World Meteorological Organization

# FLOOD MANAGEMENT IN A CHANGING CLIMATE

## A Tool for Integrated Flood Management

ASSOCIATED PROGRAMME ON FLOOD MANAGEMENT

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The Associated Programme on Flood Management (APFM) is a joint initiative of the World Meteorological Organization (WMO) and the Global Water Partnership (GWP). It promotes the concept of Integrated Flood Management (IFM) as a new approach to flood management. The programme is financially supported by the governments of Japan and Switzerland.

The World Meteorological Organization (WMO) is a specialized agency of the United Nations. It coordinates the activities of the meteorological and hydrological services of 188 countries and territories and such is the centre of knowledge about weather, climate and water.

The Global Water Partnership is an international network open to all organizations involved in water resources management. It was created in 1996 to foster Integrated Water Resources Management (IWRM).

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**Note for the reader**

This publication is part of the "*Flood Management Tools Series*" being compiled by the Associated Programme on Flood Management. The contained Tool for "Urban Flood Management" is based on available literature, and draws findings from relevant works wherever possible. This Tool addresses the needs of practitioners and allows them to easily access relevant guidance materials. The Tool is considered as a resource guide/material for practitioners and not an academic paper. References used are mostly available on the Internet and hyperlinks are provided in the "References" section.

This Tool is a *"living document"* and will be updated based on sharing of experiences with its readers. The Associated Programme on Flood Management encourages flood managers and related experts engaged in environmental assessment around the globe to participate in the enrichment of the Tool. *For the purpose comments and other inputs are cordially invited.* Authorship and contributions would be appropriately acknowledged. Please kindly submit your inputs to the following Email address: apfm@wmo.int under Subject: "Urban Flood Management Tool".

**Acknowledgements**

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APFM Technical Document No. 14, Flood Management Tools Series

# FLOOD MANAGEMENT IN A CHANGING CLIMATE

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# 1. INTRODUCTION INCLUDING SCOPE AND STRUCTURE

1. The technological developments of recent decades have resulted in a significant increase in the quality of life for one part of the world's population. Most of the remainder have yet to benefit from these developments and the thrust of international assistance is to bring this about. Some of the main challenges to society arising from the evolution of technology are discussed in the following sections.

2. The central theme of this tool is to bring the different aspects of climate variability and climate change as it effects flood risks with the aim to show possibilities of how they can be managed successfully. It will be argued that only the combination of spatial, technical and organizational measures will lead to a more sustainable and effective management of increasing flood risks under climate change regime. Based on a holistic paradigm of Integrated Flood Management this paper is structured into three main chapters.

3. Audience targeted by this is broad as the implications of climate change and variability on flood risks has to be dealt by various stakeholders. However, since flood management is primarily a public task with full involvement of stakeholders the target group is primarily the staff of the respective municipal authorities, national flood planners, emergency response authorities and the public at large. These include: flood managers, spatial planners, civil engineers, water supply and sanitation services, civil defence authorities and health and social services.

4. This paper should not be seen as a technical manual but rather an initiator and starting point for the adaptation to climate change through integrated flood management. Wherever possible, references to more specific sources of information, predominantly online sources, are provided. As climate change impacts are better understood and experiences in dealing with them are gained, the tool will remain a living document in the true sense.

5. As a number of climate related terms can be easily mis-understood, Chapter 2 provides some essential concept on climate change which might be important for an initiator. However the experienced reader may like to skip this chapter. Chapter 3 looks at the various ways the climate change will affect the hydro-meteorological parameters that determine the magnitude of flooding and at the same time puts the other global changes, other than the climatic, that may determine the flood processes or flood risks. Section 4 addresses climate change and how its impacts are likely to increase the vulnerability of the society. Section 5 explores ways of containing the increased flood risks within an acceptable level and thereby helps sustainable development. Section 6 focuses on the approaches that can be taken to put IFM into practise as part of the adaptation strategies and brings out the advantages of doing so.

# 2. ESSENTIAL CONCEPTS

## 2.1 CLIMATE VARIABILITY AND CLIMATE CHANGE

6. The Fourth Assessment Report (AR4) of IPCC has concluded that warming of the climate system is unequivocal, evident from observed increases in global average air temperatures, ocean temperatures and other observations. There is no doubt that this climate change is going to have impact on the hydrological cycle which is sensitive to the temperature. Therefore, it is imperative that good understanding is developed on some of the basic aspects of climate change and how it effects the extreme events that are reflected in the hydrological extremes.

7. Climate is a measure of what to expect in any month, season or year and is arrived at using statistics built up from observations over many years. Statistically, the climate is defined in terms of mean and variability of involved variables such as temperature and precipitation over a period of time. The World Meteorological Organization recommends 30 years as the minimum period for averaging these variables for ascertaining the variability. The data gathered over the period 1961-1990 defines the latest Normal used for climate references. Extremes are part of normal climate.

8. Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may result from natural internal processes within the climate system (internal variability) or to variations in natural or anthropogenic external forcing (external variability)[1].

9. Concept of climate change is about shifts in meteorological conditions lasting many years. Climate change refers to the change in state of the climate that can be associated to the changes in the mean and/or variability of its properties and that persist over an extended period of decades or longer. The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as: a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is, in addition to natural climate variability, observed over comparable time periods.

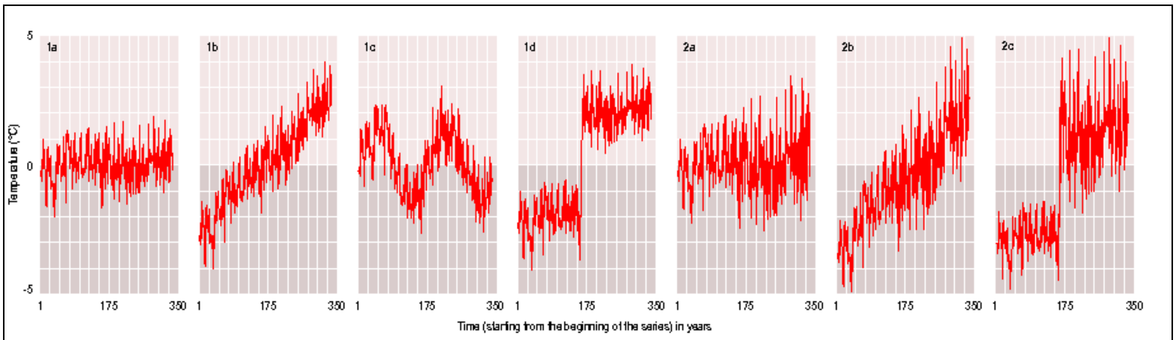


**Figure 1: Climate variability and climate change (Adapted from W.J. Burroughs in Climate – Into the 21st Century, WMO, 2003, Cambridge University Press)[2]**

10. Figure 1 illustrates a number of (notional) temperature time series under climate variability and climate change. Example 1a shows the climate variability. Here the average value over shorter periods are effectively the same, the series is known as stationary. The measure of temperature

[1] IPCC, 2001
[2] W.J. Burroughs, 2003

fluctuations about the mean is known as climate variability. Examples 1b to 1d combine variability with climate change. Example 1b represents combines variability with the trend, while 1c combines variability with a periodic fluctuation and 1d represents a fundamental shift. Example 2a indicates an increase of variability with no change in the mean. Examples 2b and 2c combine increased variability with climate change.

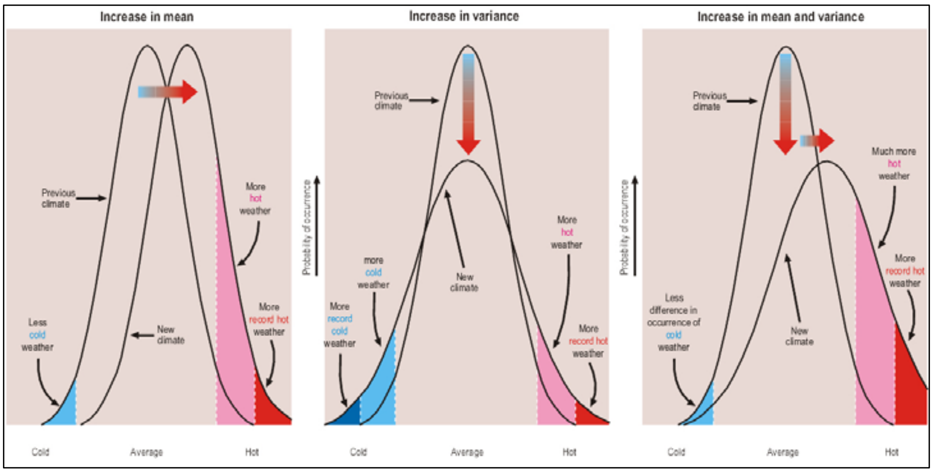


**Figure 2 Climate variability and climate change – illustrated in form of probability distributions for temperatures (Adapted from Climate – Into the 21$^{st}$ Century, WMO, 2003, Cambridge University Press)**

11. Figure 2 indicates through simple statistical reasoning how increased variability and increased mean in different combinations impact on temperature extremes.

