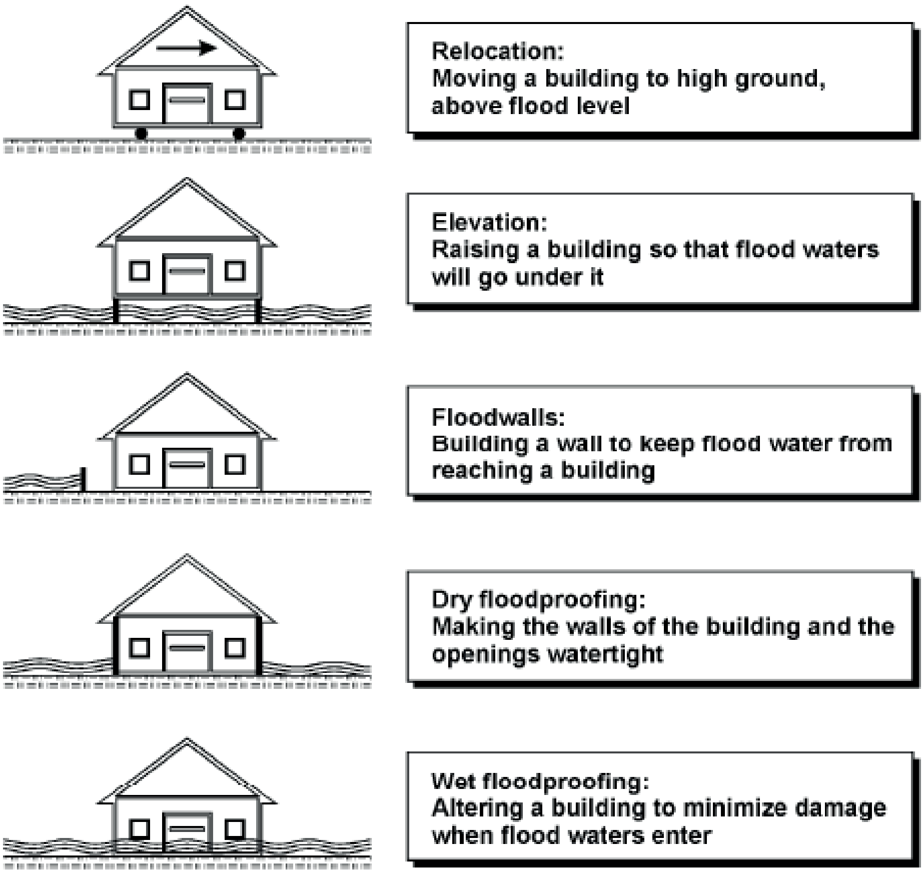


Figure 32 — Examples of flood proofing (UNESCO, 1995)

130 It is also useful to promote an orientation of the building that causes the minimum of disruption to floodflows. Likewise, the disposal of goods and materials inside the buildings may reduce potential damage. Indeed, all properties of great interest should be located on the upper floors or in a raised area. Furthermore, buildings in flood-prone areas should have an emergency exit situated in an elevated area, such as the roof.

131 Building standards and codes tend to be under a stronger local inspection regime than floodplain regulations. Therefore, compliance is more likely to be enforced. It is advisable to consider building codes as crucial elements of flood-damage reduction strategies when reforming the flood-management system.

Box 10 — Relocation of a campsite in Leutswil, Thurgau, Switzerland

The campsite of Leutswil was located on the bank of the Sitter River. It was flooded when heavy rainfall occurred. Initially, local authorities scheduled the construction of a dyke to protect the area against flood **(Figure 33a)** but, after an in-depth analysis, it was determined that the campsite would be transferred to the lowest flood-risk area **(Figure 33b)**, thus avoiding the construction of a dyke along the river.

