

Five Feet High and Rising
Cities and Flooding in the 21st Century

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Abstract

Urban flooding is an increasingly important issue. Disaster statistics appear to show flood events are becoming more frequent, with medium-scale events increasing fastest. The impact of flooding is driven by a combination of natural and human-induced factors. As recent flood events in Pakistan, Brazil, Sri Lanka and Australia show, floods can occur in widespread locations and can sometimes overwhelm even the best prepared countries and cities. There are known and tested measures for urban flood risk management, typically classified as structural or engineered measures, and non-structural, management techniques. A combination of measures to form an integrated management approach is most likely to be successful in reducing flood risk. In the short term and for developing countries in particular, the factors affecting exposure and vulnerability are increasing at

the fastest rate as urbanization puts more people and more assets at risk. In the longer term, however, climate scenarios are likely to be one of the most important drivers of future changes in flood risk. Due to the large uncertainties in projections of climate change, adaptation to the changing risk needs to be flexible to a wide range of future scenarios and to be able to cope with potentially large changes in sea level, rainfall intensity and snowmelt. Climate uncertainty and budgetary, institutional and practical constraints are likely to lead to a combining of structural and non-structural measures for urban flood risk management, and arguably, to a move away from what is sometimes an over-reliance on hard-engineered defenses and toward more adaptable and incremental non-structural solutions.

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Five Feet High and Rising: Cities and Flooding in the 21st Century

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This paper forms part of the preparation of the Global Handbook for Urban Flood Risk Management, commissioned by the World Bank and funded by the Global Facility for Disaster Reduction and Recovery (GFDRR). The Handbook will present the state-of-the art in urban flood risk management in a thorough and user-friendly way so that decision-makers and stakeholders can assist in and contribute to the development of a global strategy and operational guide on how to most effectively manage the risk of floods in rapidly urbanizing settings – and within the context of a changing climate.

The paper title refers to the Johnny Cash song, “Five Feet High and Rising” about the great flood of 1937 that devastated the Ohio River valley, most famously Louisville.

“Well, the rails are washed out north of town

We gotta head for higher ground

We can't come back till the water comes down,

Five feet high and risin'

Well, it's five feet high and risin' “

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1 Are the impacts of global urban flooding on the rise?

1.1 Introduction

Urban flooding is an increasingly important issue which may shape the destinies of whole cities or substantially change the face of them for decades to come. Major urban flooding in the last decade affected Mumbai, New Orleans, Yangon and Dresden, but smaller scale events, some regular and repeated in the same populations, can be just as disruptive to the affected areas (IFRC 2010). Two major global themes lead us to believe that the number and scale of impact of flood events will continue and possibly accelerate in the next 50 years. The first is the global trend in urbanization which is a defining trend of the early 21st century, in particular the growth in low to middle income developing countries. This rapid growth often leads to poorly planned urbanization making urban populations increasingly vulnerable to floods. The second is environmental change as the climate warms, sea levels rise and extreme weather events are more frequent. This has led to an anticipation of much higher risk of flooding in the future.

Urban floods have specific characteristics. This paper is concerned with urban flooding and the negative impacts that large and small flood events have on the populations of cities and towns. Urban settlements can be affected by all types of flood event, from the regular seasonal swell of a river through intense rainfall flash flooding, groundwater flooding, coastal storms, and coastal erosion and subsidence. As urban settlements encompass the major economic and social hubs of any national population, urban flooding is often regarded as of more moment than rural floods and typically causes massive damage and disruption beyond the scope of the actual floodwaters.

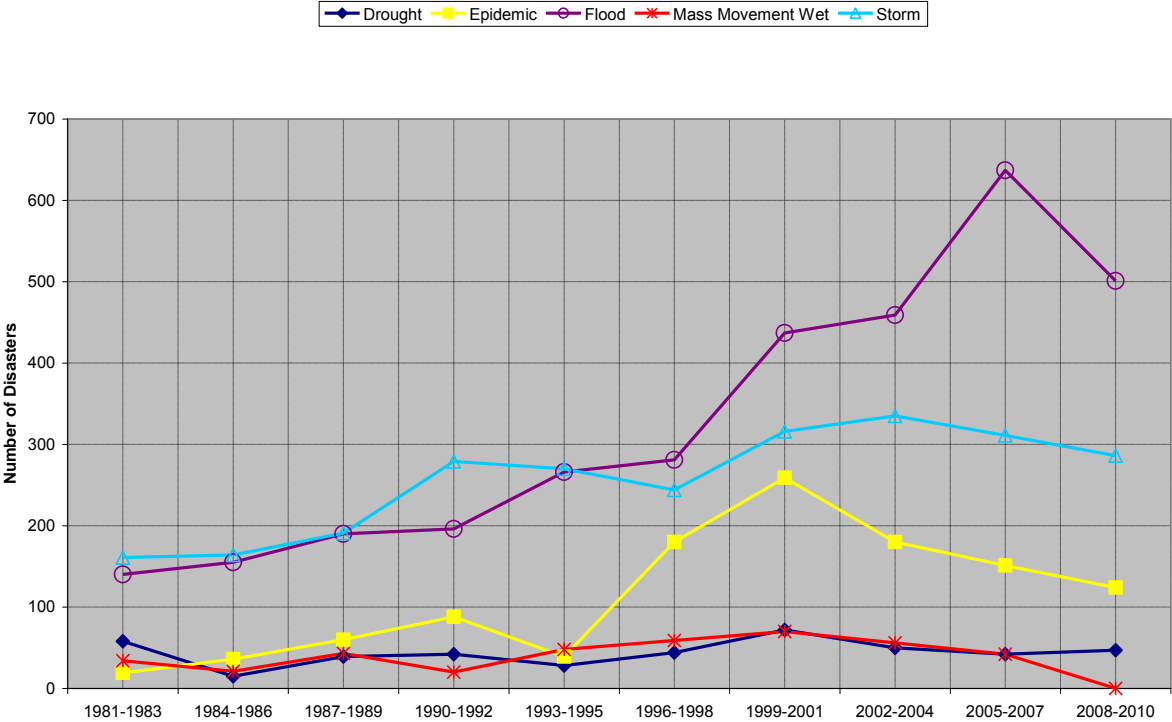
Urban flooding is a global phenomenon which caused devastation and economic losses and will continue to do so. According to the Centre for Research on the Epidemiology of Disasters (CRED), flooding in 2010 affected 178 million people and amongst all natural disasters the occurrence of floods is the most frequent. In the last century based on International Strategy for Disaster Reduction (ISDR) statistical analysis, the total numbers of hydro-meteorological events was 7,486.

In 2010, the devastating consequences of the floods in Pakistan were covered by the press worldwide. At the start of 2011 we saw the spectacle of the Queensland flooding in Australia, as well as destructive floods and landslides around Rio de Janeiro in Brazil. In addition, and under-reported, both South Africa and Sri Lanka saw large-scale floods in the period. These flood events have hit developed and developing nations alike but are often observed to have a disproportionate impact on the poor and socially disadvantaged who are least able to help themselves (ActionAid 2006). As such, urban flood risk management should already be a high priority for policy makers, city managers and urban planners. The additional questions discussed here are whether, as many policy makers are coming to believe, flooding is a growing risk for urban areas worldwide; if so,

what is driving this growth; and finally what, if anything, can be done to prevent the risk of flooding from being realized in the form of the frequent devastation of cities and towns worldwide.

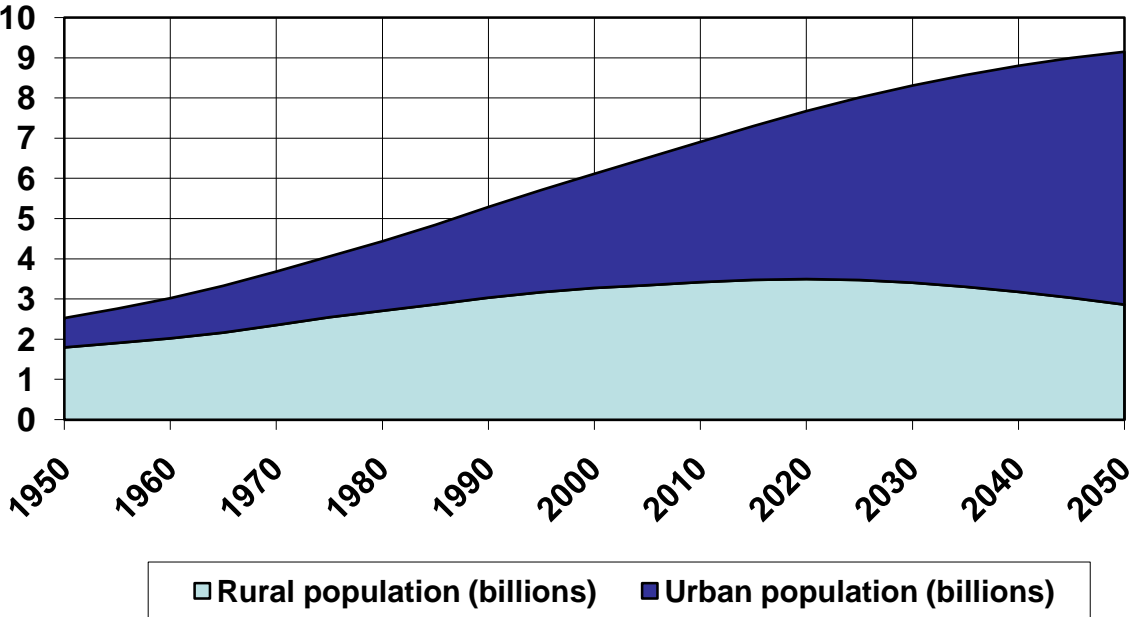
Disaster statistics appear to show flood events are becoming more frequent. At the outset we can state that studies based on reported disasters suggest that there has been considerable shift in the pattern and intensity of flood events, resulting in increased hazard for the growing world urban population. Figure 1 shows the statistic for water related hazards over the last three decades. Floods are seen to be increasing faster than other impacts. Floods are also growing faster than non-climate related hazards. Projected future increases in hazard due to climate change are predicted to impact differently in different regions, but an increase in flood hazard is a common future expectation.

Figure 1: Trends in reported water-related disasters (after Adikari and Yoshitani 2009)



Increased hazard is thus compounded by the global trend in urban population, as more people, infrastructure and resources will be affected by each event. Half the world’s population currently lives in urban areas, with two-thirds of this in low- to middle-income nations (IFRC 2010). Urban population is growing at a much higher rate than the world rural population at 2.1%, especially in the developing world, with rates of 3.3% in the Middle East and Africa, and 2.7% in Asia-Pacific. It is expected that it will reach 6.2 billion by 2050 as indicated by the United Nations in 2009, and is projected to be double the rural population at that time (see Figure 2).

Figure 2: Historic and projected growth in world population



Source: Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, World Population Prospects: The 2008 Revision and World Urbanization Prospects: The 2009 Revision.

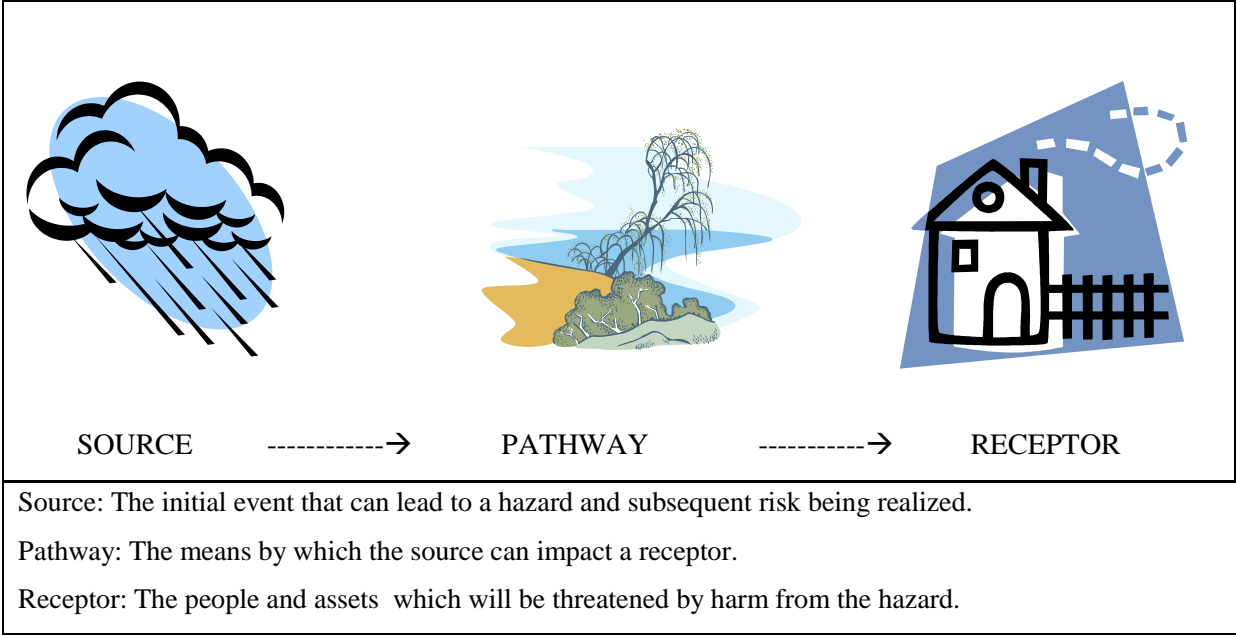
Flooding is one of the major natural disasters which disrupt the prosperity, safety and amenity of the residents of human settlements. The term flood encompasses a flow of water over areas which are habitually dry. It covers a range of types of events, many of which can also include other sources of damage such as wind. Sources of floodwater can arise from the sea (in the forms of storm surge or coastal degradation), from glacial melt, snowmelt or rainfall (which can develop into riverine or flash flooding as the volume of water exceeds the capacity of watercourses), and from ground infiltration. Flooding can also occur as the result of failure of watercourses or man-made water containment systems such as dams, reservoirs and pumping systems.

Excess water in itself is not a problem. Rather, the impacts of flooding are felt when this water interacts with natural and human-made environments in a negative sense, causing damage, death and disruption. The experience of flooding for a rural agriculturalist and an urban slum dweller will be very different: while to the farmer the flood is a natural force to be perhaps harnessed or endured for the long term benefits it may bring, for the urban dweller flooding is at best a nuisance and at worst a disaster which destroys everything she or he owns.

The impact of flooding is driven by a combination of natural and human-made factors. In describing flood impacts and discussing flood risk management solutions within this paper, two models of flooding, which are chosen from the multitude of risk frameworks available, are

particularly pertinent: the source pathway receptor model associated with Fleming (2001), and the flood risk triangle (Crichton 1999; Granger 1998; Clark et al. 2002). Fleming breaks down the process of flooding into the identification of a source of flood water, the pathway which is taken by flood water, and the receptor for the flood water which is the human settlement, building, or field or other structure or environment, as Figure 3 now demonstrates.

Figure 3: Source pathway receptor model (after Fleming 2001)



This definition is complemented by a commonly accepted definition of flood risk which defines the risk of flooding as being a function of the probability of the flood **hazard**, of **exposure** to the flood hazard, and of the **vulnerability** of receptors to the flood hazard. Many versions of such models exist for disasters generally (Thywissen 2006). In the flood context, Crichton (1999) formalizes this definition of risk into the risk triangle where, importantly, hazard is a function not only of natural processes but of anthropogenic environmental changes which alter the natural flow patterns and pathways to generate increased flood hazard from a similar magnitude of weather event. In an urban context this implies that upstream conveyance becomes part of the hazard experienced by cities. This definition also encompasses the important notion of the differences between the relative damage suffered by receptors from the hazard, with this described either as vulnerability to the hazard or alternatively as resilience against the hazard. Vulnerability and resilience are negative and positive measures of the same characteristic. Increases in past impacts and future risks from flooding can therefore result from increases in hazard, exposure of populations and their assets, or the vulnerability of exposed populations and assets to flooding.