12. All aspects of earth's climate: the wind, rain, clouds and temperature, are the result of energy transfers and transformations within the atmosphere, at the earth's surface and the oceans. There is usually equilibrium in the climate system since the amount of incoming solar radiation from the Sun and the outgoing terrestrial radiation are balanced ensuring that the earth neither continuously heats up nor cools down. This equilibrium is temporarily disturbed when the climate system responds to forcing or perturbation in energy balance of the earth. The effect of the climate forcing is transferred from one climate system to another and consequently gets modified in character or in scale. At a local scale, the resultant can be an amplification of the process (positive feedback) or opposition of the process (negative feedback).

13. Climate change is likely to result in increases to the frequency or intensity of extreme weather events such as heat waves, tropical cyclones and storms. The relationship between averages and extremes is often non-linear. For example, a shift in average temperature is likely to be associated with much more significant changes in very hot days. The disproportionate increase in the frequency of extreme events is not limited to the frequency of very hot days but could occur with many other climate extremes. In some instances the frequency of extreme events could increase even when there are small declines in averages – this is likely to be the case for rainfall.

## 2.2 OBSERVATIONS, PREDICTIONS AND PROJECTIONS

14. Our estimates of what the global climate will be like at the end of the 21$^{st}$ century depend on the computer models and the assumptions made in their formulation. The performance of the models in simulating global warming during the 20$^{th}$ century is reassuring. A number of broad conclusions drawn based on a number of scenarios of the development path that is likely to be adopted by the

mankind. However, the global climate models cannot yet provide a coherent picture of the regional climate change.

15. Progress in research depends on improvements in data availability, calling for enhancement of monitoring endeavors worldwide, addressing the challenges posed by projected climate change to freshwater resources, and reversing the tendency of shrinking observation networks. Broadening access to available observation data is a prerequisite to improving understanding of the ongoing changes. Relatively short hydrometric records can underplay the full extent of natural variability and confound detection studies, while long-term river flow reconstruction can place recent trends and extremes in a broader context. Data on water use, water quality, and sediment transport are even less readily available.

16. Much of what climate model studies predict about future weather and climate extremes is what we intuitively expect. However, the confidence level in prediction of extremes is very little as there are uncertainties about some climate processes and their inclusion in climate models. For many extreme phenomenons such as precipitations, there is currently insufficient information to assess recent trends, and the confidence in models and understanding is inadequate to make firm projections.

### 2.3 UNCERTAINTY IN SCIENTIFIC ASSESSMENT OF CLIMATE CHANGE IMPACTS

17. Uncertainty is an expression of the degree to which a value (e.g., the future state of the climate system) is unknown. Uncertainties in climate projections are abounding: different climate projections by various Global Circulation Models, different downscaling techniques, uncertain future populations, unknown future societal value, unpredictable future economic and financial conditions, or unknown future technology development. There is much uncertainity in our basic understanding of the behavior of the climate. These range from understanding of the properties of clouds, through how the frequency of extreme events might affect regional climates, to how oceans and major ice sheets could respond to global warming. Precipitation, a principal input signal to water systems, is not reliably simulated in present climate models. However, it is well established that precipitation variability increases due to climate change. Further, there are major uncertainties in quantitative projections of changes in hydrological characteristics of a drainage basin which will change in the future and may dominate the hydrological projections. Projections of future temperatures, which affect snowmelt, are more consistent, such that useful conclusions are possible for snow-dominated basins.

18. These uncertainties all together pose a serious challenge in planning and implementing adaptive actions and have two implications. First, adaptation procedures need to be developed which do not rely on precise projections of changes in river discharge, groundwater, extremes etc. Another way of coping with the uncertainty associated with estimates of future climate change is to adopt management measures that are robust. Approaches like Integrated Flood Management (IFM), for example, is based around the concepts of flexibility and adaptability, using measures which can be easily altered or are robust to changing conditions.

19. The climate science community is continuing its efforts in developing probabilistic future hydrologic projections and thereby minimizing the uncertainties. However, in spite of the very best efforts, uncertainties will not be completely eliminated. Therefore, planning methods under uncertainties with non-stationary future hydrologic events must be continuously developed and refined. The knowledge and experience that we gain locally must be shared globally to help us better prepare globally. Regional variability of future climate impacts on water resources as well as differing regional capabilities in combating the future changes will necessitate a worldwide coordination. Assistance to developing countries with data, methods, and other necessary resources will be a must for this worldwide endeavour to be successful.

## 3. CLIMATE CHANGE IMPACTS ON THE FLOOD FORMATION PROCESS

20. A variety of climatic and non-climatic processes influence flood processes, resulting in river floods, flash floods, urban floods, glacial lake outburst floods, and coastal floods. Flood magnitude depend on precipitation intensity, volume, timing and phase. Antecedent conditions of rivers and the drainage basins (frozen or not or saturated soil moisture or unsaturated) and status. A number of climatological parameters that are likely to be affected by climate change are: precipitation; wind storms; storm surges; sea level rise; and are discussed in brief[3].

**Box 1.10 Intergovernmental Panel on Climate Change Technical Report on Water and Climate Change**

Current water management practices may not be robust enough to cope with the impacts of climate change on water supply reliability, flood risk, health, agriculture, energy and aquatic ecosystems. In many locations, water management cannot satisfactorily cope even with current climate variability, so that large flood and drought damages occur. As a first step, improved incorporation of information about current climate variability into water-related management would assist adaptation to longer-term climate change impacts. Climatic and non-climatic factors, such as growth of population and damage potential, would exacerbate problems in the future. (*very high confidence*)

**Source:** IPCC 2008.

### 3.1 RAINFALL INTENSITY AND FREQUENCY

**Precipitation**

21. With the projected future warming there will be changes in atmospheric and oceanic circulation, and in the hydrologic cycle, leading to altered patterns of precipitation and run-off. The most likely will be an increase in global average precipitation and evaporation as a direct consequence of warmer temperatures. An increase in global average precipitation does not mean that it will get wetter everywhere and in all seasons. In fact, all climate model simulations show complex patterns of precipitation change, with some regions receiving less and others receiving more precipitation than they do now; changes in circulation patterns will be critically important in determining changes in local and regional precipitation patterns.

22. Precipitation levels are likely to change but could increase or decrease, depending on the region. Increase in precipitation at high latitudes both in winter and summer seasons are highly consistent across all models. Precipitation increase in some monsoon regimes are notable while not consistent locally[4], considerable agreement is found at broader scale in tropics. Heavy precipitation events are likely to increase. Intensity of precipitation events is projected to increase, particularly in tropics and high latitude areas that experience an increase in mean precipitation. In most tropical and mid- and high- latitude areas, extreme precipitation increases more than mean precipitation. Evaporation will increase with warming because a warmer atmosphere can hold more moisture and higher temperatures increase the evaporation rate[5].

23. High or concentrated rainfall could lead to flooding. Low rainfalls lead to water scarcity and increased risk of drought. This could destroy natural biodiversity and make current agricultural practices unsustainable.

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[3] IPCC, 2008, p.4, 127
[4] IPCC, 2008, p.25
[5] IPCC, 2008, p.29

**Changes in precipitation frequency and intensity**

24. Many have argued that, in addition to changes in global average precipitation, there could be more pronounced changes in the characteristics of regional and local precipitation due to global warming. For example, Trenberth et al. (2003) hypothesized that, on average, precipitation will tend to be less frequent, but more intense when it does occur, implying greater incidence of extreme floods and droughts[6]. Thus, the prospect may be for fewer but more intense rainfall – or snowfall – events.

25. At the other extreme, heavy precipitation events may result in increased leaching and sediment transport, causing greater sediment and non-point source pollutant loadings to watercourses. Floods, in particular, increase the risk of water source contamination from sewage overflows, agricultural land, and urban run-off.

**Changes in average annual run-off**

26. Run-off changes will depend on changes in temperature and precipitation, among other variables robust finding is that warming would lead to changes in seasonality of river flows where much winter precipitation falls as snow, with spring flow decreasing because of earlier snowmelt, and winter flow increasing[7]. Several climate models to simulate future climate under differing emissions scenarios was used and linked these climate simulations to a large-scale hydrological model to examine changes in annual average surface run-off by 2050. They found that all simulations yield a global average increase in precipitation, but likewise exhibit substantial areas where there are large decreases in run-off. Thus, the global message of increased precipitation clearly does not readily translate into regional increases in surface and groundwater availability.

## 3.2 SNOWMELT

27. Earlier spring run-off from snowmelt is a likely manifestation of global warming. Due to less extended snow cover both in space and time, spring peak river flows have been occurring 1-2 weeks earlier[8]. Snow cover has decreased in most regions, especially in spring and summer. The decline in snow cover has been largest in the lower elevations.

