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Large-scale Floods Report

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LARGE-SCALE FLOODS REPORT

Lessosns Learned and Best Practices for
Flood Disaster Managers and Policy Makers

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Synopsis:

The International Center for Water hazard and Risk Management (ICHARM) under the auspices of UNESCO together with the International Flood Initiative (IFI) are collected large-scale flood reports to extract from them lesson learned and best practices for flood disaster managers and policy makers. All reports are original and drafted exclusively for this book. They are covering various aspects of flood management policy from preparedness to emergency response. (September 2011)

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Preface

It is a great pleasure to present the first volume of Large-scale Floods Report compiled and edited by the International Centre of Water Hazard and Risk Management (ICHARM). It is a report of recent large floods that brought serious impacts over wide areas of different nations. Some eminent experts agreed on contributions from Poland, Canada, Germany, USA, Myanmar, Bangladesh, Taiwan, the Philippines and Mainland China. I am most grateful to the authors who kindly accepted our invitation and took their precious time to prepare their manuscripts.

This volume contains an overview article on global floods and case studies of such floods as Red River Flood of 1997, Elbe River Flood of 2002, Hurricane Katrina in 2005, Cyclone Nargis in 2008, Cyclones Sidr in 2007 and Aila in 2009, Typhoon Morakot in 2009, Typhoon Ketsana in 2009 and China floods in 2010. In this report, storm surges are included as flood-related disasters. At ICHARM, excess water disasters including storm surges, tsunamis, landslides and debris flows are classified and treated alike as flood-related disasters.

This book itself is a manifestation of the increase of flood events all over the world. So many flood disasters occurred in the past decades. This is not only because so many hazards occurred but also because societal vulnerability to floods is increasing. As Kundzewicz (Chapter 1) eloquently states, the increase in flood risk is not just a "CNN effect" but significantly intensified by humans due to "human encroachment into unsafe areas". Poor people migrating from rural to urban areas often cannot find safe areas to live in and are forced to settle in newly expanding fringes of urban areas that are vulnerable to hazards. Those people tend to be less prepared for disasters, too.

Climate change is further aggravating the situation. Frequently-flooded areas are expanding from traditionally flood-prone areas in humid Asia to all over the world including arid zones. Now an increasing number of people consider climate change not as a matter of anticipation but as an ongoing event with frequent occurrences of unprecedented extremes. As Chen et al. (Chapter 7) shows, Typhoon Morakot of 2009 brought near world-record 24- and 48-hour rainfalls over the densely populated island of Taiwan and caused a deep-seated landslide with about 650 deaths or missing. Early this month on 1-4 September 2011, Typhoon number 12 (Talas) moved very slowly over Japan from Shikoku to Chugoku and dumped a large amount of rainfall nearly all over the country. Especially in the Kii Peninsula, located on the Pacific side of central Japan, the precipitation reached up to three fourths of the mean annual rainfall within merely a few days, which triggered massive landslides leaving more than 100 people dead or missing. It is anticipated that the frequency of similar events would increase under climate change.

This book is not a catalogue of large floods describing causes, processes and consequences in detail but rather analyses of lessons and policy implications that the authors abstracted from the events. In some cases, governments have already enacted new laws for their implementation. Simonovic (Chapter 2) analyzes the policy implications of large flood incidents and concludes that "flood management must be seen in the context of day-to-day decisions rather than a response to a disaster", which often leads to a massive infrastructure investment and "a false sense of security". In Plate's report (Chapter 3) on the central European floods of 2002, he analyzes a number of reports on lessons learned in which better preparedness and governance are the central issues. He demonstrates remarkable governmental actions leading to Germany's Flood Protection Law in 2005 and the eventual enactment of the EU Flood Directives in 2007.

It is interesting to see quite a similarity between Hurricane Katrina and the tsunami of the Great East Japan Earthquake. As Bourget (Chapter 4) states with reference to the IPET and HOPE reports, the storm brought by Hurricane Katrina was "largely unanticipated", and that "the surge was far larger than the previous one-storm design" was the major reason for the wave overtopping the surge barriers. The IPET's key lesson was therefore "future planning and design methods should be systems-based" that can consider "the performance of the system beyond the design criteria". The magnitude of the tsunami caused by the East Japan Earthquake was also far beyond expectation and thus the failures happened without inadequate preparation. In both cases, the conclusions are similar; that is, there should not be "beyond expectation" in disaster management. We must prepare for any potential failure within a holistic disaster management system.

"Beyond expectation" may be the most common words heard, similar to "the act of god", when any disaster happens. The case of Ketsana, which hit the Luzon Island in 2009, presented another example as Nilo and Espinueva (Chapter 8) report. The flow rates in the Pasig and the Marikina rivers upstream of Metro Manila "far exceeded their design values" of the preventive upstream diversions called the Manggahan Floodway and the Napindan Channel. The unusually swollen rivers eventually flooded areas along the rivers and about 80% of Metro Manila. "Exceeding the design values" should not be "beyond expectation" in disaster management.

The disaster management in Bangladesh and China in the past several decades is considered as success stories. It looks very much so if we compare the death tolls of Cyclones Bhola (1970), Gorky (1991) and Sidr (2007) in Bangladesh and similarly of the floods in 1931, 1954 and 1998 in China. But the recent two cases, Cyclone Aila in 2009 in Bangladesh and the 2010 floods of China, show a remarkable contrast. Although Aila, which hit the West Bengal adjacent to West Bangladesh, was another deadly cyclone, the death toll was as small as 190 while it was 3268 in Sidr. This was because, as Khandakar (Chapter 5) reports, Aila directly hit the West Bengal of India, "where Bangladesh's nearby coast was protected by the Sundarbans, the world's biggest mangrove forest". In the case of the 2010 flood of China, on the other hand, Cheng et al. (Chapter 9) report that the human losses were as high as 3185 persons while that of 1998 was 4150. Here the proportion of the death tolls in mountain areas was 91% in 2010 while it was around 40 % in 1998. They say "due to the intensified human activities in mountain areas, such as mining, road building, hydropower exploitation, traveling development etc., it becomes more difficult to reduce the casualties in mountain areas." These two cases symbolically indicate the importance of the natural environment and the increased vulnerability by human settlements in risky areas.

Another contrast found in these success stories is the case of Cyclone Nargis, which hit Myanmar in 2009. Lwin (Chapter 6) reports that the WMO mission visited the Myanmar Department of Meteorology and Hydrology immediately after the cyclone onset and issued a press release saying "Cyclone warnings were sufficient: Deaths inevitable". The number of the dead and missing resulting from the cyclone was nearly 140000, an extremely tragic consequence. The most obvious lesson from this disaster is that early warning alone cannot save lives. As one of Lwin's tables shows, more than 55 % of people in the Myanmar Delta had food stock only for one day or less. How could they survive isolated with no food? Still worse, they had no shelters, no hazard maps, no past experiences. This is clear evidence for the disaster risk-poverty nexus.

The book is a product of our best effort despite the tight schedule to deliver it at the occasion of the 5th International Conference on Flood Management (ICFM5). We would welcome any feedback you may have regarding the book to be considered in the future publications. On behalf of ICHARM, I hope that the volume will be a useful reference to different experiences of flood management in various parts of the world and beneficial to practitioners, decision makers and researchers for their sincere efforts in flood management.

Prof. Kuniyoshi Takeuchi
Co-editor and Director of ICHARM

Policy Effective Large-Scale Flood Reports

An Introduction to the Book

Flood management strategies adopted in many basins have continuously evolved over the last 50 years with mixed experiences. Usually the effectiveness of a flood management policy becomes clear only after an extreme flood event. Although technical knowledge on hydrological sciences and other associated fields are in a state of continuous development, policy-related issues should not be outdated within a matter of a few years. Hence, it is crucial for disaster managers and decision makers in a particular basin to have a sufficient vision on experienced strengths and weaknesses of flood management policies in other basins to minimize the failure risk of any flood management policy planning to be introduced.

In order to understand best flood management policy practices and lessons learned, ICHARM has launched a project to collect the experiences of past large-scale floods. In total, 11 original reports have been collected from around the world to cover different socio-economic and climate conditions. This book is to publicize the outcome of the research project. The target groups and audiences of this book are policy makers and flood risk managers, particularly those who are involved in decision making to deal with large-scale floods with national and regional impacts. It is quite difficult to cover all aspects of comprehensive flood management policy in a single book due to lack of proper documentation and access to information. Instead, we tried to discuss the following policy aspects using real case studies:

- Flood forecasting and early warning systems
- Climate change issues
- Land use management
- Flood preparedness and emergency response
- Structural measures and/or non-structural measures
- Economic development effect on flood risk management
- Flood risk management in the privatization era
- Subsidy and flood insurance
- Public awareness and education
- Central government and local authority; decentralization of flood management
- Integrated Flood Management
- Flood damage assessment and reconstruction
- Flood risk mapping
- Flood hazard maps and evacuation routes

The following 11 reports have been collected to cover the above flood policy aspects:

1- Global Change and Flood Risk Management

Zbigniew W. Kundzewicz

Institute for Agricultural and Forest Environment, Polish Academy of Sciences and Potsdam Institute for Climate Impact Research

2- Evolution of Flood Management Policy in Canada and Flood of the Century in the Red River Basin

Slobodan P. Simonovic

Professor, Department of Civil and Environmental Engineering and Director, Engineering Studies, Institute for Catastrophic Loss Reduction, The University of Western Ontario, London, Canada

3- Consequences of the Central European Flood of August 2002 with emphasis on the Elbe River in Germany

Erich J. Plate
Emeritus Professor of Hydrology and Water Resources Planning,Universität Karlsruhe (TH), Karlsruhe, Germany

4- Hurricane Katrina: Key US Task Force Findings and Measures
Paul G. Bourget
Institute for Water Resources; US Army Corps of Engineers

5-Report on Damages by Recent Cyclonic Floods (2007-2009) in Bangladesh
Md. Abu Taher Khandakar
Chief Engineer, BWDB, Dhaka and former Director General of Bangladesh Haor and Wetland Development Board (BHWDB)

6- Disasters Caused by Cyclone Nargis and Their Underlying Causes
Tun Lwin
Myanmar Climate Change Watch, Director-General (Retired), DMH, Yangon, Myanmar

7- Lesson Learned from Typhoon Morakot—Typhoon Morakot's Impact on Taiwan's Disaster Prevention and Relief Strategy
Liang-Chun Chen, Lung-Sheng SHIEH, and Shen Chiang
National Science and Technology Center for Disaster Reduction, Taiwan (ROC)

8- Metro Manila Flash Flood of 26 September 2009: Causes, Impacts and Lessons Learned
Prisco Nilo[1] and Susan Espinueva[2]
[1]Administrator, Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA)
[2]Officer-In-Charge, Hydro-Meteorology Division (HMD), PAGASA

9,10 &11- Flood Management in China (one report and two appendixes)
Xiaotao Cheng[1], Ao Tianqi[2] and Guoqiang Wang[3]
[1] Professor, China Institute of Water Resources and Hydropower Research
[2] Professor, Department of Hydrology and Water Resources College of Water Resources and Hydropower Sichuan University
[3] Beijing Normal University

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Dr. Ali Chavoshian
Editor-in-chief, ICFM5 Secretary at ICHARM

Chapter 1

Global Change and Flood Risk Management

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EXECUTIVE SUMMARY

This contribution deals with the risk of river flooding and risk management, in the context of global change, with particular reference to observations over the last two decades and projections for the future. Flood risk and vulnerability tend to change over many areas, due to a range of climatic and non-climatic impacts whose relative importance is site-specific.

Climate-driven changes in future flood frequency are complex, because they depend on the generating mechanism. In many places flood risk is likely to grow, due to a combination of anthropogenic and climatic factors. Recent modelling studies show that plausible climate change scenarios project future increases of both amplitude and frequency of rain-caused flooding events. It is very likely that there will be an almost ubiquitous increase in precipitation intensity in the warming world. Decreasing flood magnitudes can be expected in many areas where floods are generated by spring snowmelt. However, global warming may not necessarily reduce snowmelt flooding everywhere.

Several ongoing land-use changes, such as urbanization, deforestation, and reduction of natural storage (floodplains, wetlands), can be regarded as adverse from the viewpoint of flood safety. They diminish the available water storage capacity and increase the runoff coefficient, leading to growth in the flow amplitude and reduction of the time-to-peak of a flood triggered by a 'typical' intense precipitation (e.g. design precipitation). Furthermore, human encroachment into unsafe areas has increased the potential for damage. Societies become more exposed, developing flood-prone areas (maladaptation).

In such a global change, mitigation of the flood risks calls for a change from reactive to an anticipatory stance. An immediate challenge is to improve flood forecasting at a range of time horizons of concern, from short-term weather forecasting and quantitative precipitation forecasts (indispensable for flash floods) to long-term forecasting, based e.g., on snow cover information or seasonal forecasts based on an ENSO index, or sea surface temperature in ENSO- or NAO-affected regions.

It is also necessary to take lessons from flood events, i.e. to build awareness and understanding of reasons of the failure of performance and identification of weak points in the flood preparedness system. A single weak point in a system, which otherwise contains excellent components, may render the overall system performance non-satisfactory. The system requires adequate integration of components, while responsibility for them may reside in different agencies. This means that an adequate (often difficult) collaboration and co-ordination between multiple institutions is often needed. In emergency situations, it may become evident that distribution of roles of agencies is unclear, and possibly redundant.

1. INTRODUCTION

The term "river flooding" describes destructive abundance of water, inundating normally dry locations outside of the river channel, where damage potential is present. Floods are intermittent events, possibly of rare recurrence in a given location. However, at some sites floods are commonplace events, e.g. occurring every spring when the abundant snow cover melts. River flooding is a natural phenomenon, manifesting natural spatial and temporal variability of such geophysical variables as the river water level and discharge, which, from time to time, may take on extremely high values. Several flood-generation mechanisms can be involved, such as rain (intense and/or long-lasting), snowmelt (possibly cum rain), ice jam, landslide, glacier-lake outburst, or dam break.

River floods, jeopardising settlements located in floodplains, have been an ever-present hazard accompanying the mankind since the dawn of civilisation, and their tracks can be found in old epics, myths and narratives. For millennia, people have been settling in river valleys in order to till fertile soils, to benefit from flat terrain, to have easy access to water supply, and to use water for transport. Dwelling in higher lands, riparian people lived in harmony with nature, benefiting from valuable services, which benign floods provided to ecosystems, wetlands, wildlife, fisheries, and agriculture.

Has the flood risk increased indeed? Some people claim that it is just a "CNN effect" accompanying technology development and globalization. Wherever a destructive deluge occurs, we have a report in the evening news worldwide, likely on the same day. We are informed now about events that were overlooked in the past. The CNN effect is real, but it is much more than that. The increase in the flood risk (understood as a product of probability and consequences) is beyond any doubt. Flood risk has been intensified by humans, who - to use the parlance from mechanics have contributed to the increase of the load and to the decrease of the resistance of the system. The former can be interpreted as the increase of flood magnitude corresponding to a given design precipitation, while the latter can be understood as amplification of the flood damage potential.

Therefore, floods continue to be an acute problem, causing high material damage worldwide and considerable death toll. This, in fact, pertains in general to weather extremes. The costs of extreme weather events (among which floods are a major category) have exhibited a rapid upward trend. Yearly material damage from large events has increased globally by order of magnitude within four decades, in inflation-adjusted monetary units. Damages caused by natural disasters, mostly weather and water-related, have increased much more rapidly than population or wealth (Mills, 2005). Hence, the climatic driver behind the increasing flood risk has been vigorously sought.

In each of several individual flood events in the last decades, the material losses exceeded US$ 10 billion, while in each of record-deadly events in less developed countries the number of flood fatalities exceeded a thousand. Many flood fatalities have been recorded in Asia. Indeed, destructive floods are quite frequent in China, India, and Bangladesh.

Yet, numerous deluges have virtually hit all parts of the world, including Europe. The material flood damage recorded in the European continent in 2002 (above 20 billion Euro) was higher than in any single year before. Since 1950, there have been 12 flood events in Europe with the number of fatalities exceeding 100 in each (Barredo, 2007), including five events in Italy. The killer-flood in Spain in 1962 was the only event in the last 50 years in Europe leading to more than 1000 fatalities.

Table 1 embraces a subjective list of chronology of selected important flood-related events in the last two decades.

Table 1 Chronology of selected important flood-related events in the last two decades.

1994	After the 1993 flood in the US Midwest, the US Interagency Floodplain Management Review Committee suggests to relocate people off the floodplains and to reclaim wetlands
1997	Large floods in Central Europe (Odra/Oder Czech Republic, Poland, Germany) and Vistula; 110 fatalities and billions-level damage
1998	Floods in China cause material damage of 30 billion US$ and over 3600 fatalities
1998	Major flooding in Bangladesh with two-thirds of the country's area inundated
2002	Dramatic floods in Europe (Germany, Austria, Czech Republic, France) with total damage in excess of 20 billion Euro
2007	Approval of the Directive of the European Parliament and of the Council on the assessment and management of floods
2010	Record-high destructive floods in China and Pakistan

2. GLOBAL CHANGE AND FLOOD GENERATION MECHANISMS

Having observed that flood damages have been increasing with time, worldwide, one is curious to understand the reasons for this growth. Several factors may be responsible, such as changes in socio-economic, terrestrial, and climate systems. Relevant socio-economic changes include increasing exposure and damage potential due to population growth, increasing GNP, economic development of flood-prone areas, land-use change leading to land-cover change (e.g. urbanization, deforestation), and changing risk perception. Changes in terrestrial systems include changes in hydrological systems and ecosystems, therein: land-cover change, river regulation river straightening and shortening, channelization, constructing embankments. Conditions of transformation of precipitation into runoff in hydrological systems are subject to change, leading to reduction of water storage area and volume (drainage of wetlands and elimination of natural vegetation; increase of impermeable areas), increase of the value of runoff coefficient, increase of the flood peak and decrease of the time-to-peak. Last, but not least, changes in climate are important, such as increase of water holding capacity and water contents of the atmosphere in the warmer world, increase of frequency of heavy precipitation, changes in seasonality and in circulation patterns.

On average, 2% of agricultural land has been lost to urbanization per decade in the European Union. Direct urbanization effects are particularly visible in small or middle size floods, which often constitute a substantial contribution to flood losses in the longer term. Van der Ploog et al. (2002) attributed the increase in flood hazard in Germany to climate (wetter winters), engineering modifications, but also to intensification of agriculture, large-scale farm consolidation, subsoil compaction, and urbanization. For example, the meadowland area in former West Germany decreased between 1951 and 1989 from 15.7 to 10.8%. Simultaneously, the small grain acreage grew from 18.5 to 22.3%. Additionally, nearly 20% of the agricultural land area was drained artificially during this period. The urbanized area in West Germany more than doubled in the second half of the 20th century. The timing of river conveyance has been altered by river regulation (channel straightening and shortening, construction of embankments).

Human encroachment into floodplains appears to be the major cause for increased flood-related damages in most areas. It may grow as people become wealthier and more exposed. Technology helps populate more “difficult” areas. Many wrong locational decisions have been taken, which cause the flood loss potential to increase. According to assessment reported by Newson (1997), one sixth of all urban land in the USA was located within the 100-year flood area and around ten per cent of population of the USA lived there. In Japan half the total population and about 70% of the total assets are located on flood plains, which cover only about 10% of the land surface. In some less developed countries, this portion is very much higher. Hope to overcome poverty drives poor people to migrate to informal settlements in endangered, flood-prone, zones around mega-cities in developing countries, which are left uninhabited on purpose, since effective flood protection cannot be assured. In Bangladesh, during the 1998 flood two thirds of the country area were under water.

An important factor influencing the flood risk is an unjustified belief in the absolute security provided by structural defenses. Further, a short memory syndrome can be observed. During a flood-free interval, decision makers gradually reduce the funding of flood preparedness systems, and citizens become increasingly less risk-aware. This occurs in developing and developed countries alike, including the United States, where the Katrina event unveiled the inadequacy of the emergency preparedness system.

Although land use controls flood risk, it is less so in case of very high-intensity rainfall, which causes high surface runoff in both urban and forested basins. There is a potential for floods becoming much higher than ever observed, e.g. if record-high precipitation occurs in areas with high (and dynamically growing) damage potential, e.g. a megacity. The records (cf. WMO, 1998) of highest observed point precipitation for different time intervals are, for instance, 1340 mm in 12 hours, 1825 mm in one day (this happened on Réunion, a humid-climate island on the Indian Ocean), and 3847 mm in eight days. If precipitation of a record size occurs over a large city, consequences are utterly destructive.