This paper adopts this approach and critically examines the changes in hazard, exposure and vulnerability of urban settlements with a view of identifying the underlying causes of any

increases in flood impacts and trends which may influence future flood risk. The paper then goes on to present an overview of methods which can be employed to decrease hazard, reduce exposure and increase resilience and/or decrease vulnerability of exposed receptors. There are three main sections, followed by initial policy conclusions. First, statistics for past trends in flood impacts and future projections of impact drivers are assessed to determine whether urban flooding has been increasing and whether it is likely to continue to do so. The second section examines the underlying causes of flood impacts, hazard, exposure and vulnerability, to establish what is driving their growth. Understanding these underlying drivers and their relative importance in the growth of flood risk is crucial in directing flood risk management policy towards the most effective interventions. The third section contains an overview of management options which may be useful in tackling the various underlying factors causing growth in flood impacts. It summarizes these interventions in terms of appropriateness for types and scales of flooding, and discusses the issues around selection and implementation of flood risk management solutions. The final section draws out the policy implications and summarizes the paper's conclusions.

1.2 How to define the specificity of urban flooding

Urban flooding is hard to define precisely. In this paper we discuss the increase in urban flood impacts. We therefore need to understand why we should consider urban flooding separately from flooding in general. What is it that makes urban flooding specific and are the treatments of urban flooding different from those of flooding as a whole? In this endeavor we are not necessarily assisted by the recording of past events as damage statistics are not classified by urban versus rural location (Lall and Deichmann 2009). The very concept of defining urban as opposed to rural settlements in a consistent way across countries and regions is daunting (Cohen 2004). As urban populations expand we see increased populations in urban settlements of all sizes, increase in the number of very large or megacities, and the phenomenon of urban expansion which can generate bands of settlement which cover vast corridors of land and link traditional towns and cities into a wider agglomeration. Several of the greatest floods in the last decades such as the New Orleans disaster and the Mumbai floods hit major urban settlements very hard. However, it is not possible to apportion losses between urban and rural populations (IFRC 2010). Developing unified statistics is therefore beyond the scope of this paper and the specificity of urban flooding will be defined by the typology of settlement and measures appropriate to different city scales.

Urban floods are more costly and difficult to manage. We can nonetheless examine the functional differences between urban and rural flooding. While rural flooding may affect much larger areas of land and hit the poorest section of the population, the impacts of urban floods are characteristic in that the concentration of population in the urban environment is usually much higher. Therefore damage is more intense and usually more costly. The solutions to urban flood

risk issues will also need to be tailored to the nature of the urban built environment. They will be hampered by the concentrated nature and density and the relatively high cost of land within urban environments. The urban environment is also more dynamic requiring consideration of distribution of population at various timescales. Many people living in the peripheral or non-central areas of cities commute to the city center or other employment nodes during workdays. As a result the affected number of people may rise significantly should an event occur during daytime in workdays. An example from Mumbai confirms this situation: the dynamics of night-time and daytime population density varies between the average normal densities of 27,000 persons per sq km to 114,001 persons per sq km (UNISDR 2009).

Impermeable urban areas add to the flood hazard problem. High levels of urbanization in river flood plains and different parts of its catchment might also change the frequency of occurrence of flooding in a particular area. In the mid-1970s when urbanization was just starting to accelerate, a study by Hollis (1975) showed that small floods might increase up to 10 times with rapid urbanization, and big floods with return periods 100 years or over might double in size if 30% of roads were paved. In addition, because of the complications associated with impermeable surfaces, drainage systems, solid waste, debris, movable assets and the sites of buildings, the predictability of flood flows was much lower once the affected urban settlement was reached.

Changing climate means we can no longer expect to keep water away from urban settlements. This dynamic leads to unpredictability in hazard, exposure and vulnerability. It has often been overlooked by the traditional approach to the defense of urban areas. In this approach, water has been directed away from urban settlements using hard-engineered defenses often early on in the pathway near to the source of flooding, where well-understood hydrological and hydraulic models result in high levels of predictable protection. However, changing flood patterns resulting from climate change, increased intensity of rainfall and rising sea levels are likely to ensure that such an approach will be less feasible in the future. Flash flooding and overtopping mean that the full complexity of flooding within an urban setting will need to be addressed.

1.3 Is the number of flood events increasing?

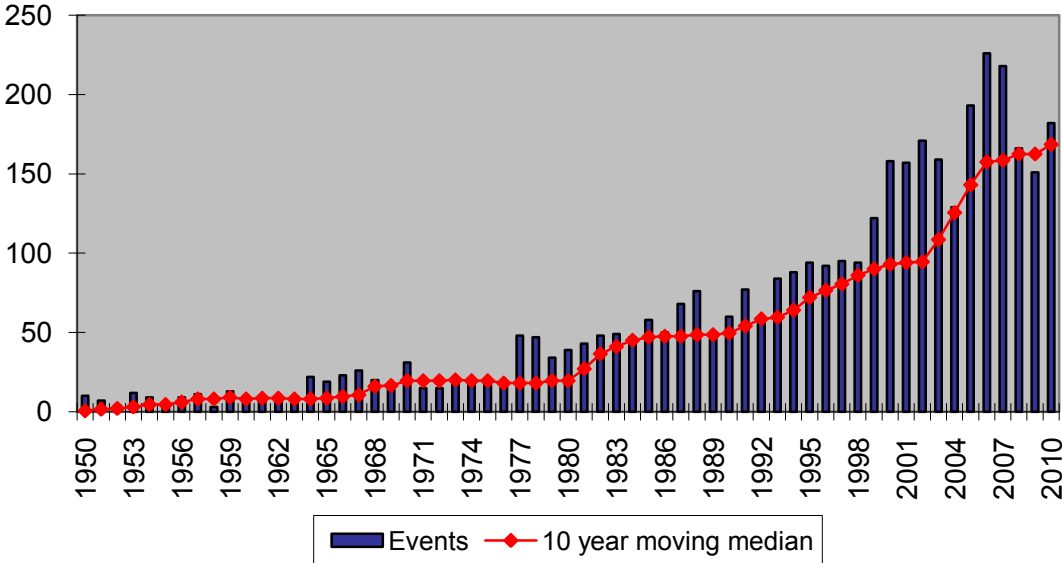
Many of the major flood events over the last decade (listed in Annex 1) and in previous decades have occurred in highly concentrated urban areas. Clearly there are many other incidents which have cost enormous numbers of life and property. The list demonstrates that in the short span of 10 years there are enough events in every region of the world to identify flooding as a global problem and to warrant urgent and concerted international action towards risk reduction. In the different parts of the world, Asia-Pacific is the worst affected in terms of economic impact and size of population involved, followed by Africa. There has been a

significant increase in the trend of large magnitude floods, with this in the face of a lack of effective flood management systems (UNDP 2006).

During the last 30 years, the total number of flood events which occurred in Asia was about 40% of all the events in the world as compared to 25% in the Americas, 17% in Africa, 14% in Europe and 4% in Oceania (IPCC AR3; CRED). The most affected country is China followed by India, Indonesia, Bangladesh, Vietnam, Thailand and Pakistan. In the last century, the number of major events occurring in Asia was the highest at 1,551, the Americas was 893, Africa was 739, Europe 473 and Oceania 117 (EM-DAT).

The question then arises as to whether the number of flood events is increasing, and whether in the future the frequency of flood events will increase causing even more devastation. In examining the trends in flood events an internationally recognized source of data is the above cited reported events database held by EM-DAT. Data from this source shows the number of reported flood events has in fact increased dramatically as shown in Figure 4 below.

Figure 4: Number of reported flood events



Medium-scale events are increasing the fastest. Recent events such as the Pakistan floods and to some extent the events in New Orleans may lead us to believe that only large scale disasters are becoming more frequent and devastating. Somewhat surprisingly, the growth in reported events is stronger in medium events characterized by between 5-50 deaths, 1,500-150,000 affected or 8-200 million 2003 USD of damages (Guha-Sapir et al. 2004). The number of reported large-scale events also grew but by a smaller percentage. The fact that the growth is stronger in small to medium size events may imply that the scale of impact from the reported events will not have grown quite as sharply as the number of events might suggest.

Reported events are clearly accelerating over time but this does not necessarily prove that the number of extreme weather events that resulted in excess flows of water has increased. More flood events could arise from the same flows because of the increased presence of people in their path. The under-reporting of events in the past might also lead to a false perception that events are accelerating when they are not. Both these effects are probably operating to some extent in the growth in reported events. Certainly the profile sources of incident reports has changed over time as was illustrated in Guha-Sapir et al. (2004) such that the balance of sources is very different now from what it was 30 years ago. However, the distribution of scale of reported flood events is revealing because the amount of under-reporting is likely to be greatest in small scale and short duration floods which suggests that the increase in frequency observed in medium and large scale floods is more robust.

An increase in number and to some extent scale of flood events from static water flows may also be adding to the increase in reported events. Section 2 will discuss in detail the ways in which this may occur. This therefore represents a real acceleration in the number of flood events that destroy lives, property and livelihoods. The argument towards addressing the associated growth in impact is compelling.

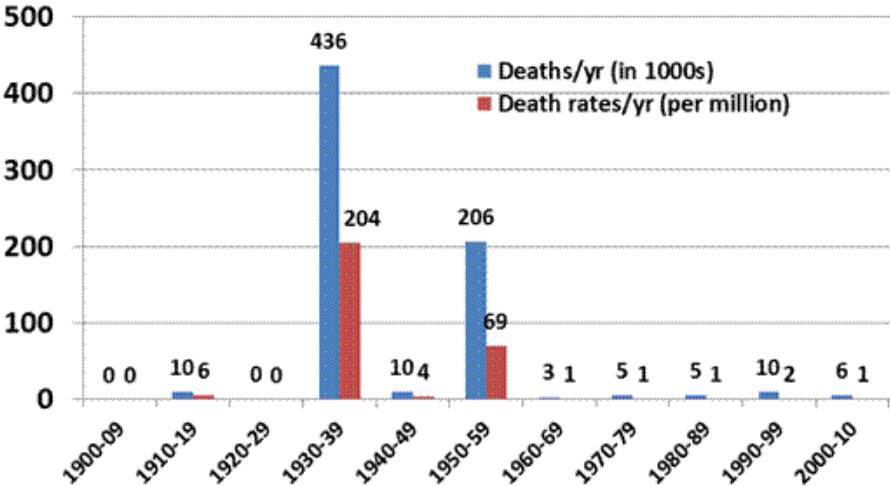
1.4 Is loss of life increasing?

The most devastating floods in terms of loss of life have tended to occur in less developed nations. The most tragic and irreversible impact of flooding on human settlements is the loss of human life. Mortality rates, some of which can be as a direct result of flood waters such as drowning, being swept away or collision with flood debris, are a key impact which varies widely across urban and rural floods, flood scale, type, speed of onset and development scale. Jonkman and Kelman (2005) have estimated that two-thirds of immediate deaths from flooding worldwide are from drowning, with the remaining one-third arising from physical trauma, heart attack, electrocution, carbon monoxide poisoning or fire. Other, more indirect, deaths are caused by disease, disruption of food supplies, ill-health or shock after the event and are also related to flood and development characteristics. Annex 2 details some of the most devastating events in terms of loss of life globally over the last century.

While it is unlikely that deaths from flooding can ever be entirely eliminated, the natural focus of flood mitigation programs naturally centers on the protection of human life. There is some evidence that such efforts have been successful. Identification of flood-related deaths is problematic as in many cases only immediate deaths from trauma are recorded. In addition, when examined over long time periods, loss of life statistics are dominated by a handful of disasters of epic proportions such as the large peak in 1999 relating to the Venezuelan (Caracas) disaster, which was a mud and debris flow event, and the 1931 Yangtze river flooding in China. This

variability in the number of deaths caused by events makes comparison over time difficult. However, there is some evidence of a general long term decrease in deaths directly caused by flooding, particularly in population-adjusted deaths as illustrated in Figure 5, as well as in deaths per flood event.

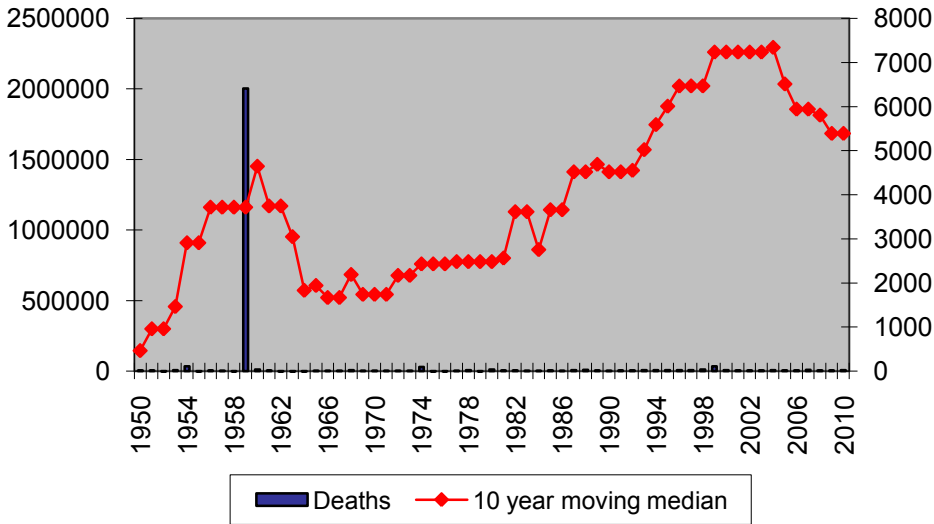
Figure 5: Global deaths and death rates per million of the population due to flooding



Source: Goklany 2011

The trend over time from 1950 to the present day excluding the largest events as represented by the ten year moving median appears to show a slow growth in flood related deaths (Figure 6). However, this growth is of far lower magnitude than other flood impacts and may have peaked and now be starting to decline.

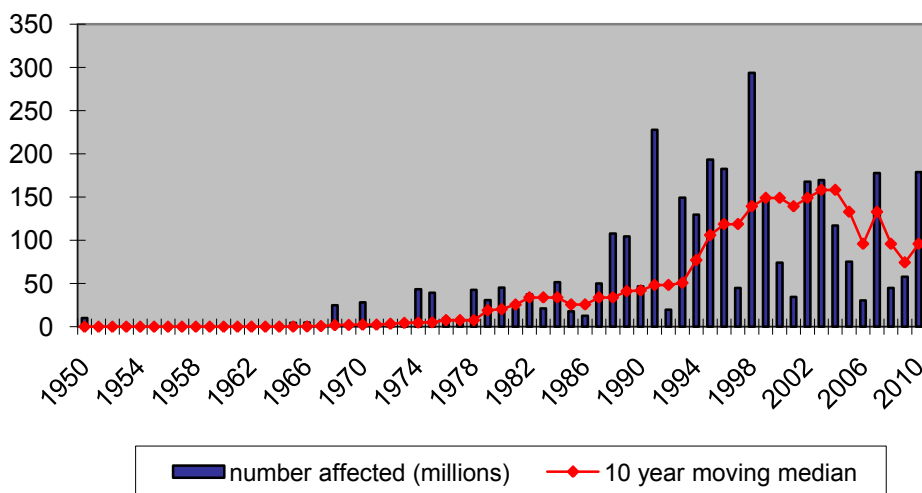
Figure 6: Number and moving median number of flood related deaths (EM-DAT)



1.5 Numbers affected

Many more individuals are affected by floods to a greater or lesser degree than are deemed to be killed by them. According to EM-DAT, on average over the past three decades more than 100 million people each year have been affected by floods. This is reason enough for governments to take action towards reducing these statistics. The numbers affected has grown since 1950 from around 4 million a year to the present level, which represents more than 1% of the global population. Figure 7 shows the numbers and 10 year moving median. However, it is difficult to determine whether the number affected by events is still on an upward trajectory, has peaked or has stabilized.

Figure 7 Number affected by flooding



1.6 Are damages – economic, financial and insured losses – increasing?

On the whole, the developing nations have insurance coverage lower than 25% of total losses. In evaluating the monetary impact of flooding there are two main perspectives typically adopted: that of economic losses, which attempts to measure the impact on society of the actual damage and disruption; and that of financial, or insured losses, which covers the cost of the replacement of damaged items and associated expenditures. These types of losses can differ significantly, depending on the items included and the scale of the economic entity considered (Barthel and Neumayer 2010). For example, from Munich Re records (Kron 2011) the difference between actual and insured losses is clear. Insured losses represent between less than 1% to over 70% of actual losses (see Table 1) depending largely on country and insurance coverage rates which also vary greatly (Gaschen et al. 1998). For example, in 2010 the Pakistan flood with an estimated \$9.5bn in economic loss resulted in very low insurance claims of \$100m as it occurred in very low income areas of a low income country where insurance coverage is almost negligible (Munich Re 2011). In contrast, the recent Queensland floods were among the most expensive

events. Typically, in examining global data on losses, it must also be recognized that recording of losses will differ over time and between data sources.