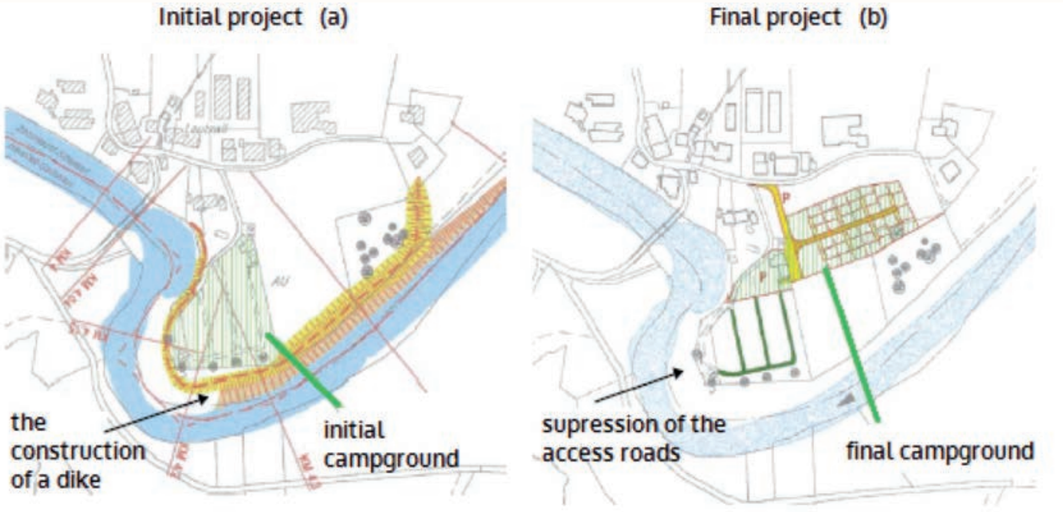


Figure 33 — Campsite of Leutswil before and after land-use plan modification

5.5 Multifunctional land use

132 Due to the scarcity of available land and the new demands of land and natural resources, multifunctional land use plays an important role for land-use planners. There are many possible win-win solutions to meet the challenges faced by land-use planners as they seek to create attractive land-use combinations to satisfy various demands in the context of a flood hazard. Examples of widely applied multifunctional land uses include the use of water-storage areas during floods for recreational purposes, such as outdoor sports facilities, parks and nature reserves.

133 In Japan there are severe constraints on land resources. This is why "super levees" are implemented in urban areas to combine the spaces used for flood defence with other urban uses such as residential or office space **(Figure 34)**. Other benefits can be derived from this approach, such as the use of these elevated lands as evacuation points during disasters and they are less prone to fail from being overtopped. This example shows that countries with vast population growth and urbanization trends or delta regions will require bold and unconventional solutions in the future to balance development needs and flood risks.

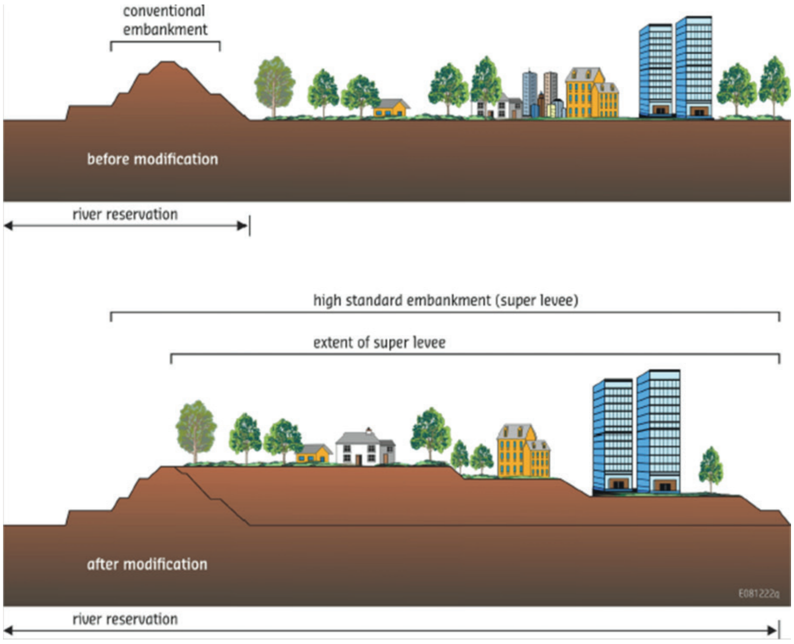


Figure 34 — Example of multifunctional land use in Japan (World Water Council, http://www.worldwatercouncil.org/fileadmin/wwc/Library/Publications_and_reports/Climate_Change/PersPap_13._Deltas.pdf)