3. CLIMATE CHANGE: ISSUES AND POLICIES

3.1 Climate Change Observations

The Fourth Assessment Report, AR4, of the Intergovernmental Panel on Climate Change (IPCC, 2007) concludes that warming of the global climate system is unequivocal. This is now evident from observations of increases in air temperature at a range of scales. Moreover, recently observed climate change has not been limited to temperature, but also embraced other variables, leading to a range of impacts.

The updated 100-year linear trend (1906 to 2005) shows a 0.74 °C [0.56 °C to 0.92 °C] global mean temperature increase, while the linear warming trend over the last 50 years (0.65 °C) is nearly twice as strong as that for the last 100 years (IPCC, 2007).

In the global scale, the year 2010 was record-warm and terminated the globally-warmest decade in the history of direct temperature observations. It was the 34-th consecutive year with global temperature exceeding the 20th century mean. Global temperature has been growing for 40 years and since 1960s, each decade is warmer than the former one. The list of 11 globally warmest years (since 1880, i.e. in the period for which we can determine the global mean temperature based on many thermometer observations) contains each individual year from 2001 onward.

While observed temperature increases are quite regular, precipitation changes are less regular. Nevertheless, precipitation increases over land north of 30°N over the period 1901 2005 and decreases over land between 10°S and 30°N after the 1970s were observed (Trenberth et al., 2007). Several studies lead to the conclusion that, over the last 50 years, there has been an increasing probability of heavy precipitation events for most extra-tropical regions (cf. Groisman et al., 2005; Trenberth et al., 2007). It is likely that there have been widespread increases in the contribution to total annual precipitation from very wet days (Fig. 1) in many land regions, even in those areas where a reduction in total precipitation amount has been observed. This agrees with observed significant increase in water vapor amount in the warmer atmosphere (consistent with the theoretical Clausius-Clapeyron law). However, only a few regions have sufficient data to assess trends in rare precipitation events in a reliable way (Trenberth et al., 2007). The rainfall statistics are strongly influenced by inter-annual and inter-decadal variability.

The effects of climate change on observed climatic water balance (equal to precipitation minus evapo-transpiration), which vary regionally, largely follow changes in the prime driver, precipitation, and changes in temperature in snow-impacted basins. However, stream flow generation is a complex process, integrating influences of many climatic and non-climatic factors, such as volume and timing of precipitation, catchment storage, evapo-transpiration and snowmelt, and whether precipitation falls as snow or rain, as well as watershed management practices and river engineering works (e.g. dikes and dams) that alter the water conveyance system over time. It is difficult to disentangle the climatic effects on river flow from the effects of human interventions in the catchment.

Globally, results of a change detection study of annual maximum river flows (Kundzewicz et al., 2005) do not support the hypothesis of a ubiquitous increase of annual maximum river flows. However, out of 70 time series of river discharge in Europe it was found that the overall maxima (for the whole 1961 2000 period subject to study) occurred more frequently (46 times) in the second 20-year sub-period, 1981 2000, than in the first 20-year sub-period, 1961 1980 (24 times). A regional change in timing and nature of floods has been also observed in many areas of Europe, and less snowmelt and ice-jam-related floods were recorded. Among observed climate-related phenomena impacting on floods in Europe are increase in precipitation intensity; increase in westerly weather patterns during winter; and shrinking snow cover.

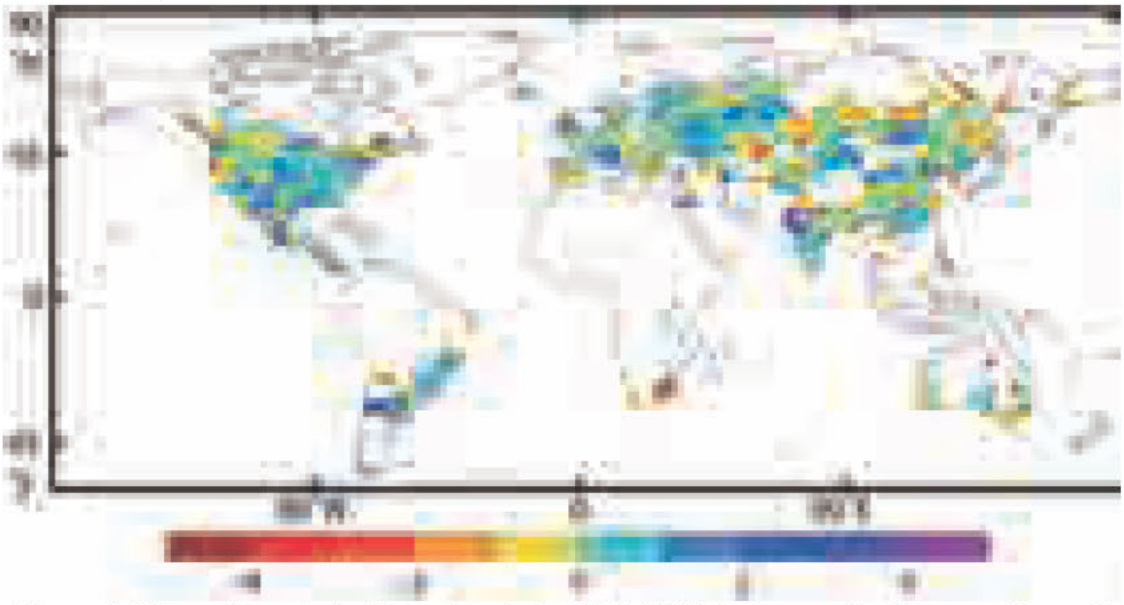

Figure 1 Observed trends, in % per decade for 1951-2003, in the contribution to total annual precipitation from very wet days (above 95th percentile). Trends were only calculated for grid boxes where both the total and the 95th percentile had at least 40 years of data during this period and the data extended until at least 1999. *Source: Trenberth et al. (2007).*

3.2 Causes of Climate Change – Climate Policy

Global air temperature is a result of the energy balance of the climate system. The climate change mechanisms are related to: the solar radiation; change of parameters of Earth's movement around the Sun (orbital forcing); composition of the atmosphere (in particular atmospheric content of greenhouse gases, dust, and aerosols); and land-surface properties. The first two categories of above mechanisms are beyond human impact. However, there is a considerable anthropogenic influence on the last two categories of mechanisms. People introduce more and more carbon dioxide, methane, and nitrous oxide to the Earth's atmosphere. Furthermore, there is a large-scale anthropogenic, and large-scale, change of such important land-surface properties as albedo (reflection coefficient) and water storage capacity (including ground permeability), related to land-use and land-cover changes (deforestation, urbanization). In order to explain the warming, one has to examine changes in the drivers of the climate system. Variability of temperature indices, at various spatial scales, can be also partly explained by the natural oscillations in the system of ocean and atmosphere i.e. process of quasi-periodic change of processes of ocean heat intake and heat release. (such as ENSO El Niño Southern Oscillation, NAO North Atlantic Oscillation, AMO Atlantic Multi-decadal Oscillation).

According to the IPCC Fourth Assessment Report (IPCC, 2007) „most of the observed increase in globally averaged temperatures since the mid-20th century is very likely [this can be interpreted as likelihood assessed at > 90%; comment added] due to the observed increase in anthropogenic greenhouse gas concentrations" in the atmosphere. This means that the strength of the most important statement has considerably grown with the consecutive number of IPCC assessment reports. The IPCC Third Assessment Report (TAR) in 2001 conveyed the message that „most of the observed warming over the last 50 years is likely [likelihood at > 66%; comment added] to have been due to the increase in greenhouse gas concentrations", the Second Assessment Report (SAR) in 1995 mentioned „discernible" human influence, while the First Assessment Report (FAR), published in 1990 (i.e. when the global warming was not as pronounced as now), found little evidence of detectable anthropogenic influence on climate.

The global atmospheric concentrations of greenhouse gases (carbon dioxide, methane and nitrous oxide, Freons, etc) are the only factor in the global energy system influencing the temperature that has been subject to persistent monotonic change (increase) over long time. In result of human activities, the atmospheric concentrations of greenhouse gases exceed now by far not only the pre-industrial values, but also much older concentrations, spanning many thousands of years, that were determined from ice cores (IPCC, 2007). For example, the present atmospheric concentrations of carbon dioxide (the seasonal maximum and minimum values of the observations at Mauna Loa in 2011 were 394 and 386 ppm) have been much higher than the pre-industrial mean of 280 ppm and, in fact, highest since at least 650,000 years (length of the available ice-core record). The global increases in carbon dioxide concentration are primarily due to increases in fossil fuel use and land-use change (decrease in carbon sequestration caused by deforestation and urbanization), while those of methane and nitrous oxide are primarily due to agriculture and animal husbandry.

The climate projections (without mitigation policy) for the future indicate considerable further warming. The projected global climate change depends on the rate of changes of the composition of the atmosphere and the land-cover changes. For a larger warming, the IPCC assessments suggest that net aggregate global effects would be negative. Hence, the European Union supports the policy objective of limiting global warming, so that by the end of the 21st century it will be no more than 2°C above the pre-industrial level (Commission of the European Communities, 2007). Such warming is held by many as a relatively safe limit, beyond which adverse impacts would be severe.

However, to constrain the warming to not more than 2°C with reference to pre-industrial situation (i. e. 1.5°C with reference to average global temperature in 1980-1999), global and concerted mitigation efforts are necessary. Without effective mitigation, a much stronger warming is projected to occur. The rate of warming strongly depends on such uncertain factors as population growth and socio-economic development, and changes in the energy and land-use systems. The average estimate of the temperature increase in the end of the 21st century, without climate change mitigation, would be around 4°C above the pre-industrial level.

While impacts associated with a 4^{o}C warming scenario are likely to be substantial, and predominantly adverse, some adverse impacts would occur for 2^{o}C warming. Actually, climate risks in some systems and regions, including many less developed countries, can already be considerable for a 2 °C warming.

It is clear that climate change impacts depend on the time horizons of interest, on the amplitude and rate of climate change, and on the adaptation. Amplitude and rate of climate change, in turn, depend on greenhouse gas emissions and sequestration of carbon by land and ocean.

3.3 Water-Related Projections for the Future

Climate projections using multi-model ensembles show increases in globally averaged mean water vapor and precipitation over the 21st century. Yet, precipitation scenarios show strong regional differences. Moreover, various climate models do not consistently project precipitation change, disagreeing even as to the sign of change. This is in contrast to temperature projections where all the models project the warming. Generally, precipitation extremes are likely to be impacted more than the means. Multi-model climate projections for the 21st century show increases in average annual precipitation intensity defined as the annual total precipitation divided by the number of wet days (Fig. 2), which increases in most areas. Climate models are not good at reproducing local climate extremes yet, due to, inter alia, inadequate (coarse) resolution. Hence, projections of extreme events for future climate are highly uncertain.

In Europe, there is a marked contrast between predicted future winter and summer precipitation change. Wetter winters are predicted throughout the continent (in many places less snow and much rain), while in summer, a strong difference in precipitation change between Northern Europe (getting wetter) and Southern Europe (getting drier) is projected. Over much of Europe, the behavior of precipitation extremes is projected to be notably different from the mean precipitation. The highest quartiles of daily precipitation amounts and annual maximum daily precipitation are anticipated to increase over many areas, also some of such areas where the mean precipitation is projected to decrease (Christensen and Christensen, 2002; Kundzewicz et al., 2006).

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Figure 2 Changes in spatial patterns of precipitation intensity (defined as the annual total precipitation divided by the number of wet days) over land, based on multi-model simulations from nine global coupled climate models. (a) Globally averaged changes in precipitation intensity for a low

(SRES B1), middle (SRES A1B) and high (SRES A2) scenario (b) Changes in spatial patterns of simulated precipitation intensity between two 20-year means (2080–2099 minus 1980–1999) for the A1B scenario. Solid line in (a) is the 10-year smoothed multi-model ensemble mean; the envelope indicates the ensemble mean standard deviation. Stippling in (b) denotes areas where at least five of the nine models concur in determining that the change is statistically significant. Each model's time series was centred on its 1980 to 1999 average and normalised (rescaled) by its standard deviation computed (after de-trending) over the period 1960 to 2099. The models were then aggregated into an ensemble average, both at the global and at the grid-box level. The changes are given in units of standard deviations. *Source: Meehl et al. (2007)*

Figure 3 Projections of changes in runoff volume from ice-free land by the middle of the 21st century (relative to historical conditions from the 1900 to 1970 period). Color denotes percentage change (median value from 12 climate models). Where a country or smaller political unit is colored, 8 or more of 12 models agreed on the direction (increase versus decrease) of runoff change under the SRES A1B emissions scenario (cf. Nakicenovic and Swart, 2000). *Source: Milly et al. (2008)*

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Palmer and Räisänen (2002) projected a considerable increase in the risk of a very wet winter in Europe and a very wet monsoon season in Asian monsoon region. For example, for CO2 doubling (61-80 years from present), an over five-fold increase of the risk of a very wet winter was projected over Scotland, Ireland and much of the Baltic Sea basin, and even over seven-fold increase for parts of Russia.

Changes in river flows due to climate change depend primarily on changes in the volume and timing of precipitation and, crucially, whether precipitation falls as snow or rain. A robust finding is that warming would lead to changes in the seasonality of river flows where much winter precipitation currently falls as snow, with spring flows decreasing because of the reduced or earlier snowmelt, and winter flows increasing, possibly with consequences to flood risk. In regions with little or no snowfall, changes in runoff are much more dependent on changes in rainfall than on changes in temperature, and studies often project an increase in the seasonality of flows, with higher flows in the peak flow season (Meehl et al., 2007).

Due to the uncertain precipitation projections, projected direction of change of long-term average annual runoff is not consistent across different climate models. Figure 3 (Milly et al., 2008) indicates areas of high change, for which models agree on the direction of change. Over large areas, even for large river basins, running the same greenhouse gas emissions scenario on different climate models may result in very different projections of future runoff change. Comparison of projections of mean annual runoff corresponding to the same emissions scenario but to different climate models (Kundzewicz et al., 2007) clearly demonstrates that even the direction of change over many areas may differ among models (e.g. for Australia, South America, and Southern Africa).

The expected increase in heavy precipitation has multiple adverse impacts, such as: increased floods, landslides and mudslides (possibly leading to flow obstructions), increased soil erosion; and increased pressure on government and private flood insurance systems and disaster relief.

Milly et al. (2002) demonstrated changes in the flood risk over several large basins, worldwide, based on monthly flow values. The control 100-year flood was found to be exceeded more frequently as a result of CO2 quadrupling, in some areas even every 2 to 5 years.

Hirabayashi et al. (2008) developed projections of recurrence interval of river floods. The return period of 100-year floods with respect to the 20th century (1901 2000) simulation was found to change (Fig. 4). In many low-latitude regions and in eastern Eurasia, a 100-year flood in 20th century was projected to become much more frequent (with a return period of less than 30 years). In contrast, flood frequency was projected to decrease over central and northern North America, eastern Europe and western Russia.

Figure 4 Projected return periods of the 20th century 100-year floods for 2071–2100, estimated by the Japanese MIROC model. *Source: Hirabayashi et al. (2008)*

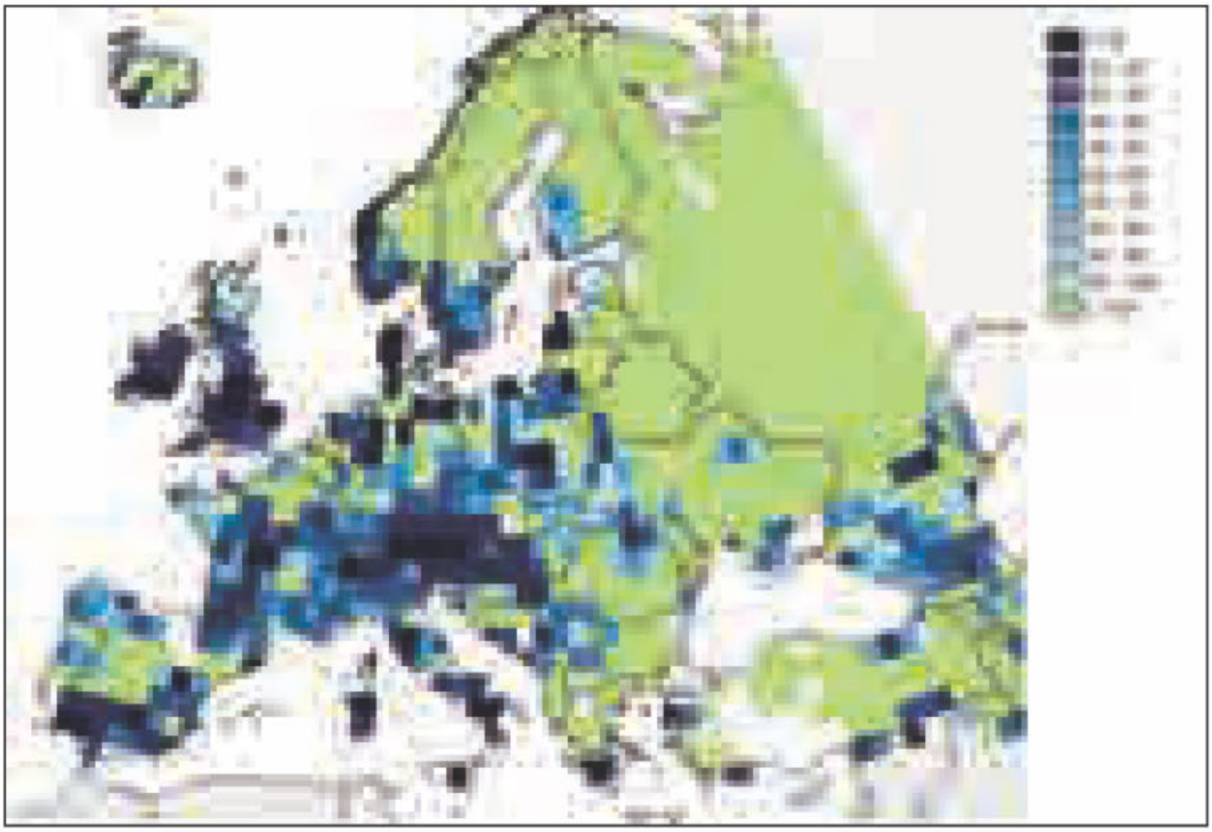

Figure 5 Recurrence interval (return period) of today's 100-year flood (i.e. flood with a recurrence interval of 100 years during the period 1961-1990) at the end of the 21st century (2071-2100), in case of scenario SRES A1B. *(Source: Kundzewicz et al. 2010; adaptation of results from Hirabayashi et al., 2008)*

Lehner et al. (2006), Hirabayashi et al. (2008), and Dankers and Feyen (2008) developed projections of flood hazard in Europe based on climatic and hydrological models. They produced maps of changes of recurrence of a 100-year flood, comparing the control period with scenarios. Figures 5 and 6, based on the works by Hirabayashi et al. (2008) and Dankers and Feyen (2008), respectively, show that, typically, what used to be a 100-year flood in the control period becomes either more frequent or less frequent in the future time horizon of concern. For a large part of the European continent, a 100-year flood becomes more commonplace, occurring every 50 years, or even more frequently. However, comparison of Figs 5 and 6 illustrates considerable discrepancies between model results. Figures 5 and 6, resulting from studies based on different assumptions (different models, different resolutions, different scenarios, different control periods) should not be directly compared. They only serve as illustrations of broad features of possible futures. Uncertainty makes it difficult to formulate a meaningful message that could be conveyed to practitioners and decision makers, interested in flood defenses in a particular locality.