28. Due to increased summer air temperatures and changes in depth and duration of snow cover has resulted in permafrost warming and degradation of frozen ground[9]. This is leading to changes in the land surface characteristics and hydrological processes. Some of the steep slopes in these areas will be destabilized resulting in many more landslides. As glaciers melt and retreat, they are creating lakes, which have high potential of causing floods due to bursting[10]. For example, global warming is causing the melting of glaciers in the Himalayas. In the short term, this means increased risk of flooding, erosion, mudslides and Glacial Lake Outburst Flood (GLOF) in Nepal, Bangladesh, Pakistan, and north India during the wet season. Because the melting of snow coincides with the summer monsoon season, any intensification of the monsoon and/or increase in melting is likely to contribute to flood disasters in Himalayan catchments.

## 3.3 SEA LEVEL RISE

29. Global sea levels are projected to continue to rise as the world warms, increasing mean sea level rise at a local level. The 2007 Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) projected that global mean sea levels would rise by 18 – 59 cm above 1990 levels by the 2090s (where the lower bound corresponds to the lower estimate for the lowest emissions scenario, and the higher bound corresponds to the upper estimate for the highest scenario)[11]. These

[6] Trenberth K.E., A.G. Dai, R.M.Rasmussen and D.B. Parsons, 2003
[7] IPCC, 2008, p.35
[8] IPCC, 2008, p.22
[9] IPCC, 2008, p.19
[10] IPCC, 2008, p.35,37
[11] IPCC, 2008, p.28

projections, however, do not fully include contributions from the melting ice sheets (due to the limitations of the modelling techniques used).

30. A different technique was used to estimate future sea level change. This technique uses the observed relationship between global sea levels and temperature to project future sea levels from temperature projections. While very simplistic, this technique has the advantage of using real data and avoiding many of uncertainties introduced through using global climate models. According to this projection, global sea levels could increase by around 50 – 140 cm above 1990 levels by 2100.

31. Greenland and Antarctica could accelerate the rise above the higher level, although this was not modeled in the report. Subsequent research suggests that positive feedbacks and non-linear melting of the Greenland and West Antarctic ice sheets could result in higher sea level rises. A 5 m rise in sea levels caused by the sudden collapse of the Greenland and West Antarctic ice sheets by the end of the century has been discussed as a serious possibility. This makes sea level rise both a chronic and an acute hazard. However, according to the IPCC view, there is almost certain to be a gradual increase in sea level rise and there is a non-negligible probability of relatively rapid ice sheet collapse, which would cause considerable non-linear jumps in sea level rise[12].

32. In terms of regional changes, the sea level rise could be greater than the global average around northern Europe. AR4 gives evidence that, for a medium emissions scenario (21 – 48 cm rise by the 2090s), sea levels could rise by an additional 15 – 20 cm around Denmark[13].

33. The IPCC identifies several key impacts of sea level rise on water providers located in coastal areas, including:

- Lowland inundation and wetland displacement,
- altered tidal range in rivers and bays,
- changes in sedimentation patterns,
- more severe storm surge flooding,
- increased saltwater intrusion into estuaries and freshwater aquifers, and
- increased wind and rainfall damage in regions prone to tropical cyclones.

34. In addition, any local vertical land movements would need to be added to estimate the impacts of sea level change. Therefore, for adaptation planning, detailed estimates of local vertical land movements and uncertainties in regional climate change-driven sea level rise must be considered.

35. Tens of millions of people in low-lying coastal areas of south and Southeast Asia affected by sea level rise and an increase in the intensity of tropical cyclones. In Small Islands Developing States (SIDS), arable land, water resources and biodiversity are already under pressure from sea level rise. Increases in population and the unsustainable use of available natural resources add further problems. Tropical storms and cyclones cause storm surges, coral bleaching, inundation of land, and coastal and soil erosion with resulting high-cost damages to socio-economic and cultural infrastructure. Coastlines will almost certainly suffer from accelerated coastal erosion as well as inundation of settlements and arable land with associated social and economic consequences.

36. It is found that the increase in risk due to climate change is likely to be unacceptable in many cities, calling for an upgrade of flood protection in response to sea level rise. Even with upgraded defences which maintain unchanged the flood probability, the mean annual loss, i.e. the flood risk, increases because of the enlargement of the area subject to flooding. Flood probabilities, therefore, will have to be decreased to maintain the current level of risk. Moreover, while flood probability can be reduced to extremely low levels with appropriate protective measures, sea level rise will always

[12] IPCC, 2008, pp.28-29
[13] IPCC, 2007

increase the consequences of defence failure or overtopping by affecting increasingly large areas of the city.

### 3.4 TROPICAL CYCLONES

37. Major storms in the tropics, with wind speed in excess of 63 km per hour near the centre are known by the generic name tropical cyclones and are also called typhoons and hurricanes depending on the region where they form. The most important ingredient needed to fuel a tropical storm is a copious amount of warm, moist and rapidly rising air. Generally the horizontal extent of tropical storms is about 300 km in radius. Consequent wind and rain start to be felt about 400 km from the centre. The tangential wind speed can range typically from 100-200 km per hour. When tropical cyclones move over cool waters or land they loose their energy and tend to decay rapidly. Some storms are formed in extra-tropical regions.

38. There has been little apparent variation in the number of tropical cyclones, but there does appear to be an increase in the average intensity and the frequency in certain regions (for example the North Atlantic) and in the proportion of storms reaching a higher intensity. However, even if the frequency and magnitude of storms were to remain at historic levels, damage from storms is likely to increase because of rising sea levels and other climate-related vulnerabilities (for example damage to coral due to increased temperatures and ocean acidity). Apart from direct wind damage, wind storms are usually accompanied by storm surges, as well as inland flooding and mudslides. If storm intensity does increase, this will magnify damage.

39. Tropical cyclones give rise to storm surge: the offshore winds pushing water ahead of the storm. Storms, in particular extra-tropical cyclones, cause storm surges through a combination of the effects of winds in forcing higher wave heights and local sea level change due to the lower atmospheric pressure associated with the storm. An increase in the frequency of extra tropical cyclones would reduce the return-period of present-day storm surge events; whereas an increase in the intensity of events could increase the return-period of weak events and reduce the return-period of intense events. Both could potentially increase the risks associated with storm surges. On top of these mean changes in sea level, the water height will continue to vary over time as a result of weather-related effects (including storm surges). Climate change affects the amplitude of these variations in two ways, firstly by simply raising the water level (in line with the rise in background water level), and also (potentially) by changing the frequency of the variability through, for example, changes in storminess.

40. Latin America region has already been experiencing climate-related changes with the frequency and intensity of extreme events, particularly those associated with the ENSO phenomenon[14]. Torrential rains and resulting floods, including those associated with tropical cyclones, have result in tens of thousand of deaths and severe economic losses and social disruption in the region in recent years.

### 3.5 LAND USE CHANGE

41. There is a clear correlation between flooding and land use. The burgeoning population is putting pressure on the natural resources. Clearance of forests for agriculture and to meet the fuel and fodder needs and at the same time development activities in terms of infrastructure for roads, railways, and urbanization are changing the drainage systems and their capacity to evacuate flood flows. In addition, climate change impacts are displacing people from their rural surroundings towards urban conglomerates. These demographic changes are bringing unprecedented changes in the land use. Urbanization increases the risk of flooding. When land is covered by impermeable surfaces such as

[14] IPCC, 2008, p.22

roads and roofs, the frequency and severity of flash floods increase. Urbanizing 50 per cent of a watershed can increase the frequency of floods from once every 100 years to once every 5 years.[15] Under the IPCC scenarios, indirect factors are likely to outweigh direct land loss; these include erosion and damage to coastal infrastructure, salinization of water supplies, damage to sewage treatment systems and loss of ecosystems. In turn, this is likely to lead to accelerated loss of agriculture (due to land loss, soil salinization and reduced water availability) and increased vulnerability to wave and storm damage, which, combined with reduced rainfall and higher temperatures, could result in water shortages in coastal areas. Sea level rise could also lead to a dramatic reduction in land value in what are currently thought of as prime locations, because the land will become uninsurable.