Box 11 — Example of multifunctional use in Japan

In order to deal with the increase of river levels and peak discharges due to the extended paved areas in Tokyo, the Tokyo Metropolitan Government and the city of Yokohama produced a master plan for an overflow location with multifunctional facilities: the Tsurumi multipurpose detention basin. The detention basin enhances storage capacity and regulates the amount of water flowing into the Tsurumi River, thus reducing flooding. At the same time, the basin serves as a sports venue with the International Yokohama Stadium and as a recreational and nature area. This project demonstrates that it is possible to combine water storage and urban activities to cope with flood hazard.

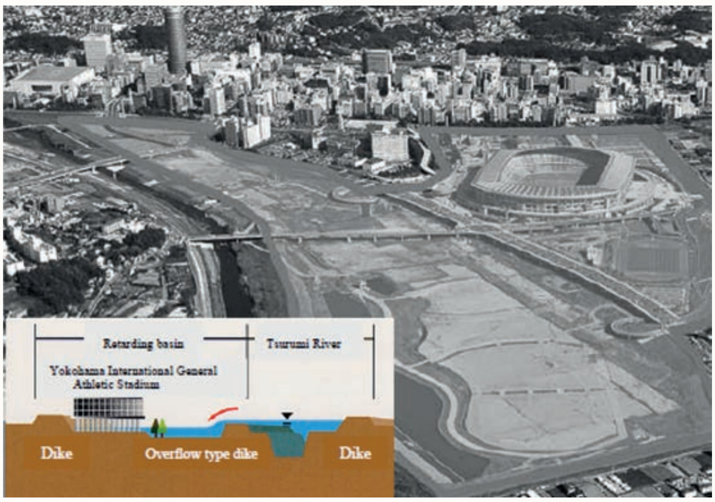


Figure 35 — Tsurumi multi-purpose retention basin (Jha et al., 2012)

For further information see: http://www.worldwatercouncil.org/fileadmin/wwc/Library/Publications_and_reports/Climate_Change/PersPap_13._Deltas.pdf

6 CONCLUSIONS

134 This publication explores the role of land-use planning in the context of integrated flood management **(Figure 36)**. The importance of land-use management is highlighted for several aspects of flood management, from technical to policy and economic points of view, with a global perspective from basin to local scales. Land use can influence all elements of flood risk and therefore has a key role in decreasing losses and damage from a flood event, especially when included in a mix of structural and non-structural measures.

135 Sound land management organizes the territory efficiently so as to achieve the economic, social and environmental goals of societies. Natural resources of floodplains are then better protected, which contributes to increased ecosystem service benefits. Emergency situations are also a key aspect to consider when planning land resources, since infrastructure such as hospitals should be located in specific areas where they can be better protected.

136 Several tools for the integration of land-use planning in the flood-management process were discussed throughout the publication. One of the main tools is the development of flood-hazard and risk maps, which are useful both for flood managers and land-use planners, as well as for the general public. It is important to make flood information publicly available, firstly for awareness-raising and secondly for public use, for example in the context of land transactions.

137 The development of a sound land-use policy is another key aspect of flood management, based on flood-risk assessments. Floodplain-zoning and the risk-sensitive approach are examples of tools that can be used in order to reduce exposure to floods. Authorities can rely on a mix of interventions in order to encourage a responsible use of the territory. Measures such as taxes, planning permits and public investments are often used. Enforcement of the law can be an issue that brings long-term challenges to achieve efficient land use.