Table 1: Ratio of actual to insured losses

Table 1 The costliest floods in the 21st century (original values, not adjusted for inflation)

Lines with storm surge floods are indented and written in italics

* Numbers include windstorm losses

** Preliminary numbers (as of 1 April 2011)

Year	Country/ies (mainly affected regions/rivers)	Deaths	Total losses	Insured losses	[%]
			US\$ m	US\$ m	
<u>Asia</u>					
2000	India (Osten, Norden)	1,429	1,850		<1
2000	Japan: Typhoon Saomai	9	1,450	1,050	72
2002	China (various parts)	900	5,200		<1
2003	China (Yangtze, Huai)	923	10,090		<1
2004	China (Yangtze, Yellow, Huai)	1,196	8,270		<1
2004	India, Bangladesh, Nepal	2,200	5,000		<1
2005	China (Pearl)	685	2,520		<1
2005	India (Mumbai)	1,150	5,000	770	15
2006	India (Gujarat, Orissa)	365	5,300	400	8
2007	Indonesia (Jakarta)	90	1,700	410	24
2007	Tajikistan	13	1,000		<1
2007	Oman: Tropical Cyclone Gonu	49	3,900	650	17
2007	China (Huai)	900	7,935		<1
2007	Pakistan: Tropical Cyclone Yemyin	420	900		<1
2007	<i>Bangladesh: Tropical Cyclone Sidr</i>	<i>3,200</i>	<i>3,700</i>		<i><1 *</i>
2008	<i>Myanmar: Tropical Cyclone Nargis</i>	<i>140,000</i>	<i>4,000</i>		<i><1 *</i>
2008	China (Pearl)	212	2,670		<1
2010	<i>Oman, Pakistan: Tropical Cyclone Phet</i>	<i>39</i>	<i>1,080</i>	<i>150</i>	<i>14 *</i>
2010	Pakistan (Indus)	1,760	9 500	100	1
2010	China (various parts)	2,451	19,100	380	2
<u>Europe</u>					
2000	Italy (north), Switzerland (south)	38	8,500	480	6
2000	United Kingdom	10	1,700	1,100	65
2002	Central, Eastern Europe (Elbe, Danube)	232	21,500	3,415	16
2002	France (Rhône)	23	1,200	700	58
2003	France (Rhône)	7	1,600	950	59
2005	Romania, Bulgaria, Hungary	95	2,330	15	<1
2005	Switzerland, Austria, Germany	11	3,300	1,760	53
2007	United Kingdom	5	8,000	6,000	75
2010	Eastern Europe (Poland, Hungary, Czech R.)	7	3,800	280	7

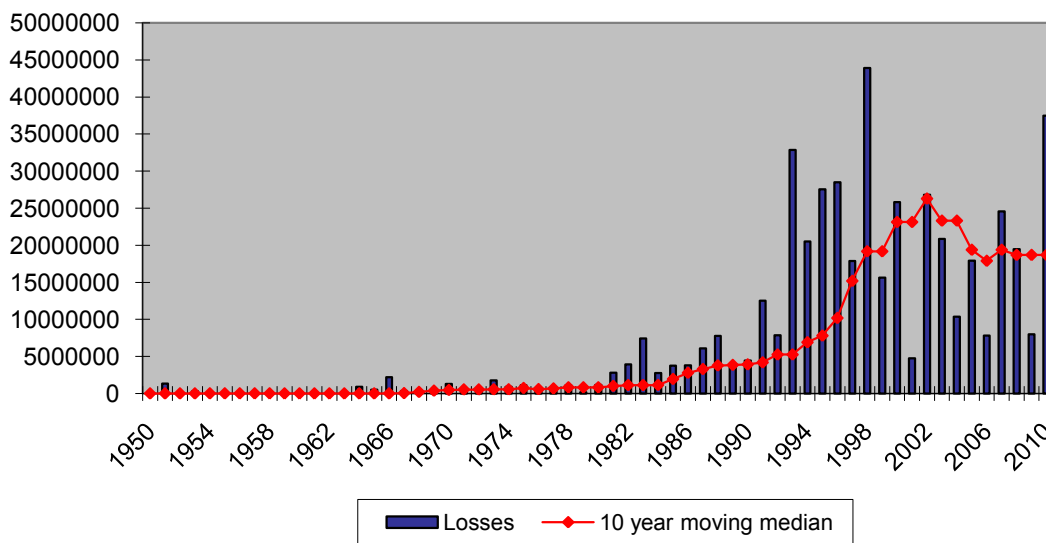
2010	France (south)	25	1,500	1,070	71
2010	Portugal (Madeira)	43	1,350	70	5
2010	Germany, Czech Republic	16	1,300	500	38
<u>America</u>					
2001	USA: Tropical Storm Allison (Houston, TX)	25	6,000	3,500	58
2001	Argentina	1	750		<1
2005	Canada (Alberta)	4	860	190	22
2005	USA: Hurricane Katrina (Gulf Coast)	1,322	125,000	62,200	50 *
2007	Mexico (Tabasco)	22	2,500	350	14
2008	USA (Midwest)	24	10,000	500	5
2008	Brazil	131	750	470	63
2009	USA, Canada (Red River)	3	1,000	75	7
2010	Colombia	195	2,000	140	7
2010	Brazil	72	870		<1
2011	Brazil	842	<1,000		<1
<u>Australia</u>					
2007	Australia (East Coast)	9	1,300	780	60 *
2008	Australia (Queensland)	2	1,700	1,340	79
2010/11	Australia (Queensland, Victoria)	30	>10,000	5,000	≈50**
<u>Africa</u>					
2000	Mozambique, Zimbabwe, South Africa	1,000	715	50	7
2001	Algeria	750	300		<1
2007	Sudan	150	300		<1
2009	West Africa	215	300		<1

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Source: Kron 2011

Notwithstanding these issues, reported economic and insurance losses are seen to have increased over time as shown below in Figure 8. The total losses in exceptional years such as 1998 and 2010 can exceed \$40 billion. Clearly the cost of flooding will be related to the nature of exposed assets and tends to be higher, per capita, in wealthier nations. It may therefore be more constructive to consider economic and financial losses in relative terms, as a proportion of national GDP. In this way, the hardship caused by flooding may be more accurately represented. In the longer term, some argue that major natural disasters can be seen as a spur to economic activity and technological renewal (Kim 2010; Crompton and McAneney 2008; Noy and Bang 2010). However, the success of countries in achieving growth through rebuilding and redevelopment after tragic disasters is limited by the capacity of nations to invest in rebuilding or by the volume of international aid and capital investment. In addition, such investment may divert funds from other development projects.

Figure 8: Global losses due to flooding



Future expectations of loss from flooding generally predict further growth in impacts. For example, a foresight report based on IPCC climate predictions estimated that the increasing risk of urban flooding in the UK alone might cost from 1 to 10 billion pounds a year by 2080 (Office of Science and Technology 2003; Evans et al. 2008).

The reduction of flood losses could potentially be tackled quite dramatically in the short to medium term via reduction of exposure and vulnerability of populations to flood risk. Analysis of economic and insured losses have been carried out extensively by Pielke (2000; 2006), Munich Re (2001; 2003; 2004a; 2004b; 2005; 2011), Barthel and Neumayer (2010), Crompton and McAnaney 2008, Swiss Re (2010) and others. These studies demonstrate that the attribution of increased losses across exposure, vulnerability and hazard is currently weighted towards exposure and vulnerability rather than hazard.

1.7 Are other losses increasing?

Other losses, which are harder to quantify and are less well-represented in statistics, include the effects on health and stresses on local health services. Stagnant water, the lack of safe drinking water and damaged sanitation systems afflict flood-affected populations, especially children less than five years of age. The incidence of acute diarrhea, malaria, respiratory infections and skin diseases is high. As an example, the floods in Dhaka in 2007 triggered the largest number of patients ever to attend the already overstretched International Centre for Diarrheal Disease Research Bangladesh Health Centre in Dhaka City (ALNAP 2008). There are also long term impacts which are generally not seen immediately after flooding. Studies such as Ahern et al. (2005) and Few and Matthies (2006) reveal that floods have long-term, “hidden” effects, in the form of stress and trauma during and after the flood event. Increased flooding

activities and challenges during disasters have aggravated the sociological (Whittle 2010) and epidemiological effects and increased psychological and physical distress (Reacher 2004).

Other post-flood effects, for example increased levels of poverty and famine, can be cited from the Pakistan 2010 event, as indicated in a report by UNESCO on the flood's impact on the Millennium Development Goals which demonstrated that 5 million people were affected by undernourishment, and that severe damage of crops has led to higher food prices which caused lower food security for the affected people and increases in poverty. Other indirect effects, like closure of schools and damage to educational buildings, also have a long term effect after flood events, which lengthen the duration of the activity of resettlement and restoration to normal life.

Another post-flood impact which directly or indirectly affects already suffering people is the burden of debt for restoration of the economy. According to the country's economic survey 2009-10, about 34% of Pakistan's GDP is being used for debt reduction after the 2010 flood. This puts extra pressure on people and reduces their financial ability to cope with the changed situation, making them in turn more vulnerable.

1.8 Summary

The foregoing analysis of the trends in flood impacts across the world concludes that there is evidence that the impact of flooding is increasing globally. Trends in number of events, numbers affected by those events and financial, economic and insured damages have all risen over the period since 1950. Immediate loss of life from flooding seems to be increasing more slowly or even decreasing over time which can be attributed to successful warning, evacuation and emergency actions, as well as increased investment in flood defenses.

The need to mitigate the devastation caused by flood events across the world is justified by the cost in human life, massive damages and impact on the lives of millions of people annually. As recent events in Pakistan, Australia and Brazil show, floods can occur in widespread locations and can sometimes overwhelm even the best prepared countries and cities. The perception that these events are increasingly frequent and costly and might continue to worsen in a changing climate has led to calls to act urgently to prevent further catastrophes.

Urban areas which are at risk from flooding have particularly been hard hit by this increase. Indeed as urban populations represent an increasing proportion of world populations, urban floods account for an increasing percentage of the total flood impact. Reported data does not allow us to summarize urban flooding as a global distinct entity but many of the most devastating recent events affected major urban centers and the specific problems of urban floods have been identified.

As will be shown in Section 2, projections of future flood trends vary widely but there is a consensus that flood impacts will continue to rise well into the future (Stern 2006; UNEP 2007).

The current and projected levels of flood impacts demand that flood risk reduction, notably in urban settlements, be placed high on the political and policy agenda. Understanding the causes of impacts and designing and implementing and investing in solutions which minimize them must become part of mainstream development thinking and be embedded into wider development goals.

2 Causes of increased impacts

The situation described above has emphasized the need to analyze the causes of flooding and to understand what can be done to reduce impacts. This calls for an investigation in the field of physical and anthropogenic issues related to urban flooding. Impact from flooding in the urban environment is caused by the action of hazard on exposed and vulnerable receptors. Increases in impacts from flooding can result from increases in hazard, in the exposure of populations and their assets, or in the vulnerability of these exposed populations and assets to flooding. Recent increases in impacts observed by sources such as the CRED database are seen to be fuelled by changes in all three underlying factors. Hazard, exposure and vulnerability all appear to be increasing and are likely to continue to do so in the future unless active steps are taken to prevent this. Table 2 shows the major factors underlying increases in hazard, exposure and vulnerability of urban populations to flooding. Some of these factors affect more than one underlying driver, but in subtly different ways. For example, urban expansion affects the flood hazard by widening the area of impermeable surface and increasing runoff while simultaneously increasing the exposure by increasing the development outside existing defenses. Increases in urban density, however, often expose more receptors to overtopping of existing defenses while also making areas more vulnerable to damage by higher volumes of flood debris.

Table 2: Causes of changes in hazard, exposure and vulnerability

Hazard	Exposure	Vulnerability
Climate change and variability	Larger population in urban areas	Changing wealth/ poverty of population
Increased rainfall	Higher urban density	
Sea level rise	Development outside	Changing demographics of populations
Increased storminess	defenses	
Changing rainfall patterns	Uncontrolled development	Building design without regard to flood risk
Land use change	Lack of operations and maintenance	Lack of preparedness
Urban expansion		
Decreased permeability	Reliance on insurance and aid	Over reliance on defenses
Poor drainage		
Urban microclimate	Land use change	Poor operations and maintenance
Ageing infrastructure		Urban density
Land subsidence		Increased efficiency and just in time management

It is still an open question as to what are the largest contributing factors to the increase in observed impacts. Studies addressing this question often involve normalizing economic losses to adjust for inflation, changes in wealth and population changes (Neumayer and Barthel 2010; Crompton and McAneney 2008). As a result, trends in losses may be wholly attributed to inflation, wealth and population changes as no further trends in losses are observed after normalization. Clearly these drivers related to exposure are highly influential in the past growth of flood impacts.

However, these studies do not prove conclusively that hazard is not increasing or that vulnerability is not important, as the possible impact of mitigation is not taken into account during normalization. Authorities and individuals have taken steps towards minimization of losses. Increased frequency could be masked by their success (Neumayer and Barthel 2010). Furthermore, the balance of drivers in the future may differ from the past. Therefore it is impossible to say with any certainty which drivers are the most important. Accordingly, the causes of increased impacts are categorized below in a structured way to illustrate that all underlying causes are considered in the process of designing strategies to limit flood damages in the future.

2.1 Causes of increased urban flood hazard

The sources of urban flooding are similar to the general flood scenario as urban settlements are subject to the same natural forces as rural areas such as rainfall, snowmelt, sea surge and failure of water systems. The pathways by which these sources of flooding threaten urban settlements include rivers and overland flows. An additional major pathway for urban flooding is intense rainfall overwhelming the drainage holding capacity of a city. More importantly, within the urban environment it is not only increases in the sources of flood water which increase flood hazard. Other anthropogenic factors, which have an impact on the conveyance of water towards urban areas and which decrease the ability of urban spaces to disperse water, will also tend to increase the flood hazard within the urban environment and are considered in this section.

2.1.1 Climate change impact

In a recent report the World Meteorological Organization (WMO) summarizes some of the climate anomalies that have been observed recently. For instance the 10 warmest years on record have all occurred since 1998. At the end of the melt season in September 2010, the ice extent in the Arctic Sea was the third smallest on the satellite record after 2007 and 2009. Global

mean sea level is rising faster than at any other time in the past 3,000 years, at approximately 3.4 mm per year from 1993 to 2008.²

Moreover, the observed increase in weather extremes is consistent with a warming climate. The IPCC Fourth Assessment Report states that since 1950 increases in heavy precipitation over the mid-latitudes have been observed, even in places where mean precipitation amounts are not increasing (Solomon 2007). Large increases in the number and proportion of strong hurricanes globally since 1970 has also been recorded even though the total number of cyclone and cyclone days decreased slightly in most basins. The extent of regions affected by drought has also increased due to a marginal decrease of precipitation over land with a simultaneous increase in evaporation due to higher temperatures.³

The alterations in meteorological patterns which are associated with a warmer climate during the second half of the last century are potentially all drivers of increased impact of meteorological disasters such as flooding. Observed and projected patterns of climate change can have a compounding or amplifying effect on existing flood risk, for example by:

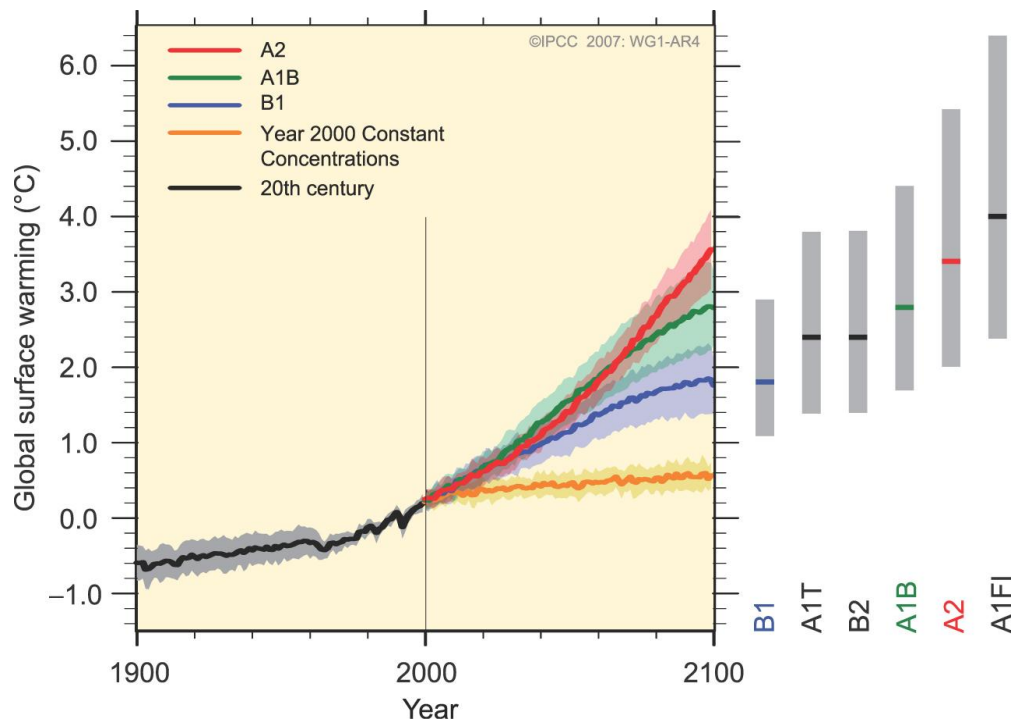
- 1 Augmenting the rate of sea level rise which is one of the factors in causing increased flood damage in the coastal areas (World Bank 2010b).
- 2 Changing local rainfall patterns that could lead to more frequent and higher level riverine floods and more intense flash flooding.
- 3 Changing frequency and durations of drought events that lead to groundwater extraction and land subsidence which compounds the impact of sea level rise (World Bank 2010b).
- 4 Increasing storminess leading to more frequent sea surges.