**Table 1. Characteristics of the systems and potential impacts due to climate change**

| *System* | *Characteristics* | *Impact of the change in the system* | *Water resources potential impacts* |
|---|---|---|---|
| Overland flow | Surface flow which is the main volume in the floods and affects soil erosion together with diffusive pollution | Due to increase in the rainfall intensity there are flood risks in small basins; more soil erosion with loss of fertile soil and increasing diffusive pollution | • Increase the flood frequency for the same risk;<br>• Increase the soil erosion and loss of fertile soil;<br>• Increase the pollution load in rivers |
| Groundwater | Important reservoir of water (mainly in dry areas), is vulnerable to changes in rechargeable water from rainfall. This is the flow component which allow the perennial conditions of the rivers | • High rainfall in short period and increasing dry days may decrease the amount of water recharge for groundwater.<br>• Decreasing the water recharge, increases overland flow and decreases low flow in rivers and its capacity for natural flow regulation. | • Increase the frequency of droughts<br>• Increase the need for artificial flow regulation by reservoirs<br>• Water quality deterioration because of the decreasing capacity for pollution dilution. |
| Lakes and Reservoirs | This system regulate the flow of the basin;<br>it has large surface water for evaporation;<br>temperature regulates its water quality. | • Decreasing low flow can affect the lake and reservoir regulation, decreasing its levels;<br>• Rainfall-evaporation balance is important for the change conditions of the lake overtime;<br>• Increasing temperature can affect water environment (fauna and flora). | • Decrease in the reservoir regulation capacity can affect: water supply, irrigation, navigation and hydropower at different stages.<br>• Change in lake levels along time affect population on the border of the lakes and its environment. |
| Coastal areas | River basin which drains to the sea has an important environment. It brings sediments with nutrients and flow energy which creates an equilibrium at the coast. | Decreasing the river flow together with the sea level rise allow the sea water to enter upstream in the system, affecting the salinity, change the sediment deposition areas and increase the coastal erosion. | • Vulnerability to population in the coast due to erosion;<br>• Decreasing nutrients and fishing productivity;<br>• Salinity intrusion affecting water supply;<br>• Change navigation conditions. |

### 3.6 CLIMATE CHANGE AND FLOOD PROCESSES

42. To take the risk of flooding properly into account requires insight into the nature and magnitude of the risks; in other words, the processes that produce floods, probability of floods and their consequences (economic damage, numbers of casualties and how people will react to a

[15] Hollis, G.E., 1988

catastrophic flood). It is important to distinguish between the climate factors that contribute to flooding and the anthropogenic reasons due to changes in the land use patterns.

43. Due to global warming many subsystems of the global water cycle are likely to intensify, resulting in many regions in an increase of flood magnitude as well as flood frequency. Climate change is making weather less predictable, rains more uncertain and heavy storm rainfalls more likely. Heavy thunderstorm rains appear to have increased in frequency. Urban areas may help to increase thunderstorm activity because their built-up surfaces attain higher temperatures than surrounding areas and create a local air circulation that produces an 'urban heat island'. Dust particles caught up in that circulation act as nuclei on which moisture in clouds condenses, forming rain droplets that eventually may develop into the large rain drops of a major thunderstorm.

44. Sea-level rise increases the risk of coastal floods, particularly in case of storm surges. Many million more people are projected to be flooded every year due to sea-level rise by 2080s. Those densely populated low-lying areas where adaptive capacity is relatively low are especially at risk. Climate change also works in an indirect way to aggravate urban flooding.

## 4. CLIMATE CHANGE IMPACTS ON FLOOD VULNERABILITY

45. Vulnerability refers to those conditions in a society that make it prone to suffer the impacts of a given physical event. The relationships between climate change and the other drivers of vulnerability are complex and interwoven. Climate change may have potentially far-reaching effects on social life. Climate change and its accompanying risks have direct and indirect effects on development and economic growth. The potential impacts of climate change on the global economy were documented by *The Stern Review* in 2006. Its conclusion was that by 2050 extreme weather could reduce global GDP by 1% and that, unabated, climate change could cost the world at least 5% in GDP each year. Over the longer term incremental climate change will impinge on decisions about food security, energy security and land use. Climate change is likely to intensify existing pressures, increasing risk, vulnerability and uncertainty.

46. Vulnerability to floods is a community's proneness to be impacted adversely by flooding and is represented by the inability or incapacity of a community or a group: to anticipate, cope with, resist and/or recover from its impacts. It is the condition that determines the transformation of a hazard into a disaster. It not only impedes appropriate response but accentuates the severity of the impact that may be further exacerbated long after a disaster has struck. Vulnerability to floods is a combination of complex, dynamic and interrelated, mutually reinforcing conditions that can be divided into three major groups: Physical or material; Constitutional or organizational; and Motivational or attitudinal.

47. *Mass migration:* The impacts of climate change, including increased water scarcity and flooding, have the potential to accelerate human migration. The recent Intergovernmental Panel on Climate Change (IPCC) report notes that millions of people in densely populated low-lying coastal areas risk increasing exposure to flooding by storm surges over the 21st century. Frequent flooding, resulting in loss of livelihoods, production and other prolonged economic impacts and types of suffering can trigger mass migration or population displacement. Migration to developed urban areas creates overcrowding in the cities. These migrants swell the ranks of the urban poor and end up living in marginal lands in cities that are prone to floods or other risks. Selective out-migration of the workforce may create complex social problems. In a majority of cases where able-bodied male members are forced to migrate, the safety of women, children, the elderly and the disabled who are left behind becomes an important issue. It may damage the community function and social structure and further increase the vulnerability of the population.

48. *Food security, poverty and the reliance on floodplains:* There is clear evidence of a relationship between climate variability and economic performance in countries in which agriculture is a large share of GDP. Frequent flooding of agriculture lands results inadequate productivity and lack of surplus income that prevents investment in better agricultural practices and perpetuates the poverty that leaves the flood plain agriculturists vulnerable. Similarly in the urban dwelling sector also the inhabitants are reluctant to use the surplus incomes for improving their dwellings if they are flooded too often. Government investment in the infrastructure in such areas is also slackened due to their vulnerability to flooding.

49. Increase in frequency of flooding due to increased climate variability will further deteriorate the situation. The impact will be greatly magnified through rising sea levels, and possibly increased storm intensity. Estimates suggest that by 2080 there could be a fivefold increase in the number of people affected by floods due to storm surge in a typical year (49). In many coastal cities, climate change and sea level rise have the potential to significantly increase coastal flood risks in absence of upgrading of current flood protection infrastructure. With no adaptation, the increase in risk due to climate change is likely to be unacceptable in many cities, calling for an upgrade of flood protection in response to sea level rise.

### Environmental Vulnerability

50. Environmental degradation influences the effects of natural hazards by exacerbating their impacts and limiting the natural absorptive capacity and resilience of the areas affected. With the

increase in climate extremes: higher temperatures, longer dry periods and higher winds the flora and fauna, the wetlands, and the soil structure would be adversely effected thereby reducing the environmental resilience and environmental services. Coastal inundation is likely to seriously affect the aquaculture industry and infrastructure particularly in heavily-populated mega deltas. Stability of wetlands, mangroves, and coral reefs increasingly threatened.

51. With increasing population and greater agriculturally productive areas in the flood plains and coastal areas subjected to flooding, the forest land would be diverted to agricultural uses. Conflict in land use for the pastor and agriculture is already being experienced in sub-Saharan Africa. These conflicts are likely to accentuate the vulnerability of the eoc-systems as well as the societies depending for livelihood on these systems.

52. The size of the agricultural sector is also a significant factor. We will measure economic vulnerability as the potential for loss in infrastructure and agriculture. Government failure to provide appropriate maintenance for the public infrastructure, such as highways, secondary roads, and bridges can contribute to the flood vulnerability. Private infrastructure, especially housing, do not take into account whether they are on a river's flood plain, an unstable hillside, or a dry riverbed in a flood-prone area when they build their houses. Also, they do not use good materials for residential construction.

53. Integrated flood management (IFM) is based on the principle of reducing vulnerability through building resilience and developing a culture of prevention through preparedness rather than reactive responses alone.

## 5. IFM AS A TOOL FOR ADAPTATION

54. Climate change poses a major conceptual challenge to water managers. In addition to the challenges caused by demographic changes, land-use change and often unplanned development, climate change is shaking the foundation of the normal assumption that the past is the mirror to future. It can no longer be assumed that past hydrological conditions will continue into the future. At the same time the future development path and the consequent impacts on climate change can at best be presumed in terms of storylines.

### 5.1 ADAPTIVE MANAGEMENT PRACTICES

55. There are inherent uncertainties in various inputs that determine the risks, both at the hazard assessment stage as well as at the impact assessment stage. However, the scientific knowledge about the climate change and its impacts on the hydro-meteorological extremes such as floods and droughts is far from fully understood thereby making it difficult to assess future risks. Due to this uncertainty; managers can no longer have confidence in single projections of the future. It will also be difficult to detect a clear climate change effect within the next couple of decades, even with an underlying trend. Therefore, use of an adaptive management strategy is essential.

**BOX 1 Precautionary Principles**

The existing knowledge of ecosystems is fragmentary and the impact of human interventions on them is not fully understood. In order to account for this lack of scientific certainty, precautionary principles have been recommended in international agreements. In the context of environmental protection, principle 15 of the Rio Declaration[16] on Environment and Development provides that:

> "In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost effective measures to prevent environmental degradation."

A similar precautionary approach is also recommended by the United Nations Framework Convention on Climate Change with respect to factoring climate change issues[17]. These uncertainties can be dealt in a variety of ways. The first, at one's own peril, is to act arrogantly and ignore it. Second option is to avoid it through incremental implementation of development plans through adaptive management approach.