138 Land-use management has a predominant role in the adaptation of new challenges, such as demographic pressure, urbanization and climate change. It is then a multidisciplinary task that involves many different stakeholders. An understanding of the development plans of the main economic sectors is therefore crucial and opens up a range of possible flood-management

measures by considering, for example, multifunctional land use. In order to have good communication and coordination between all stakeholders, clear roles and responsibilities should be defined with a good understanding of each other's interests and tasks. This multi-disciplinarity is one of the main aspects of integrated flood management, which reaffirms the role of land-use planning in the context of a responsible management of floods.

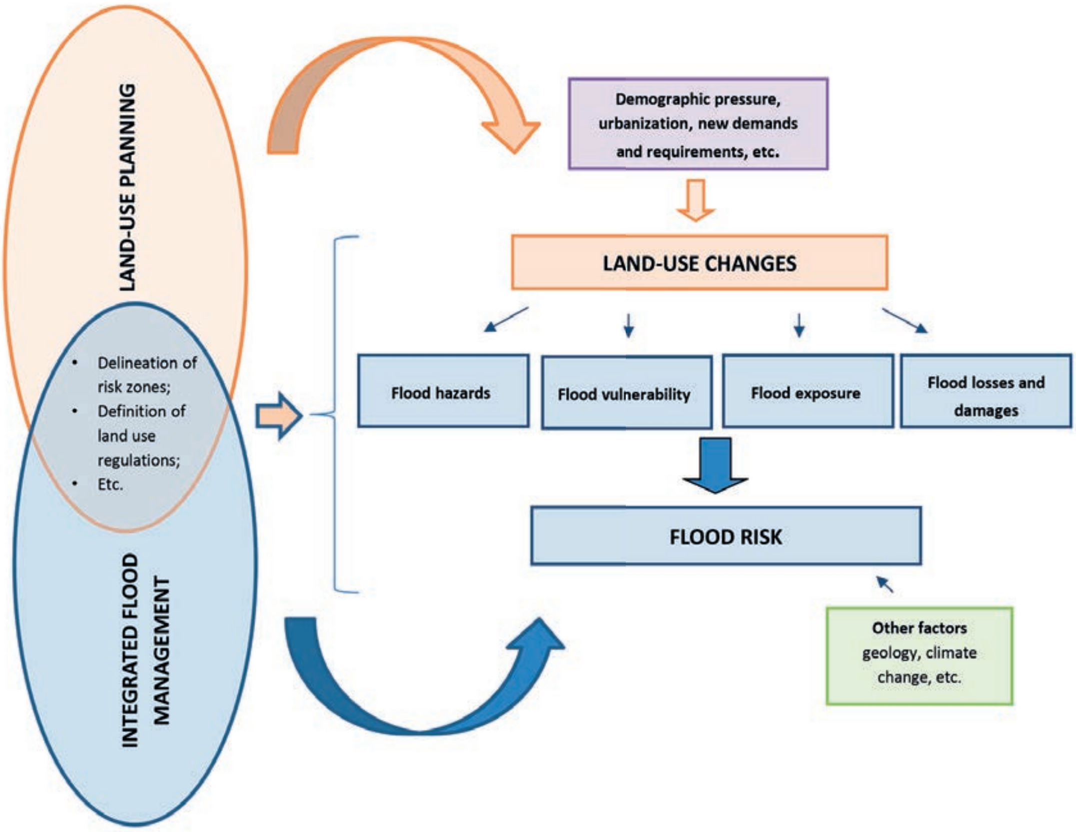


Figure 36 — Interaction between land-use planning and flood management

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ANNEX 1 - INTEGRATION OF HAZARD MITIGATION WITH COMPREHENSIVE PLAN

Fact component

1 **Map information**
Delineation of location of hazard
Delineation of magnitude of hazard

2 **Emergency response data**
Emergency shelter demand and capacity
Evacuation and clearance time data