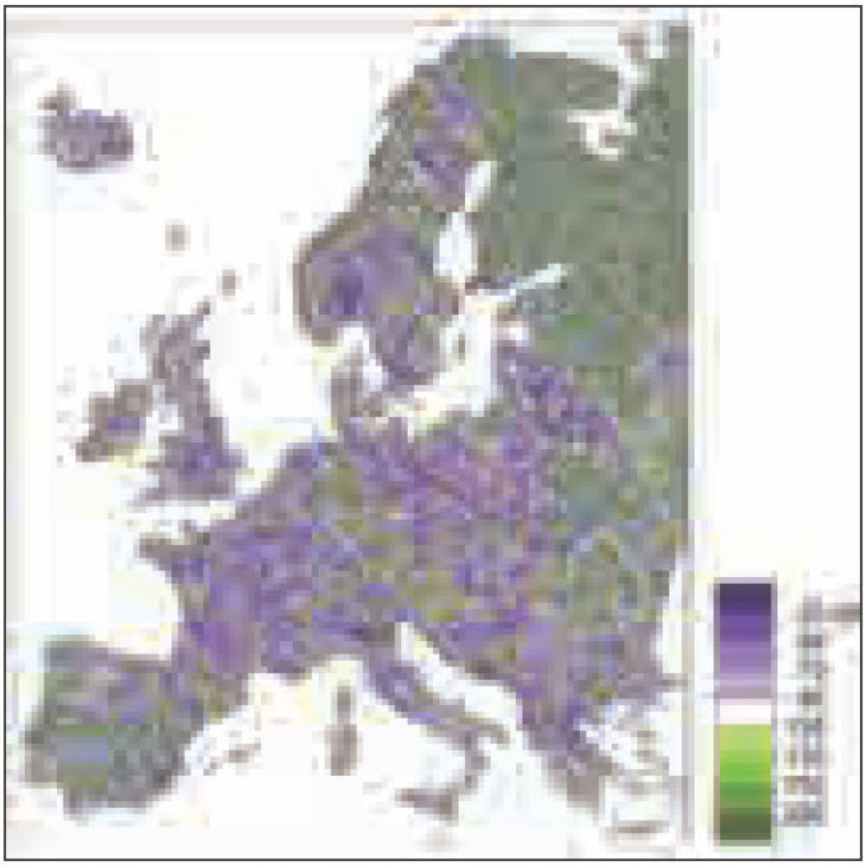

Figure 6 Recurrence interval (return period) of today's 100-year floods (i.e. flood with a recurrence interval of 100 years during the period 1961-1990) at the end of the 21st century (2071-2100), for emissions scenario SRES A2. *Source: Dankers and Feyen (2008)*

Dankers and Feyen (2008) project that in several major European rivers, such as the Oder (Odra), Elbe, Po, Loire, and parts of the Danube, the average return period of what used to be a 100-year flood in the control period reduces to once every 50 years, or even every 20 years. However, in Northeastern Europe, and in several rivers in Central and Eastern Europe, and in the Iberian Peninsula, probability of exceedence of a control design flood is projected to decrease in the future.

4. FLOOD PROTECTION MEASURES: STRUCTURAL AND NON-STRUCTURAL

One can never achieve complete flood safety in low-lying areas adjacent to rivers. Yet, the flood risk can be considerably reduced; if an adequate preparedness system is built, possibly consisting of a site-specific mix of measures.

There have been three basic adaptation strategies of coping with floods (cf. Kundzewicz and Schellnhuber, 2004):

I. Protect (as far as technically possible and financially feasible, bearing in mind that the absolute protection does not exist);
II. Adapt i.e. accommodation (prepare to living with floods); and
III. Retreat (relocate from flood plains to flood-safe areas). This latter option aims to rectify maladaptation (inappropriate adaptation) and floodplain development.

Strategies for flood protection and management may modify flood waters and/or system susceptibility to flood damage and impact of flooding. They depend on the rate of recurrence of floods: natural measures are appropriate for frequent floods, engineering measures for rare floods, while organization advances are essential for very rare floods (Kron, 2005). This latter category contains extreme, yet possible floods, also those beyond the limits of the so-far experience.

Site-specific adaptation may include some of the following components of holistic flood management (cf. Kundzewicz and Takeuchi, 1999). The pre-flood preparedness may comprise (cf. Kundzewicz and Schellnhuber, 2004):

- flood risk management under consideration of all possible causes of flooding;
- construction of physical flood defense infrastructure;
- legislation;
- investment on research and development on floods;
- development control within the flood plains;
- increasing source control, infiltration and storage/retardation facilities in urban basins;
- land-use planning and management;
- building codes, flood proofing;
- implementation of flood forecasting and warning arrangements;
- public communication and education of the extent of flood risk and actions to take in a flood emergency;
- disaster contingency planning; maintenance of preparedness of community self-protection activities; and
- insurance schemes.

Operational flood management includes:

- detection of the likelihood of flood formation;
- forecasting of future river flow conditions from hydrometeorological observations;
- warning issued to the appropriate authorities and the public on the extent, severity and timing of the flood;
- emergency protection of levees from breach and overtopping;
- strengthening of defenses; decision to operate reservoirs and retardation ponds;
- issuing prior warning on emergency spill to the people to be affected;
- emergency rescue of lives and property from the flooded areas;

Finally, the post-flood response comprises such activity areas as:

- relief for the immediate needs of those affected by the disaster;
- reconstruction of damaged buildings, infrastructure and flood defenses;
- recovery and regeneration of the environment and the economic activities in the flooded area;
- review of the flood management activities to improve the process and planning for future events.

There exist a roster of measures of flood protection and management, falling into the categories of structural ("hard") or non-structural ("soft") approaches. The former refer mostly to large-scale defences, such as dikes, dams and flood control reservoirs, diversions, floodways, etc and to improving channel conveyance capacity. Structural defences have a very old tradition, as dams and dikes have been built for millennia. Constructing reservoirs where the excess water can be stored allows a regulated temporal distribution of streamflow, with reduction of the natural peak flow.

In several developed countries, costly structural protection facilities are in place, designed to withstand a high, rare flood. Reinforced dikes, or super-dikes of 300-500 meter width, play an important part in flood protection of major cities in Japan, where a very high level of safety must be assured (cf. Kundzewicz and Takeuchi, 1999).

Among non-structural flood protection measures are: source control (watershed management), laws and regulations, zoning, economic instruments, efficient flood forecast-warning system, system of flood risk assessment and management, awareness raising and improving information, e.g. via flood-related data bases, etc.

Source control modifies the formation of floodwater by "catching water where it falls", enhancing infiltration, reducing impermeable area, and increasing storage in the catchment, hence counteracting such adverse effects of urbanisation as drop in storage potential, growth of runoff coefficient and flood peak, and acceleration of a flood wave. Important is enhancement of all forms of water storage capacity in the river system (floodplains, polders, washlands).

Existence of appropriate schemes of insurance, that is distribution of risks and losses over a high number of people and long time; and aid, that is capacity to compensate dramatic losses not covered by insurance, are important components of flood preparedness. Insurance and aid are needed in order to help flood victims recover after losses. Post-flood disaster aid, based on voluntary solidarity contribution, national assistance, and international help, is essential to restore livelihood and employment of survivors.

Despite some encouraging example (e.g. in the USA, after the 1993 flood), permanent evacuation of floodplains is virtually unthinkable in many countries. This is definitely true for Bangladesh - a densely populated and low-lying country, indeed the most flood-prone country of the globe. The people of Bangladesh, dynamically growing in number, have to live with floods. Most of the country area is constituted by floodplains and soil fertility depends on regular flood visits. In 1998, two-thirds of the country area was inundated. New flood embankments, even if they were affordable, would take scarce, and highly demanded, land. Thus, the options include reinforcing of the existing structural defenses and enhancing non-structural measures, such as the forecast-warning system. This example demonstrates that the optimum strategies for flood protection must be site-specific.

Considerable progress in reducing the number of flood fatalities can be achieved if flood risk awareness and management is improved. Efficient actions aimed at awareness raising can reduce flood losses. Many fatalities could have been avoided, were the awareness better. Most flood fatalities in several developed countries, e.g. the USA, are vehicle-related (e.g. car drivers who underestimate the danger and drive into water of unknown depth).

Important discussion of strategy of flood protection dates back to the mid-19th century USA (cf. Williams, 1994), when the US Congress looked into the problem of the Mississippi floods. One expert recommended that large areas of the Mississippi floodplains be used as flood storage and overflow areas, but the US Congress heeded another expert who recommended embanking the River Mississippi in a single channel isolated from its floodplain attempting to control the floods. This decision has largely influenced the flood protection policy in the USA and elsewhere, leading to transformation of rivers and reduction of wetlands worldwide. In 1936, the US federal government assumed primary responsibility for flood damage reduction across the nation and over the next half a century embarked on a multi-billion programme of structural defences (Galloway, 1999). Yet, the great 1993 US Midwest flood proved that structural defences cannot guarantee absolute protection. In result, the US Interagency Floodplain Management Review Committee (cf., IFMRC, 1994, Galloway, 1999) recommended that the administration should fund acquisition of land and structures at risk from willing sellers in the floodplains and many vulnerable families have been relocated from risky areas (Galloway, 1999). However, this is not a universal attitude. In most countries, people who suffered in a flood. rebuild their houses (possibly - in a better, more robust way) and try to regain their livelihood in the same place, once devastated by a flood, rather than moving to another, safer, location. But the hazard may not have decreased and another flood may come again to this place, sooner or later.

Despite the critiques of structural flood protection measures like dams and levees, they are needed to safeguard existing developments, in particular in urban areas. An effective flood protection system is generally a mix of structural and non-structural measures. The latter approaches better conform to the spirit of sustainable development.

The principal flood protection and flood preparedness measures in Europe include: technical flood protection (e.g. dikes, dams, relief channels); and non-technical measures: natural storage of flood water; restriction of settlement in risk areas; standards for building development; forecasting and warning; insurance schemes, awareness raising. Upgrade of structural defenses (e.g. increasing the height and strengthening of levees, enlarging reservoirs etc.) and revision of the management regulations for water structures are carried out. Upgrade of drainage systems (in particular of urban drainage) for a future wetter climate is also found necessary. The need for costly defense and relocation measures, e.g., relocating industry and settlements from river flood plains, is being envisaged. A small-scale structural action is flood-proofing on the site, i.e. adapting existing building codes to ensure that infrastructure with a long life time will withstand future climate risks.

In general, countries of Europe have been increasingly acknowledging the importance of not relying only on technical flood protection. Land-use planning measures are regarded as efficient and allow to combine flood management and nature protection. One of the options is watershed management ("to keep water where it falls" and to reduce surface runoff and erosion). Restoration of wetlands and floodplain forests and re-connection of old river arms are being considered. There is a call (e.g. in Germany and the Netherlands) to „give more space to the rivers", to designate flood areas ("dry rivers", "compartmentalization") and to devise flood plain protection measures. Further, legal regulations are implemented/envisaged related to use of flood-plain areas, possibly assisted by flood risk maps. Flood risk maps also facilitate estimation of insurance premiums for properties (e.g. in the UK). There are restrictions on new infrastructure and on handling substances dangerous to water (e.g. ban on use of oil-fired heating systems).

However, some non-technical measures based on land-use planning face difficulties in implementation. They may bring results in a longer term and they involve complex changes in the socio-economic system. A study by Daniel et al. (2007) shows that in the Netherlands, the announcement of an area designation for emergency inundation, resulted in decrease of the prices in the local housing estate market. Despite developing compensation schemes and reducing probabilities of a critical event, the social reaction was cautious.

In 2002, in response to massive river flooding throughout central and eastern Europe, the European Union launched the Solidarity Fund, with the purpose "to show practical solidarity with Member States and candidate countries by granting exceptional financial aid if these were the victims of disasters of such unusual proportions [...] that their own capacity to face up to them reaches to their limits". This new Fund is one of mechanisms enhancing economic and social cohesion throughout the European Union (Hochrainer et al., 2009). Under the Fund, Member States and access countries can request aid for emergency measures (e.g., restoring public infrastructure, providing services for relief and clean up, and protecting cultural heritage) if a natural disaster causes direct damages above €3 billion (at 2002 prices) or 0.6 percent of GNP.

The European Union Solidarity Fund can be regarded as a high-layer reinsurance, spreading and diversifying risks across the larger European economy. The Fund plays an important role in flood relief in much of Europe, where penetration of insurance is not high, so that costs of relief and reconstruction are largely paid either by the victims themselves (self insurance) or by their governments (Hochrainer et al., 2009). For instance, in case of the 1997 floods in Poland, insurance covered only 8% of direct losses, the government 48%, while the remaining 44% was a contribution of the private sector and net loss. In case of the 2002 floods in Austria, insurance covered 20%, the government 32%, while the remaining 48% was a contribution of the private sector and net loss. In contrast, in case of the 1998 floods in the UK, the widespread private insurance covered 39% and there was little post-disaster government assistance (Hochrainer et al., 2009).

Since many large rivers cross national boundaries, many international river commissions have been established that consider the totality of issues related to a transboundary river, including flood preparedness (e.g. the Danube, Rhine, Odra/Oder, Mekong, Red River). There have been many success stories, where river commissions substantially enhance the flood preparedness, undertaking joint initiatives, exchanging data and information (e.g. flow forecasts) and agreeing on flood preparedness.

5. FORECASTING AND WARNING

An efficient flood preparedness system should be seen in a holistic perspective, including the suite of monitoring, forecasting, warning, dissemination, and response. In an ideal system, an accurate forecast with adequate forecast lead time is translated into a reliable warning, which is broadly and effectively disseminated to the communities at risk who, in turn, take adequate loss-reducing actions.

Flood forecasting and warning are very important components of modern flood preparedness systems, in the category of non-structural flood protection measures, which may save lives and reduce material losses and human suffering. The system embraces detection of danger of occurrence of a flood-triggering situation, quantitative flood forecasting, construction of a warning message, issuing and dissemination of warning, response action, and finally post-audit, in order to learn a lesson and improve the system for the future.

Flood warning has been present in human living memory for thousands of years - the Old Testament mentions the oldest “early warning”, received by Noah from the God. For centuries, floods were believed to be a divine punishment for sins of the mankind. There have been some early, not really scientifically-based, flood forecasts, also covering longer time horizons. For instance, in 1523, a forecast of a flood to occur in February 1524 was published in Augsburg, based on a peculiarity of conjunction of planets. That forecast flood did not materialize (Brazdil et al., 2006).

In order to detect the danger of occurrence of a flood-triggering situation, a meteorological and hydrological monitoring system (possibly embracing manual, automatic, and remotely-sensed observations) should be set. Time series of observed records of rainfall (also radar-based information) and river stage are fed (usually in a real-time mode), to a mathematical model (e.g. rainfall-runoff model) and a flood forecast is obtained. In other words, forecasting allows experts to convert the information on the past-to-present (or foreseen) rainfall, present status and changes of moisture and snow cover into a flood forecast for a future time horizon. A flood forecast should deliver possibly reliable and accurate information on the future development of an event, based on which an alert and warning can be issued. A forecast expresses when, where, and how intense (flood magnitude: water stage, discharge, inundated area, duration of flooding) flood is likely to occur in the near future (minutes, hours, days, up to weeks ahead), how it will travel downstream and evolve, and what secondary effects it may cause.

For small and/or urban, catchments and for flash floods in steep and rapid mountain streams, a time lag between an intense precipitation and the destructive river flood peak may be very short (minutes to hours). Then, observation of rising river water level and intense precipitation may come too late for a flood forecasting; therefore deployment of radar and quantitative precipitation forecast is required in order to estimate the future river flow. In case of propagation of a flood wave in a large river, when high flows are already observed upstreams, a hydrodynamic flood-routing model can be used, allowing visualization (via GIS) of the forthcoming inundation in downstream cross-sections of the river. Propagation of a flood wave in a large river may take several weeks, allowing ample time for response to flood forecast. It is attempted to improve the forecast accuracy and to extend the forecast lead time. One of challenging avenues is to make use of the Atmosphere-Ocean track in medium and long-horizon (e.g., seasonal) forecasts.

Flood warning is a timely information based on a reliable forecast that high water level (or high river discharge) is expected to occur in a cross-section of interest at some defined future time point, so that emergency actions, such as strengthening dikes or evacuation, can be undertaken. A warning should be issued sufficiently early before the peril, in order to allow adequate human preparations. It should persuade people to take appropriate action in order to reduce damages caused by the forthcoming flood.

Flood warning should contain additional information to flood forecast, including recommendations or orders for action by the population affected, such as evacuation or emergency flood proofing, specifically designed to safeguard life and property (Smith and Ward, 1998). The warnings should capture the nature of the loss-reducing actions, being tailored in terms of their contents and delivery, to achieve an optimal behavioral response from an intended group of recipients.

Speed of reaction to warning is essential, because there may be quite a short warning lead time before the occurrence of high risk, when emergency pre-flood actions (such as strengthening the defenses, evacuation) should be completed. Among the useful criteria or indicators of warning quality are such as: warning errors ratio, penetration of warning (proportion of those who need information and receive it to those who need information), degree of satisfaction, etc.

Two warning errors can be defined: (i) when a warning was issued while the risk has not materialized, or (ii) when no warning was issued while a risk, and disaster itself, occurred. The former case does not embrace situation when the risk has materialized, but the disaster has not (i.e., there was a high risk of levee breach, yet, ultimately, it did not happen). For instance, flood warning in the Netherlands in 1995 resulted in massive evacuation. A disaster did not arrive, as the levees withstood the high load of water masses, but the warning, and the evacuation, were justified, and taken positively by the population. The risk of dike failure was high. Similarly, during the summer 1997 flood on the Odra, the Polish town Słubice was evacuated due to high inundation risk. Yet, in consequence of major dike-strengthening action (and occurrence of dike breaches upstream, on the German side), Słubice was not inundated.

As noted by Nigg (1995), there is an official hesitancy to issue warnings, due to fear of error, recognition of disturbances, and myths about response, especially when warning systems are just developing and officials have little experience or when there is still a great deal of uncertainty about the occurrence of the future event. Among issues, which are of importance for the efficiency of message dissemination are: the source credibility (person-specific), dissemination channel accessibility, redundancy and system´s resistance to floods.

Developments of the system of flood forecasting and warning usually result in reduction of the number of flood fatalities. Thanks to improvements in the advance time and accuracy of a forecast, it has been possible to reduce the number of flood fatalities in many countries. As noted by Kundzewicz and Takeuchi (1999), preparedness to floods varies with the wealth (Fig. 7). In countries with a high GNP level, when an extreme flood arrives, it is not possible to avoid high material damage, but it is possible to save lives, thanks to a well-functioning forecast-warning system.

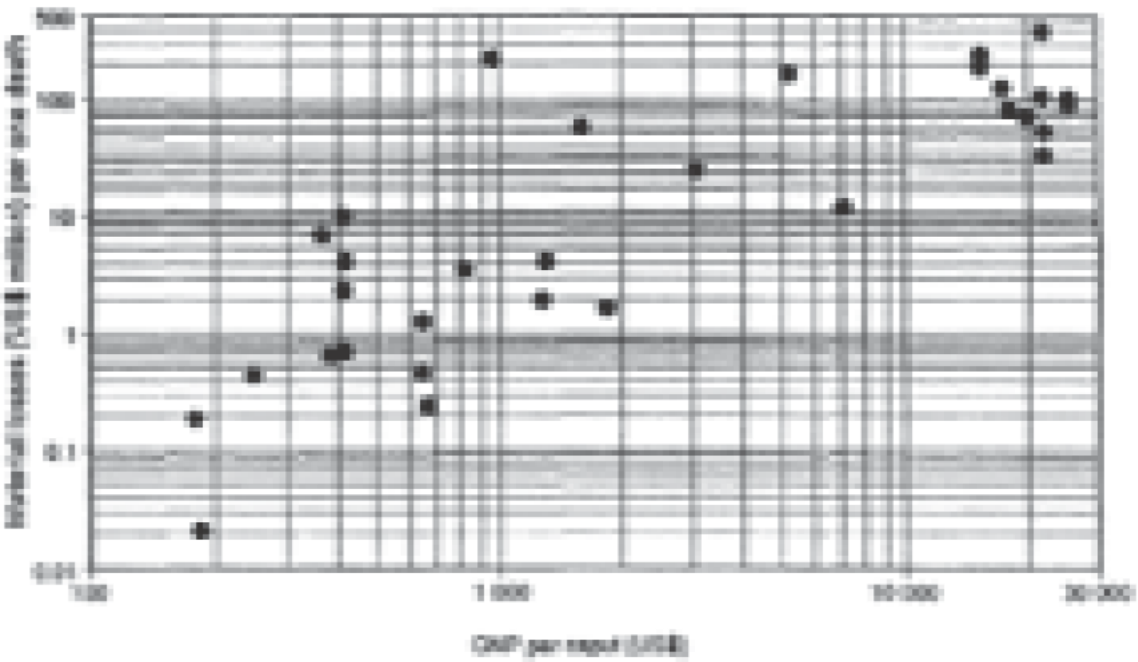

Figure 7 Relationship between the ratio of material losses in million USS to number of deaths and GNP per caput, in US$, for flood data for most disastrous floods of 1990-1996. *Source: Kundzewicz and Takeuchi (1999)*

6. FLOOD RISK MANAGEMENT

Structural flood protection measures, e.g. levees, are dimensioned based on the probability theory, to withstand a “design flood” of a certain magnitude, i.e. an N-year flood, i.e. a flood discharge whose probability of exceedance in any one year is 1/N, where N may differ between countries and land-use classes within the range from 10 to 4000 years. In the Netherlands, the protection level of flood defenses is probably higher than in any other country (even up to 4000-year flood for major dikes). In many countries, the principal design standard for river dikes is a 100-year flood. As regards low-probability events, there has always been an “unreliability of reliability estimates” (Vit Klemes, personal communication), due to small-sample and uncertainty problems, even if the stationarity assumption were justified.