56. However, it is an irresponsible strategy to wait for less uncertain assessments before implementing adaptation measures, since climate change and its impacts are already taking place. Furthermore, waiting for less uncertain scenarios is a treacherous hope; the results will remain uncertain in future even with increased refinement of scientific methods. Impacts vary among scenarios, and the use of a scenario-based approach to water management in the face of climate change is therefore widely recommended. There are, however, two problems. First, the large range for different climate-model-based scenarios suggests that adaptive planning should not be based on only a few scenarios since there is no guarantee that the simulated range represents the full range. Second, it is difficult to evaluate the credibility of individual scenarios. By making assumptions about the probability distributions of different drivers of climate change, however, it is possible to construct probability distributions of hydrological outcomes.

57. Adaptive management approach requires that decisions are made as part of an ongoing science-based process. It involves planning, acting, monitoring and evaluating applied strategies, and incorporating new knowledge as it becomes available into management approaches. It is a departure

[16] UN, 1992
[17] UNFCC, 1994

from traditional management, and views management actions as learning experiments. It allows change in course or even reversal of the decisions. Adaptive management explicitly defines the expected outcomes, design methods to measure responses, collects and analyses information to compare expectations with actual outcomes, learns from the comparisons, and changes actions and plans accordingly. Monitoring and evaluation forms an integral part of this approach where results are used to modify management policies, strategies and practices[18].

58. Options that are reversible, have adaptive capacity, and allow incremental enhancement, are favored. For example, flood protection provided by earthen embankments is easily reversible as compared to the one provided by concrete walls. Therefore, adjusting management direction requires a willingness to experiment and accept occasional failures.

### 5.2 USING IWRM FOR ROBUSTNESS

59. Flood issues are influenced not only by the physical causes of flooding but the overall social economic and political setting of the area concerned. Therefore, those issues are addressed within the framework of social and economic development planning, particularly water resources development, within the framework of Integrated Water Resources Management (IWRM) which has been defined by GWP[19] as ‘a process which promotes the coordinated development and management of water, land and related resources in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital eco-systems’.

60. Water managers have long had to cope with the challenges posed by climate and hydrologic variability, both intra-annually and inter-annually. Their adaptation strategies include responding to both seasonal variability and extreme wet and extended drought periods using integrated reservoir and irrigation systems that allow for the capture of water during the wet season for use during dry seasons and extended drought periods. Other adaptations have been the use of levees and dams in concert to protect communities from heavy precipitation and high flood flows during extreme wet periods. Climate change might challenge these conventional adaptations.

61. Such challenges beyond conventional adaptations stem from the uncertain nature of climate change and the potential for nonlinearities in impact. Traditional approaches could be defined relative to climate projections, demographic outlooks, and other planning drivers, shown as “top-down” in Figure 3. These top-down perspectives are limited by current state of the art of climate change models, downscaling techniques, and observations. These approaches contrast with “bottom-up” approaches defined within a sensitivity analysis where thresholds of operations flexibility are revealed by incrementally adjusting planning drivers[20]. In the “bottom-up” approaches, water managers start with their knowledge of their system and utilize their measures to identify what changes in climate would be most threatening to their long-range plans or operations, and identify the system’s vulnerabilities which would cause critical problems, e.g., a 10% increase in flow from the 100-year flood. The next step is to assess what adaptation can be made to cope and roughly at what cost. By examining the outputs of climate models or studies, water managers can then assess the likelihood of such system critical vulnerabilities. Climate change information can be incorporated into either top-down scenario-driven or bottom-up vulnerability assessments, so both approaches are not exclusive naturally.

[18] WMO, 2006b
[19] GWP 2000
[20] Colorado Water Conservation Board (CWCB), 2008, pp.40-43

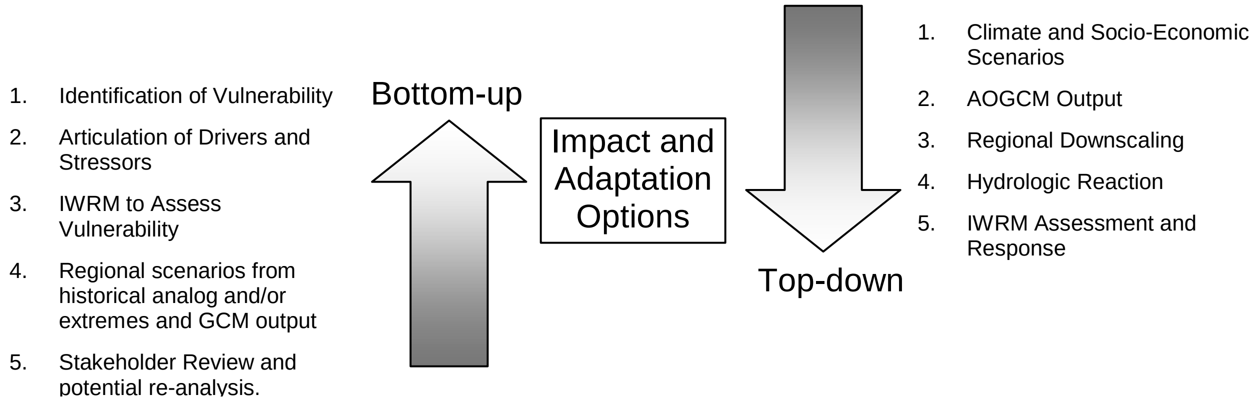


**Figure 3. Top-down vs. bottom-up approaches to climate change assessment**[21]

62. At the same time a robust decision making incorporates following four elements[22].
- Consider ensembles of large number of scenarios.
- Seek robust, rather than optimal, strategies that perform "well enough" by meeting or exceeding selected criteria across a broad range of plausible futures.
- Employ adaptive strategies to achieve robustness.
- Design the analysis for interactive exploration of the multiplicity of plausible futures.

63. A robust strategy is flexible and can be adapted to changing conditions to seek resilient response. Such strategy would be multi-faceted with a mix of options being used to create a layered strategy, appropriate to the given conditions[23].

### 5.3 INTEGRATED FLOOD MANAGEMENT

64. Flood control and protection measures have played an important role in protecting people and socio-economic development from flooding in the past. Until recently, they have been engineering centered, with little or no consideration being given to the social, cultural and environmental effects of the chosen strategy or to long-term economic sustainability. They have largely relied on structural solutions, such as embankments, bypass channels, dams and reservoirs. Although structural flood control measures over the last 50 years have been complemented with non-structural measures, such as flood forecasting and land use regulations, the need for a paradigm shift from flood control to flood management has been recognized only during the past decade.

65. This shift is enshrined in the Integrated Flood Management (IFM) approach which aims at:
- Maximizing the net benefits from flood plains
- Reducing loss of life as a result of flooding
- Reducing flood vulnerability and risks
- Preserving ecosystem and their associated biodiversity

66. IFM addresses the interplay between the beneficial uses of floods, on the one hand and risks posed by extreme events to the sustainable development in flood-prone areas on the other. It aims at a fundamental re-orientation of social perception of floods from the "need to control" to the "need to manage" and shifting the focus from a reactive to a more proactive response. Living harmoniously with floods is an important strategic option in IFM, which seeks to integrate land and water resources development in a river basin within the context of IWRM and manage floods based on risk management principles in order to optimize the net benefits from floodplains while minimizing the

[21] Colorado Water Conservation Board (CWCB), 2008, pp.40-43
[22] Lempert, R.J., Popper, S.W., and Bankes, S.C., 2003
[23] APFM, 2004, pp.19-21

loss of life from flooding.[24] (Figure 4). Over the centuries people have been living with floods. Unfortunately, such areas have not seen much economic prosperity and improvement in the quality of life, compared to those where flood protection has been provided. IFM, by reducing the vulnerability of the people and activities in the flood plains, addresses these issues.

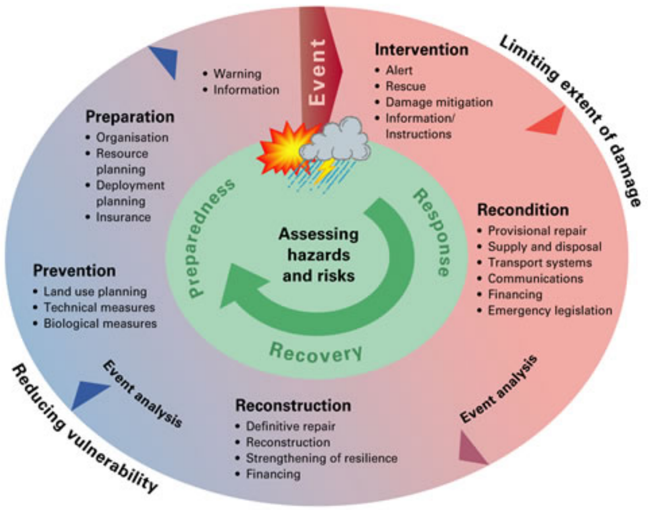


**Figure 4. Risk Management Stages**[25]

67. The basic concept of the approach has been presented in the *Integrated Flood Management Concept Paper*[26]. Accordingly, IFM is based on five key elements:

- Adopting a basin approach to flood management;
- Bringing a multi-disciplinary approach to flood management;
- Reducing vulnerability and risks due to flooding;
- Addressing climate variability and change; and
- Enabling community participation.