3 **Exposure data**
Population exposed
Public infrastructure exposed
Value of private structures exposed
Critical facilities exposed
Loss estimates for private structures
Loss estimates for public structures

Goals component

1 **Goals related to hazard**
Reduction of private property losses
Protection of population safety
Reduction of damage to public property
Minimization of fiscal impacts of disasters
Equitable distribution of hazard program costs
Promotion of hazards awareness

2 **Goals related to environmental protection**
Preservation of natural areas as part of reduction of hazard losses
Preservation of open space and recreation areas as part of reduction of hazard losses
Maintenance of good water quality as part of reduction of hazard losses

Policies component

1 **Policies to build awareness of hazard**
Educational programs
Voluntary disclosure of hazard by estate agents
Disaster warning and response
Post signs delineating hazardous areas
Encourage purchase of hazard insurance
Technical assistance about mitigation actions

2 **Regulatory policies**
Permitted land uses
Density of land use
Transfer development rights outside floodplain
Cluster development
Setback from floodway
Site plan review/impact assessment
Special study/impact assessment
Building standards
Mandatory disclosure by estate agents
Land or property acquisition
Financing of mitigation projects
Mandatory retrofitting of private structures

3 **Policies to create incentives for mitigation**
Voluntary retrofitting of private structures
Voluntary land and property acquisition
Tax abatement for using mitigation
Density bonus outside floodplain
Low-interest loans for retrofitting buildings

4 **Infrastructure policies**
Structural controls
Capital improvement adjustments
Retrofitting public infrastructure
Addressing critical facilities

5 **Recovery policies**
Land-use changes
Building design changes
Moratorium on new construction
Establishment of a recovery organization
Capital improvement adjustments
Private acquisition and relocation
Financing recovery programs

6 **Preparedness policies**
Evacuation provisions
Sheltering provisions
Requirements for emergency plans