Figure 9 shows the projections of global mean temperature change under different emission scenarios.

² http://www.wmo.int/pages/prog/wcp/documents/wmoextremeevents.rev.dsg_sg-ob.pdf

³ http://www.ipcc.ch/publications_and_data/ar4/wg1/en/faq-3-3.html

Figure 9: Range of future climate predictions



Source: IPCC 4AR

Projections for the highest emissions scenario (SRES A2) and the lowest emissions scenario (SRES B1) overlap until the 2020s. In the case of changes in global mean precipitation, they are masked by its natural variability in the short term, partly because precipitation is a noisier variable, and partly because its response to higher greenhouse gas concentrations is not as direct as for temperature.

The picture is different for longer term projections. Beyond the short to medium term, the emissions path does matter. For instance, changes in global mean temperature for SRES A2 and for SRES B1 do not overlap at the end of the 21st century (Solomon and Qin 2007). Changes in global mean precipitation become distinguishable from its natural variability, and some robust patterns emerge across the ensemble of Global Climate Models (GCM), such as an increase in the tropical precipitation maxima, a decrease in the subtropics and increases at high latitudes. However, due to larger uncertainties in the simulation of precipitation, the confidence in precipitation response to greenhouse gas increases is much lower than the confidence in simulated temperature response (Stone 2008).

Clearly, regional changes can be larger or smaller than global averages. In general, the smaller the scale, the less consistent the picture is across the ensemble of GCM projections, particularly for some climate variables. The IPCC Fourth Assessment Report, in its Regional Climate Projections chapter, presents projections at continental scales, and goes down to sub-continental scales (Giorgi regions) in order to provide quantitative information at spatial scales

not as coarse as continents, but which at the same time are still assumed to provide robust projections (Solomon and Qin 2007).

At the regional level, the seasonality of changes is also important, since changes in annual averages do not uniquely determine the way in which the frequency or intensity of extreme weather events might change in the future. For instance, in Europe, where the annual mean temperature is likely to increase, the largest warming is projected to be likely in winter in Northern Europe and in summer in the Mediterranean area (Christensen and Hewitson 2007).

Levels of confidence in projections of changes in frequency and intensity of extreme events, in particular regional-level statements concerning heat waves, heavy precipitation and droughts, can be estimated using different sources of information including observational data and model simulations. For extreme rainfall events, it is expected that these will be unrelated to changes in average rainfall. Average rainfall amount depends on the vertical temperature gradient of the atmosphere which in turn depends on how quickly the top of the atmosphere can radiate energy into space. This is expected to change only slightly with changes in carbon dioxide concentrations. On the other hand, extreme precipitation depends on how much water the air can hold, which increases exponentially with temperature. Thus it is reasonable to expect that in a warmer climate, short extreme rainfall events could become more intense and frequent, even in areas that become drier on average. Some studies have found that in regions that are relatively wet already, extreme precipitation will increase, while areas that are already dry are projected to become drier due to longer dry spells (Fussel 2009). The spatial extent of areas with severe soil moisture deficits and frequency of short-term drought is expected to double until the late 21st Century, and long term droughts are projected to become three times more common, in particular in the Mediterranean, West African, Central Asian and Central American regions (Fussel 2009).

Uncertainties in climate projections are not only due to the fact that the future trajectory of socio-economic development is inherently unknown. In Figure 9, this uncertainty is represented by different colors corresponding to the different SRES scenarios. Uncertainty is also a consequence of the incomplete knowledge of the climate system, and the limitations of the computer models used to generate projections (part of this uncertainty is represented by the different color bands for each of the SRES scenarios). The relative and absolute importance of different sources of uncertainties depends on the spatial scale, the lead time of the projection, and the variable under consideration. Over shorter time scales, for many systems the natural variability of the climate system and other non-climatic risks are expected to have a higher impact than climate change. For example, in the next few years, changes in urbanization and urban development could increase significantly the risk of flooding independently of climate change. On longer time scales, climate change might play a more significant role.

The implication of these findings for decisions about future adaptation to anticipated flood risk are complex and dependent on the temporal distribution of expected expenditure and losses. For example, provision of warning services can be designed incrementally to deal with the changing risk of flooding as and when it occurs, whereas hard engineered defenses, which may be planned to last hundreds of years, will become more difficult to design to specific protection standards (World Bank 2010a). According to Walsh et al. (2004), cited in Boateng (2008), the best approach here might be through risk assessment that is based upon the estimated probability of various estimates of sea level rise. However, an alternative and likely more robust approach is to select “no regret” solutions which will be cost beneficial and socially equitable under the maximum range of future climate scenarios regardless of their probabilities. The full range of climate projections will need to be considered here, as a solution which is most beneficial under the midpoint future projection may be disastrous under a higher estimate of climate impacts. “No regret” solutions will be discussed further below.

2.1.2 Land use change

The weather is just one of a number of perpetrators of flood hazard. River basins and coastal areas are complex environments which deal with natural fluctuations in water levels as a matter of daily occurrence. Problems arise when increases in rainfall and sea level rise exceed the normal carrying capacity of rivers and overwhelm sea defenses and natural buffer zones. Changes in the use of land can contribute to the increased hazard from flooding by reducing the flexibility of the system to absorb excess water. Land use change in any part of a catchment may contribute to increases in urban flooding downstream. The increase in impermeable concrete surfaces and urban expansion is explored further below. Other land use impacts include new infrastructure development such as transportation networks which may introduce elevated structures obstructing previous natural flow paths. Other more natural land use changes can also destroy the delicate water and land balance leading to reduced storage and increased overland flow. For example, increased need for food crops could lead to the draining and protecting of fields against water ingress. This reduces the storage capacity of land and forces water to take an alternative path which may include vulnerable receptors.

In developing countries, the removal of primary natural canopy forest reduces the ability to naturally dissipate rainfall energy and promote the retention of water. Deforestation in particular can contribute to a reduction in land cover, and with increasing precipitation there can be an increase in sediments in rivers. The natural development or planting of secondary vegetation cover is not normally as efficient at dissipating rainfall energy. The removal of ground vegetation for farming further increases the risk of accelerating the rate of rainfall runoff and causing erosion. The sudden influx of people into upper catchments, often associated with extraction of

minerals, can cause serious land degradation and increase the speed of rainfall runoff. Figure 10a shows the removal of natural vegetation in the catchment close to the city of Butuan in the Philippines. Figure 10b shows the clearance for cultivation in the same catchment and Figure 10c shows the result of an influx of people for gold mining in the upper catchment of the same river basin.

Figure 10: Removal of natural vegetation



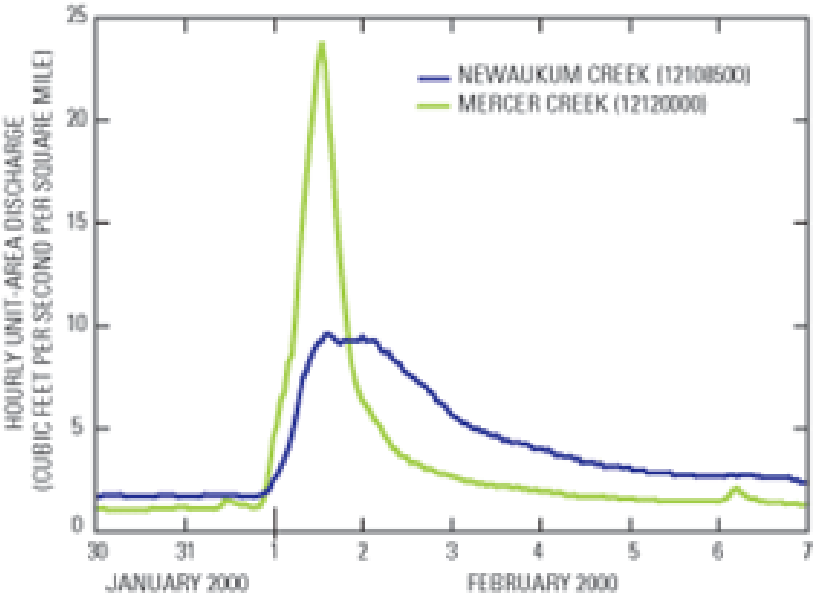
Copyright: Alan Bird

2.1.3 Impact of increased urbanization and urban expansion

One important land use change which contributes to excessive discharge of water leading to flood conditions is urban expansion, particularly development in flood prone areas. The changes in land use associated with urbanization affect soil conditions and the nature of run-off in an area. Changing land use increases the percentage of impermeable surfaces leading to enhanced overland flow and reducing infiltration. It also affects the natural storage of water and modification of run-off streams (Wheater and Evans 2009). Natural watercourses are often altered during urbanization, with their capacity restricted or more narrowly channeled, or perhaps piped. Periodic narrowing and obstruction such as bridges and culverts are erected. Smoothing of channels leads to faster conveyance causing alteration in downstream flow and possible flood hazard. The overwhelming run-off water is transported to the drainage system creating high discharge in a short time, leading to breakdown of the system. Overland flood flows which could be conveyed through this land are now either diverted by the development causing increased hazard elsewhere or continue to flow through the settlement causing increased flood hazard on the development itself.

With more runoff and less storage capacity even small streams which were not dangerous before the stage of rapid urbanization may subsequently pose danger. The following Figure 11 taken from a small experiment by the U.S. Geological Survey (USGS) team shows a rapid increase in less time and a higher peak volume of water in the urban stream in Mercer Creek than a nearby rural Newaukum creek which actually has greater stream flow than the smaller urban stream (Konrad 2003). The way land is used increases the damage potential of floods. An example of such “wrong policies and land use planning” also occurred in Turibala, Costa Rica, where urban expansion reduced the river channels and their water holding capacity.

Figure 11: A comparative graph between the stream flows of two nearby streams with urban and rural settings



Source: USGS

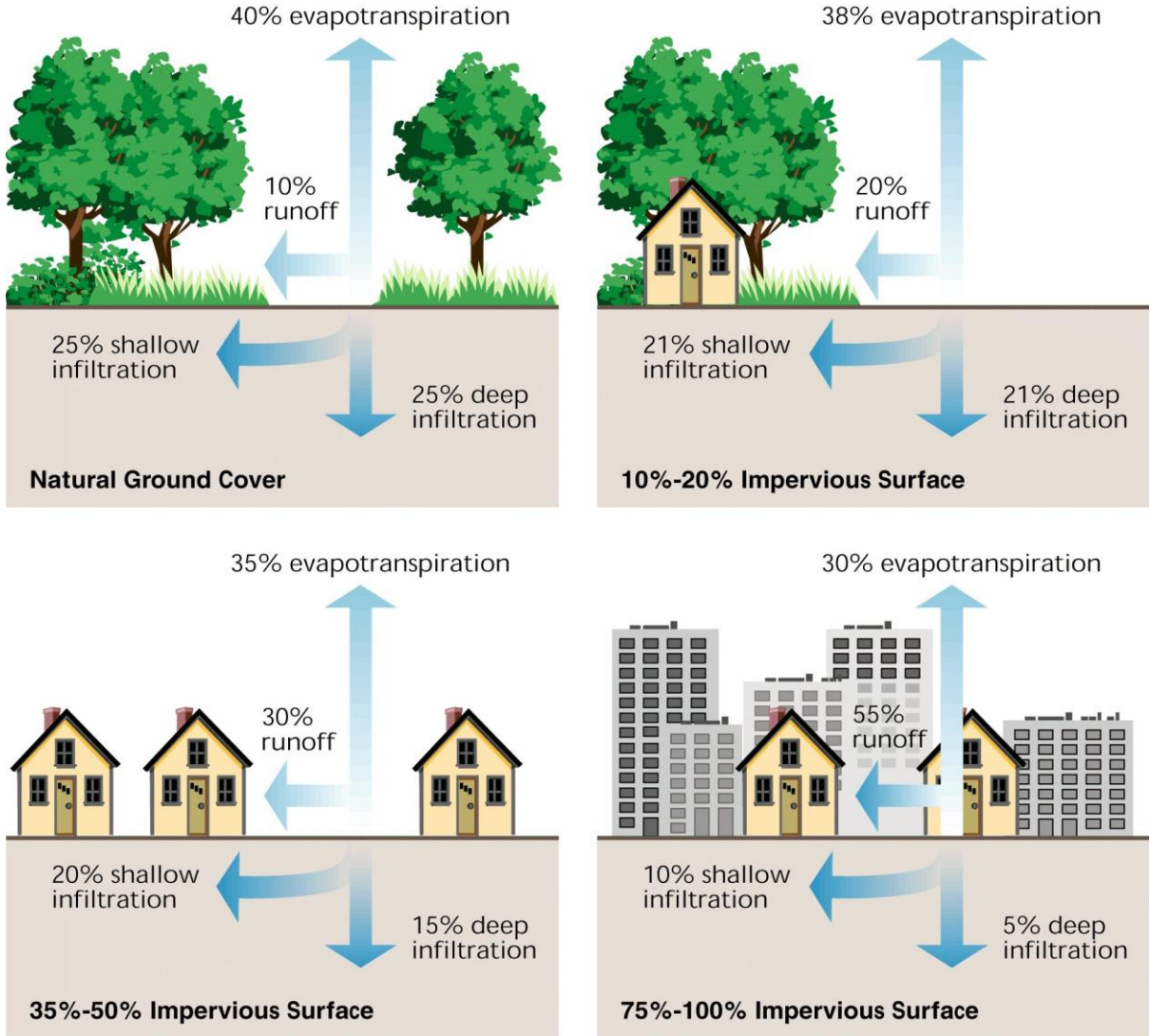
2.1.4 Decrease in permeability of open spaces

Green spaces and unmade roads provide temporary storage to rainwater by increasing permeability of the ground. This also increases ground water storage. These however are hindered by construction of concrete structures and building on flood plains and open spaces in urban areas. The increasing densification of towns and cities is often seen as desirable in order to meet sustainability targets by reducing transportation requirements and preserving rural land. However, densification implies that every space is utilized to the maximum for the use of urban dwellers. This leads to an increase in hard surfaces and a decreasing permeability of open space left after the construction of buildings. A small but relevant example is the paving of front gardens in the UK to allow for parking spaces in terraced streets without parking and garaging provision. Leisure and recreational uses also tend to involve concrete. Cost-cutting measures designed to

limit the regular maintenance of green spaces can also lead to the concreting or de-greening of spaces.

The change in the water cycle and increased strain on artificial drainage systems is illustrated in Figure 12. As a result there is a decrease in the level of permeability leading to excessive runoff and overload of the existing drainage systems. These increase the risk of flooding and are major causes of concern for urban planners in the age of rapid urbanization.