The longer the assumed return period of the design flood the better the level of protection (albeit at higher costs). Should one design dikes to withstand a 100-year flood or perhaps more robust levees, withstanding a 500-year flood? The latter solution would give a better (but not absolute) protection being far more costly. It is a clear trade-off situation. Societies should protect themselves against floods up to an agreed level, being a compromise between the requested safety and the accepted willingness-to-pay. Preparing to rare floods can be counter-productive, because more important public priorities may exist in other sectors, providing better cost-benefit ratio for the society.

Dikes protect well against small and medium size floods, but when a deluge is of disastrous size and dikes break, losses in a levee-protected landscape can be higher than would have been in a levee-free case, since existence of a dike is taken by the riparian population as a guarantee of absolute safety, and this false feeling of security of the riparians drives the growth of the damage potential. However, no matter how high a design flood is, there is always a possibility of occurrence of a greater flood, inducing losses. Even a perfectly maintained dike designed to withstand, for example, a 100-year flood does not guarantee absolute protection. It can be overtopped and destroyed by a more extreme flood (e.g. with return period of 1000 years).

An early warning notion in the long-term context is a statement that a high water level / discharge is likely to occur more frequently in the future (Kundzewicz, 2009), that is, in a site of concern, a present (i.e. corresponding to a control period, e.g. 1961-1990) 100-year flood may occur more frequently, e.g. becoming a 50-year flood in some defined future time horizon (e.g. 2031-2060). Finding that a 100-year flood in a past control period is unlikely to be of the same amplitude as a future 100-year flood is of importance for design and operation of large water infrastructure (e.g. dikes, dams and spillways), which are intended to serve over a long time. It clearly results from Figs. 5 and 6, that, over much of Europe, what used to be a 100-year flood under current climate conditions will occur more frequently in the future. Hence, in order to maintain the same standard of protection against a 100-year flood, a need for a costly overhauling comes about. One can expect that in those areas where 100-year floods become lower and the adequate, and properly maintained, protection systems are already in place, the existing defenses will provide higher-than-standard protection level.

Such an early warning, in large temporal scale, is (or should be) an important signal of relevance to decision makers, informing them that the requested (current) level of protection is not likely to be maintained in the future, unless adequate efforts are taken. Upgrade of flood preparedness system is needed in order to assure the necessary protection level. If studies come to reliably predict that a present design flood, e.g. corresponding to a 100-year return period in the control period, becomes more frequent in the future, changed, climate, then the consequences for the existing procedures for designing dikes, dams, spillways, by-pass channels, reservoirs, and storm sewers, traditionally based on the assumption of stationarity of river flow, would be severe. For instance, one would have to design and build bigger storage volumes, at higher costs, in order to accommodate larger flood waves in the future and to strengthen levees (activity being both time consuming and resource-intensive).

Existing infrastructure may not guarantee an adequate level of protection and may need to be re-developed, since as phrased by Milly et al. (2008) “stationarity is dead”. Without changing design codes, systems will be over- or under-designed and will either not serve their purpose adequately, or will be overly costly (e. g., with large safety margin). Existing design procedures would have to be revised, accounting climate change (and other changes of relevance).

Projections by Hirabayashi et al. (2008), illustrated in Fig. 5, indicate that, in aggregate terms, over 40% of the area of Europe the control 100-year flood is projected to become more frequent. Over 30% of the area of Europe its mean recurrence interval of the 100-year-flood from the control period is projected to decrease to below 50 years. In much of Poland, Germany, Austria, Switzerland, France, and Italy the floods corresponding to the return period of 100 years are expected to become considerably more frequent. In contrast, over much of Russia and Scandinavia, floods corresponding to 100-year return period in the control period may become less frequent in the future.

Results of the study by Dankers and Feyen (2008) show that at 52% of the total number of river cells presented in Fig. 6, the return period for a flood corresponding to a 100-year event in the control period becomes longer (>100 years); i.e. there is an decrease in flood frequency. However, at 48% of cells, there is an increase in frequency, i.e. 100-year flood in the control period is exceeded, on average, more frequently than once in 100 years. At 31 % and 9%, respectively, the future return period is shorter than 50 and 20 years, respectively.

There are a few regional studies devoted to the impact of climate change on flood damages in Europe. A study on the pan-European scale conducted by Feyen et al. (2009), arrived at averaged expected annual damages at the EU and country level. It was assumed that the flood protection level depends on the country's GDP in relation to the EU average (protection up to 100-year, 75-year, and 50-year flood for countries with GDP above 110 %, in the range from 55 to 110 %, and below 55% of the average EU 27 GDP level, respectively). This assumption, together with additional simplifying assumption of no adaptation to increasing flood levels and no growth in exposed values, allowed interesting and useful indicative results to be obtained. The present expected annual damage of 6.5 billion Euro was projected to rise to 18 billion Euro in 2071-2100 under the SRES A2 scenario (cf. Nakicenovic and Swart, 2000). In five countries the expected annual flood damage in the future horizon is projected by Feyen et al. (2009) to exceed 1 billion Euro, with highest value being 4 billion Euro. Out of these 25 countries of the EU showing significant flood damages in the control period, 20 countries showed increases in the scenario period, varying between 40 and up to 80%, while the remaining five countries are projected to show decreases (between 17 and 85%).

Among regional studies, Hall et al. (2005) conducted a scenario analysis of damage due to river and coastal flooding in England and Wales in the 2080s, combining different scenarios of emissions and socio-economic change. In all scenarios, flood damages are predicted to increase unless current flood management policies, practices and infrastructure are changed. For a 2°C temperature increase in a SRES B1 world (cf. Nakicenovic and Swart, 2000), by the 2080s annual damage is estimated to be £5 billion as compared to £1 billion today, while with approximately the same climate change, damage is only £1.5 billion in a B2 world. For A1 scenario, with a warming of 2°C, the annual damage would amount to £15 billion by the 2050s and £21 billion by the 2080s (Hall et al., 2005; Evans et al., 2004). These numbers strongly support the need for a considerable investment in adaptation to climate change in the context of flood risk management (cf. Kundzewicz et al., 2007).

There are many sources of uncertainty in future projections related to river flooding, starting from impossibility to foresee future human behavior (population change; social and economic development; effectiveness of the climate mitigation policy: controlling intensity of greenhouse effect via the future greenhouse gas emission and carbon sequestration; and adaptation to climate change impacts). Uncertainties are also introduced by several coupled transfer functions in the cause-effect suite of processes from greenhouse-gas emissions/sequestration to atmospheric concentration of greenhouse gases, and then further to climate change (including feedbacks) and to climate change impacts. Every transfer function in the above system bears large uncertainty, so that amplification of uncertainty can be observed, throughout the logical chain from greenhouse gas emissions to climate change impacts. Already the climate model uncertainty (related to numerical converting of greenhouse gas concentrations into climatic variables, such as temperature and precipitation) is large. Uncertainties of climate change projections increase with the length of the future time horizon. In the near-term (e.g. 2020s), climate model uncertainties play the dominant role, while over longer time horizons, uncertainties due to the selection of emission scenarios become increasingly significant.

Uncertainty in practical flood-related projections is also due to a spatial and temporal scale mismatch between coarse-resolution climate model, the scale of a drainage basin, and a "point" scale of a locality (e.g. flood-prone areas in a small riparian town) where adaptation is undertaken. Further, time scales of interest may differ from those for the available climate model results (typically given at monthly/daily intervals). For heavy precipitation resulting in flash flood, the dynamics of flood routing is at the scale of minutes to hours. Scale mismatch renders downscaling (disaggregation) necessary and this is another source of uncertainty. Uncertainty in findings about future climate change impacts refers particularly to extreme events. Part of uncertainty is due to deficiencies of hydrological models and available observation records for model validation. There is an overwhelming scarcity of available homogeneous long-term observation records. The inherent uncertainty in analysis of any set of flood flows stems also from the fact that direct measurements in the range of extreme flows are problematic (rating curves not available for the high flow range, gauges destroyed by the flood wave, observers evacuated), and recourse to indirect determination is necessary.

However, due to the difficulty in isolating the greenhouse signal in the observation records and the large uncertainty of future projections of precipitation and related variables, no precise, quantitative information on future flood risk can be offered by scientific research. Despite this, water managers in some countries (e.g. the Netherlands, the UK, and Germany) have begun to consider the early climate change warning explicitly in flood protection design codes. In parts of Germany (e.g. in the Federal State of Bavaria), flood design values have been increased by a safety margin, based on climate change impact scenarios. The projections for 2050 include an increase of 40-50 % in small and medium flood discharges and of around 15 % in 100-year floods. In the UK, design flood magnitudes are increased by 20% to reflect the possible effects of climate change, based on early impact assessments. Measures to cope with the increase of the design discharge for the Rhine in the Netherlands from 15 000 to 16 000 m^3/s will be implemented by 2015 and it is planned to increase the design discharge to 18 000 m^3/s in the longer term due to climate change, to maintain the existing high safety level. A safety factor (climate change factor) has been proposed, which is to be taken into account in any new plans for flood control measures in the Netherlands (EEA, 2007).

In response to destructive recent floods in the European continent and projections of growing risk in many areas, the Floods Directive (CEC, 2007) was adopted on the European Union (EU) level, embracing river floods, flash floods, urban floods, sewer floods and coastal floods. The Directive calls for assessment, mapping, and management of flood risk as mandatory activities aimed at upgrading the preparedness systems at an unprecedented multi-national scale. The Directive states that EU Member States shall, for each river basin district or the portion of an international river basin district lying within their territory, undertake:

- a preliminary flood risk assessment (a map of the river basin; description of past floods; description of flooding processes and their sensitivity to change; description of development plans; assessment of the likelihood of future floods based on hydrological data, types of floods and the projected impact of climate change and land use trends; forecast of estimated consequences of future floods);
- preparation of flood hazard maps and flood risk maps (i.e. damage maps), for areas which could be flooded with a high probability (return period of 10 years on average); with a medium probability (return period of 100 years), and with a low probability (extreme events);
- preparation and implementation of flood risk management plans, aimed at achieving the required levels of protection, by 2015.

It is expected that implementation of the European Union Floods Directive, the most advanced legislation worldwide in the area of flood protection and flood preparedness, will considerably improve the flood preparedness and reduce the flood risk throughout the 27 EU Member States.

Floods are natural events and cannot be avoided. Since no flood protection measures guarantee complete safety, a general change of paradigm is needed in order to reduce the human vulnerability to floods. The attitude of "living with floods" and accommodating them in planning, via flood risk management, seems more sustainable than a hopeless striving to eradicate them (Kundzewicz and Takeuchi, 1999). There must be action plans for events exceeding the design flood (i. e. when defenses are bound to fail)   early warning can save many lives.

7. OUTLOOK AND CONCLUDING REMARKS

It is necessary to take lessons from flood events, i.e. to build awareness and understanding of reasons of the failure of performance and identification of weak points in the flood preparedness system. It is necessary to take a holistic, systems view. A single weak point in a system, which otherwise contains excellent components, may render the overall system performance non-satisfactory. The system requires adequate integration of components, while responsibility for them may reside in different agencies. This means that an adequate (often difficult) collaboration and co-ordination between multiple institutions is often needed. In emergency situations, it may become evident that distribution of roles of agencies is unclear, and possibly redundant.

People's experience of flood may reduce damages in the next flood. Where large floods visit a place twice in a short time period (e. g., on the Rhine in Cologne in December 1993 and January 1995), losses during the second flood occurrence are typically far lower than during the first occurrence (cf. Munich Re, 1997; Kundzewicz and Takeuchi, 1999). Lessons from the first flood incidence are taken by a riparian living near a river, a farmer living on high ground, whose fields and meadows are on the floodplain, a professional in a water district, a legislator, spatial planning (zoning) officer, and a public administrator (at different spatial levels   country, province, town, community). Lessons from flood events, and human failures, are indeed being learnt, but the memory fades with time after the flood.

Typically, an occurrence of a destructive flood boosts willingness to strengthen the flood preparedness system and heavy expenditures follow. After an occurrence of a deluge, ambitious plans are laid out and works are launched, but the lessons are not remembered for long. After some time without floods, the willingness-to-pay drastically decreases and projects are downscaled or suspended. When a next deluge comes, it acts as a reminder and starts a new cycle. This vicious circle, known as "hydro-illogical cycle" (concept introduced in the drought context by Donald A. Wilhite in mid 1980s) is a general principle, valid across different social, political and economic systems. A return period of a destructive flood is usually much greater than the political horizon of primary interest of decision-makers and the electorate, marked by the term of office and the next elections. The above rule of hydro-illogical cycle is at odds with the precautionary principle.

People take lessons from failures of past policies. According to the UK Environment Agency (1998, p. 9), sustainable flood defence schemes, while protecting the present generation from destructive floods, should "avoid as far as possible committing future generations to inappropriate options for defence". Some flood protection infrastructure has been criticised in the context of sustainable development for closing options for future generations and introducing grave disturbances in ecosystems and social systems. In some locations, people regret that levees were built and low-lying areas were developed. Now, the issue of river renaturalization and reconstruction of wetlands may come about. Some large reservoirs, whose construction required inundation of large areas and/or displacement of high number of people, do not match the principles of sustainable development (Kundzewicz, 1999). Studies on decommissioning reservoirs have been made and in some countries, e.g. France, decommissioning has indeed taken place (cf. Takeuchi et al., 1998). When looking back into past developments, one often finds one-sided arguments supporting a major decision (e. g. on construction of a large dam), with important aspects neglected. This was, on the one hand, due to a lack of knowledge and understanding and, on the other, due to value judgements changing over time.

Misconceptions and myths about floods and flood protection are deeply rooted in the society the general public, politicians and decision-makers alike. People naively believe that floods occur in large time intervals, that a term "return period" or "recurrence interval" can be taken at face value (without the important restriction on average) and that embankments offer a perfect safety.

Every time instant in a flood-free interval marks the time after the last flood, but also a time before the next flood. It is important to prepare oneself to a next flood by many means rigorous implementation of zoning (regulation for development of flood hazard areas, leaving floodplains with low-value infrastructure), strengthening the existing defenses, building (or enhancing) a flood preparedness and mitigation system of monitoring, forecasting, warning (issuing and dissemination), evacuation, relief and post-flood recovery, flood insurance, capacity building (improving flood awareness, understanding and preparedness) and enhancing participatory approach (including consultation process on the preparedness strategy and the level of flood protection). Only informed stakeholders can make rational decisions and agree on an acceptable flood protection strategy, being aware of costs and benefits. There may be conflicting interest between those living in floodplains and demanding efficient, and very costly, protection, and the rest of the nation.

Mitigation of the flood risks calls for a change from reactive to an anticipatory stance. An immediate challenge is to improve flood forecasting at a range of time horizons of concern, from short-term weather forecasting and quantitative precipitation forecasts (indispensable for flash floods) to long-term forecasting, based e.g., on snow cover information or seasonal forecasts based on an ENSO index, or sea surface temperature in ENSO- or NAO-affected regions. There are areas, where intense-precipitation and floodings are more likely to happen during El Niño conditions, and other areas where intense-precipitation and floodings are more likely to happen during La Niña conditions.

Smith and Ward (1998, p. 5) blame the development of floodplains as the major factor increasing the flood hazard. Floods constitute a hazard only then, when humans encroach into flood-prone areas, and become vulnerable. If endangered locations have already been developed, a remedy is that humans, and infrastructure, move out of harm's way. However, in many countries the strategy of retreat is unpalatable, and not favoured by the broader population, and decision makers alike, hence unlikely to be implemented.

Observations to-date provide no conclusive and general proof as to how climate change affects flood behaviour. Widespread increases in the contribution to total annual precipitation from very wet days have been observed, consistent with observed significant increase in water vapor amount in the warmer atmosphere (Trenberth et al., 2007). However, ubiquitous increase in flood maxima is not evident based on the data observed so far (e.g. Kundzewicz et al., 2005).

Flood risk and vulnerability tend to change over many areas, due to a range of climatic and non-climatic impacts whose relative importance is site-specific. Climate-driven changes in future flood frequency are complex, because they depend on the generating mechanism. In many places flood risk is likely to grow, due to a combination of anthropogenic and climatic factors. Recent modelling studies show that plausible climate change scenarios project future increases of both amplitude and frequency of rain-caused flooding events. It is very likely that there will be an almost ubiquitous increase in precipitation intensity in the warming world. Decreasing flood magnitudes can be expected in many areas where floods are generated by spring snowmelt. However, global warming may not necessarily reduce snowmelt flooding everywhere. An increase in winter precipitation in higher-latitude areas is expected, possibly augmenting snow cover in areas where the temperature is still below 00C, despite the warming. In some areas, where snowmelt is the principal flood-generating mechanism, the time of greatest flood risk would shift from spring to winter. Winter (rain-caused) flood hazard is likely to rise for many catchments under many scenarios.

Several ongoing land-use changes, such as urbanization, deforestation, and reduction of natural storage (floodplains, wetlands), can be regarded as adverse from the viewpoint of flood safety. They diminish the available water storage capacity and increase the runoff coefficient, leading to growth in the flow amplitude and reduction of the time-to-peak of a flood triggered by a 'typical' intense precipitation (e.g. design precipitation). Furthermore, human encroachment into unsafe areas has increased the potential for damage. Societies become more exposed, developing flood-prone areas (maladaptation).

Yet, quantification of flood statistics is difficult and subject to high uncertainty. Statement made in IPCC Third Assessment Report in 2001: "[t]he analysis of extreme events in both observations and coupled models is underdeveloped" remains basically valid now. Due to a large uncertainty of climate projections, at this time, it is not possible to devise a scientifically-sound procedure for redefining design floods (e.g. determination of a 100-year flood) for future, changing climate and land use. For the time being, it is recommended to adjust design floods using an expert judgment-based climate change-related safety factor.

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Chapter 2

Evolution of Flood Management Policy in Canada and Flood of the Century in the Red River Basin

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EXECUTIVE SUMMARY

Flood protection infrastructure must be combined with non-structural adjustments in order to alleviate a false sense of security that follows implementation of only structural protection solutions. It is the fact that the primary and visible response in the wake of recent floods in Canada has been on structural adjustments. Unfortunately, structural measures do not prevent flood damages, but postpone them.

There are elements of the institutional arrangements for flood management in Canada that appear to support a cycle of escalating flood losses and transferring responsibility. Relief programs are largely funded by senior governments. The public places much of the blame for the flood on inadequate government effort. In response, bigger and more structures are built with most of the funding coming from senior governments. Since senior governments provide neither consistent nor strong signals on the need to truly integrate structural and non-structural adjustments, intensive development continues on flood-prone areas and the cycle of escalating economic losses continues.

It is pointed out that Canadian flood management is at a crossroads and now faces difficult choices about whether to address the fundamental challenges confronting it, or to accept a trend of increasing flood damages. The dilemma concerning which road to choose reflects, in large part, the choice of approaching flood problems as being primarily technical or institutional in nature. The traditional approach extends a 60-year tradition in flood risk management. A relatively narrow set of alternatives is actually employed to solve flood problems. In the end, the construction of more, larger and better structures encourages more floodplain development and increases the loss potential. Better monitoring and information programs are developed. The other option, confronting traditional approach, suggests that decisions made by people and governments in the course of their day-to-day lives and in response to disasters exacerbate the vulnerability of communities. It is the choices and decisions made by people and their institutional arrangements that contribute to people's vulnerability. A difference in the outcomes associated between the two approaches lies in what proportion of funds will be spent on disaster relief versus reduction of long-term vulnerability.

1. INTRODUCTION

While people cannot do much about floods, they can influence the nature and extent of flood losses. The latter can be achieved through flood management policies and programs. On the one hand, Canada has been identified as a leader in flood management. In 1975, Canada introduced the Flood Damage Reduction Program (FDRP), which was innovative for its time. The fact that many nations requested Environment Canada's assistance in mapping floodplains is evidence of the high regard for that program. Public Safety Canada (at that time known as Emergency Preparedness Canada) was recognized as a model that Britain could follow in enhancing its institutional arrangements for emergency planning and management. Some of these early successes with flood management initiatives and the accolades they had drawn internationally must be assessed in the context of massive flood losses. Between 1975 and 1999, 63 floods resulted in payments of almost $720 million (1999 dollars) through the federal government's Disaster Recovery Financial Assistance Arrangements program. Between 1984 and 1998, insurance claims for flooding, which do not include residential losses, were in excess of $750 million (1999 dollars).

Although the amount of damage varies dramatically on an annual basis, governments and the insurance industry are concerned about the recent and high incidence of catastrophic flood losses particularly in the Saguenay region, Quebec, in 1996 and the Red River basin, Manitoba, in 1997. Despite our past best efforts, are Canadians becoming more vulnerable to flood hazards? Recently, the collaborative aspects of Canadian flood management programs and their adequacy are questionable or to have failed. Environment Canada is not renewing any of the 10-year General Agreements under the FDRP. Budget reductions and administrative changes during the late 1980s and early 1990s led some Canadian water experts to conclude that the federal government was unable "to understand and deal with pressing water issues".