68. IFM, like IWRM, requires adopting a river basin approach to planning through multidisciplinary inputs. A number of flood risk reduction options tend to simply transfer the flood risks to elsewhere in the basin. At the same time, certain infrastructure works like flood diversion works, bridges, railways and highways, if not provided with appropriate waterways, tend to increase the flood risks upstream thereby increasing the overall flood risks. Instead of fixing flood problems at local level in an ad-hoc manner, it lays emphasis on the development of flood management plans for the river basin as a whole.

69. With the need to address the vulnerability and risks, the IFM requires a close collaboration and coordination between various development ministries, sectors and institutions from various level of administration, through a multi-disciplinary approach. Dealing with flood risks requires addressing not only the scientific and engineering aspects but also the social, environmental, economic and legal and institutional aspects. IFM being a multi-sectoral and multi-disciplinary pursuit encourages various stakeholders and players to play their part under a perceived set of conditions according to their experiences. These varied perceptions of flood risks that bring differences in opinions and approaches to the task at hand are addressed by bringing all the players together and with exchange of data, information and knowledge, in order to contribute to the overall objective of economic well being. The social aspects and involvement of all stakeholders – including civil society – from planning to implementation is an integral part of the IFM process. The IFM process requires a multi-disciplinary

[24] APFM, 2004, pp.1-2
[25] Swiss Confederation
[26] APFM, 2004, pp.18-23

approach and the involvement of all stakeholders including the civil society and the communities that are directly affected.

70. IFM enables adopting a best mix of strategies, both structural and non-structural through short and long term measures. It attempts at managing the land phase of the water cycle as a whole while considering all floods: small, medium and extremes. The concept recognizes the benefits of the smaller and more frequent floods, the importance of flood plains and the increasing development demands they face, while at the same time recognizing the disruptive nature of floods. The influence of floods on the ground water recharge, can be far reaching.

71. The measures adopted in IFM take a full account of the impact of land use and spatial planning on the flood generation processes thereby integrating land and water management. Certain other hazards such as landslides within the basin have a potential to modify the flood risks down-stream and, combine together with floods, can generate mudflows. Such mutually impacting hazards are accounted for and addressed by adopting a multi hazard approach, wherever they co-exist and influence each other.

72. The process of making choices among various options, particularly where a compromise has to be made between development and the ecosystem preservation needs should be based on an environmental sensitive framework. Such a framework should be based on scientific understanding and analyses of various processes, environmental assessment and adaptive management through monitoring and evaluation. Where appropriate level of certainty in the knowledge, such as in the case of climate change impacts, is missing the adaptive approach. This would help in developing a three fold approach of avoiding, reducing and mitigating adverse environmental impacts.

73. Stakeholders' involvement in all the stages of the decision making process: policy formulation, development of basin flood management plans, making choices among available options, implementation of the activities and above all building resilience in the society, would thereby develop ownership. Such an approach allows all stakeholders to share their views, raise concerns, and build consensus and commitment thereby ensuring sustainability of the measures taken. An institutional mechanism providing appropriate platform for various stakeholders, such as a river basin organisation, facilitates the process. Such a process requires building capacity of all the stakeholders, by building awareness about the issues and sharing relevant data and information.

74. The Integrated Flood Management (IFM) approach provides a suitable framework for flood risk management. It is based on the proactive strategy of risk management through a three pronged attack on reduction of risks by reducing magnitudes, vulnerability and the exposure of the economic activities and applying risk management principles, addressing issues at all the three phases of the risk management cycle: prevention, rescue and rehabilitation. It goes a step forward by aiming at maximizing the net benefits from flood plains and preserve ecosystems and their associated biodiversity to reduce vulnerability and develop resilience. Vulnerability to flood hazards can be reduced to a certain extent by measures to promote resilience, adaptation and flood risk reduction. This still leaves residual hazards caused by extreme flood events that are beyond the design flood events or to that which societies would have experienced from natural climate variability. To manage flood hazards, a variety of approaches should be used, including flood risk reduction measures, resilience building, risk pooling and risk transfer[27].Risk transfer requires the establishment of new mechanisms whereby the extra risks to the vulnerable caused by climate change are spread more widely. In addition to humanitarian motives, there are strong socio-economic reasons for developed countries to participate in new insurance mechanisms. IFM is based on the assessment of flood risks with the basin as a unit and an understanding of the downstream- upstream relationship of risk transfer.

75. The multidimensional nature of flood management options owing to constraints, risks, uncertainties and conflicting objectives poses challenges and opportunities for the participatory

[27] APFM, 2009

approach towards decision-making, as such options should not only be technically appropriate but should also address broader socio-political issues. The need to deal with social concerns and involve experts and civil society in the decision-making process is key to IFM. These concerns can be qualitatively incorporated through the active participation of all stakeholders, including civil society at various decision-making levels and stages and through the implementation of flood management measures. Multi-stakeholder engagement is a key to the success of IFM as it ensures strong stakeholder support and is a catalyst for proactive engagement in flood issues.

76. IFM is to be carried out when flood management decisions take into account not only their effect on flood risk alleviation, but also of the resulting economic and environmental impacts. Consequently, the planning and decision-making processes of a number of separate development authorities, whose decisions in any form influence the hydrological response of the basin, must be coordinated to ensure that the common goal of sustainable development is achieved[28]. In order to achieve the required objectives of IFM, there is need for an appropriate legal and institutional framework. for collaboration and coordination between different entities, making the basic data and information for informed decision making and building an enabling environment for all the stakeholders to participate in decision making.

[28] WMO, 2006a, pp.8-15

## 6. APPROACHES TO FACTOR CLIMATE CHANGE INTO FLOOD MANAGEMENT PRACTICES

77. Adaptation is a process by which individuals, communities and countries seek to cope with the consequences of climate change, including climate variability. It should lead to harmonization with the country's or community's pressing development priorities such as poverty alleviation, food security, disaster management of economic development. It can be undertaken in a pro-active mode: through strategic planning in incremental stages; or autonomous mode where ad-hoc tactical adjustments are made as the events and situations unfold. Accordingly, UNDP recommends four basic approaches towards adaptation[29]:

- Hazard based approach;
- Vulnerability based approach;
- Policy based approach; and
- Adaptive capacity approach.

78. Opportunities for adaptation in flood management may arise either while planning new investment, for capacity expansion or major rehabilitation of the existing system. The opportunity to adapt during the operation and management is (Box 2) always present but has to be appropriately planned.

**BOX 2 Reservoir operations under changing climate**

An intensified hydrological cycle could make reservoir management more challenging, because there is often a trade-off between storing water for dry period use and evacuating reservoirs before the onset of the flood season to protect downstream communities. Reservoirs have been usually sized to handle a certain amount of stream flow variability, determined from a relatively short historical record. If the variability increases, reservoirs may be undersized to meet demands or adequately serve flood moderation. Thus, it may become more difficult to meet delivery requirements during prolonged periods between reservoir refilling without also increasing the risk of flooding. To the extent that adequate reservoir space is available, changing the operation procedures of reservoirs could mitigate some of these effects.

Protecting growing communities from the risk of flooding also has increased in importance. Two adaptation strategies are flood control operating rules for large reservoirs and flood bypasses that move water away from human settlements. In many cases, flood conveyance restricts land use to not allow permanent structures, so during periods of high flow, large volumes of water can be diverted from the main river channels, thereby reducing the risk of flooding along the developed riverfront areas. Climate change adaptation could include the re-operation of reservoirs to maintain their important services and, in some cases, the construction of new facilities to help in flood protection or to secure water supplies. These adaptations would require careful consideration to ensure their usefulness in adapting to climate change, with an IWRM modelling process a key in assessing the benefits of alternative strategies for adaptation to climate change.

### 6.1 HAZARD BASE APPROACH

79. A gradual warming or a drift to either wetter or drier conditions could probably be absorbed as part of the continual process of development. The most immediate climatic threats to humankind relate to increased variability of storms and rainfall patterns and the impact of rising sea level on low lying coastal areas. How we face up to these challenges may define our ability to adapt to long term changes. Figure 5 shows that, due to increase in the variability due to climate change, the design discharge for various structures would be exceeded more often than it exceeded in the past.

[29] UNDP, 2004, 33-46, 67-182

80. In case of flood management structures the options are that either the structures are strengthened to a higher design discharge or a conscious decision is taken to accept higher frequency of the overtopping of the levees, for example. The decision is essentially socio-economic and has to be taken through economic evaluation within a public policy framework [30]. Where the flood defenses do not meet the current standards and technical specifications, it is important to work on administrative and financial arrangements to improve management efficiency. Sensitivity analysis of the cost-effectiveness of the improvements, for different design discharges, combined with a multi-criteria analysis, can be one of the options.