Figure 12: Change in watershed characteristics after urbanization



Source: Federal Interagency Stream Restoration Working Group 2001

2.1.5 Aging infrastructure and lack of operations and maintenance

Flood management infrastructure often requires large upfront investment. Equally important is the long term maintenance of structures to ensure they function to the designed level. There is a very big chance of increased flood risk in urban areas where the infrastructures are old and there is a lack of operations and maintenance. This is often the case in both developing

and developed countries, since proper maintenance of these infrastructures requires regular large sums of money which might not be a priority for the local management. The lack of maintenance of levees was blamed in part for the devastating floods in New Orleans in 2005. Another example of a catastrophic disaster was the Buffalo creek flood in 1972 where 125 people were killed, 1,121 injured, more than 4,000 made homeless, and 507 houses were destroyed all because of a lack of attention paid to proper planning, operation and maintenance of infrastructure. Lack of maintenance in Jakarta has led to 50% of the drainage capacity being lost due to blockages. The importance of maintenance of existing infrastructure which mitigates flood risk is not always recognized. Small actions taken regularly can have a real impact on flood risk.

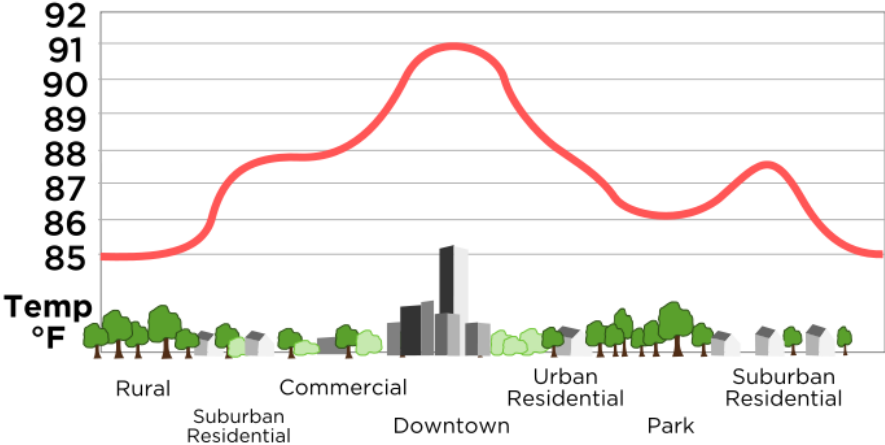
2.1.6 Lack or overload of drainage systems

Flooding may be caused by intense rainfall overloading the drainage capacity of existing systems. This might be influenced by inadequate water carrying capacity as a result of short-sighted design and installation as well as lack of maintenance. It may also be a consequence of a rain event which exceeds the criteria for design of the drainage system. For example current design guidance in the UK is that storm sewers for residential areas are designed for a rainfall event with a return period of two years. In extreme events, exceeding the capacity of the urban drainage system is a significant cause of surface flooding. In the 2007 floods in the UK, it was estimated that the inundation of two-thirds of the 57,000 properties affected was a result of sewer flooding (DEFRA 2008). However, in this case the sewer system cannot be considered in isolation since its capacity is reduced by rising levels in the receiving waters. Another example is Vietnam where the issue of old, fragmented and deteriorated drainage systems is one of the urgent challenges for urban planners. The country is suffering from the consequences of flooding in a number of cities as a result of drain blockages.

2.1.7 Impact of urban microclimate

Urban micro climates especially urban heat islands owing to lack of vegetation can modify the hydrology of an area. Heat islands create higher temperatures over cities and the temperature variation within cities can be marked as illustrated in Figure 13. For example during the summer heat wave of 2003, differences of up to 10°C between city and rural temperatures were measured in London.

Figure 13: Stylized microclimate graph showing the temperature range between city and the surrounding region



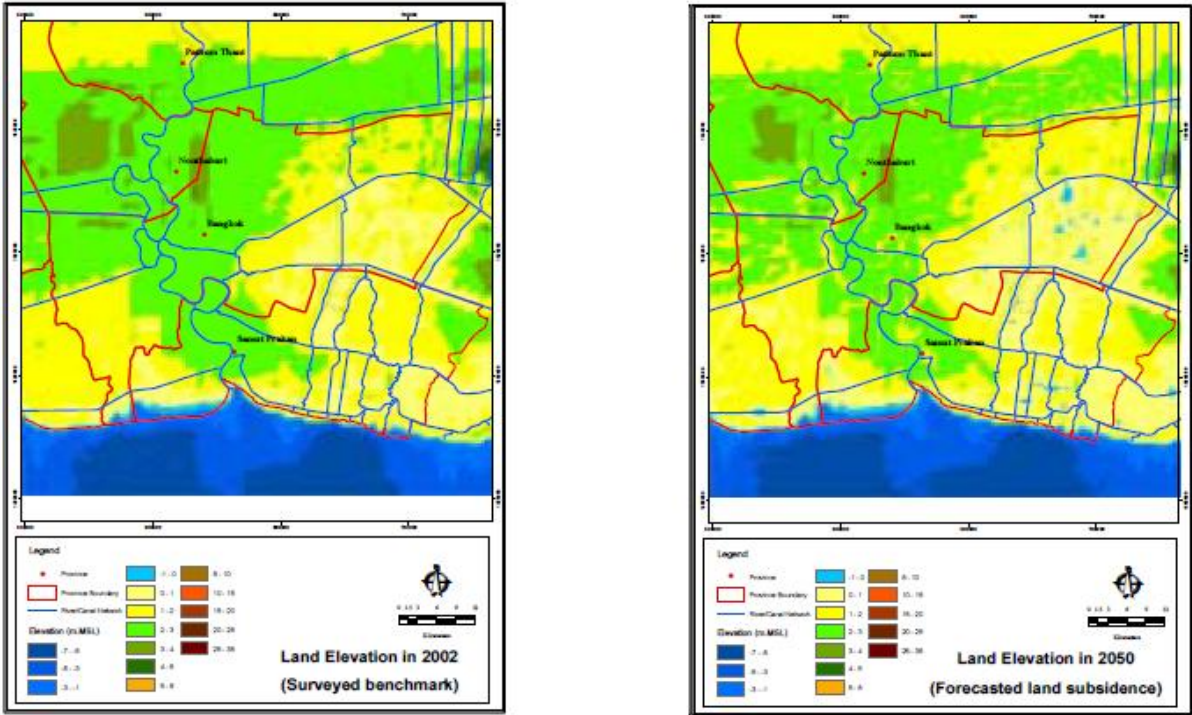
Source: TheNewPhobia via Wiki-Commons adapted from NASA data.

Heat islands affect flooding by reducing permeability due to drying surfaces so that the amount of runoff can be much higher. They also may bring delay in the onset of rainfall and lead to more intense events. Intense rainfall is also caused by a combination of aerosols and localized regions of hot air which generate cumulonimbus clouds (Shimoda 2003).

2.1.8 Land subsidence

Relative sea level rise causing increased risk of coastal flooding is partly a result of climate shifts but can also be due to land subsidence. Subsidence due to natural compaction of sediments is made worse by extraction of groundwater (Nicholls et al. 2007). In a number of Asian cities the issue of land subsidence on coastal flooding is greater than the effect of sea level rise. For example in Bangkok (see Figure 14) it is predicted that land subsidence will result in a trebling of the flood damage increases due to other causes (World Bank 2010b). Large deltas are sinking at rates of at up to six cm per year due to land compaction or extraction of groundwater. The Pearl River and Mekong River deltas are particularly vulnerable (Fuchs 2010).

Figure 14: Land subsidence in Bangkok



Source: Panya Consultants 2009 in World Bank 2010b: 28

2.2 Causes of increased exposure to hazard

It can be demonstrated that even without an increase in flood hazard, over time the impact of flooding would still be rising and will continue to rise because of increased exposure of primary and secondary receptors to the hazard. Population, infrastructure, assets, environment and ecosystems all are at stake when it comes to exposure to hazard. With increased human intervention and changing natural systems, the exposed factor is expanding its horizon to an extent that few socio-cultural units or human settlements can actually be called safe with certainty. The following section explains and quantifies where possible the increased exposure to hazard engendered by changing settlement patterns and behaviors.

Increase in urban size is generated both by the migration of rural populations into urban area and by the general population expansion. Within the developing world about half the urban population increase is due to rural to urban migration with the remainder due to natural population growth (Lall and Deichmann 2009). Urban centers are often exposed to flood risk as historic settlements have favored fertile floodplains and the ease of transportation offered by rivers and seas. According to Boaten (2008):

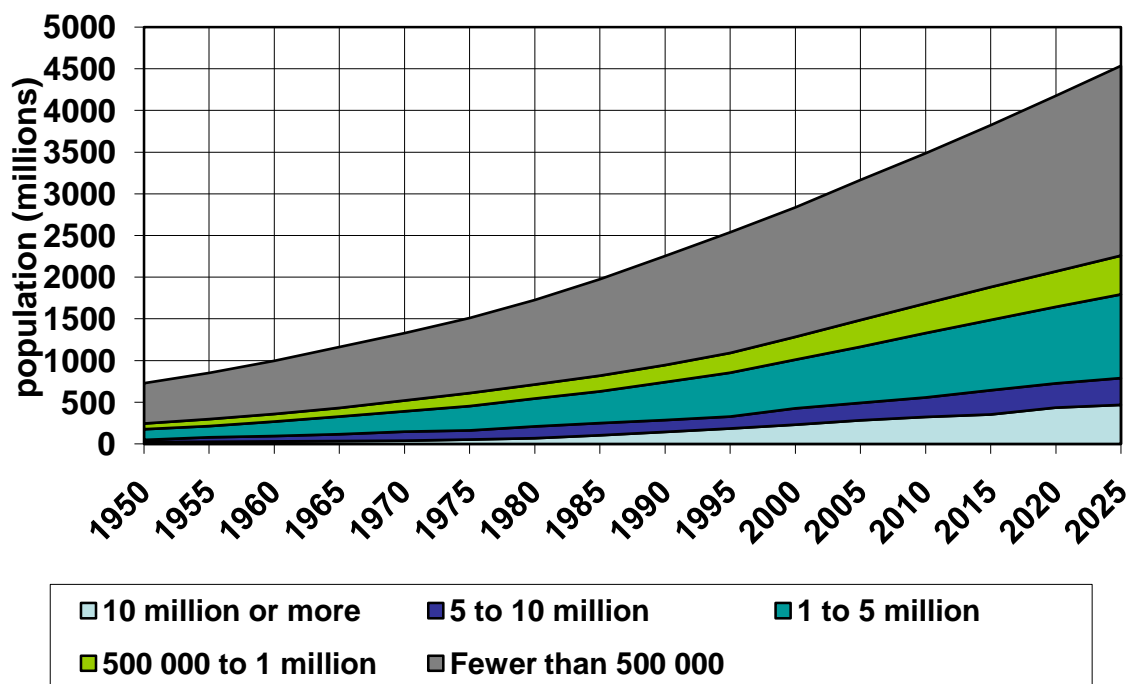
Sixty percent of the world’s 39 metropolises with a population of over 5 million are located within 100km of the coast, including 12 of the world’s 16 cities with populations greater than 10 million (IPCC 2007). The growing trends of human

development along coasts exacerbate their vulnerability due to increased risk to life and property. Dang, (2003) identified that in China, 100 million people have moved from inland areas to the coast in the last twenty years. Nicholls and Mimura (1998) have estimated that 600 million people will occupy coastal floodplain land below the flood level by 2100.

With increased population levels comes, at the very least, an increase in the number of people at risk from a flood event. Urban flooding has become more dangerous and more costly to manage simply because of the size of population exposed within urban settlements.

This change is predicted to continue over the next two decades: in 2030 the forecast is for 75 agglomerations of over 5 million inhabitants. However urban populations in all sizes of towns and cities are also expected to continue to grow. Management of urban flood risk, therefore, is not an issue that is confined to the megacities. By 2030 the majority of urban dwellers will live in towns and cities with populations of less than 1 million as illustrated in Figure 15.

Figure 15: Growth in populations by city scales



Source: Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, World Population Prospects: The 2008 Revision and World Urbanization Prospects: The 2009 Revision.

2.2.1 Uncontrolled development in flood plains

A major cause of overexposure to flood is uncontrolled development of flood plains.

Development on flood plains is often seen as necessary, but if it is done in an unplanned fashion, it may lead to devastation. When development is not guided, planned or controlled, the land exposed to flood hazard is liable to be more highly developed due to its lower cost. According to the WMO (2007), choices of development are often made without proper awareness of the risk in the prevailing area. Despite increases in knowledge of where and how frequently floods may occur, resulting in predictive flood maps, the maps fail to be used for development control as other priorities take precedence. Equally, in the developing world the proportion of structures subject to planning or building controls is low. The lack of controls implies that the most sensitive receptors may well be increasingly placed at risk. Uncontrolled development is likely to be denser, especially in informal settlements, and is typically characterized by substandard accommodation with no view towards minimizing risk to others. Uncontrolled development behind existing flood defenses will lead to a larger impact if defenses are breached; outside these defenses it may lead to totally unprotected settlements. The continued expansion of Buenos Aires, for example, has rendered obsolete the old drainage system.

2.2.2 Development outside defenses

Allied to the lack of control of developments is the increased development of settlements which are outside the protection of any flood defenses. The pressure of population growth leading to increased need for residential and other buildings leads to development in previously unoccupied areas. If an urban area is subject to flood hazard then the most likely areas to be defended against flood risk are traditional settlements. Newer development is more likely to be in undefended neighborhoods. However, it is also possible that traditional settlements are likely to be closer to the source of flooding than newer buildings and so these may be areas of lower hazard. On the other hand, if riverine defenses push river levels higher downstream the very presence of defenses may increase the hazard to underdeveloped land which is increasingly being pushed into service. Flood defenses may need to be raised based on change scenarios otherwise there will make more people exposed to floods. Restoration areas should be extended away from risk zones to maintain the standard of protection. In any case, the need for defenses must be assessed carefully before further development: when defenses breach, great damage is caused as could be witnessed in the 2010 flood in Poland.

2.2.3 Land use change and increased urban density

Changes in the use of land within urban settlements can increase the exposure of receptors to the risk of flooding. This may be the result of increasing land prices dictating that

every square meter is utilized to the maximum extent. Open spaces and brownfield land are developed for commercial, residential and industrial uses. With changing land use and the concentration of resources in urban areas, exposed property and the rate of damages grow.

2.2.4 Infrastructural and lack of operations and maintenance

Continuous maintenance and management of the existing infrastructure is an essential activity in flood risk reduction. Maintenance and operations expenditure may not be fully allowed for in upfront project evaluation resulting in neglect of expensive infrastructure. Therefore maintenance and operations are not performed effectively in many urban areas resulting in more socio-economic units exposed to risk. Rehabilitation of aging infrastructure, replacement of functionally impaired units and renewal of mitigation measures with a changing situation and showing foresight in designing new construction all demand knowledge and expertise as well as a flow of funds which is often lacking.

2.2.5 Reliance on insurance and aid

Increased reliance on others to fund replacement and reconstruction costs can make individuals and organizations more willing to accept exposure to flood hazard. Where flood insurance is available the phenomenon of moral hazard is often encountered (Freeman and Kunreuther 1997; Clark et al. 2002). Populations are encouraged to develop in flood prone areas knowing that the insurance company will pay for their losses in case of an event. Those with insurance have less incentive to take action to prevent flood damage which leads to unpreparedness. This is of course environmentally irresponsible necessitating reconsideration from risk assessment agencies on the number of people and properties that are at risk. Sometimes unanticipated flood events like the Mississippi flood in June 2008 cause heavy losses (12 to 15 billion dollars) to those properties which were uninsured in spite of being in the flood risk zone, and remain uncompensated by the National Flood Insurance Policy (CRS Report 2008). Reliance on emergency aid can engender a similar attitude and leads to increased exposure of assets to the flood hazard.

2.3 Causes of increased vulnerability to flooding

The third element of flood risk is the vulnerability of exposed populations and assets to flood hazard. It is possibly even desirable to expose large populations to areas of flood hazard if the population is equipped to deal with the hazard without danger of damage. Historically, this approach was common as the advantages and necessity of coastal and riverside living were seen to outweigh the risks associated with the occasional flood. Over time, the desire to control nature has led to lifestyles which are less flexible and receptive to flooding. In addition, demographics

have contributed to a population which may be less aware, less adaptable and therefore suffer more from flooding.