At this time, federal and provincial governments are reviewing their flood management programs. The Canadian Council of Environment Ministers (CCME) is surveying provincial and territorial governments concerning the present status and future directions. Therefore, it is timely to review the state of flood management in Canada. The objectives of this paper are: (1) to describe the causes of flooding in Canada in order to identify the scope required and the challenges facing flood management policy and programs; (2) based on available literature, describe current practice approaches to flood management with a focus on land use regulation and disaster relief; (3) describe current practice and evolution of flood management policy on the basis of the recent experience with flooding in the Red River basin; and (4) to outline future options for practice and research.

Flooding is a fact of life along the Red River. The disastrous flood of 1997, while a rare event, was neither unprecedented nor unforeseen. As the 1997 International Red River Basin Task Force report, *Red River Flooding: Short-Term Measures* concluded, "The flood of 1997 or an even larger one could happen any year." The Task Force conducted historical, geological and statistical analysis that supports this conclusion. In this paper, I will explore the policy implications associated with large floods that is, floods of the magnitude of 1997 or larger for the people, communities, and governments in the Canadian portion of the Red River basin. The paper will also discuss issues of particular concern arising from the 1997 flood.

2. FLOODS AND FLOOD DAMAGES IN CANADA

There are a variety of natural flood mechanisms, the mix of responses to effectively deal with them as well as diverse socio-economic conditions must also be broad (Shrubsole et al., 2003).

2.1 Causes of Flooding

Flooding in Canada is caused primarily by hydrometeorological mechanisms, acting either individually or in combination. The regional variability in the intensity of these mechanisms reflects the diversity of climate across Canada. Particularly severe flooding may result when several of these mechanisms occur coincidentally, as can happen in the spring.

Snowmelt: The melting of a snowpack that has accumulated during the winter months is a common flood type in Canada. This occurs in watersheds of all sizes, often in combination with storm-rainfall runoff and/or ice jams. The amount of snowmelt runoff is controlled directly by the thickness, ripeness and extent of the snowpack, and by the rate of melting. The greater the amount of snow on the ground during a melt period, the more water is potentially available for snowmelt runoff. Relatively cool weather causes slow melting of the snowpack and the gradual release of meltwater, while warm weather speeds melting and releases meltwater more rapidly, thereby increasing the possibility of flooding. Severe flooding from snowmelt can happen when there is a rapid shift from cold to warm temperatures in the spring following a winter of high snow accumulation. Since the climatic factors influencing both the accumulation of snow and the rate of melt are regional, snowmelt flooding commonly occurs over large areas and affects numerous watersheds.

Storm-rainfall: Heavy or torrential rainfall associated with convective storms and mid-latitude and tropical cyclones (including hurricanes) can cause flooding. This type of flood develops rapidly, particularly when the ground is saturated and the rate of rainfall far exceeds the capacity of the ground to absorb the water. The magnitude of storm-rainfall flooding depends on the intensity and duration of the rainfall, the areal extent of the storm, pre-storm ground moisture conditions, and drainage basin characteristics. Storm-rainfall floods can significantly affect watersheds of up to 100,000 km^2 in size throughout Canada. Rivers with larger watersheds generally are unaffected because the zone of intense rainfall within a storm system commonly is concentrated within a smaller portion of the drainage basin.

Rain-on-snow: Rain-on-snow floods are a combination of snowmelt runoff and storm-rainfall floods. They occur when rainfall runoff is augmented by snowmelt, which increases the amount of water flowing into a stream system. The rate of snowmelt during a rainstorm is affected directly by air and rainfall temperatures, amounts of rainfall and wind speeds. When heavy or sustained rainfall occurs in combination with other meteorological conditions leads to ripening and significant melting of a moderately deep snowpack, rain-on-snow can generate substantial runoff causing very severe flooding. The most extreme event recorded along many Canadian rivers commonly is a rain-on-snow event.

Ice jams: Ice jam floods result from the temporary obstruction of river flow by the build-up of ice fragments within the channel, and can occur during both the freeze-up and break-up periods. Once formed, an ice jam causes the river to rise immediately upstream and may overtop its banks, depending on the height of the obstruction relative to the sides of the channel. Flooding from ice jams tends to be localized since it is dependent directly on the formation of an ice jam, and the tendency for an ice jam to form at any given location along a river is variable. The severity of ice jamming varies from year to year, depending on factors such as the harshness of the winter, the amount of ice decay and melting prior to break-up, and the amount of rise in river level immediately prior to and at the time of break-up. Commonly associated with larger, north-flowing rivers, ice jams have also caused significant flooding on many rivers throughout Canada.

Natural dams: Floods can also be caused by the formation and failure of natural dams, although these events are far more localized and less frequent (at the national scale) than hydrometeorological flooding. Floods from natural dams occur due to the blockage of drainage by landslides, glaciers, and moraines. Flooding occurs upstream of the natural dam as a result of ponding, but also downstream if there is a failure of the dam (or in some instances the development of a tunnel under a glacier) that allows the rapid drainage of the impounded water. In Canada, the occurrence of landslide, moraine and glacier dams has been documented in the Cordillera, and for landslide dams, also in the St. Lawrence Lowlands. Natural dams are also likely to occur in the mountains and at the margins of ice fields in the Arctic Archipelago.

2.2 Damaging Floods in Canada

Flooding in Canada has resulted directly and indirectly in the deaths of at least 198 people and at least $2 billion of damage during the 20th century (Brooks et al., 2001). This figure of 198 deaths and damage of $2 billion must be considered a minimum because damaging floods not included in the database have almost certainly claimed additional lives. In terms of loss of life, by far the greatest Canadian flood disaster was the Hurricane Hazel that struck southern Ontario in October 1954, killing 81 people. Although flood disasters occur in every month of the year, about 40% takes place in April and May, the latter coinciding with the snowmelt period throughout much of southern Canada. This period also coincides with the likelihood of several common flood mechanisms, such as snowmelt runoff, storm rainfall and ice jams, thereby increasing the likelihood of high flows. The database suggests that the number of flood disasters has increased through the 20th century with about 70 percent occurring after 1959. This trend likely reflects several factors: (i) a general increase in the magnitude of flood events a shift in climate; (ii) an increase in development on flood prone lands as Canada's population has grown along with a general increase in personal wealth; (iii) better reporting of flood disasters over the past several decades; and (iv) the availability of senior government disaster assistance in the second half of the century undoubtedly has led to improved record keeping.

Using data available on the Public Safety Canada (PSC) disaster data base, Brooks et al. (2001) calculated that the twelve provinces and territories experienced 168 flood disasters between 1900 and June, 1997. In eastern Canada, the flood disasters have occurred predominately in the south where the population is concentrated. The distribution of disasters is much more scattered in western Canada, although there is notable clustering in southern Manitoba and in southwestern and northwestern British Columbia. About 62% of the disasters have occurred in four provinces: Ontario (37 events), New Brunswick (26 events), Québec (23 events) and Manitoba (18 events). Specific areas that have experienced recurrent flood disasters are the Saint John River basin, New Brunswick, (16 disasters) and the Red River basin, Manitoba (15 disasters, including the Assiniboine River).

2.3 Implications

This information has relevance to flood risk management. For instance, floodplain mapping in the past was based exclusively on open water floods. The effects of ice jams and other intervening factors were not incorporated. Providing flood information that better reflects the physical nature of events would be one element to improve present practice.

An underlying assumption supporting flood modeling and floodplain is stationarity - the climate, weather and runoff processes and patterns of the past will operate in the future.

According to Milly et al (2008) and the Intergovernmental Panel on Climate Change (2007), precipitation patterns, the timing and magnitude of runoff, the frequency and intensity of storms as well as other elements of the climate will change. A shorter winter season is reducing the size of snowpacks. Storm surges along the ocean coastlines are increasing. On the basis of available evidence, climate models suggest an increase in flood events, as a result of a trend toward more convective precipitation and greater atmospheric absolute humidity. This conclusion has significant implications for flood management. While there has been a relatively large effort devoted to the impacts of global climate change on water resource systems, little has been done to review the adequacy of existing water planning principles and evaluation criteria and related impact procedures in the light of these changes.

To date, Global Circulation Models (GCMs) have also been unable to precisely and accurately predict precipitation and runoff forecasts and their variability. In addition, there is discordance between large-scale global climate change model output to small-scale flood models. Research suggests that climate change models not be used in water planning because of the high level of uncertainty associated with long-term GCM forecasts. However, scenarios may be developed using the output from GSM models that can illustrate a range of potential outcomes Cunderlik and Simonovic, 2005, 2007).

In terms of flood management, a central question pertains to whether, and if so the extent to which, climate change should influence the treatment of climate variability or if it another variable that should be considered in evaluating, comparing and trading off the economic efficiency, technical performance, social acceptability, and environmental quality of any set of proposed flood management measures. Decisions on this issue will likely have implications for the selection of interest rates, project life and multiple objectives. One strategy to reduce human and economic losses, and minimize environmental impacts is to employ best management practices (Simonovic, 2009; 2011).

3. REDUCING RISK THROUGH THE FLOOD MANAGEMENT POLICY INSTRUMENTS

3.1 Disaster Management in Canada – Brief Overview

Flood management is part of disaster management which is in Canada carried out by different levels of government in many departments and ministries (Simonovic, 2011). There are some deficiencies in their coordination. However, Public Safety Canada (PSC) is established to provide, among other tasks, for the coordination of disaster management process. The broad portfolio of PSC is well suited to effective disaster management.

3.1.1 Emergency management act

When an emergency strikes, lives are at stake and effective response means knowing who is in charge. The *Emergency Management Act* (PSC, 2008a) sets out clear roles and responsibilities for all federal ministers across the full spectrum of emergency management. This includes prevention/mitigation, preparedness, response and recovery, and critical infrastructure protection.

The main purpose of the Act is to strengthen emergency management in Canada. The Act reinforces efforts to ensure that Canada is well prepared to mitigate, prepare for, respond to and recover from natural and human-induced risks to the safety and security of Canadians. The Act:

- Gives responsibility to the Minister of Public Safety to provide national leadership and set a clear direction for emergency management and critical infrastructure protection for the Government of Canada;

- Clearly establishes the roles and responsibilities of federal Ministers and enhances the Government of Canada's readiness to respond to all types of emergencies;
- Enhances collaborative emergency management and improves information sharing with other levels of government as well as the private sector; and
- Gives authority to the Minister of Public Safety, in consultation with the Minister of Foreign Affairs, to coordinate Canada's response to an emergency in the United States.

Protecting critical infrastructure is one of the emerging challenges of integrated disaster management. Critical infrastructure consists of physical and information technology facilities, networks, services and assets that are vital to the health, safety, security or economic well-being of Canadians or the effective functioning of governments in Canada.

3.1.2 National disaster mitigation strategy

The Government of Canada, together with provincial and territorial governments, launched Canada's National Disaster Mitigation Strategy on January 9, 2008 (PSC, 2008b). This Strategy is based on the recognition by federal, provincial, and territorial governments that mitigation is an important part of a robust emergency management framework, and that all stakeholders are committed to working together to support disaster mitigation in Canada.

Federal/Provincial/ Territorial (FTP) governments have worked together to develop the National Disaster Mitigation Strategy (NDMS) for Canada. Responding directly to national consultation findings, the NDMS supports all-hazards emergency management, with an initial focus on reducing risk posed by natural hazards, an area that stakeholders agree requires urgent attention.

While the Strategy does not replace existing enterprise risk management programs at all government levels, the incorporation of NDMS principles into FPT initiatives will benefit the management of internal government risks. The **goal** of the National Disaster Mitigation Strategy is: *To protect lives and maintain resilient, sustainable communities by fostering disaster risk reduction as a way of life.* The **principles** that reflect the essence of what the National Disaster Mitigation Strategy aims to achieve are:

- *Preserve Life* Protect lives through prevention.
- *Safeguard Communities* Enhance economic and social viability by reducing disaster impacts.
- *Fairness* Consider equity and consistency in implementation.
- *Sustainable* Balance long-term economic, social and environmental considerations.
- *Flexible* Be responsive to regional, local, national and international perspectives.
- *Shared* Ensure shared ownership and accountability through partnership and collaboration.

The proposed Strategy will establish ongoing national disaster mitigation program activity areas. Implementation of program activities will be structured around four key elements:

- Leadership and Coordination;
- Public Awareness, Education and Outreach;
- Knowledge and Research; and
- FPT Cost-Shared Mitigation Investments.

3.1.3 Joint emergency preparedness program

The Government of Canada established the Joint Emergency Preparedness Program (JEPP) to enhance the national capability to manage all types of emergencies and ensure a reasonably uniform emergency response and recovery capacity across Canada. JEPP is administered by Public Safety Canada. Whether it is through training, the purchase of emergency response equipment, for emergency planning or for capacity building, this shared investment is aimed at reducing injuries and loss of human life, property damage, and assuring the continuation of our critical services in an emergency. Currently, over $8 million is made available annually for emergency preparedness, urban search and rescue and critical infrastructure protection projects from coast to coast.

JEPP projects are proposed annually by the provincial and territorial governments and selected for funding based on national and regional priorities. Projects are cost shared and the Government of Canada's contribution depends on the nature of the project, other projects under consideration, and the amount of funds available. To be eligible for Government of Canada funding, JEPP projects must: (i) have a clear objective that supports priorities aimed at enhancing the national, provincial and territorial emergency response capability; (ii) have an agreed, identifiable beginning and end; (iii) include a statement of the nature and extent of federal involvement and take into account how federal participation will receive visibility and recognition; and (iv) include a provincial or territorial commitment to the project through funding or in-kind contribution.

3.1.4. Emergency response

Emergencies are managed first at the local level: hospitals, fire departments, police and municipalities. If they need assistance, they request it from the provinces or territories. If the emergency escalates beyond their capabilities, the provinces or territories seek assistance from the federal government. The coordination and provisioning of resources can move quickly from the local to the national level.

PSC's emergency response includes the Government Operations Centre (GOC) and Urban Search and Rescue Program (USAR). The GOC is housed at PSC and monitor emerging threats and provide around-the-clock coordination and support in the event of a national emergency. The GOC is Canada's strategic-level operations centre. It is the hub of a network of operations centres run by a variety of federal departments and agencies including the Royal Canadian Mounted Police, Health Canada, Foreign Affairs, Canadian Security Intelligence Service and National Defence. The GOC also maintains contact with the provinces and territories as well as international partners such as the United States and NATO. It operates 24 hours a day, seven days a week, gathering information from other operations centres and a wide variety of sources, both open and classified, from around the world. The GOC deals with anything real or perceived, imminent or actual, natural disaster or terrorist activity that threatens the safety and security of Canadians or the integrity of Canada's critical infrastructure.

The USAR is the capacity to rescue victims from major structural collapse or other entrapments. Heavy USAR teams locate trapped persons in collapsed structures and other entrapments using search dogs and electronic search equipment. Heavy USAR involves work to breach, shore, lift and remove structural components, the use of heavy construction equipment to remove debris, and the medical treatment and transfer of victims. USAR is a general term for a group of specialized rescue skills that are integrated into a team that includes search, medical and structural assessment resources.

PSC provides national leadership for USAR development to ensure that program development is coordinated and appropriately shared among the federal government, provinces and territories, major urban centres, and other national and international stakeholders. The USAR program is one aspect in the enhancement of Canada's National emergency response capacity.

The main elements of a national USAR program are based on operational readiness and capacity to deploy at short notice in response to domestic disasters. PSC has identified the five following priorities for the development of a national USAR program: (i) Plans, policies and protocols to outline responsibilities of the federal government, and of USAR teams deployed in afflicted areas outside home jurisdictions; (ii) Standard equipment designed for USAR operations; (iii) Training in technical skills and joint operations with other teams; (iv) National guidelines or standards, where required; and, (v) Exercises to improve capability and develop interoperability. Four Canadian cities (Vancouver, Calgary, Toronto, and Halifax) and the Province of Manitoba currently have, or are developing, interoperable USAR capacity.

PSC works with provincial and territorial Emergency Management Organizations to ensure first responders and emergency management personnel are well-prepared through education, support and exercises.

For example, Emergency Management Ontario (EMO) devotes a great deal of time and effort to the citizens of Ontario, to help prevent or ease the effects of emergencies by making sure they are better prepared. It is our strong belief that the better prepared we are - as a family, as a community, as a province the more confident we become when responding to an actual disaster. EMO has developed a variety of public education materials tailored to different needs. But, EMO goes beyond simply publishing materials. They have experts assigned to specific areas of the province who are in regular contact with municipal officials responsible for emergency management in their communities. Their focus is to get the message of prevention and preparedness out to as many Ontarians as possible. EMO is involved in developing emergency scenarios, as well as practicing such response scenarios with many federal, provincial, municipal and private sector partners.

3.1.5 The role of federal government in disaster recovery

In the event of a large-scale disaster where costs exceed regional resources, PSC provides financial assistance to provincial and territorial governments. Assistance is paid to the province or territory not directly to individuals or communities. The provincial or territorial governments design, develop and deliver disaster financial assistance, determining the amounts and types of assistance that will be provided to those who have experienced losses. The following programs for disaster recovery are delivered through PSC.

Disaster financial assistance arrangements. The Disaster Financial Assistance Arrangements (DFAA) program, designed in consultation with the provinces and territories and administered by Public Safety Canada, details how the federal government should respond to a natural disaster. Provinces and territories are responsible for designing, developing and delivering financial assistance to the victims of emergencies and disasters as they see fit, with no restrictions placed on them by the federal government. The federal government does not directly provide disaster relief funding to individuals or businesses. It is up to the provincial or territorial government affected by the disaster to request assistance from the federal government, in accordance with DFAA guidelines.

Under the DFAA program, provincial/territorial governments can ask the federal government for disaster relief when eligible expenditures surpass $1 per capita (based on provincial/territorial population). The program sets out guidelines respecting what expenses resulting from a disaster qualify for relief, following a graduated funding formula based on the size of the disaster. Generally speaking, DFAA guidelines stipulate that the federal government will not provide funding to the province to cover costs already insured or where insurance was available at a reasonable price but was not purchased. There is nothing in the law, however, preventing the federal government from covering any cost it wishes.

From a theoretical perspective, the DFAA rule against providing aid to those who choose not to purchase insurance helps protect the federal government against the danger of moral hazard. In short, should the government agree to pay for all damages regardless of whether insurance was available, people would have a strong incentive not to buy insurance. Such a result would increase the cost of a natural disaster borne by the taxpayer. Moreover, it would also decrease the pool in insured risks, thus increasing the risk of insolvency for insurers.

Federal disaster assistance initiative. The goal of the FDAI is to provide provincial and territorial governments with a comprehensive suite of disaster recovery programs that respond to the needs of Canadians. This will be accomplished in three ways: (1) revision of the existing Disaster Financial Assistance Arrangements (DFAA); (2) development of new or improved disaster assistance instruments to complement the DFAA; and (3) creation of an inventory of existing federal and provincial programs, policies and legal tools for disaster assistance and recovery.

3.2 Flood Management Background

Early flood risk management efforts were the responsibility of individuals and local governments. Senior governments became more involved between 1953 and 1970. During that period, the *Canada Water Conservation Assistance Act* guided the federal government's involvement in water management. Senior levels of government could provide up to 37.5% each to cover the capital cost of structural adjustments (Shrubsole et al., 2003). By the 1970s, some of the shortcomings of existing programs were becoming apparent. A number of these shortcomings contributed to the development of the Flood Damage Reduction Program (FDRP) under the provisions of the *Canada Water Act* (1970), which supported joint federal-provincial initiatives. First, major floods in 1973 and 1974 suggested that the protective works, which dominated the type of response under the *Canada Water Conservation Assistance Act*, had not curbed the potential for damage. These floods also led to significant federal disaster financial assistance payments to provinces. Second, structural measures were seen not as effective to prevent development in floodplains. Third, the collective demand for structural adjustments, disaster relief and clean up assistance was straining senior government budgets. Fourth, instead of fully participating in project planning, the federal government simply accepted or rejected proposals submitted by provincial governments. Fifth, there was a belief that the present system was inequitable because it subsidized those residents who occupied flood-prone areas. Sixth, there was a lack of opportunity for public participation or consultation.

Under the Flood Damage Reduction Program (FDRP) provinces were enticed to sign 10-year General Agreements with the federal government, in part, because Environment Canada had a competent core of professionals and available funds. These General Agreements identified basic approaches to reducing flood damages and the policies agreed upon. The 10-year agreements could be supplemented by subsidiary agreements on mapping to delineate and designate flood risk areas for which the following FDRP policies would apply: (i) federal/provincial governments would not build, approve or finance flood-prone development in a designated flood risk area; (ii) the governments would not provide flood disaster assistance for any development built after an area becomes designated (unless in the flood fringe and adequately flood proofed); and (iii) provinces would encourage local authorities to zone on the basis of flood risk.