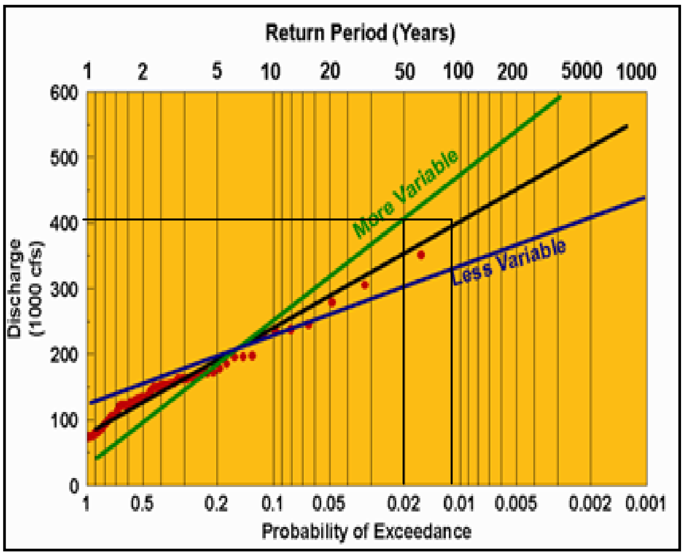


**Figure 5. Change in climate may result in increased variability**

81. Better protection can be provided by higher and stronger flood barriers, but also by more ‘robust’ flood defenses: dikes and barriers that do not fail collapse when design discharge is exceeded, but still provide a certain amount of protection, like the overflow dikes, should be considered and tested.

82. Far bigger challenge of course is to assess the magnitude of a flood of a given frequency. Since the assumption of stationarity of the flow series, which is the foundation of frequency analysis, is no more valid under the changing climate, new approaches have to be developed to be able to quantify the risks. There is a scale mismatch between the large-scale climatic models and the catchment scale. Water is managed at the catchment scale and adaptation to flood is carried out at the basin level, while global climate models work on large spatial grids. Increasing the resolution of adequately validated regional climate models and downscaling can produce information of more relevance which could be used in conjunction with the distributed river basin models.

83. Apart from climate change, a number of drivers such as population growth and related social dynamics, livelihood requirements, economic development, land use development, environmental degradation etc., determine the hydrological response of a river basin. Each of these drivers is dynamic and continues to evolve, as do the direct and indirect pressures they exert on hydrological response of the basin. It is difficult to draw a comprehensive picture of the future by examining each driver independently. The drivers interact and can have even more of an impact on future water resources collectively than they can individually. Future scenarios that consider these interactions offer a more holistic picture and need to be developed.

84. Whatever approach is adopted it has to be flexible and integrated incorporating hard as well as soft measures. Particularly, given the limitation of the hard (structural) measures, there are always

[30] WMO, 2007

certain residual risks. Strengthening the measures to deal with residual risks would help deal with uncertain design parameters. In any national planning for adaptation following elements shall be strengthened for overall national plans for adaptation:

- *Conduct assessments of changing hazards, vulnerabilities, risks and capacities* to provide national and community baselines and priorities for intervention. These should be updated regularly.
- *Strengthen early warning systems*, by improving capacities for detecting and forecasting current and future hazards and associated vulnerabilities and risks, ensuring that warnings reach all populations, and enabling people's preparedness to respond to emergencies.
- *Update emergency preparedness programmes and contingency plans* for effective response to disasters, supported by legislation, institutions, resources and coordination mechanisms.
- *Ensure wide engagement of stakeholders and decentralized planning* in national, provincial, city and local government, and with the private sector and civil society; promote community participation in disaster risk reduction; and recognise the differing vulnerabilities and capacities of men, women, children and people with disabilities.
- *Implement or strengthen legislation* to reduce risks from natural hazards so that it addresses climate change impacts, identifies lines of responsibility and engagement at all levels, mandates inter-sectoral cooperation, ensures linkages into development planning and makes provisions for budgets at all levels of government. Strengthening of land-use zoning, infrastructure development planning and building codes, including revisions to address the changing frequency and severity of extreme events.

## 6.2 VULNERABILITY APPROACH

85. In order to reduce vulnerability, various factors have to be considered; economic activities and degree of development of the area; frequency and intensity of floods in that area; nature of land and land use; anticipated impacts of development activities of one place on another; and demand for utilization of basin resources[31]. Vulnerability varies widely across communities, sectors and regions. International comparisons of vulnerability tend to focus on national indicators, e.g., to group less developed countries or to compare progress in human development among countries with similar economic conditions. At a national level, vulnerability assessments contribute to setting development priorities and monitoring progress. At a local or community level, vulnerable groups can be identified and coping strategies implemented, often employing participatory methods[32].

86. Vulnerabilities are generally not just the given circumstances, but rather unsafe conditions which have developed by human actions or inactions. When reinforced through certain social factors such as poverty, gender or livelihoods, material, organizational and attitudinal conditions create factors that contribute to vulnerability. It is essential to be aware of the root causes of these vulnerabilities in order to mitigate whenever possible the underlying causes and not merely the consequences. The goal of reducing vulnerability is to reduce the susceptibility of people, livelihoods and infrastructure to floods. One possibility to structure the numerous facets of vulnerability is to distinguish between physical, constitutional-economic and informational-motivational aspects of vulnerability, which is shown as vulnerability reduction strategies[33]. The decision as to what specific interventions should be carried out in a particular area to address vulnerability depends on the following factors:

- Economic activities and degree of development of the area;
- Frequency and intensity of floods in that area;
- Nature of land and land use, for example farms that might need to be flooded occasionally or developed lands that should be safeguarded all year round;
- Anticipated impacts of development activities of one place on another;
- Demand for utilization of basin resources.

[31] WMO, 2006c, pp.27-30
[32] UNDP,2004, 67-90
[33] WMO, 2006c, pp.27-30

87. Conditions determining vulnerabilities, particularly material conditions, can be improved by economic development and are influenced by a variety of public development policies, largely beyond the ambit of flood management policies. Some of the strategies aimed at mitigating conditions while addressing flood management policies are listed[34].

88. Risk sharing has often been advocated as a long-term non-structural measure for building resilience among flood victims[35]. For instance, flood insurance provides a mechanism fro sharing potential economic losses with others. The basic principle is to spread the risks over time, and among individuals and organizations, which pay insurance premium against a specific risk. Coupled with the appropriate land use control and flood emergency management measures, flood insurance can serve as a useful tool to deal with residual risks[36].

### 6.3 POLICY BASED APPROACH

89. Adaptation Policy Framework is structured around following four major principles:

- Adaptation to short-term climate variability and extreme events serves as a starting point for reducing vulnerability to longer-term climate change.
- Adaptation policies and measures are best assessed in a developmental context.
- Adaptation occurs at different levels in society, including the local level.
- The adaptation strategy and the process by which it is implemented are equally important.

90. The policy response has to be to twofold: flood defense infrastructure has to be retrofitted to retain their structural integrity during extreme events (e.g. allow overtopping of levees without levee erosion). The residual risks when a flood is larger than the design standard need to be explicitly strengthened (i.e. through land use planning and regulation, enhanced public flood awareness and response capacity, risk sharing mechanisms, enhanced flood emergency response capacity).

91. The preparation and implementation of national adaptation plans should be undertaken through a strong inter-ministerial and multi-stakeholder platforms or committees addressing disaster risk reduction that comprise all relevant sectors, such as planning and finance, education, health, agriculture, food security, environment, emergency response, appropriately including private sector, scientific and other civil society representation. The Hyogo Framework (Box 3) provides the basis[37].

92. Such committees or platforms should incorporate long-term climate change risk planning and support related climate change platforms. Respond to ministerial-level mandates and direction and engage the planning and finance ministries. Identify incentives to guide and influence decisions of the private sector and local development actors. Recognize communities' priorities and capacities.

[34] The table of vulnerability reduction strategies is shown in the document above.
[35] APFM, 2009, Risk Sharing in Flood Management, tool for Integrated Flood Management (in printing)
[36] WMO, 2006c, p.30
[37] UN ISDR, 2005

**BOX 3 Hyogo Framework**

The Hyogo Framework sets out strategies for reducing disaster risks through the five priorities for action. Of these priority areas, three immediate and cost-effective areas where action can be taken to advance adaptation to climate change through disaster risk reduction are:

*Risk assessments:* These involve the collection and summary of national risk information, including socio-economic data on existing vulnerability and capacity. They should cover the entire territory and all populations, and should be routinely updated to assess emerging risks including those related to climate change. The information is most often represented in risk maps. It should be made widely available to all relevant users, in order to support policymaking, raise community awareness, and enable populations to reduce their own risks.

*Early warning systems.* Effective early warning systems involve four elements: risk knowledge, monitoring and warning service, dissemination and communication, and response capability. Early warning systems are highly effective in saving lives and livelihoods. Although all four elements of the system need to be strengthened in many countries, it is the communication of warnings and people's readiness to act that usually fails in disasters.

*Sector-specific risk reduction plans*. To be effective, national plans and strategies to reduce disaster risk need to be integrated in the plans and programmes of every sector and area of development. Land-use planning, the locating of critical infrastructure, the management of natural resources, the protection of key assets —all should ensure that risk is identified and reduced at all stages from planning through to implementation.