2.3.1 Increased prosperity

In-migration takes place to urban areas because they are considered to be better potential sites for economic development, and for gaining a better standard of living with easier access to secure housing, healthcare, economic and social resources. With increasing economic activity and investment the wealth of people also increases. The increasing wealth of urban populations leads to an increase in the value of assets at risk (Changnon 2003). There may also be a tendency for those assets to be in and of themselves more vulnerable to flood hazard (an example is the replacement of mud floors with other coverings such as carpets which are now seen as non-luxury goods). This results in more economic damage when there is a disastrous event. Disasters are usually more serious in terms of loss of life in poorer countries than in richer ones. In richer countries there may be fewer casualties but total economic damage is typically much greater due to greater levels of wealth thus making people more vulnerable to economic damages.

2.3.2 Lack of preparedness

Being prepared for floods to occur can decrease the amount of damage and disruption caused by flooding. However, there is a tendency within growing populations which are not familiar with the flood history of an area to be completely unprepared for flooding (Lamond and Proverbs 2009). There is evidence that populations at long duration risk become familiar with the hazard, are resigned to the inevitable and develop coping strategies which lead them to be prepared for the next event (Harries 2008). With expanding populations there can be also a decrease in the average experience level with flooding and therefore an increased lack of preparedness for flooding. Instead of it becoming the norm to take sensible precautions it becomes the preserve of older and more settled residents and may be seen as a minority activity. The mentality that these hazards are a thing of the past which “could never happen to me” can become more prevalent.

2.3.3 Changing demographics of populations

The demographics of populations affect the ability to withstand shocks to the system including the impact of flooding. Ageing populations are a major issue of concern especially in developed countries. In the developing world, children under the age of 18 are usually the fastest growing sector of the population.

Elderly people are also more vulnerable to flood risk because of their limitations in mobility and disabilities compromise fast reaction to the situation. As populations become less mobile and more dependent on cars, whether family members or service providers, their ability to evacuate, take physical measures or even to raise finance to protect themselves all decrease. On the other hand, high concentrations of young children will reduce the capacity of adults to protect themselves and their assets from flood damage as they strive to save their offspring, are physically hampered from taking avoidance actions or have lower disposable income to invest in measures.

Migrants and minority ethnic groups may face also many challenges including isolation from the mainstream and social exclusion, poverty, low socio-economic status or language difficulties which can make them less resilient to flooding. As half of the overall growth of urban areas is due to migration this can be an increasing vulnerability among urban populations. Thus vulnerability analysis will be specific to the particular country, region or city and must consider the needs of the local population.

2.3.4 Poor maintenance of existing structures and makeshift construction

Vulnerability of buildings and other infrastructure to flood events increases with the age of structures. It is evident that with lack of regular funding and well-organized institutions for operations and maintenance, the level of vulnerability rises with a changing climate and growing populations. There are situations when makeshift constructions are done as an improvisation to quicken remedial options. With rapidly growing urban areas, the pressure to build quickly is greater than the demand for quality construction resulting in low standard construction. Appropriate construction designs and proper maintenance of existing infrastructures can reduce the vulnerability level considerably.

2.3.5 The drive toward increased efficiency, just in time, and lack of redundancy

It is a feature of modern lifestyles that technological change and the drive towards ever-increasing productivity have left little space for excess capacity or flexibility in systems. As a result, the tolerance of disruption to these systems is lowered. This is particularly problematic in the developed world where efficiency is demanded by market structures and the unit cost of manpower is very high. This large advantage which is brought by technology also leaves systems highly sensitive to any shocks whereby a small disruption in one element leads to a ripple effect across linked systems in a potentially devastating way. Food supply is one example where economies of scale dictate that food is held in large warehouses and transported just in time but also where reliance on imports means that the disruption to transport caused by flooding may potentially affect a much wider population (Weir 2009). Similarly, with increasing development for business and government there is increased reliance on information technology which may be

irreparably damaged during a flood event leading to loss of functionality but also massive data loss if the organization is unprepared.

2.3.6 Building design without regard to flood risk

Building and development without due regard to flood risk and future flooding is a common problem and can often present a dilemma for authorities and planning officials. For example, there is often a desire to construct new developments close to existing urban areas, these often located on major waterways, or alongside coastlines and inland rivers. Shortage of available land, economic pressures and other factors can lead to the development of floodplain land in full or partial knowledge of the hazard. This is likely to be increasingly the case in the future as populations expand as it may not be possible always to avoid floodplain development.

Consequently, in such cases there is a necessity to focus on resilient building design. Buildings designed without regard to the flood hazard can result in unnecessary risk to life and destruction to the buildings. Well-designed building and landscape designs are also more resistant to water entry, and more easily repairable. The materials used in such constructions have the characteristics of low water penetration and high drying capacity and the structural integrity of the buildings are not compromised because of these added advantages. Such buildings can not only offer protection to property but also better evacuation times to prevent loss of life. Unless regulations are in force, developers and designers may have the tendency to ignore flood resilient designs because of increased cost and lack of expertise. For example, residents of Brisbane have observed that the practice of raising houses on stilts, which used to protect them from flooding, has largely been discontinued to great cost in the recent flooding (Funnell 2011).

In the developing world, the growth in cities and pressure to construct homes quickly and with limited resources makes it even more likely that flood resistance and resilience will be ignored in the design. In China, many houses at risk from flood are built of mud and are therefore washed away each time it floods. They offer little time to evacuate persons or belongings and then have to be rebuilt each time. Slum dwellings also typically offer little protection to their occupants from flooding (ActionAid 2006).

2.3.7 Overcrowding leading to increased solid waste and flood debris

Most of the megacities in the world which are at risk of flooding are characterized by high levels of density and congestion. For example, the city of Mumbai is extremely overcrowded which constantly threatens the city management system, leading to overburdens in sewage and wastewater, the dumping of household and commercial garbage disposals in open landfills and direct discharges to water bodies. Safety standards are also overlooked to fulfill the demand for space and development of property and creation of slums. As a result of the already

existing difficulties in management, a flood in such cities causes havoc. Flood waters carry with them the debris of waste but also the treasured belongings of a dense and overcrowded city. The materials from buildings damaged by floodwater are also swept along. In an overcrowded space this may lead to an avalanche of further damage.

2.3.8 Over-reliance on defenses

People sometimes become over-reliant to existing infrastructures due to lack of knowledge and awareness. Existing infrastructures might give them the mental satisfaction of being protected, but this does not necessarily correspond to changing situations which increases their level of vulnerability to be affected by unanticipated surprises. Such events thus cause much higher damage and bring more people within the higher level of vulnerability. Lack of preparedness and rejection of upcoming risk are major issues which makes people non-responsive. Time and again it has been seen that over-reliance on defense mechanisms have proved to be fatal. These tend to be piecemeal in nature in any event. In Bangladesh, for example, earthen embankments, polders and drainage are a major form of flood defense. Most of them have breached or eroded more than once since their completion but residents often feel a false sense of complete security living within them. This is despite the fact that embankment breaching during the 1999 flood, for example, caused substantial damage.

Other examples include the already mentioned flood in Poland during 2010 which according to WWF was caused by over-reliance on embankments and flood plain over-development with up to three-quarters of the Odra and Vistula Rivers are confined within the zones of development.

2.4 Summary

The causes of increased flood impacts have been explored in detail in this section. It can be seen that there are a range of natural and human-made (anthropogenic) drivers of increasing flood risk. It is also been seen that these causes have different consequences depending on the city, region, and its development status and existing flood management regimes.

Climate related factors are seen to be most important in considering long term investment decisions in hard-engineered defenses. Observed changes in climate such as acceleration of sea level rise rate and increased frequency of extreme events, and future projections suggest that climate change might induce changes in flood risks beyond those expected from natural climate variability. However, climate change projections are plagued with uncertainties, particularly at the scales relevant to compute changes in flood risks. The inevitable uncertainties and scale issues contribute to the difficulty in designing measures to specific protection standards. In addition,

wholesale development of entire catchments can cause increased flow independent of any changes in the water cycle but can also contribute to a changing local climate. In this context, the design of flood management strategies that are robust under a wide range of future projections appears to be the way forward.

In the shorter term, population demographics notably the huge growth in urban populations can be seen to have a greater impact on flood risk. Growing populations, particularly in situations in which urban poverty prevails, bring with them many associated challenges such as uncontrolled development, destruction of natural defenses, construction of outside defenses, overcrowding, and sub-standard buildings. Likewise, higher populations often result in overstretched city budgets causing decline in regular operations and maintenance standards thus weakening existing flood risk control measures.

Lack of awareness, overreliance on defenses or on others to fund repair and resulting lack of preparedness is another growing problem. Populations have historically displayed a lack of awareness of flood risk but this worsens when there is large population growth either due to migration of populations not aware of any flood risk or where lack of funding on education and dissemination programs mean that previously educated populations forget or have never been informed of the risks they face. These new residents will build inappropriately, fail to register for warning services, and be unaware of emergency procedures during an event.

Research suggests that these population-based factors are currently the main drivers of observed increases in flood impact worldwide. These factors vary by region, country, city, and development status. The solutions to these underlying population drivers are complex and may be beyond local government to control. The problems caused by growing urban populations need to be made amenable to policy and practical solutions.

Finally, whether or not all the drivers of increased flood risk can be managed, there are tried and tested measures to respond to and to address the impacts of flooding. These will likely have to be increasingly employed where necessary, and combined and integrated with greater vigor to offset the increasing risk caused by factors which cannot be controlled. The following section discusses these solutions.

3 What can be done for risk reduction?

In the management of urban flood risk due consideration must be given to the source, type and frequency of flooding. Risk reduction methods may address any or all of the three components of risk namely hazard, exposure or vulnerability. The foregoing analysis has suggested that factors relating to exposure to flood hazard have been the greatest influence on increasing flood impacts and short term increases in future flood risk. Tackling exposure may therefore be a priority for flood risk management but may conflict with other social and economic targets resulting in an inability or reluctance to tackle exposure directly. Inevitably some people and assets will remain at risk, and potentially increasing numbers may be put at risk. Therefore measures to address hazard and vulnerability are also vital.

Table 3 shows the main general measures appropriate to tackle each dimension of flood risk. However, it is vital to gain a thorough understanding of the risk in order to select the most appropriate measures to pursue. Under-estimating the hazard or choosing the wrong measure could result in the risk management program making the eventual flood damage worse, as for example if inadequate flood walls are overtopped causing more rapid onset and higher velocity flooding.

Table 3: Measures appropriate to tackle hazard, exposure and vulnerability to flooding

Hazard	Exposure	Vulnerability
Conveyance and storage upstream	Development control	Plan location of critical infrastructure
Land use control	Upgrade infrastructure	Emergency/ contingency planning
Greening of urban space	Flood defenses	Search and rescue
Improved drainage	Barriers and barrages	Increase awareness / preparedness/ adaptability
Groundwater management	Encourage self protection	Plan to prioritize vulnerable people
	Warning and evacuation	Building design and resilience
	Relocation	Planned redundancy
	Urban planning	Better operations, maintenance and management
		Solid waste management
		Planned recovery
		Insurance and aid
		Health planning

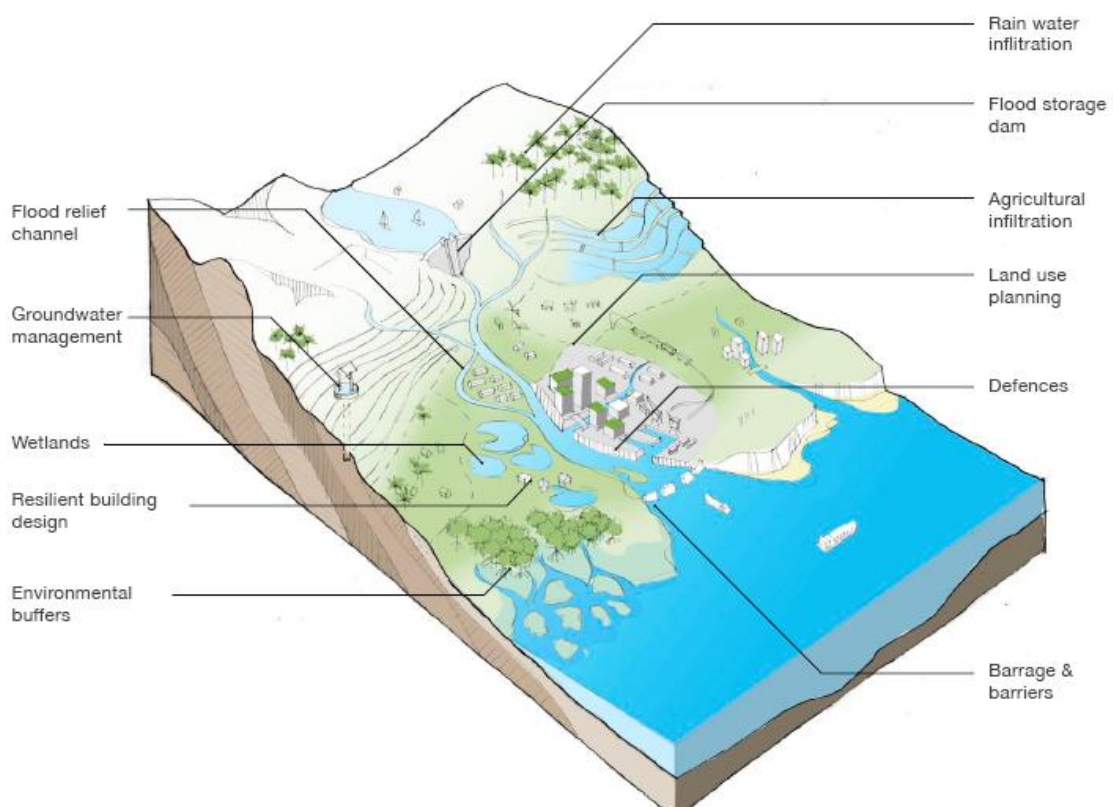
3.1 An overview of appropriate measures

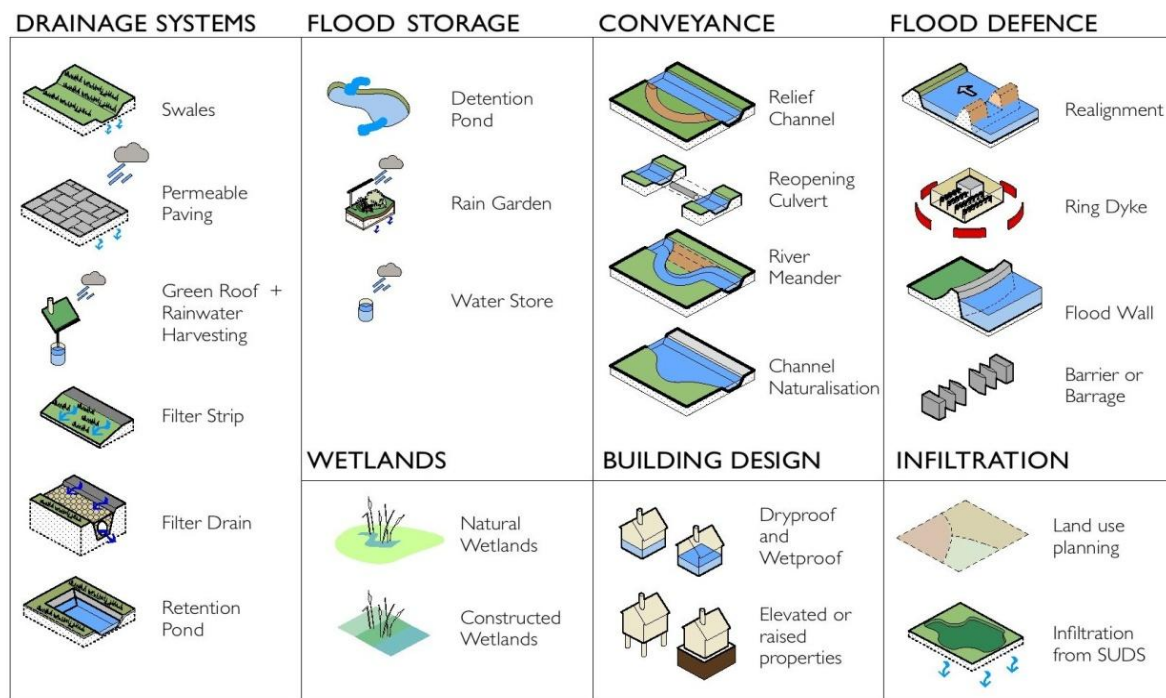
From the outset, it must be emphasized that an integrated approach to flood risk management is the key requirement. Flood management requires the holistic development of a long-term strategy on both a current need and future sustainability basis. This strategy will differ with geographical location, size of urban area and the source or sources of the flood threat. Measures to tackle the issues of increasing hazard, exposure and vulnerability have been listed above. Most management plans will include a combination of hazard reduction, exposure limitation and resilience enhancement. There are also solutions included which can be undertaken during any part of the disaster recovery cycle.