3.3 Defining Floodplains

The primary purpose of the FDRP program was to map urban flood prone lands. This was achieved by defining the floodplain as the land inundated by floods of one hundred-year or greater magnitudes. Once these lands were identified, the program encouraged provincial and municipal government to enact floodplain regulations in order to designate, zone and control future development on those lands. The floodplain was divided into two components: a 'floodway' where risks were particularly high and the 'flood fringe' where some development could be allowed. Studies completed under the program examined the flood history of a basin in order to identify its flood-prone areas, assessed the hydrology in order to define the one-percent or hundred-year floods and floods of other magnitudes, and conducted hydraulic analyses to determine water surface profiles, depths and velocities of high-magnitude floods in the study area. Notes associated with Table 1, which reports on some of the characteristics and results of the program, suggest that delineating the floodway was a political, as well as, a technical issue.

Table 1 Floodplain Management in Canada (after Shrubsole et al., 2003)

Province/ Territory	Communities	Number Mapped	Number Designated	Regulatory Flood	Definition of Floodway
B. C.	143	77	73	1:200	See Note 1
Alberta	67	20	11	1:100	Hydraulic
Sask.	24	22	16	1:500	Hydraulic
Manitoba	26	18	16	1:100	Hydraulic
Ontario	445	318	211	See Note 3	1:100
Quebec	510	211	24	1:100	1:20
N. B.	15	12	12	1:100	1:20
N. S.	6	6	5	1:100	1:20
P. E. I.		0	0		
Nfld. & Labr.	53	19	16	1:100	1:20
Yukon		0	0		
NWT	9	9	9	1:100	Hydraulic
Nunavut	0	0	0	1:100	Hydraulic

Notes:

1. The floodway in British Columbia is defined as the natural channel width plus a minimum 30 m setback.
2. The hydraulic floodway uses criteria of less than 1.0 m/s velocity, less than 1.0 m depth and no more than 0.3 m rise.
3. Ontario's regulatory flood uses the Hurricane Hazel rainfall, the Timmins storm, and the 100-year flood elsewhere.
4. The Atlantic Provinces may also use a historic event or flood from a specified input, provided the water levels are higher than those of a 100-year flood.

When the program was developed, there were no significant flooding problems in Prince Edward Island, Yukon, and Nunavut. Thus, in these jurisdictions, there was little systematic effort to determine the extent of flooding.

Most provinces applied hydraulic criteria (*i.e.* depth and velocity of water) to delineate floodways. Others used a statistically defined flood. Under the FDRP, the federal government agreed to share the cost as long as the minimum requirements were met. Provinces were free to use more stringent requirements. Another technical aspect that made mapping difficult was a shortage of hydrometric data for small Canadian watersheds. On a technical front, there is uncertainty in the determination of regulatory floodplains. This information is an important basis for floodplain mapping and warning systems. In order to develop longer-term databases, efforts have been made, for example, in the Red River basin, Manitoba, to utilize tree ring, alluvial and lacustrine sediments, and other proxy data to determine past climate conditions (IRRBTF, 1997).

3.4 The General Agreements

After the 10-year period, there was no plan to renew the General Agreements. However, there were amendments that extended the original agreements. In the early 1990s, there was a significant decline in the *Canada Water Act* Fund due to departmental pressure to wind down flood-related agreements. In addition, despite reductions in flood damage under the FDRP, the federal government started recognizing some problems with the program. These included the following: restrictions of floodplain development were difficult to apply with an even hand; some regions were not applying the policies as effectively as others; flood damage compensation and disaster assistance claims on the federal government continued to grow; and the costs of managing the FDRP were accrued in one department but the benefit of reduced disaster relief were accrued in another. In the mid 1990s these concerns, coupled with a widely recognized need for greater financial stringency in government programs, led to the termination of federal involvement in the Flood Damage Reduction Program.

The late 1990s have witnessed a decrease in flood risk management capacity by all levels of government. Between 1995 and 1998, budget allocations for the hydrometric network were reduced by 35 percent. Federal and provincial programs have also been slashed, resulting in a reduction of governments' professional capability in water management and flood control. Federal participation in flood management has specifically diminished with the end of the FDRP. There was also no plan to renew the General Agreements with the provinces after their 10-year operating periods or even to continue the maintenance phase of three basic FDRP policies. The federal role in water management is now being reconsidered and the direction of federal involvement in flood risk management is unclear.

3.5 Implementation of Floodplain Regulations

The FDRP accomplished the mapping and designation of 982 communities (Shrubsole et al., 2003). The detailed hydrologic and cartographic specifications of the FDRP mapping program also implemented uniformly high standards across the country and allowed for special needs in each region. Administrative benefits, especially through strengthening and enhancing local land use planning, and considerable environmental benefits through the preservation of wetlands and many plant species, have been noted under various FDRP. Studies have concluded that the FDRP was cost-efficient in many provinces. Several factors, however, complicate evaluation of the FDRP: (1) it is difficult to evaluate the FDRP separately from other provincial water management initiatives; (2) analysis of the FDRP using benefit and cost measurements cannot be precise since they involve estimates of damages that would have occurred in the absence of the program; and (3) flood damages have not, and will never, be fully eliminated so long as people occupy flood-prone areas.

Since 1975, Province of Ontario has not received payments for flood damages through the Disaster Recovery Financial Assistance Arrangements Program. This point helps reflect the success of Ontario's flood management program. Shrubsole et al. (2003) concluded that relative to their stated goals, floodplain regulations by Conservation Authorities (CAs) have achieved an acceptable level of efficiency, equity and performance. The existence of CAs and the establishment of a *Provincial Policy Statement* are the cornerstones that have supported this level of success. The CAs use the watershed as the administrative unit, receive funding from provincial and local governments, and generate their own funds. They have the primary responsibility for flood and erosion control on a watershed basis, which reflects a long-standing cooperative approach to renewable resource management (Conservation Ontario, http://www.conservation-ontario.on.ca/, last accessed Aug, 2011). The *Flood Plain Planning Policy Statement* commits the province to structural adjustments, floodplain regulation, flood warning, and disaster relief.

Most of the available studies suggest that local governments have not always effectively managed floodplain development. This is partly explained by a lack of political will, competition for development among floodplain communities, and inadequate mechanisms for promoting watershed-based responses. There is also a lack of integration between structural adjustments and floodplain regulations. A related concern pertains to the desired balance between non-structural and structural approaches. The explicit and innovative goal of the FDRP was the mapping of flood-prone areas. Implicitly, it was hoped that once municipalities were made aware of the flood risk through the maps, they would establish floodplain regulations.

Since no flood risk management program can provide absolute protection, it is also appropriate to examine the institutional arrangements for responding and recovering from floods. Section 3.1 briefly describes response and recovery arrangements in Canada (more details in Simonovic, 2011).

4. EXPERIENCE FROM THE FLOOD OF THE CENTURY IN THE RED RIVER BASIN

We learn from experience. Here is a personal story of the 1997 flood on the Red River. At the time of 'Red River flood of the Century' I lived in Winnipeg, Manitoba, Canada (Simonovic, 2011).

4.1 Red River Flooding

Situated in the geographic centre of North America, the Red River originates in Minnesota and flows north (one of eight rivers in the world that flow north). The Red River basin covers 116,500 km^2 (exclusive of the Assiniboine River and its tributary, the Souris) of which nearly 103,600 km^2 are in the United States, Figure 1. The basin is remarkably flat. The elevation at Wahpeton, North Dakota, is 287 meters above sea level. At Lake Winnipeg, the elevation is 218 meters. The basin is about 100 km across at its widest. The Red River floodplain has natural levees at points both on the main stem and on some tributaries. These levees (some 1.5 m high) have resulted from accumulated sediment deposit during past floods. Because of the flat terrain, when the river overflows these levees, the water can spread out over enormous distances without stopping or pooling, exacerbating flood conditions. During major floods, the entire valley becomes the floodplain. The type of soil in this region also contributes to flooding because, while topsoil is rich, beneath it lies anywhere from 1 to 20 m of largely clay soil, with characteristic low absorptive capacity. Water tends to sit on the surface for extended periods of time. In general the climate of south-eastern Manitoba is classified as sub humid to humid continental with resultant extreme temperature variations. Annually, most of the precipitation received is in the summer rather than the winter. Approximately ¾ of the 50 cm of annual precipitation occurs from April to September. Consequently, most years spring melt is well managed by the capacities of the Red River and its tributaries. However, periodically weather conditions exist which instead promote widespread flooding through the valley. The most troublesome conditions (especially when most or all exist in the same year) are as follows: a) heavy precipitation in the fall b) hard and deep frost prior to snowfall c) substantial snowfall d) late and sudden spring thaw e) wet snow/rain during spring breakup of ice.

In Manitoba, almost 90 percent of the residents of the Red River/Assiniboine basin live in urban centres. Metropolitan Winnipeg contains 670,000 people, and another 50,000 live along the Red River north and south of the city. The Red River valley is a highly productive agricultural area serving local, regional and international food needs. There has been an extensive and expanding drainage system instituted in the basin to help agricultural production by increasing arable land. The purpose of agricultural drainage is to remove, during the growing season, water in excess of the needs of crops and to prevent sitting water from reducing yields. However, the contribution of drainage activities, if any, to flooding and damages is both a concern and a source of disagreement. Faster removal of the spring water from the fields is considered to be one of the contributors to the regular spring flooding in the basin. Often problems with maintenance of drainage infrastructure are claimed as a source of infield flooding.

The basin floods regularly. Early records show several major floods in the 1800s, the most notable being those of 1826, 1852 and 1861. This century, major floods occurred in 1950, 1966, 1979, 1996 and 1997, Table 2. The Red River basin has 25 subbasins, which have different topography, soils and drainage that result in different responses during flood conditions. One common characteristic is overland flow during times of heavy runoff. Water overflows small streams and spreads overland, returning to those streams or other watercourses downstream. Existing monitoring and forecasting systems do not track these flows well, leading to unanticipated flooding. The earliest recorded flood in the basin was in 1826, although anecdotal evidence refers to larger floods in the late 1700s. The flood of 1826 is the largest flood on record; it was significantly larger than the devastating 1997 flood. A sudden thaw in April of 1826, followed by ice jams on the river and simultaneous heavy rainfall, had water on the Red River rise 1.5m downtown in just twenty-four hours. Preservation of life took precedence over preservation of property, thus losses were enormous. Whole houses were carried by the River. The estimated maximum flow was 7,362 m^3/s The water apparently took over one month to recede completely.

Table 2 Red River Floods in m^3/sec (after IRRBTF, 1997)

Location	**1950**		**1979**		**1997**	
Red River at Emerson	May 13	2,670	May 1	2,620	May 2	3,740
Red River at Winnipeg	May 19	3,058	May 10	3,030*	May 4	4,587*

** Computed natural flow as would have occurred without existing flood control works.*

A pivotal event in the Red River flood history was the 1950 flood which was classified a great Canadian natural disaster based on the number of people evacuated and affected by the flood. A very cold winter and heavy snowpack in the United States, combined with heavy rain during runoff, were the primary causes. All towns within the flooded area in the upper valley had to evacuate. Over 10,000 homes were flooded in Winnipeg and 100,000 people evacuated. A plan to evacuate all 350,000 people in Winnipeg was prepared, although luckily it did not have to be used.

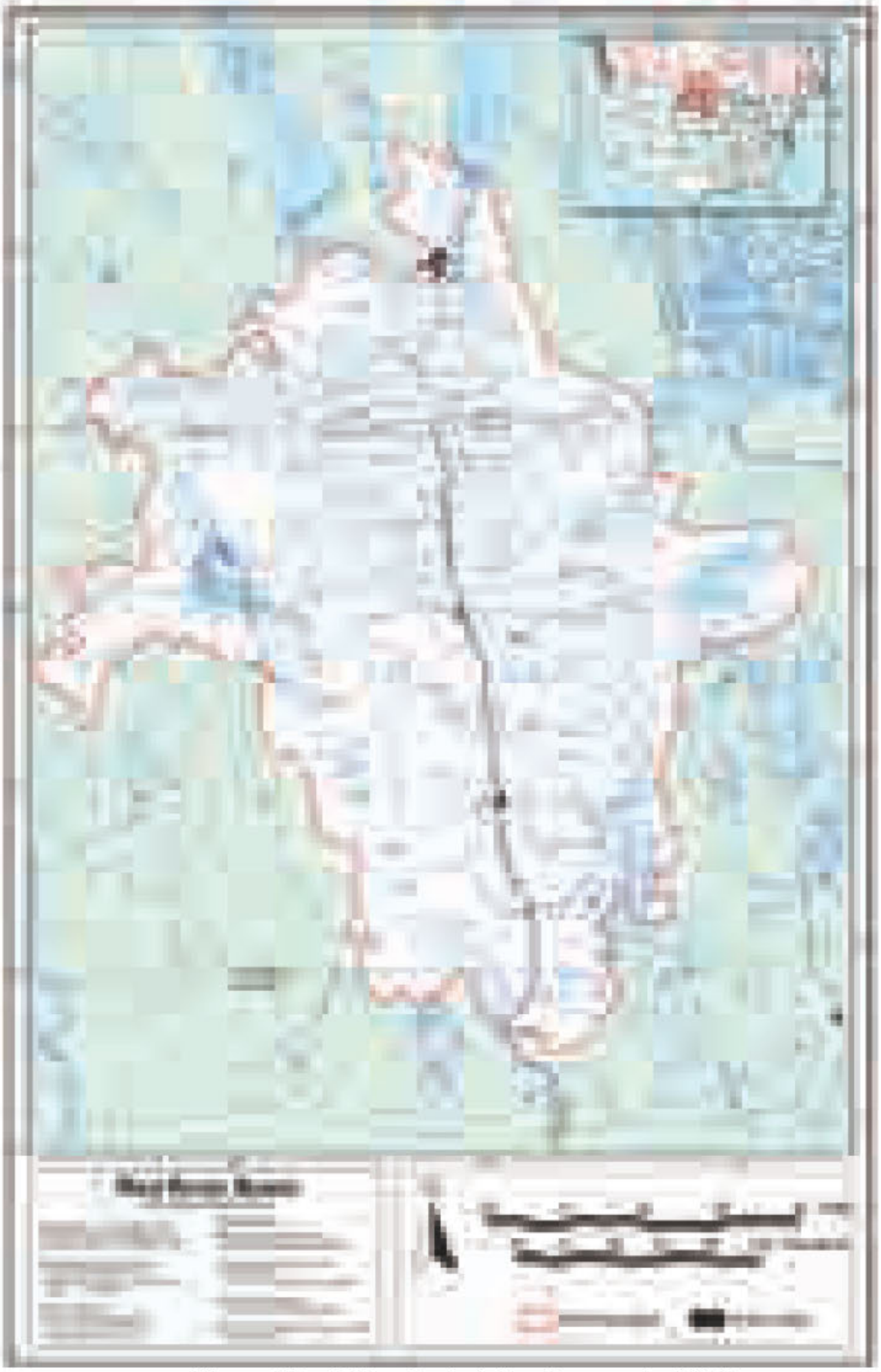

Figure 1 Red River basin (after Simonovic, 2011)

Most of the flood management planning in Manitoba was initiated after the 1950 flood. This flood was the turning point in the history of flooding and flood control in Manitoba's portion of Red River basin. Construction of elevated boulevards (dikes) within the City of Winnipeg and associated pumping stations was initiated in 1950. The current flood control works for the Red River valley consist of the Red River Floodway, the Portage diversion and Shellmouth Dam on the Assiniboine River, the primary diking system within the City of Winnipeg, and community diking in the Red River valley (Simonovic, 2004). Following the 1950 flood on the Red River, the federal government and the Province of Manitoba set up a fact-finding commission to appraise the damages and make recommendations (Royal Commission, 1958). The commission recommended in 1958 the construction of the Red River Floodway (completed in 1966), the Portage Diversion (completed in 1970) and the Shellmouth Reservoir (completed in 1972). As a consequence of the concern over flood protection for the Red River Valley, a federal-provincial agreement led to the construction in early 1970s of a series of ring dikes around communities in the Valley. Moreover, financial aid programs encouraged rural inhabitants to raise their homes, as well as to create individual dikes around their properties. All the decisions regarding the capacity of current flood control works were based primarily on economic efficiency, getting the largest return for the investment.

4.2 'Red River Flood of the Century', Manitoba, Canada

Sunday, April 6, 1997 was a day off for most people, but it was not a standard day of rest. Most homes in the City were surrounded by drifts of snow (Figure 2), at some places up to the window frames. The city was virtually shut down.

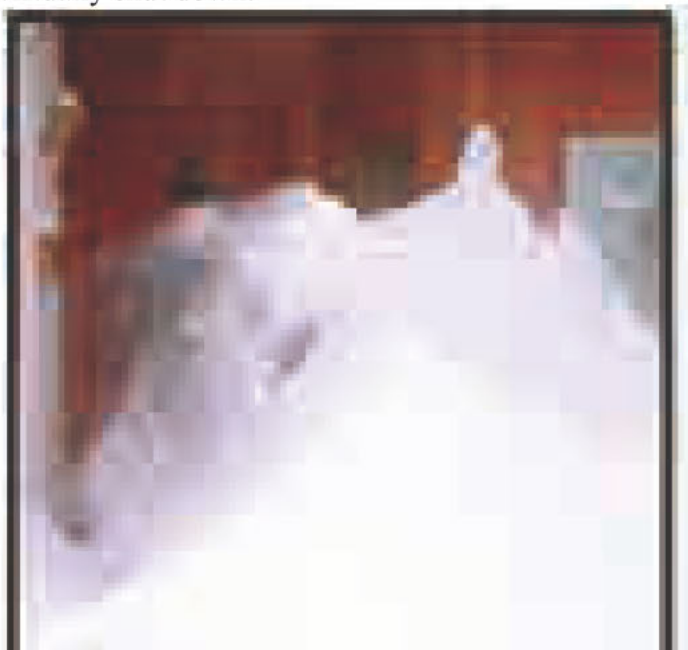

Figure 2 Blizzard of April 6, 1997 (courtesy of the Winnipeg Free Press)

Radio was announcing that the whole Red River valley from North Dakota to Lake Winnipeg was already under the snow varying in depth from over 2 meters along the upper reaches to more than 1.5 meters around Winnipeg (more than most people could remember seeing). Temperature just began to peak over the freezing level when this massive snow storm piled more snow on already high snow cover. Flooding was already accepted certainty in the valley. Early forecasts of my friend Alf Warkentin from the Water Resources Branch were a

10% chance for flood as bad as that of 1979. That flood inundated southern Manitoba and turned it into a lake 90 km long from north to south and 20 km across at its widest point. After the blizzard, Alf's forecast was revised and the Red River valley was facing the flood bigger than the flood of 1950.

The life slowly returned to normal after the weekend. However, the work of Emergency Management Manitoba and Water Resources Branch just started. Preparations for the flood were in the full swing. Life, for many citizens of Winnipeg, was kind of unreal. Everyone was talking about the flood. The flood was a reality south from Winnipeg. Red River Valley was under siege. The Water Resources Branch was providing regular information about hectic effort to get the best estimate what is going to hit us and to get prepared as good as we can and as soon as we can. People from the Water Resources Branch like Larry Whitney, emergency flood spokesman; Rick Bowering, head of the Water Resources; and Doug McNeil from the City became everyday guests in every Winnipeg home through regular process of updating information about incoming flood. About eight million sandbags were laid into ramparts around Winnipeg. It's not known how many sandbags were used outside the City because each municipality took care of those matters. But at one point, the province leased a 747 jet for $225,000 to airlift three million sandbags from California to the Red River Valley.

April 19 was a special day. Nearly two weeks had passed since the blizzard and under the stronger sun the massive snow blanket had began to melt. Our neighbors in North Dakota were fighting the flood. Cities were falling to the Red, one after another. All this information was coming to us, but nothing hit us as the front page of the Winnipeg Free Press on Sunday April 20th. It showed the downtown Grand Forks the Security Building submerged by Red and on fire. It was a strange image showing two forces of nature acting together with destructive power, and nature was winning. Grad Forks was under the water and 35,000 people were homeless. This image, repeated on the TV many times and shown in other local papers got stack in my mind.