## 6.4 ADAPTIVE CAPACITY APPROACH

### 6.4.1 Enhancing and sharing knowledge

93. Knowledge of flood risk related areas of adaptation can be enhanced by strengthening existing regional centres and mechanisms that address disaster risk reduction and risk management for sectors such as water, agriculture, health, and humanitarian response. Link regional sectoral centres concerned with adaptation into a global adaptation network to share sectoral experience for adaptation within and across regions. Engage existing experienced centres and organizations as front line actors and institutional partners in adaptation planning and implementation. Prioritize the sharing of information and tools required to enable the prompt development of national and regional risk and capacity baselines, especially in high-risk areas. Support the replication of successful initiatives in community-based disaster risk reduction and community-based adaptation to strengthen people's livelihoods resilience. Strengthen technical institution capacities at international, regional and national levels, to facilitate the development of standard methodologies and tools founded on best science and to provide climate information and climate projections for adaptation and disaster risk reduction strategies and measures.

### 6.4.2 Strengthening technical capacity

94. Greater research needs to be directed towards understanding the nature of regional climates, and hydrological regimes, including their variability and potential for change. Such knowledge is essential in order to estimate the potential frequency of natural hazards, the resulting risks, and understand the options available for adaptation.

95. Monitoring, forecasting and early warning play a pivotal role in the risk management cycle. Regular monitoring of elements that constitute water-related hazards is crucial during the preparedness, response and reconstruction phases. There are clear and disturbing indicators that governments around the world, both in developing as well as in developed countries, are moving away from investments in such monitoring networks. Gaps in observational data, both in time and space, reduce the global

capabilities of monitoring, forecasting and warning of water-related hazards. Early warnings are effective only if they reach the affected people who have to respond to such a situation. Science and technology should try to break the barrier of financial resources to enable such warnings to reach even the remotest corners of the affected areas.

### 6.4.3 Bridging scientific knowledge gaps

96. Unpredictability of climatic extremes for specific regions and their extent, which create uncertainty for water managers, is the vital gap in the knowledge on climate change, which needs to be addressed. Latest scientific research (Box 4) should be applied in monitoring water-related hazards through appropriate networks of seismological, hydrological, meteorological and marine parameters.

97. Sound water flood management should be based on a quantitative understanding of the flood risks. When sufficient observational data are lacking, models cannot be used to generate information for decision-making, since they lack baseline data from which to be calibrated. To take the risk of flooding properly into account requires insight into the nature and magnitude of the risks; in other words, the probability of floods and their consequences (economic damage, numbers of casualties and how people will react to a catastrophic flood). These are still not fully understood and call for inter-disciplinary research.

98. Improved hydrologic networks can minimize uncertainties in forecasting and prediction, thereby lessening decision-making risk. This can be achieved in several ways, including new and better-quality information from improved measurements (quantity, quality, timeliness) and measurement techniques. The level of uncertainty for assessment and forecasting varies, but is generally high in subtropical, tropical, polar and mountainous regions. Networks also tend to be weak in developing countries, especially the least developed amongst them. Aside from technical considerations, uncertainty in hydrologic data can be attributed to the access of hydrological data.

99. Developments in remote sensing, satellite communication and information technology should be used for improving monitoring and developing computational models for forecasting and early warning of impending hazards. The challenge before the international community is to support these activities particularly in developing countries, where resources for such activities are limited.

100. There is a critical need for more availability and access to *global* hydrologic data, information and products for climate and hydrologic research and applications –including the validation and refinement of global circulation models and the quantification of the water balance and its variation over large basins and regions up to the global level.

### 6.4.4 International cooperation

101. In reality, there are but a handful of countries that do not have the technological know-how to implement some form of water-related risk management measures. So, why are we so far behind in solving the problem of adequate water related risk management in the whole world? Here we have again the “local” vs. “global” scale contrast. Most measures have to be implemented at the local level, with local decision-making, local knowledge, considering local situations. But at this “ideal” level of action, it is very common not to have the scientific and technical knowledge for adequate water-related risk management. Sometimes, the lack of this knowledge at the local level is so marked that there is not even conscience of the risk involved in local decision-making (unless of course nature has recently reminded us with an extreme event). Availability of scientific and technical expertise at the national level does not mean that problems in this area are being reasonably solved or even considered throughout a country.

## 6.5 BRIEF CASE STUDIES

102. A growing number of countries and cities are including water-related adaptation into their planning, policy and institutional response to such predicted impacts as rising sea-levels, more frequent floods and increased precipitation (box 14.11)[38].

**Box 14.11 Water-related responses to climate change**

London and Venice are redesigning their urban stormwater drainage systems to accommodate predicted changes in precipitation frequency and intensity. Tokyo is designing urban holding ponds under roads and parks to temporarily store storm runoff to avoid flash floods. Jakarta recently initiated a programme to construct a major stormwater drainage canal system (East Canal) to provide adequate drainage to its eastern half. Viet Nam has developed an extensive system of dikes, including 5,000 kilometres of river dikes and 3,000 kilometres of sea dikes, to protect from typhoons and rising sea levels.

Countries in the lower Danube River basin in Eastern Europe restored thousands of hectares of aquatic habitat through floodplain restoration.

In Andhra Pradesh, India, removing silt from water tanks allows the capture of more monsoon runoff, resulting in additional benefits of less groundwater pumping, restoration of some dry wells and irrigation of an extra 900 hectares of land. Reconnecting lakes in the Hubei Province in China to the Yangtze River – by opening sluice gates and applying sustainable management techniques – increased wetland areas and wildlife diversity and population and will make the area more resilient to flood flows. There are potential scaling-up possibilities with this approach, as there are hundreds of sluice gates along the Yangtze River that disconnect it from nearby lakes.

Source: World Bank 2008.

103. Water managers in a few countries, including the Netherlands, Australia, the UK, and the USA, have begun to consider the implications of climate change explicitly in flood and water supply management (Box.4).

[38] World Bank, 2008

**BOX 4 Predicted changes in precipitation by 2030**
November 2008

The decadal prediction system (DePreSys) from the *Met Office Hadley Centre* – designed to provide realistic predictions for changes in climate over the next few decades, by including both natural and man-made influences on the climate system – is used here as the basis for predictions of changes in precipitation, all around the world, over the next 20 years. This study is aiming to inform adaptation strategies in the sector of water supply and sanitation technologies.

Predictions are provided for annual, seasonal and monthly averages, as well as for large-scale extreme events. The model predictions are subject to uncertainties, an estimate of which is provided alongside the prediction maps in the report.

A summary of relatively-confidently predicted changes in annual-mean precipitation is highlighted below, grouped by the level of confidence in the predictions.

- Patterns of change predicted for the period around 2020 appear spatially coherent, and are mainly large scale. They are broadly similar to the patterns of predictions for the period around 2030, suggesting that the changes expected by 2020 are in most places predicted to continue in the same direction for at least another decade.

- Annual-mean precipitation is predicted to increase in high-latitude areas, in both hemispheres, with changes predicted to become apparent by the 2020s; precipitation is predicted to decrease in southern Africa, parts of Central America and of the Mediterranean basin by the 2030s. These predictions are supported by more than 66% of members of the DePreSys ensemble.

- Additionally, annual-mean precipitation is predicted to decrease over northern South America and some parts of Central America, starting by the 2020s and continuing at least to the 2030s, and is predicted to increase over South Asia, already by the 2020s, persisting or increasing further by the 2030s, as well as over parts of central Africa. These predictions are supported by more than 66% of members of the DePreSys ensemble.

- Additionally, annual-mean precipitation is predicted to decrease in coastal regions of western North America, starting by the 2020s, and in the Mediterranean region, by the 2030s; annual-mean precipitation increases are predicted for some parts of the Sahel region of western Africa. These predictions are supported by all members of the DePreSys ensemble.

A limited analysis of predicted changes, around 2030, in large-scale extreme events lasting a few days, reveals uncertainty in the sign of the expected changes, in most parts of the world. However, some features are supported by 90% of members of the DePreSys ensemble; these are summarised below.

- The intensity of wettest 5-day large-scale 1-in-1-year events is predicted to decrease in parts of the Middle East and northeastern Africa, as well as in northeastern Brazil and some coastal areas in western North America; areas in eastern Asia and parts of the northern extratropics show relatively large risk of increase in intensity of such events.

- The number of dry 10-day periods is predicted to increase over parts of southern Africa, over large areas in central and eastern South America, areas of the Mediterranean basin and the coastal region of western North America. These changes are consistent with changes predicted as best estimate for annual-mean precipitation.

Although case studies analysed here suggest that realistic predictions of annual-mean precipitation are achievable with DePreSys, at present there is no statistically-significant evidence on the performance of the system in reproducing precipitation patterns observed in the recent past for either long-period means or extremes. More work is needed to understand and address the limitations of models in representing the physical processes which determine changes in precipitation, and more ensemble climate predictions are required to robustly generate estimates of most likely outcomes and fully quantify the associated uncertainties.

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