An integrated approach to urban flood risk management requires a combination of measures, both structural and non-structural as defined below, to protect those urban areas currently at risk. To curb the growth in flood impacts a forward-looking urban development policy must also be put in place into which flood risk management imperatives are integrated.

Flood risk reduction, including for urban areas as political or economic units, must also consider the catchment as a whole. This is due to the fact that the source of flooding may be at some distance from the affected receptor (i.e. the city) and often the best option may be to tackle the flooding problem before it reaches the urban environment. Figure 16 illustrates multiple risk management techniques in their appropriate catchment locations surrounding an urban settlement.

Figure 16: Overview of risk management options





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In addition to the structural methods pictured above which control the pathways and location of receptors there are also, then, non-structural or “softer” management techniques which recognize that it is not always possible to keep floods away from urban settlements, and that plans therefore need to be developed to reduce the impact of future floods. Non-structural measures (see Table 4) require no major construction of physical infrastructure, therefore they may be cheaper and quicker to implement than structural measures and can prove most effective in reducing the consequence of flooding.

Table 4: Non-structural measures

Emergency planning	Increasing preparedness	Speeding up recovery
Forecasting and warning systems	Awareness campaigns	Recovery plans
Temporary barriers Evacuation	Community engagement	Insurance, aid, financing schemes
Havens	Improve operations and maintenance	Emergency supply chains
Search and rescue	Solid Waste Management	Health planning
Planned redundancy	Incentives for self protection	Community engagement Resettlement plans
Contingency plans		Standard temporary settlement designs

Structural and non-structural measures do not preclude each other. Such interventions have to work together, with the most appropriate measures being selected for

implementation at specific locations and situations. It is also crucial to take account of temporal and spatial issues when determining strategy. Structural solutions such as hard-engineered defenses and conveyance systems can form a long-term solution to flood risk which can render floodplains habitable by protecting existing settlements. However, particularly in the developing world, they may be seen only as longer term goals requiring large investments which will not always be available. Non-structural solutions such as flood warning systems, evacuation planning and coordinated recovery procedures are also necessary for the protection of the populations of cities and towns already at risk of flood whether protected by defenses or not. Measures which can be implemented more quickly such as operations and maintenance, greening of urban areas, improved drainage, building design and retrofitted protection measures can also enable occupation of flood risk areas while minimizing the expected damage from flooding.

At the same time, one of the major tools for heightened resilience against the increasing risks caused by expansion of urban population and the growth of urban settlements is the redirection of such settlements away from areas at high flood risk. The use of urban land use planning can reduce both exposure to flood hazard and the run-off into urban areas. In the developing world in particular, the opportunity to better plan the formation of new settlements and new buildings is absolutely central to preventing the predicted increase in future flood impacts from being realized. It is realistic to recognize that floodplain development will likely continue due to pressure on land and other political and economic considerations. However, where new settlements are better planned – rather than just occur – within areas at risk from flooding, flood-receptive design can be employed at a lower cost during the build phase than to attempt to later retrofit.

Non-structural measures need to be seen as potentially applicable to all types of urban settlements. The matrix below in Table 5 gives an initial overview of which structural measures may be appropriate to consider for particular flood and settlement types. However, given the differences in the future challenges faced by urban settlements worldwide and their development goals and resource constraints, it is not possible to be prescriptive in the application of management strategies. Therefore the specific solution or set of solutions which is optimal in a particular location can only be arrived at after extensive evaluation, cost benefit analysis and consultation with multiple stakeholders. The measures selected will need to be negotiated by stakeholders, and to be adaptable to natural, social and economic conditions which can be expected to change over time.

Table 5: Flood-risk management measures (by scale)

Size of urban area	Non-coastal	Coastal
Small	<p>Conveyance – channels</p> <p>Conveyance – storm drainage</p> <p>Conveyance – floodplain restoration</p> <p>Storage – pond/ basin</p> <p>Storage – rainwater harvesting</p> <p>Sustainable Urban Drainage</p> <p>Infiltration</p> <p>Building design, resilience/ resistance</p> <p>Wetlands and environmental buffers</p>	<p>Resettlement/ retreat</p> <p>Defenses</p> <p>Conveyance – storm drainage</p> <p>Conveyance – floodplain restoration</p> <p>Storage – pond/ basin</p> <p>Sustainable Urban Drainage</p> <p>Building design, resilience/ resistance</p> <p>Wetlands and environmental buffers</p>
Medium	<p>Defenses</p> <p>Conveyance – channels</p> <p>Conveyance – storm drainage</p> <p>Storage – pond/ basin</p> <p>Storage – rainwater harvesting</p> <p>Sustainable Urban Drainage</p> <p>Infiltration</p> <p>Building design, resilience/ resistance</p>	<p>Defenses</p> <p>Conveyance – storm drainage</p> <p>Storage – pond/ basin</p> <p>Storage – rainwater harvesting</p> <p>Sustainable Urban Drainage</p> <p>Building design, resilience/ resistance</p> <p>Wetlands and environmental buffers</p>
Large	<p>Defenses</p> <p>Conveyance – channels</p> <p>Conveyance – storm drainage</p> <p>Conveyance – diversion</p> <p>Storage – pond/ basin / public square</p> <p>Storage – dam</p> <p>Sustainable Urban Drainage</p> <p>Building design, resilience/ resistance</p> <p>Solid Waste Management</p>	<p>Defenses</p> <p>Conveyance – storm drainage</p> <p>Storage – pond/ basin / public square</p> <p>Sustainable Urban Drainage</p> <p>Building design, resilience/ resistance</p> <p>Barrier and barrage systems</p> <p>Solid Waste Management</p>

3.1.1 Examples of integrated flood management in practice

Integrated flood management schemes are naturally designed to fit in with water-related issues and can be part of a wider agenda such as urban regeneration or climate change adaptation. The following examples illustrate real applications of the sort of integrated thinking and practices needed to tackle flood risk successfully.

Chengdu Urban Revitalization

As part of a revitalization scheme of slum districts in Chengdu the inhabitants were moved away from the river bank into new accommodation. About 30,000 households were moved and this created space for a green buffer zone along the riverside (UN-HABITAT 2003a).

In 1985, the municipal government initiated the plan with the work carried out from 1993 to 1998. The plan had several best practice features including a clear target to reduce flood risk. In the past, households in the slums projected over the river and were often swept away by floods in rainy seasons. The rainy season brought constant vigilance so that evacuation could be effected. After the rain stopped, all the families had to deal with the mess brought about by the flood, resulting in great hardships, suffering and economic loss. As part of the plan the two rivers, Fu and Nan, were de-silted and widened thus reducing flood risk to a 200 year return period expectation (UN 2001).

Engagement of the local community ensured that the public participated in the scheme and resettlement was completed without litigation. Per capita living space rose by a factor of 1.4 and the relocation of the slum dwellers reduced congestion in the city (Jun 2003). There was also the benefit of 30 to 35% of owners gaining property rights which they had not held before. Green zones were created which improved the environment greatly and allowed for the construction of an award winning natural park area with water purification facilities which is now on the national tourist register.

Maputo, Matola, Xai-Xai and Chokwe, Mozambique

Mozambique stands on the confluence of many major South African rivers including the Zambezi. The Cahora Basso dam together with the Kariba dam in Zimbabwe serves several Southern African nations as a dual purpose system which generates electricity and also helps to control river flow. Previous regular flooding of the river basin was much reduced by the controlling of the output from the dams (ADPC 2006).

Dam building is not primarily a flood control mechanism but dams have impacts on river flows which clearly affect flood frequency and severity. Mozambique has been hit by 34

significant cyclones or tropical depressions and four major flood events (2000, 2001, 2007 and 2008).

Maputo, the capital of Mozambique, houses 45% of the total Mozambican urban population, 50% of which was considered to live below the poverty line. Recent data indicates an increasing rural-urban migration contributing to higher poverty and vulnerability levels. Throughout Mozambique, urban rural and agricultural areas are at risk of flooding but during the 2000 flood 70 percent of flood deaths were in urban areas near to Maputo, mainly in the cities of Xai-Xai and Chokwe (UN-HABITAT 2007). Maputo is highly vulnerable to the effects of climate change since it faces the Indian Ocean and therefore at risk from a rising sea level. There is also risk from intense rainfall and from the Incomati, Umbeluzi and Limpopo rivers.

Flood risk mitigation efforts in Mozambique and in Maputo in particular, are multifaceted with multiple initiatives, the majority aimed at softer and non-structural measures. In Mozambique preparedness is facilitated by an early warning system coordinated by the National Directorate of Water, together with the National Institute of Meteorology and the National Disaster Management Institute. The system provides forecasts of flood risk, detects and monitors flooding, and puts out flood warnings when necessary, paving the way for a coordinated response (Hellmuth et al. 2007).

Improved urban drainage projects have resulted in the construction of urban drainage channels, for example in the Mafala district of Maputo. However, despite improved drainage systems in 2010 solid waste blocked the channels resulting in flash flooding and necessitating emergency clearance of the drainage channels. This was despite the fact that after introducing a “garbage tax” to finance citywide solid waste management improvements, the government negotiated public service contracts that institutionalized the primary collection as a free-of-charge public service for all residents (Kruks-Wisner 2006).

Inclusive measures by UN-HABITAT for slum upgrading in Maputo where 70% of the population live in slums incorporate flood risk reduction through participatory land use planning and reform of planning policies (UN-HABITAT 2007). Local government, state ministries and community groups participated.

Santa Catarina, Brazil

Tucci (2007) shows an example of a system of flood-control dams in the valley of the river Itajaí-Açu, Santa Catarina, Brazil. A system of three dams constructed over the 1970s and 1980s includes the West dam located on the river Itajaí-Oeste *upstream* of the city of Taió, the South dam on the Itajaí do Sul upstream of the city of Ituporanga, and the Ibirama dam on the river Hercílio.

The design of these dams with a very large capacity and bottom sluices allows for discharging of spate water over a very long period. The first dams made an insignificant contribution to the 1983 flood owing to the high volume of precipitation that fell in seven days. For the 1984 flood, which lasted only two days, they made a greater contribution.

Network of micro-dams in Managua, Nicaragua

The city of Managua, the capital of Nicaragua, has a population of approximately one million and in 2007 had an annual growth rate of 2.5% (Tucci 2007). The city is sited on steep rugged terrain and formed of dispersed urban centers with areas of lower population in between. The recent accelerated growth led to deficits in basic facilities and services. In particular, the city identified that weak urban governance led to shortcomings in the refuse collection service.

The city is subject to earthquakes and flooding. Heavy storms lead to flooding from the many watersheds which cross the city. These floodwaters carry both agricultural and urban waste matter. Since 1980 a system of micro-dams has been established with the dual purpose of attenuating floods and retaining refuse. Over 16 dams have been constructed, and extract excess of 500m³ of sediment from the river system.

Tsurimu river basin, Yokohama, Japan

The Tsurumi river basin spreads from Machida city through to the Tokyo Bay and was the target of comprehensive flood control projects in the 1980s. Part of this master plan was the construction of a multi-purpose retarding basin which stores flood water from the river in times of spate but at other times is used for leisure purposes including the international stadium of Yokohama. Due to the low height of the levee between the river and the retarding basin, water flows over the levee as it reaches flood height thus preventing overtopping on the other side. Water is released after the flood using the sewage gate. The stadium itself is raised on piles which ensures that it can still be used in the event of a flood as are the main roadways. A flood information center and notice boards in the retarding basin are educative facilities for the general public and provide warning facilities.

Other measures on the Tsurumi River include dredging, levees, regulating reservoirs and greenery reservoirs.

German Flood Act 2005

National policies can contribute towards flood management. Legislation forms a vital part of that policy. The flood control sections of the 2005 German Water Act are an example of good practice in this area which has many features in common with other water and flood protection acts. The act holds to three core principles which place stringent flood control obligations on government and individuals to manage flood risk in advance of flooding, and also on how flood zoning is managed and how warnings are issued:

- Surface waters have to be managed in such a way that as far as possible floods are held back, non-harmful water run-off is ensured and flood damage is prevented. Areas that may be inundated by a flood or where an inundation may help to alleviate flood damage have to be protected.
- Within the bounds of possibility and reasonability, any person potentially affected by a flood is obliged to undertake adequate measures to prevent flood-related risks and to reduce flood damage, particularly to adjust the land use to a possible risk created for humans, the environment or material assets through floods.
- A land law shall stipulate how the competent state authorities and the population in the areas affected are informed about flood risks, on adequate preventive measures and rules of behavior and on how they are to be warned of an expected flood in a timely manner.

In practice this means that (Government of Germany 2005):

- Extensive improvements to flood zoning and mapping are occurring in accordance with this Act as well as the European Water Directive. Importantly, public consultation is built into the process.
- New building in the floodplain is forbidden in most cases. Where it is permitted the design of new construction is strictly controlled, for example the placement of oil heating systems and computer control centers.
- Flood protection plans have to be drawn up for the 100 year flood and must consult with upstream and downstream riparian owners.
- Flood zone maps are to be integrated into all spatial maps and plans such as land use plans and development plans.

Commentators have noted that for German flood risk management this Act is a shift away from the “protection” mentality towards “adaptive risk management.” However, the success of this shift in practice has yet to be realized (Garrelts and Lange 2011).

3.1.2 What is beyond our control?

It has to be recognized that flooding is a natural phenomenon which will continue to occur despite the best efforts at prevention. The predicted increase in weather extremes resulting in increased intensity of the water cycle is a factor in increased flood hazard which is beyond the control of individuals and local and national governments. In the short to medium term, the inertia of the climate system will result in sea level rise even if dramatic reductions in the level of greenhouse gas emissions are achieved (Fuchs 2010). We must accept the possibility that floods might become more frequent and that improvements in hazard management will be necessary just to maintain flood damages at current levels.

Urbanization has also been argued to be an unstoppable force due to the huge increases in urban populations which are happening now and projected for the future. It may be feasible for governments but not necessarily desirable to enforce settlement patterns which locate populations away from urban centers in attempts to reduce overcrowding. In making choices, the dictates of reducing flood hazard may conflict with other socio-economic prerogatives as urbanization and population growth bring economic benefits which are often seen to outweigh the risk from flood hazard. If it is fruitless to attempt to prevent greater urbanization, then it is all the more critical to plan and control the location and design of the built environment to mitigate against the increased risk of flooding.

Planning and coordination from both public and government organizations at all levels are required for managing the flood risks associated with urbanization. Integration of flood risk thinking within urban planning and management at policy level, to begin with, can facilitate a more mature approach which recognizes the limits and seeks to balance flood risk priorities with other development goals.

3.2 Challenges to and opportunities for implementation of integrated flood risk management

Action to tackle flood risk is clearly warranted but it has been observed that action is often delayed or completely neglected. This is often despite the fact that there exist known solutions that can effectively reduce risk. Where measures are taken it is also sometimes seen that the implementation of the solutions falls short of the original strategy or falls into disuse. The pursuit of the optimal strategy may be constrained by a variety of factors.

3.2.1 Constraints to actions

The road to action has two stages namely the desire to act and the ability to act. Desire to act involves awareness, perception and ownership, the ability to act depends on knowledge, resources and belief. For individuals and also for national and local governments

these steps must all be in place to generate action. It is important to recognize what step has been reached in determining the best approach towards moving forward. Constraints to acting for reducing the risk in urban areas are likely to founder on the issues of ownership, knowledge and resources. The failure of these stages will lead to a lack of belief which may also prove corrosive.

Ownership of the flood risk problem can easily fall between individuals, the private sector and government or between different governmental organizations unless clear direction is provided at a national or even international level. Therefore clarity in establishing responsibility for flood mitigation is crucial. Flood management institutions, which can be local government or separate administrative bodies, have to face the challenge of managing the system properly. When large river basins are under consideration, the responsibility can cross national boundaries and therefore decisions may be grounded on purely political motivations.