The battle with Red was raging in the Valley. Tremendous effort to protect the property and reduce the damage was going on in parallel with the expansion of the water over the land. The 'Red Sea' reached up to 37 km wide and covered 1,850 km^2 in Manitoba (Figure 3). Towns of Emerson, Morris, Ste. Agathe, St. Adolphe, Grande Point and farms around the Valley were receiving help from volunteers, responsible agencies and Canadian Arm Forces. The ring dikes around communities were raised. Shortly after midnight on Tuesday, April 29, 1997, the Red River struck the small town of Ste. Agathe, 25 kilometres south of Winnipeg. It was the first indication that parts of Manitoba thought safe could be vulnerable. The water didn't flood from the east side as one might expect that's where the Red River flows past town and where the towns dike was built. Instead, the water blindsided the village from the west, flowing overland and crossing Highway 75. All other communities survived. Beside Ste. Agathe, the Red River flood got in one more bite. It took that bite at Grande Pointe, a suburb of Winnipeg bordering southeast city limits. Hundred Grande Pointe homes were flooded. It was time for heroics because, in spite of Winnipeg's and the province's best efforts, the planning and preparations weren't complete.

Figure 3 The 'Red Sea' (courtesy of the Winnipeg Free Press)

The province introduced the mandatory evacuation of thousands of rural people living outside ring dikes. The order created bands of 'outlaws' who ignored the authorities and drove their boats through flooded fields to save their homes and those of others. RCMP (Royal Canadian Mounted Police) wanted evacuation and they wanted it in a hurry. They thought there was a grave threat to life and therefore pressured other authorities into supporting an evacuation. Shortly after Grand Forks went under on April 18, the province moved out 3,400 Red River Valley residents. This was not controversial. Most were people in ring dikes or who had health or mobility issues. But on April 23, EMO (Emergency Management Organization) dropped the bombshell. It announced a total evacuation of the valley, about 17,000 people. Within days, more than 800 rural homes were reported flooded.

Some residents did not follow the orders. They stayed and raised the height of dikes, plugged leaks in dikes, and made sure pumps were running and properly positioned. They also phoned owners when they discovered problems.

Water was at the doorstep of Winnipeg. The city filled 6.5 million sandbags. But even 6.5 million bags were not enough. City built 14 earth dikes inside the city limits. The floodway was used to maintain the 24.5 foot level at James Avenue. That was considered to be the level that the city's dikes could be expected to hold back. Maintenance of 24.5 foot level at James Avenue meant almost a week where the Red was at its record high level in Winnipeg and almost two weeks where it was above the level it had reached in any previous year (even the pre-floodway 1950). Emergency dikes were under enormous strain and plugging leaks became a 24-hour-a-day job. Hectic pace to protect the city was confronted with surreal 'life as usual' for most of the people leaving and working in the city.

The water was still coming up. The last frontier was the extension of Brunkild Z-dike designed to keep the Red River water out of the La Salle River (considered at that time Winnipeg's Achilles heel). The La Salle is the Red River's last tributary before Assiniboine and it flows into the Red at La Barriere Park in St. Norbert. That is north of the floodway gate and behind Winnipeg's primary diking system As many as 100,000 Winnipegers, would be forced from their homes if enough water got over the high ground and came down the La Salle. Resources were scarce and available time was short. The province put all its energies and earth-moving equipment into, 72-hour dash to build the 24-km Brunkild Z-dike extension. When the water reached the critical Brunkild gap on April 29, the Z-dike blocked the way.

The river had crested in Winnipeg on May 1, and all the city's defenses held. But a water elevation of 24.5 feet above winter ice levels at the James Avenue pumping station was considered all Winnipeg could safely handle, so floodway gates were raised to hold water inside Winnipeg to that level.

Not everyone understands exactly how the floodway works. Its two gates are actually in the Red River, where the river and diversion channel meet. The two gates are raised to elevate water enough to push water into the diversion channel. The reason the water level has to be raised is because there is a large mound at the opening of the diversion channel to stop ice going into the floodway. Large ice would damage bridges and other structures along the floodway.

But raising those gates caused artificial water levels south of the floodway. On May 2, some 125 of 150 homes in Grande Pointe took on water. The province initially denied the floodway had caused artificial flooding. But a review later determined that the floodway operation caused artificial flooding of two feet above what water levels upstream should have been. Many residents of Grand Pointe felt 'sacrificed'.

With river crest passing the city on May 1st the flood was not over. Communities' north from Winnipeg were just starting their battle with Red and Winnipeg with those south of the city were embarking on difficult path of recovery. Many homes were bought out because their location made flood-proofing too difficult. For example, on St. Mary's Road just south of Winnipeg, 25 homes were purchased by the government because the cost of flood-proofing was too high.

Assessment of damage started in May. However, the process was slow and plugged with problems. Initially, the province was only going to pay 80 per cent compensation to flood victims, even though 90 per cent of the money came from the federal government. Claimants had to pay 20 per cent deductible, and the maximum government compensation was to be $100,000. The province later eliminated both the $100,000 cap, and the 20 per cent deductible, for Disaster Financial Assistance funds. Compensation covered essentials for living only.

At the end a total of 3,747 private homes had claims for flood damage approved according to the province's Emergency Management Organization. Another 633 flood damage claims from full-time farms were approved. Also, claims for 383 full-time businesses were approved. The Disaster Financial Assistance payments for those claims reached $257 million. That does not include business losses.

In addition to the government support, the effort of many volunteers and donations from all over the country made a difference. In the Red River Valley south of Winnipeg, the Mennonite Disaster Service built 14 new homes, did major reconstruction on 71 homes, minor reconstruction on 28 homes, relocated five homes, and cleaned 802 flooded homes and yards.

MDS volunteers put in 21,061 volunteer days, worth an estimated $2.5 million in labour. MDS used donations of nearly $1.9 million for food, transportation and lodgings for volunteers. They also used donations to buy building materials, for which they were later reimbursed by Emergency Measures Organization, so people didn't have to wait for their claims to be settled before they had roofs over their heads.

The most humbling event may have been the donations that poured in to help flood victims. The Canadian Red Cross collected $25 million in donations from over 144,000 private citizens across the country. But 70 per cent of the $25 million came from other Manitobans. The Red Cross employed 250 people on flood relief, and mobilized another 2,200 volunteers in Manitoba. It helped rebuild or restore 230 homes, and plug gaps between government aid and family incomes. Salvation Army also provided free cleanup supplies, toys for children, tickets for local sporting events, and covered grocery costs. It even took seniors on a two-day bus trip to Gimli.

Many families in the valley were under stress. The financial bottom line for people just collapsed. There were divorces, there were suicide attempts and trauma teams were working overtime to help population under stress (Morris-Oswald and Simonovic, 1997).

4.3 Evolution of Flood Management in the Red River Basin

By letters of June 12, 1997, the Governments of Canada and the United States requested the International Joint Commission (IJC) to examine and report on the causes and effects of damaging floods in the Red River basin and to recommend ways to reduce and prevent harm from future flooding. The IJC is a binational Canada-United States organization established by the Boundary Waters Treaty of 1909 that assists the governments in managing waters shared by the two countries for the benefit of both. To assist it with the Red River flood of 1997 binational investigation, the Commission has appointed an International Red River Basin Task Force. The Task Force, comprised of members from a variety of backgrounds in public policy and water resources management, was to provide advice to the Commission on matters identified in the letters from governments. The Governments asked the Commission to examine a full range of management options, including structural measures (such as building design and construction, basin storage, ring dykes, etc.) and non-structural measures (such as floodplain management, flood forecasting, emergency preparedness and response, etc.) and to identify opportunities for enhancement in preparedness and response that could be addressed to improve flood management in the future. More information is available at the IJC International Red River Basin Task Force's web site: http://www.ijc.org/rel/boards/rrbtf.html (last accessed Aug, 2011). The Task Force prepared a December 1997 interim report (IRRBTF, 1997) that cautioned against complacency and made 40 recommendations for better flood preparedness in the short-term. At the end of our work we submitted the final report (IRRBTF, 2000).

The International Red River Basin Task Force defined required projects, coordinated the funding and scheduling, exercised quality control, provided oversight of subgroups, synthesized the findings, and prepared the recommendations. The concept for accomplishing the required tasks included three main activities: database development, modelling and the development of damage reduction strategies. A coordinated database was found to be fundamental as it supports the development of models and flood damage reduction strategies. Each of these working topics ended up as a key element in the decision support system. The Task Force's final report (IRRBTF, 2000), drew together the findings and made recommendations on policy, operations and research issues.

The IJC used the final report as the basis for public hearings in the basin prior to the submission of its report to the governments. Public participation was an important part of the process. Following the distribution of the Interim Report, the IJC and the Task Force conducted a series of public meetings throughout the basin in February and October 1998. The results from these meetings were incorporated into the work plan. Efforts were made to keep people in the basin informed throughout the study using the Internet, news releases and other means of contact. Public and technical inputs were invited throughout the study period.

The fact that this work involved two countries implied two different ways of doing business, two political systems, two or more ways of collecting, analysing and storing data, and many other political dichotomies. These dichotomies created a unique challenge for this work, but the reality that floodwaters do not recognize an international border made a basin-wide approach to flood management an imperative. Although this work did not develop a comprehensive basin-wide water management plan, the work of the Data, Tools and Strategies Groups contributed to more effective and efficient floodplain management, facilitated integrated flood emergency management in the basin, and fostered improved international cooperation and communication.

In investigating what can be done about flooding in the Red River basin, the Task Force examined the issue of storage through reservoirs, wetlands, small impoundments or micro-storage and drainage management. The conclusions (IRRBTF, 2000) are:

Conclusion 2: It would be difficult if not impossible to develop enough economically and environmentally acceptable large reservoir storage to reduce substantially the flood peaks for major floods.

Conclusion 4: Wetland storage may be a valued component of the prairie ecosystem but it plays an insignificant hydrologic role in reducing peaks of large floods on the main stem of the Red River.

Since the Task Force concluded that storage options provide only modest reductions in peak flows for major floods, a mix of structural and non-structural options were examined. Winnipeg, the largest urban area within the basin, was found to remain at risk. The city survived the 1997 flood relatively unharmed, but it cannot afford to be complacent. If it had not been favoured with fair weather during late April 1997, it could have suffered the fate of its southern neighbours. The Task Force made a number of recommendations to address the city’s vulnerabilities and better prepare it for large floods in the future. To achieve the level of protection sufficient to defend against the 1826 or larger floods, major structural measures on a scale equal to the original Floodway project were found to be needed to protect the city. Two options were suggested: expansion of the Floodway, and construction of a water detention structure near Ste. Agathe to control flood waters for floods larger than 1997. After detailed feasibility studies, the Floodway expansion project was selected as a preferred alternative.

Structural protection measures are only part of the response to living with major floods. The Task Force looked at a wide range of floodplain management issues to see how governments and residents might establish regulatory and other initiatives to mitigate the effects of major floods and to make communities more resilient to the consequences of those floods. It made a number of recommendations on defining the floodplain, adopting and developing building codes appropriate to the conditions in the Red River basin, education and enforcement.

In an effort to gain a better understanding of the flooding issues, and in recognition of weaknesses in technological infrastructure within the basin, the Task Force devoted much of its energy and resources to data issues and computer modelling. On reviewing current data availability, the Task Force concluded that further improvement and maintenance of the Red River floodplain management database was required. Federal, state and provincial governments and local authorities needed to maintain a high level of involvement in further database development, and in improving data accessibility. The Red River Basin Decision Information Network (RRBDIN) (RRBDIN, 2005) now provides information about water management within the basin, and links to other relevant resources. While RRBDIN concentrates on information and activities on the US side, the Government of Manitoba has been involved in collecting and disseminating flood information from the Canadian side (Province of Manitoba, 2005). Information from RRBDIN includes databases, references, technical tools, communication tools and GIS data, as well as the most up-to-date information available on weather and flood forecasting. The Task Force found difficulty in securing public access from Canadian agencies to data and other flood-management related information. The Task Force recommended that Canadian data be made available at no cost and with no restrictions for flood management, emergency response and regional or basin-wide modelling activities. The website of the Government of Manitoba now provides up to date reports on daily flood conditions, in the form of maps and reports, along with miscellaneous information on flood management. A prototype version of the real time flood decision support for the Red River basin is operational (Province of Manitoba, 2004).

The “Flood of the Century” is more than 10 years behind us. What has been done in the basin? The major improvements are in place to increase the flood protection. Winnipeg's floodway now provides protection from a one-in-300-year flood, and will be up to one-in-700-year protection by the time it's completed in 2010. It is costing $665 million (the largest infrastructure investment in Canada in 2005).

A new system of earthen dikes and pre-formed concrete walls protecting Grand Forks in North Dakota and Minessota from a one-in-250 year flood is functionally complete. The Grand Forks system cost about US$400 million.

But outside those centres, the approach to flood-proofing in Manitoba versus North Dakota is quite different. In North Dakota, you will not see any houses elevated against flooding like in Manitoba, and you will see only a handful of personal ring dikes. Instead, North Dakota and Minnesota chose to use federal money from FEMA (Federal Emergency Management Agency) to buy out homeowners on the flood plain, instead of protecting them. Behind the decision to buy out homeowners is a government cost-benefit analysis. Government determined that it would be simply cheaper to buy people out than protect them. That was after looking at such things as the cost to protect a home versus its value, how many times it has flooded, how many times it may flood in the future, etc.

Minnesota has been especially aggressive about buyouts. But on the west side of the river in North Dakota, which has a much smaller tax base, many rural people have been ignored because there wasn't enough money. Their homes that were damaged by flooding still sit at the same elevations as in 1997. In North Dakota today, there are still 1,100 rural residences on the Red's flood plain. Authorities do not know the level of flood protection in those homes. What is known is that very few have received government assistance to protect themselves. In the ongoing buyout program, FEMA pays 75 per cent of a home's pre-flood value, the state pays 10 per cent, and the county and homeowner split the remaining 15 per cent. Most of the buyouts in North Dakota were in the cities, and most of those were in Grand Forks. There were 850 homes and 50 businesses bought out in Grand Forks. There were more than 1,200 buyouts in that state between federal programs FEMA and the Federal and Urban Development program.

Contrast that with Manitoba. In Manitoba, the government has bought out fewer than 75 homes in the Red River Valley since the big flood. Manitoba did a cost-benefit analysis, too, but concluded it was better to help people stay on the land. The Red River Valley is an extremely prosperous agricultural area, and people do need to live in that flood plain to do their business. Flood protection allows businesses to develop with a level of security that they are not going to be damaged by a major flood.

North Dakota does not help fund the elevating of houses above flood levels, like in Manitoba. However, North Dakota and Minnesota have run small programs to help rural homeowners build individual ring dikes. Under the program, North Dakota agrees to finance a ring dike 50-50 with the landowner, committing a maximum $25,000 US. The ring dikes for farms are costing well over $50,000, so the farmer must pay much more than $25,000. Minnesota's program is more generous, with the state picking up 75 per cent of costs. However, only a finite amount of funding is available for the American program, and many people have not been approved. Washington does not pay into the program. Since the program began, in 2001, 120 rural landowners have applied for assistance to build a ring dike in North Dakota. Just 16 have received funding so far. About double that number have been approved in Minnesota.

That's a meager number compared to Manitoba. Since 1997, a total 1,830 rural home owners in Manitoba's Red River Valley have received federal and provincial money to protect them from flooding. Today, virtually every home in the Red River Valley is protected to 1997 flood levels, plus two feet. Manitoba homeowners received on average $40,000 apiece to elevate their homes, build a dike, or otherwise fortify their residences. The feds and province cost-shared the program 50-50. The total program spending came to $73 million. Under the program, Manitoba homeowners could get up to $60,000 in government funds to build a ring dike or elevate a home, the most common types of flood protection. They had to contribute $10,000. But many landowners reduced their $10,000 share down to a small amount because the province knocked off dollars for labour, like a farmer using his or her tractor to help build the mound (they were paid hourly rates), and compensation for the soil they took from their land to build the mound.

It's always interesting to see how governments spend their money in Canada versus the United States, and how much they spend. Yet direct comparisons aren't fair. One shouldn't forget that North Dakota suffered much more damage than Manitoba, and had a much bigger hole to climb out of. The 1997 flood cost the state $3.7 billion US, including estimates of losses to businesses, according to FEMA. Still, public money hasn't flowed in the U.S. like in Manitoba.

Manitoba has done a much better job flood-proofing it's towns and villages, too. Every community along the Manitoba portion of the Red River is protected. There are 13 communities with new ring dikes: St. Mary's Road, Grande Pointe, Rosenort, Niverville, Gretna, Aubigny, St. Pierre-Jolys, Lowe Farm, Riverside, Rosenfeld, Ste. Agathe and Roseau River. The cost of those dikes was shared 50-50 by federal and provincial governments. They have also improved the dikes for Dominion City, Emerson, Letellier, St. Jean Baptiste, Morris, St. Adolphe and Brunkild. In total, 2,133 homes and businesses have received new or upgraded protection in the form of community ring dikes, at a cost of $42 million. Federal and provincial governments paid 90 per cent of that, and rural municipalities 10 per cent.

The same can't be said in North Dakota. The city of Fargo is still waiting on flood-proofing funds from Washington after 1997. The delay in Fargo getting flood protection is important because memory and the urgency for flood protection fades with time. Federal funding in U.S. is extremely tight now because of the costs of both the Iraq war and the flooding of New Orleans. In Breckenridge-Wahpeton, a series of diversions and dikes have been constructed and offer better protection, but are still only half-finished. Construction has been idle for two years because federal funds have dried up. The town of Drayton, 45 kilometres south of the Manitoba border, is very susceptible to flooding but can't get any flood-proofing dollars.

In North Dakota, various government officials were pleased with how the state withstood the 2006 flood. Only about 10 homes were flooded . In Manitoba in 2006, only one home had serious flood damage, and that was a home in which the owner had refused flood-proofing assistance after 1997.

Today, Grande Pointe has a ring dike. Ste. Agathe has a ring dike, too. The Brunkild Z-dike is now permanent. Casings for 500 wells on Manitoba's flood plain also have been raised to 1997 levels, plus two feet, so aquifers aren't contaminated. Winnipeg also fared well in 2006, which compared to the 1996 flood. With about 200 homes now protected by a ring dike for Kingston Row and Kingston Crescent, the city needed just 20,000 sandbags last year.

The water and climate monitoring network in the Red River Valley has been upgraded at a cost of over $1.5 million. This included activating or establishing 34 monitoring stations and installing 165 new climate stations. Manitoba forecasting office has dozens of satellite water monitors in the Red River, 60 new rain gauges in streams, and computer flood modeling programs.

A total of 1,830 Red River Valley homes and businesses outside Winnipeg received individual flood-proofing since the flood, at a cost of $73 million from federal and provincial governments. An additional 2,133 homes and businesses have been protected by community rind dikes since the flood at a cost of $38 million from federal and provincial governments. Municipalities cost-shared 10 per cent, raising the total to $42 million.

5. CONCLUSIONS

Flood protection infrastructure along rivers creates partially a false sense of security about flood risks that can lead to complacency about disaster preparedness and to greater development on the flood protected area. It is the fact that the primary and visible response in the wake of recent floods in Canada has been on structural adjustments. Mileti (1999) and Simonovic (2011) suggest that mitigative measures such as these do not prevent flood damages, but postpone them, since the design capacity of the structures can be exceeded by extreme, albeit low frequency, flood events. However, in the meantime, contravening this is the success of minimizing the damages from small to medium-sized flood events, which does suggest that the mitigative measures are in fact working. If the postponement amounts to many years and is accompanied by a significant increase in floodplain development, then the accrued losses can be very high. It is during these extreme flood events that the need to integrate structural and non-structural adjustments becomes important.

There are elements of the institutional arrangements for flood management in Canada that appear to support a cycle of escalating flood losses and transferring responsibility ('passing the buck'). The cycle begins with significant flood damages being inflicted on a community that is located on a well-known flood-prone area. Past flood events have prompted the construction of structural works and the establishment of a flood warning system and information campaigns. If floodplain regulations exist, they have likely been implemented poorly. The news media report on the flood, its damages and the emergency response efforts to the nation. Relief programs, largely funded by senior governments and non governmental organizations immediately, respond to this event. The public places much of the blame for the flood on inadequate government effort. In response, bigger and more structures are built with most of the funding coming from senior governments. Commercial properties and residences are refurbished, in part through the DFAA, to pre-flood conditions. Flood warning systems and information programs are improved.

Since senior governments provide neither consistent nor strong signals on the need to truly integrate structural and non-structural adjustments, intensive development continues on flood-prone areas. When these developments are flooded, primary blame is often placed upon municipalities. However, it is the previous steps that implicitly support this cycle of escalating economic losses.

It is a basic reality that occasionally and unavoidably, society will experience major flood disasters from rare, extreme events. It is also a reality that the need for effective flood management is growing as reflected in the increasing trend in flood losses. The approaches of the past seem to be inadequate to deal with current and future economic, social, and environmental conditions. Thus, flood management must be seen in the context of day-to-day decisions rather than a response to a disaster.