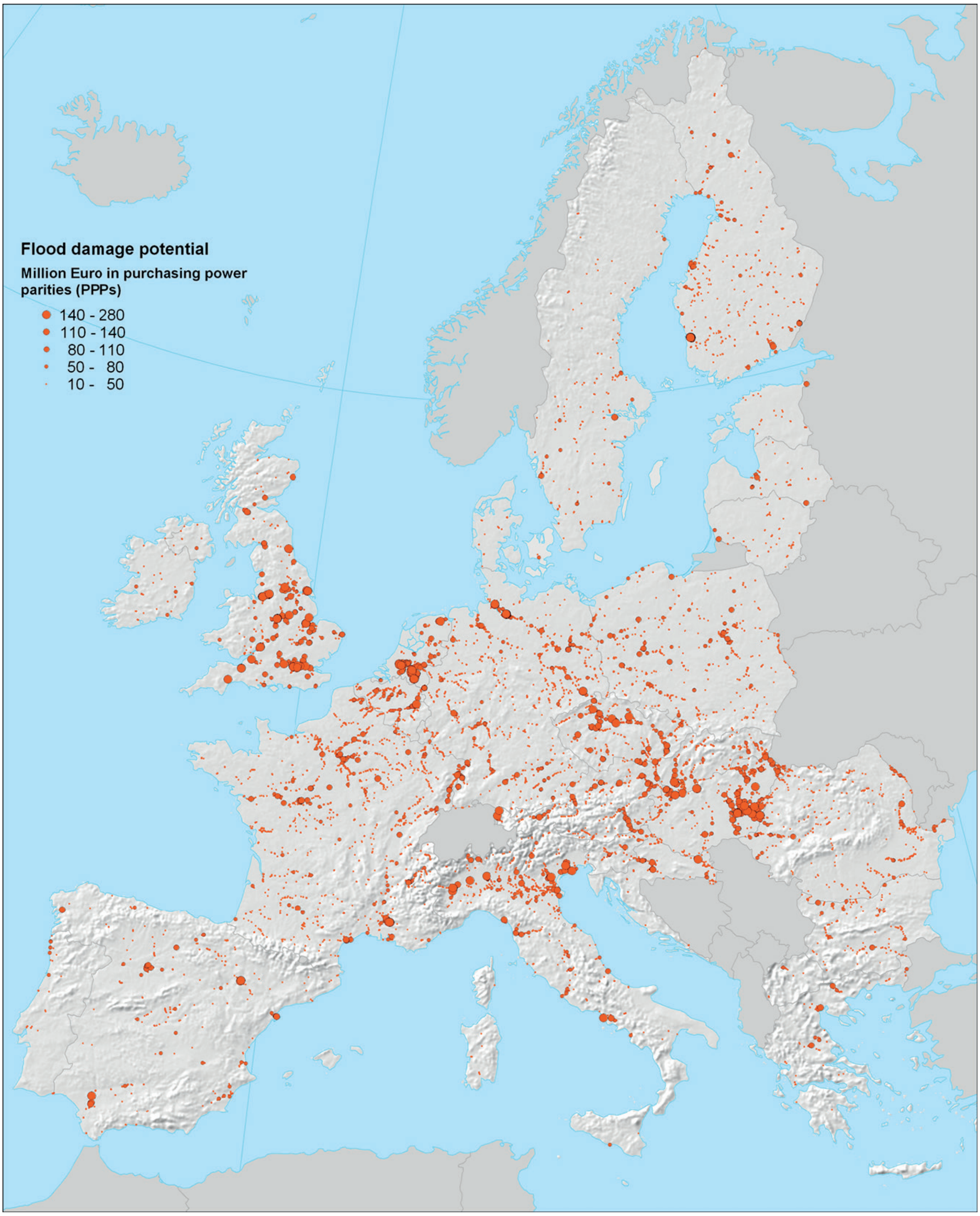
Source: Burby, 2000

ANNEX 2 - POTENTIAL IMPACT OF LAND USE CHANGES ON HYDROLOGICAL PROCESSES AND RELEVANCE FOR COMPONENTS OF THE HYDROLOGICAL CYCLE

Process	Potential impact of land use changes	Relevance for components of the hydrological cycle
Interception storage	Greatly affected by vegetation changes (crop harvest, forest cutting)	Relevant for evapotranspiration/ energy balance
Litter storage	Affected by vegetation changes, in particular forest cutting	Relevant for evapotranspiration/ energy balance
Root zone storage	Affected by management practices such as tillage method, etc.	Relevant for evapotranspiration and storm-runoff generation
Infiltration excess overland flow	Affected by crop cultivation and management practices	Relevant for storm-runoff generation in the case of high rainfall intensity and low soil conductivity (may be enhanced by soil siltation and crusting)
Saturation-excess overland flow	Only slightly affected by land-use changes (process is controlled by topography and subsurface conditions)	
Subsurface storm flow	Only slightly affected by land-use changes (process is controlled by topography and subsurface conditions)	
Runoff from urbanized areas	Highly affected by sewer system and sewage retention measures	Relevant for storm runoff from urban areas
Decentralized retention in the landscape	Affected by landscape structuring and agricultural rationalization of arable land	Relevant for storm runoff concentration from arable land