Ownership by a wider group of stakeholders is also crucial. The extent to which awareness, perception and belief affect the implementation of measures is highly dependent on the level of participation of less informed individuals and organizations and can be ameliorated by a program of effective risk communication. For example, sometimes people become reluctant to move from their homes even if they know that they are at risk. Such reluctance makes them more vulnerable to risks and they therefore expose themselves to higher level of danger. Risk communication has been the subject of much study in which the principal decisions regards which media are appropriate, the balance between alarmist messages and incentive to action and the currency or expected life of risk communication. Questions such as how to translate the language of uncertainty and probability into communications that lay individuals can comprehend fully are yet to be answered. The trust in which the messenger is held is also a determining factor for the extent to which the communication will be heard and received. In all likelihood, a variety of communication channels will need to be effected to reach every sector of an at risk population and crucially such communication should be accompanied with very direct and personal implications for the affected population together with clear guidelines as to how the risk can be mitigated and actions expected as a result of the risk communication. Without this, the communication of risk can result in a feeling of insecurity which will ultimately result in denial of risk in order to increase feelings of security (Lamond and Proverbs 2009).

Given that the appropriate bodies are identified and own the responsibility for managing the risk of flooding, the knowledge and resources necessary to take action become paramount. Determining the appropriate response to flood risk is a challenging task. It involves evaluation of current and future risk, identifying the possible options for mitigation; judging the most effective options and estimating the costs and benefits of applying the solutions. As the available options are broad and not mutually exclusive this process will involve wide consultation with experts and populations at risk and therefore considerable time and resources. Climate change is the most

important long term physical issue which makes all existing infrastructures obsolete if evaluation is performed according to the long term projections. Across the globe there is a wealth of knowledge which can meet the challenges of estimating risk, designing solutions and evaluating options. Often, however, the knowledge may be costly to obtain and is not accessible to all stakeholders equally. This can result in the adoption of sub optimal solutions or inaction. Communication within and between these stakeholders can be complicated by the lack of general knowledge about solutions and a tendency to focus on flood risk management as a technical specialist area in isolation from other development issues. Such constraints can bring in much uncertainty in the risk reduction process. This leads for a need for advice and guidance for a wide range of stakeholders which will shorten this evaluation process and ensure that the best possible options are considered.

The choice of mitigation measures will also be critically constrained by available resources to implement the chosen scheme. As an illustration, in the UK where the Environment Agency has a clear responsibility for the provision and maintenance of flood defenses and detailed risk reduction project evaluation guidance, the number of eligible projects far exceeds the funds available to the agency to carry out those projects. National government, which has responsibility for allocating funds across competing priorities of which flood defense is a very small part, is currently limiting the resources available. In the developing world the constraint on funding is even greater. Governments, which may be highly reliant on development assistance, may find that the best opportunity for fund raising is generally after an event. Even after an event it has been observed in developing countries that due to lack of measurable mitigation strategies and lack of funds they occur over and over again.

3.2.2 Understanding implementation

One of the most critical aspects of flood risk management is to actually implement the measures that have been identified. This can be difficult to achieve where municipal management suffers from underfunding or resourcing. In addition local flood risk mitigation measures must pay attention on the ways in which impacts and responses to floods may affect different groups in society. The priorities of the civil society, local governments, and the private sector must be the starting point to identify effective incentives. It will also be essential to understand the capacities of these actors, including how they choose to use their limited resources under high levels of uncertainty.

It is important that flood risk management is cognizant of the dynamics of decision-making at national, regional, municipal and community levels. Integrated flood risk management requires greater coordination between local governments, the private sector, non-government organizations, educational institutions such as universities, and the civil society. It is also

fundamental to identify the information, experience and methodologies that disaster risk, as well as climate change and development experts and practitioners can provide, and to design measures utilizing such experience and knowledge. Last but not least, overcoming institutional barriers, whether they are found to be structural, or financial, is required in order to facilitate the implementation of effective and equitable flood risk management. To promote an integrated approach there are a series of aspects and issues to take into consideration from the outset:

Information

Systematic mechanisms for collecting and managing information related to the changing nature of flood risk will increase the incentives for prevention. Existing information must be easily accessible. The measures that decision-makers and other local actors carry out need to be informed by the available data on the hazards. Collection of this data must be consistent and sufficient to facilitate effective flood risk management. Data collection must take advantage of technological progress. Collection and sharing of data and information can be made using free and open source software. However, information is not always available or shared. Thus the importance of making information about hazard risks available cannot be over-emphasized (World Bank 2010c).

Urban governance

In well-governed and well-managed cities, the impacts of flooding can be considerably mitigated because of the measures that have been implemented to protect against floods (Satterthwaite 2008). Such measures may include provision for drainage systems and scope for land use management to increase surface water management capacity. In poorly-governed and poorly-managed cities, this is not the case. Most areas have no drainage system installed and rely on natural drainage channels. In many developing countries, buildings or infrastructure are often constructed in a way, or in locations, that actually further deteriorate the problems. Even when policy-makers accept the necessity for implementing integrated flood risk management, a lack of capacity to plan, design, implement, operate and maintain flood risk management systems is likely to be a severe constraint on efforts to ensure its implementation.

Institutions

In many countries, there is a lack of suitable institutional arrangements and lack of a suitable policy framework to encourage integrated flood risk management systems. This mismatch

between the governance of official disaster management mechanisms and what is actually needed for implementing integrated flood risk management, is a major barrier to implementation of flood risk management. As it is pointed out in a recent World Bank report, countries with well-performing institutions are better able to prevent disasters (World Bank 2010c). For institutions to perform well, technical assistance and other capacity-building measures are a prerequisite. Otherwise, there is a danger that flood risk management may lead to fragmentation and a failure to address overall problems in an effective and adequate manner. Good institutions must be accountable to the wider civil society. Public involvement and oversight can ensure that effective and equitable measures are considered. In order to relate flood risk management recommendations to local realities, and make local governments more efficient and responsive, the decentralization of local governance functions must also be taken into account (Devas and Batley 2004). Cebu, Philippines and Ahmedabad, India provide examples of how city authorities can become more responsible in relation to infrastructure and service provision (Devas and Batley 2004). Due to spatial proximity, local authorities are able to make well-informed decisions. Nevertheless, the efficacy of risk management will be reduced without a supportive political and organizational underpinning.

Mainstreaming

Mainstreaming flood risk management into wider development plans is vital because local governments cannot afford to ignore risks, particularly those related to climate change, urbanization and environmental degradation (ADPC 2010). Dagupan City in the Philippines demonstrates a successful example of community resilience to flood and tropical cyclone disasters (ADPC 2010). It is one of the few cities that mainstreamed DRR into local governance during the implementation of the Program for Hydro-Meteorological Disaster Mitigation in Secondary Cities in Asia (PROMISE)⁴. Absence of integrated urban risk reduction in many low and middle income countries may be linked to the failure to mainstream risk reduction in development plans (Wamsler 2006). Hazard-related vulnerability should be addressed as an integral part of poverty reduction initiatives given that the linkages between poverty and vulnerability to natural hazards are increasingly recognized (ODI 2005; UNISDR 2008). Practical ways are needed to ensure that flood risk management in particular, and disaster risk management in general, is effectively incorporated into development plans.

⁴ <http://www.adpc.net/v2007/programs/udrm/promise/default.asp>

Public-private cooperation

Further inclusion of the private sector in flood risk reduction is required. This may relate to widening the diversification of the economy, or working with the insurance sector to mitigate the effects of flood disasters. For the private sector to get involved governments must first put in place appropriate infrastructural and institutional frameworks. Often, the outcomes of mitigation or prevention measures undertaken by private interests depend on what government does to incentivize them, or fails to do (World Bank 2010c).

The role of the private sector in the implementation and delivery of urban infrastructure has been increasingly recognized. Public-private cooperation has become a fundamental component of the strategies adopted by international development organizations (Tanner et al. 2009). In flood risk reduction, public-private partnerships can provide to the private sector a better understanding of their interdependence with the local critical infrastructure, and improve coordination with the local stakeholders before, during, and after a disaster (NRC 2011). Nevertheless, it is important to remind that such partnerships have often produced unfair outcomes for many poor and marginalized communities. For instance, this can be the case when large sections of the urban population are excluded from decision-making (UN-HABITAT 2003b).

Donors

Finally, the role of donors in prevention needs to be considered. Governments, which may be highly reliant on development assistance, may find that the best opportunity for fund raising is generally after the disaster. Data shows that between 2000 and 2008, about a fifth of total humanitarian aid was spent towards disaster relief and response, while in 2008 only 0.7 percent was spent towards disaster prevention (World Bank 2010c). This means that donors usually respond after the event of a disaster. However, flood and other disaster risk reduction activities are long-term processes that increase the sustainability of development interventions, and thus donors need to incorporate this perspective into their plans and programs.

3.3 Summary

The management of flood risk is a major challenge for city managers, local and national governments and policy makers worldwide but particularly for those in developing countries where urban growth is greatest and most rapid. There is a balance to be struck between the day to day demands of an expanding population and the strategic need to design cities and towns which will be sustainable in the long term and robust towards natural hazards such as

flooding. To that end, decision makers require information which will enable them to make smart choices within the often severe resource and other constraints facing them, and in the light of an uncertain future.

Flood risk management requires a far wider and truly global pool of experts that includes decision makers, urban planners, engineers, city managers and so on to consider the impact of their decisions on flood risk. Flood risk management principles need to become embedded or mainstreamed into thinking and practice and be set within an integrated city planning and management vision. In addition, risk awareness needs to be engendered in communities which should be involved in decision making. The coordination of the efforts of national and local governments, international organizations, insurers and communities will lead to the most successful flood risk management regimes.

4 Conclusion

From the above discussion, it is evident that flood impacts have grown in the recent past and will continue to grow into the foreseeable future. These impacts are attributable to a range of causes which contribute to increased hazard, exposure and vulnerability to flooding. The solutions for reducing flood risk are many, and can be targeted at each factor driving the increased impacts observed. These measures are variously appropriate for different types of flooding and city scales. A combination of measures to form an integrated and holistic risk management regime is most likely to be successful in reducing flood risk.

Climate induced changes in the flood hazard have been seen to have a limited impact on flood impacts in the recent past. In the near future, they are also unlikely to dramatically influence flood risk in the short term as other factors have higher impacts. In the short term, and for developing countries in particular, the factors affecting exposure are increasing at the fastest rate as urbanization puts more people and more assets at risk. While growth in population cannot be reversed, the locations where these populations settle will need to be subject to considerations to minimize flood risk. Major infrastructure needs to be designed and built to deal with growing populations: for example, many cities will require massive increases in drainage and wastewater systems.

In the longer term, however, climate scenarios are likely to be one of the most important drivers of future changes in flood risk. Current climate models often lack certainty and precision and are subject to diverse development assumptions which lead to diverging forecasts, making it possible for flood forecasts and population projections to overestimate the future impacts. Flexible solutions are preferred but some redundancy may also be necessary where new infrastructure has to be built without the benefit of detailed and robust future predictions.

Due to the large uncertainties in projections of climate change, adaptation to the changing risk needs to be flexible to a wide range of future scenarios and to be able to cope with potentially large changes in sea level, rainfall intensity and snowmelt. Climate uncertainty, therefore, as well as budgetary, institutional and practical constraints are likely to lead to a combining of structural and non-structural measures for urban flood risk management, and arguably, to a move away from what is sometimes an over-reliance on hard-engineered defenses and towards more adaptable and incremental non-structural solutions. Where structural defenses are the best or only option, the designers of defenses, barriers and barrages need to consider the most robust solutions with reference to the range of future flood scenarios.

Changes in the vulnerability of populations and assets to flooding are highly dependent on development stage, population demographics and traditional building modes and designs. Understanding the specific vulnerability of local populations is a crucial stage in risk management. Solutions may be well-known, such as the provision of flood warnings and

evacuation, but their implementation will always exhibit local features appropriate to cultural and development issues.

Implementing solutions requires multi-stakeholder cooperation as there are many constraints to action that need to be overcome. Sound information on risk, measures and resources will be necessary. Above all, communication of such information to all stakeholders will be a crucial step in engaging the support of all necessary participants. Furthermore, it is crucial to recognize that complete protection from flood risk is ultimately an impossible goal. This acceptance is necessary in order to plan for emergencies that will occur when flood measures fail. It also ensures that in progressing towards minimum flood risk, the cycle of plan, action, monitor, and review will be continuously revisited in the light of ongoing changes in the drivers of hazard, exposure and vulnerability.

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Annex 1 A list of devastating floods over the last decade

Asia	Africa	South America	Europe	Rest of America
Cambodia (2000, 2001 and 2002), India (2002, 2004, 2005, 2007), Indonesia (2002, 2004, 2007), Philippines (2008,2009), Vietnam flood (2000), Srilanka (2003) and Pakistan (2003,2010).	Zimbabwe (2000, 2001, and 2003), Senegal(2002, 2005, 2009), Burkina Faso (2003, 2006, 2007), Mali (2002, 2003, 2007), Nigeria(2001, 2003, 2007), Niger(2003, 2007, 2008), Chad(2001, 2007, 2008), Sudan(2003, 2006, 2007), Ethiopia(2005, 2006, 2007), Kenya(2003, 2006, 2008) and Uganda(2004, 2007)	Ecuador (2002, 2008), Venezuela (2000,2002), Peru (2003, 2008, 2010), Colombia (2005, 2007, 2009), Chile (2000, 2001, 2002), Brazil (2006, 2007, 2008, 2009), Bolivia (2001,2006,2007, 2008) and Argentina (2001, 2007, 2008, 2009).	Czech republic (2002, 2006), Hungary (2001, 2006), Poland (2001,2010), Romania (2005, 2007), Ukraine (2001, 2008), Austria(2002), France (2002, 2003), Germany (2002), Switzerland (2005), Bosnia-Herzegovina (2001), Greece (2000), Italy (2000) and United Kingdom (2000, 2004, 2005, 2007).	USA (2001, 2002, 2005, 2006, 2008) Canada (2003, 2005, 2006, 2008) Costarica (2002, 2007, 2008), El-Salvador (2005, 2008), Guatemala (2002, 2008, 2009,2010) Honduras (2007, 2008,2010), Mexico (2003,2005, 2007, 2008, 2009, 2010), Nicaragua(2000. 2007, 2008, 2010), Panama(2002, 2004, 2005, 2008, 2010)

Annex 2 Floods with the highest mortality

<i>Continent</i>	<i>Selected Countries</i>	<i>Year of Highest death occurrence</i>	<i>Total killed (EM-DAT) (1900-2010)</i>
Africa (East) (data available from 1961)	Burundi	2006	48
	Djibouti	1994	231
	Ethiopia	2006	1976
	Kenya	2006	990
	Malawi	1991	581
	Mozambique	2000	1926
	Somalia	1997	2824
Africa (Central and North)	Tanzania	1990	658
	Algeria	1927	4785
	Egypt	1994	719
	Morocco	1995	1615
	Sudan	1996	702
Africa (South and West)	Tunisia	1969	962
	Benin	1985	176
	Burkina Faso	2007	127
	Ghana	1995	357
	Namibia	2009	148
	Niger	1994	133
	Nigeria	2001	840
America (Central)	Sierra Leone	2009	103
	South-Africa	1987	1174
	El Salvador	1982	643
	Guatemala	1949	40849
	Honduras	1993	892
America (North)	Mexico	1959	4168
	Canada	1996	38
America (South)	USA	1972	2808
	Argentina	1958	778
	Bolivia	1983	910
	Brazil	1967 (2010)	6621
	Chile	1965	1040
	Columbia	1970	2681
	Ecuador	1982	947
Peru	1982	1761	
	Venezuela	1999	30338

Australia and New Zealand	Australia	1984	293
	New Zealand	1938	31
Eastern and Northern Europe	Hungary	1970	310
	Czech republic	1997	82
	Moldova	1994	60
	Poland	1997	113
	Romania	1000	1694
	Russia	2002	543
	Ukraine	2008	78
	United kingdom	1952	83
	Austria	1985	39
	France	2002	244
	Germany	2002	46
	Greece	1977	83
	Italy	1951	718
	Netherlands	1953	2001
	Portugal	1967	585
	Spain	1973	1284
	Yugoslavia	1981	95
Central and Eastern Asia	China	1931 (2010)	6597199
	Japan	1953	13056
	Korean D. Rep	2007	1820
	Korea republic	1972	3958
	Tajikistan	1992	1588
South and Southeast Asia	Afghanistan	1991	3714
	Bangladesh	1974	52143
	India	1968	60218
	Indonesia	1981	5893
	Iran	1954	7767
	Nepal	1993	6058
	Pakistan	1950, 2010	14774
	Philippines	1972	3005
	Sri Lanka	2003	1075
	Thailand	1988	2699
	Vietnam	1999	5143