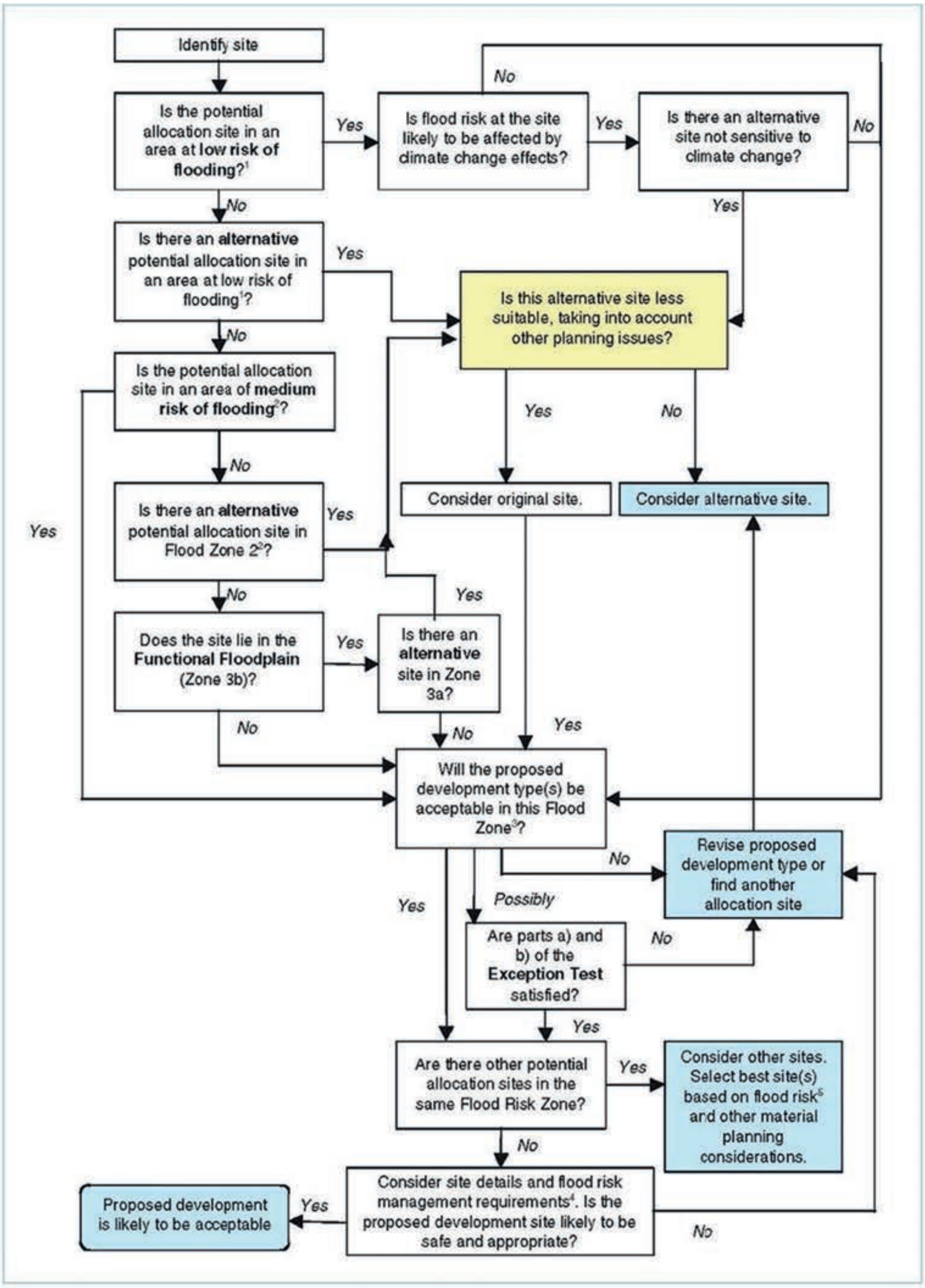
Source: Bronstert et al., 2002

ANNEX 3 - MAP OF FLOOD DAMAGE POTENTIAL IN EUROPE



Source: Barredo et al., 2008

ANNEX 4 - APPLICATION OF THE SEQUENTIAL TEST



Notes

1 Flood Zone 1 for fluvial and tidal flooding and with a low risk of flooding from other sources.
2 Flood Zone 2 for fluvial and tidal flooding and with a medium risk of flooding from other sources.
3 As defined by the Sequential Test.
4 Development to be safe and to not increase flood risk elsewhere. Required to pass part c) of the Exception Test, where applicable.
5 Including susceptibility to future climate change and residual flood risk.

Source: Department for Communities and Local Government (United Kingdom), 2007

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