Shrubsole et al. (2003) point that Canadian flood management is at a crossroads and now faces difficult choices about whether to address the fundamental challenges confronting it, or to accept a trend of increasing flood damages. The dilemma concerning which road to choose reflects, in large part, the choice of framing flood problems as being primarily technical or institutional in nature. The road well traveled essentially extends a 60-year tradition in flood risk management. A relatively narrow set of alternatives is actually employed to solve flood problems. In the end, the construction of more, larger and better structures encourages more floodplain development and increases the loss potential. Better monitoring and information programs are developed. The road less traveled suggests that decisions made by people and governments in the course of their day-to-day lives and in response to disasters exacerbate the vulnerability of communities. It is the choices and decisions made by people and their institutional arrangements that contribute to people's vulnerability. A difference in the outcomes associated between the two roads lies in what proportion of funds will be spent on disaster relief versus reduction of long-term vulnerability.

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Chapter 3

Consequences of the Central European Flood of August 2002 with emphasis on the Elbe River in Germany

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EXECUTIVE SUMMARY
Purpose of this report is to give an overview of the flood of August 2002 in Central Europe and of actions taken thereafter. The flood was the largest on record in many parts of the region of the flood, which is the catchment of the Elbe in the Czech Republic and in South East Germany and its southern tributaries, and also the reach of the Danube and her southern tributaries in East Bavaria and her tributaries in Central Austria. Experiences obtained from this major disaster should serve to learn how to prevent such a flood disaster to happen again not only in Central Europe, but everywhere! It is shown in the report how with determination and engagement it was possible in relatively short time to overcome the damages from the disaster, so that in most of the affected regions life today goes on as before the flood, with exception of numerous activities which have been initiated to improve protection of the endangered areas. In fact, in Germany rebuilding of the devastated flood area has created a small boom in reconstruction in an otherwise economically somewhat depressed area.

The flood caused damages of more than 13 Billion € in Germany alone. It led to a thorough reanalysis of the flood security situation in Germany and elsewhere n Europe - in particular for the river Elbe, where most of the damage occurred, but also for the Danube and other German rivers. The general assessment is that in recent history there never has been a flood in central Europe that has caused damage of this magnitude. Fortunately, in comparison with earlier flood disasters in Germany, losses of lives were small. However, some of the damage that occurred could have been avoided. The flood protection system - dikes, drainages and other technical protection measures - was in poor maintenance condition, and generally, responsible persons and decision makers were not prepared to handle a disaster of the magnitude of the August 2002 flood. Beyond improving conditions on the river Elbe, the discussion on all political levels has led to the conclusion that whereas extreme floods are bound to happen again - and the topic of climate change as cause of this and future even larger floods has been given much publicity - we must be prepared to handle the consequences of such floods and prevent disasters, even for floods of the magnitude as the flood of August 2002. Flood risk management for prevention of future disasters was found to be the solution, whose objective is to be able to offer complete protection by technical and non-technical means against a reasonably high flood - generally the 200 year flood on large rivers, and floods with recurrence intervals of 20 to 100 years in smaller rivers, and to be well prepared to handle floods of larger magnitude in order to prevent disasters from occurring. How the Governments, the German States (Länder) and the people are translating the lessons from the August 2002 flood into actions will be described in this report.

1. INTRODUCTION

Purpose of this report is to give an overview of the flood of August 2002 in Central Europe and to describe the actions taken thereafter. Experiences obtained from this major disaster should serve to learn how to prevent such a flood disaster to happen again. But the report also shall illustrate how with determination and engagement it was possible to overcome the damages from the disaster in relatively short time, so that today in most of the affected regions life goes on as before with exception of the numerous activities which have been initiated to improve protection of the endangered areas. In fact, in Germany rebuilding of the devastate flood area has created a small boom in construction in an otherwise economically somewhat depressed area.

The region of the flood was the catchment of the Elbe in the Czech Republic and in South East Germany and its southern tributaries, and also the Bavarian an Austrian reach of the Danube with her southern tributaries in East Bavaria and her tributaries in Central Austria. The region is shown in Fig.1, where the outline of the Elbe/Labe catchment is included for orientation, including locations mentioned in the text.

The flood caused damages of more than 13 Billion € in Germany alone. It led to a thorough reanalysis of the flood security situation in Germany - in particular for the river Elbe, where most of the damage occurred, but also for the Danube and other German rivers. The general assessment was that in recent history there never has been a flood of this magnitude. Fortunately, in comparison with earlier flood disasters in Germany, losses of lives were small. However, some damage could have been avoided. The flood protection system - dikes, drainages and other technical protection measures - was in poor condition, and generally, responsible persons and decision makers were not prepared to handle a disaster of the magnitude of the August 2002 flood. Beyond improving conditions on the river Elbe, the discussion on all political levels has led to the conclusion that whereas extreme floods are bound to happen again - and the topic of climate change as cause of this and future even larger floods has been given much publicity - we must be prepared to handle the consequences of such floods and prevent disaster, even for floods of the magnitude as the flood of August 2002. Flood risk management (see Plate, 2002) was found to be the solution for prevention of future disasters, where objective is to be able to be fully protected by technical and non-technical means against a reasonably high flood - generally the 200 year flood on large rivers, and floods with recurrence intervals of 20 to 100 years in smaller rivers, and to be well prepared to handle floods of larger magnitude, to prevent disasters from occurring. How the Governments, the German States (Länder) and the people are translating the

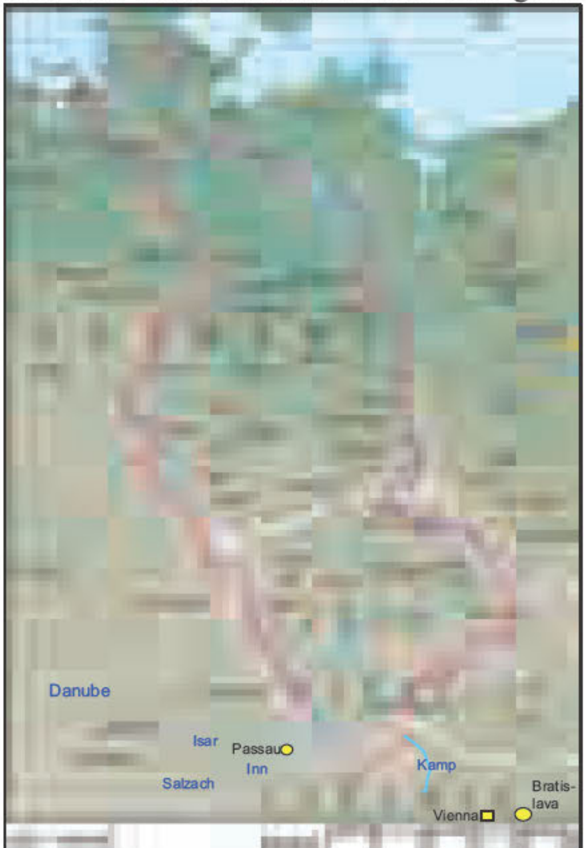


Figure 1 Area of the Elbe catchment and German and Austria reach of the Danube

lessons from the August 2002 flood into actions will be described in this report. An extensive documentation of reports on the disaster has been prepared by the Helmholtz Zentrum für Umweltforschung (UFZ, http://www.ufz.de) in Leipzig Halle.

2. THE FLOOD OF AUGUST 2002

It is not the purpose of this report to go into all the details of the flood. But it is necessary to understand the conditions which caused the flood and the flood damage. Therefore, these will be briefly reviewed (partly repeating results from the report by JSCE, 2003), and for some examples it will be shown how recent actions taken without learning from past floods had led to damages that earlier generations would have avoided. A comprehensive chronological description of the Elbe flood in Saxony is given in the report Freistaat Sachsen (2003) of February 2003, which consists of two parts: one part is the official documentation of the damage on the rivers in Saxony, and the second one is a hydrological assessment of the flood and its causes.

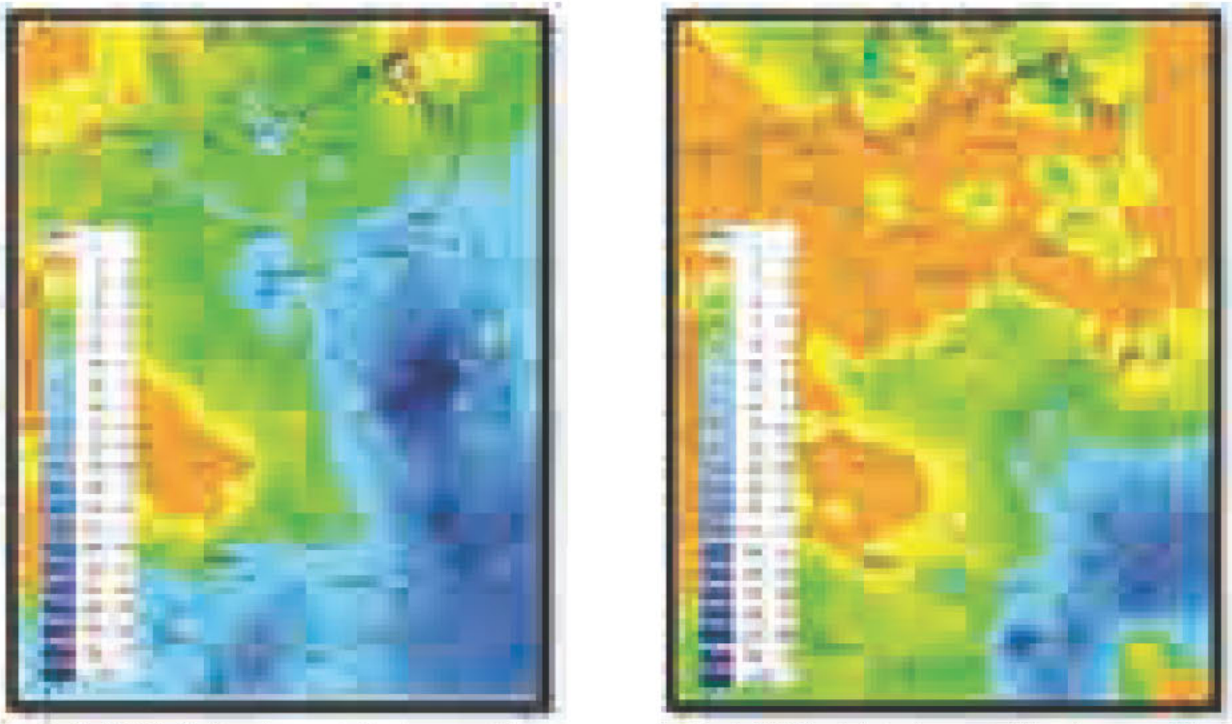
2.1 Weather for August 2002

On August 8 2000 a typical but extreme weather pattern of the type Vb (according to the German Weather Service Classification, Gerstengarbe, 1993) occurred. A cyclone generated over the North Atlantic north of England send a weather system over the Mediterranean, where it saturated with water and moved northwards, passing through the gap between Alps and Carpathian mountains to reach the Bohemian plateau, where it was blocked by cold air from the north, causing heavy rains over the Czech Republic and South East Germany. The rain fell on a soil which had been partly saturated by rains in July and August. During the days from August 6 to August 8 rainfall amounts of up to 140 mm were observed in the region, as shown in Fig.2a, with rainfall intensity centers in Bavaria and Central Austria, where heavy flooding occurred.

For the Elbe catchment the major thrust of rainfall occurred through a second depression following the first one, with even heavier rainfall during the next few days, from August 8 to August 13, as shown in Fig.2b. In many places highest ever observed 24 hr. rainfall heights occurred - typically, Dresden 158 mm, exceeding the previous high of 78 mm by more than 100%. The maximum observed rainfall of 312 mm height occurred in Zinnwald-Georgenfeld south of Dresden, exceeding the maximum 24 hr value (260 mm) ever observed before in Germany. Also, during the same period the north east of Austria and the central part of the Czech Republic around Prague had another extreme rainfall period. A detailed description of the weather and rainfall situation is given in Ulbrich et al. (2003a and b)

2.2 The Floods of August 2002

The result of these rainfall events was extensive flooding in South and East Germany, in the Czech Republic, and in Austria. In South Germany, in the State of Bavaria floods occurred mostly on the Danube and its southern tributaries. The southern tributaries of the Bavarian Danube carried floods up to exceedance probabilities of 1 in 100 years. Peaks in this area generally occurred on the 13th of August, indicating that rainfall from the rainfall event of August 6 to 8 was mostly saturating the soils of the catchment. Fortunately, communities along the Isar, the major tributary river of the Danube on which the city of Munich is located, were effectively protected by the Silvenstein reservoir which filled up with an inflowing discharge of 530m³/s and released only 30m³/s into its downstream channel. Further along on the Danube, the city of Passau, at the confluence of Inn and Danube, saw the highest water level since 1954, with an exceedance probability of about 1 in 50 years.



a. Rainfall heights August 6 - August 8 b. Rainfall heights August 10 - August 13

Figure 2 Rainfall heights on Central Europe August 6 to August 13
(Source: German Weather Service, DWD, 2002)

Since the storm moved from south to north, it crossed the Danube over a wide reach covering eastern Bavaria and the Central part of Austria. Floods in the Danube caused by the German tributaries were somewhat spread in time. However, because widespread inundations (a total of about 320 km² were inundated on the Austrian Danube) reduced flood levels from upstream reaches, the river responded strongly to the high local inflows from the tributaries, so that peaks of the Danube flood in Austria occurred almost everywhere at the same time. For example, the small river Kamp east of the city of Linz suffered the highest flood ever observed in history - about 1000 m^3/s, which is much higher than the 100 year flood - estimated at about 500 m^3/s. As a result the Danube flood in Austria had two very well defined peaks, one on August 9 due to the first rainfall event (which was particularly disastrous for the Danube region), and the other on August 14 with a maximum all along the Danube of about 11,000m^3/s. The flood did no damage to the city of Vienna, because the city has been well protected by a bypass channel parallel to the river, but further downstream in Bratislava the low lying part of the city were flooded.

The passage of the storms northward brought heavy rains on the Ore Mountains (Erzgebirge), on the border between East Germany and the Czech Republic, and on the basins of the head waters of the Elbe River. In the Czech Republic, northern, southern and central Bohemia and Prague were seriously affected, from 10 August onwards. Severe flooding of the Vitava/Moldau basin in the Czech Republic occurred. More than 440 communities in the Czech Republic were affected by the flood, 99 were fully under water. A state of emergency was declared in these areas, plus the Pilsen and Karlovy Vary regions. The city of Terezin was also flooded forcing the evacuation of 4,000 people. The old part of the city of Prague could be saved by means of sandbags and barriers, but lower parts of the city were flooded by a water level that was 7 m higher than normal. For three month the subway was under water, and the suburb of Karlin had to be evacuated part of a total of about 200000 persons in the country. Downstream of Prague a lake was generated before the narrow gorge through the Ore Mountains at Usti nad Laban of the Elbe River, from where the river entered into the State of Saxony in Germany.

Table 1: Flood of August 2002: Inundated areas in the State of Saxony *(Saxony Institute for Environment and Geology, Freiberg, August 2002)*

Basin of main river	Length of rivers (km)	Inundated area (ha)	Types of land use (ha)			
			Settlements Highways	Agricultural lands	Pasture land	**Forests**
Weiße Elster	88	676	136	218	244	**78**
Mulde	117	10754	943	6560	2368	**881**
Zwickauer Mulde	710	2283	964	664	249	**406**
Freiberger Mulde	607	4608	1320	1691	654	**943**
Elbe	1015	18957	4370	10848	2732	**1007**
Schwarze Elster	333	1112	100	775	157	**80**
Total	**2864**	**38390**	**7833**	**20756**	**6404**	**3395**

Very extensive damage occurred in the German States bordering the Elbe River. Three German States were especially affected. north of the Czech Republic and separated from it by the Ore Mountains is the State of Saxony, with capital Dresden. The State further to the north is Saxony-Anhalt, with capital Magdeburg/Halle. Both these States have common borders along the Elbe River with the State of Brandenburg, with capital Potsdam. In Saxony numerous dikes broke and large riparian areas were flooded, more than 380 km² were under water. Most of this was agricultural lands, as is indicated in Table 1. The largest damage occurred in the city of Dresden, which saw a flood of a magnitude never recorded before. Three different causes of damage are identified. First were flashfloods in small Elbe tributaries from the Ore Mountains. Small rivers Weisseritz and Müglitz upstream of the city of Dresden became torrents. Although a number of small reservoirs exist on these rivers, they could not prevent most of the flooding of downstream areas. 18 reservoirs were filled before peak floods hit, many of their spillways overtopped almost at the same time, and afterwards the reservoirs proved to be ineffective for further flood protection. On 4 dams even the spillway capacity was exceeded, and determinations of flood frequencies showed that the floods for 6 reservoirs exceeded the statistical recurrence interval of 10000 years, and only the freeboard prevented overtopping. (Freistaat Sachsen, 2003a). A small dam in the Müglitz catchment broke, fortunately without causing much additional damage. A report by the Sächsische Talsperrenverwaltung, the agency that operates the reservoirs in Saxony, claimed that more than 50% of the flood waters were retained by the reservoirs of the system - among them one of the largest reservoirs with a capacity of 14 Mio m³ which had been emptied for repairs and could retain all flood waters from upstream.

The second cause of damage is floods from the Elbe River, due to the rainfalls on Czech territory. A steady rising of the water level began on August 8, which led to a small peak on August 11 at the Elbe gage in Dresden. With onset of heavy rains of the second storm, due the Ore Mountain tributaries the water level of the Elbe River began to rise again, reaching on August 14 a peak that exceeded the mark of 7m above gage zero, which indicates the state of disaster. (A serious problem was that the original forecast for the extreme water level proved to be off by more than 2m - very likely caused in part by a stage discharge relationship for Dresden which did not reflect the depositions which had occurred in the river during the last 50 years - see DKKV, 2003). After another day the flood wave from the Czech flood began arriving, leading on August 17 to an unheard of level of 9,4 m above gage zero - as compared to 8,77 m, which occurred in 1845 and was the highest level ever observed (the highest level in the 20-th century was 7,78 m, observed in March 1940). The extent of flooding on the Elbe is evident in Fig.3, which is a satellite image of the Dresden area before (top of Fig.3), and during (bottom of Fig.3) the flood. A total of 3500 ha were flooded, of which 135 ha was industrial area. The large flooded area on the right includes complete inundation of the suburb of Röderau Süd, which had only been settled during the 1990. Houses were under water and extensive damage occurred for all occupants (see 5.3.6).

The third cause was the ground water level, which was raised by infiltration in inundated areas and by bank infiltration along the banks of the rivers and creeks. Fig.4 shows the water table as function of time near the Elbe River. The sudden rise of the groundwater level and its long persistence uplifted basement floors and generally wetted foundations of many houses with long term losses of stability and goods in basements.

On the east side of the Elbe, in the State of Brandenburg the town of Mühlberg, due east of Leipzig, proved to be a very critical point. A dike section of about 180 m was weakened so that its air face slope failed, and only the core held the dike. The town had been evacuated, but by combined actions of army soldiers and other rescue teams it was possible to prevent breaking of the dike and thus extensive flood damage in many villages.

The Elbe River carried the flood downstream into the State of Saxony- Anhalt, where near the city of Dessau it is joined by the Mulde with its heavy flood waters from the Ore Mountains. The Mulde River with its tributary creeks caused particularly extreme damage: flooding small riparian communities and destroying a large number of shore protection works and dikes. Pictures of flood waters rushing through the small city of Weesenstein were especially dramatic and went over all TV screens of Germany and other countries. Much publicity was given to damage in the small town of Grimma on the Mulde: a part of the river rushed through the main street of the town, destroying buildings right and left which just recently had been renovated after many years of neglect in DDR times. Further downstream, the threat to the large deposits of radioactive ore spoiling near Bitterfeld (south of Dessau) could be avoided, but the Mulde flood increased Elbe floods downstream of Dessau, and led to floods in the State of Brandenburg, on the other side of the river.

The State of Brandenburg had experienced a large flood on the Oder River in 1997, with had caused huge damage, mostly in Poland. In the aftermath of this disaster extensive flood protection works had been started in the State. Among these was a large retention basin, the Havel polder on the river Havel (north of Stendal). The Havel is a tributary of the Elbe River, in whose catchment the cities of Potsdam and Berlin are located. This polder had been completed recently. It proved to be very effective and released the pressure on the whole downstream part of the Elbe. The importance of this polder for the cities and village downstream was impressive, as no larger damages were observed downstream of this polder. By flooding this polder it was possible to reduce the flood level by some 50 cm (MLUV, 2004). However, there are considerable side effects and environmental damage: because under normal conditions the polder was used for agriculture, thousands of farm animals had to be evacuated. Also, long retention of flood waters in the polder gradually depleted the oxygen content of the water and caused extensive fish kills.

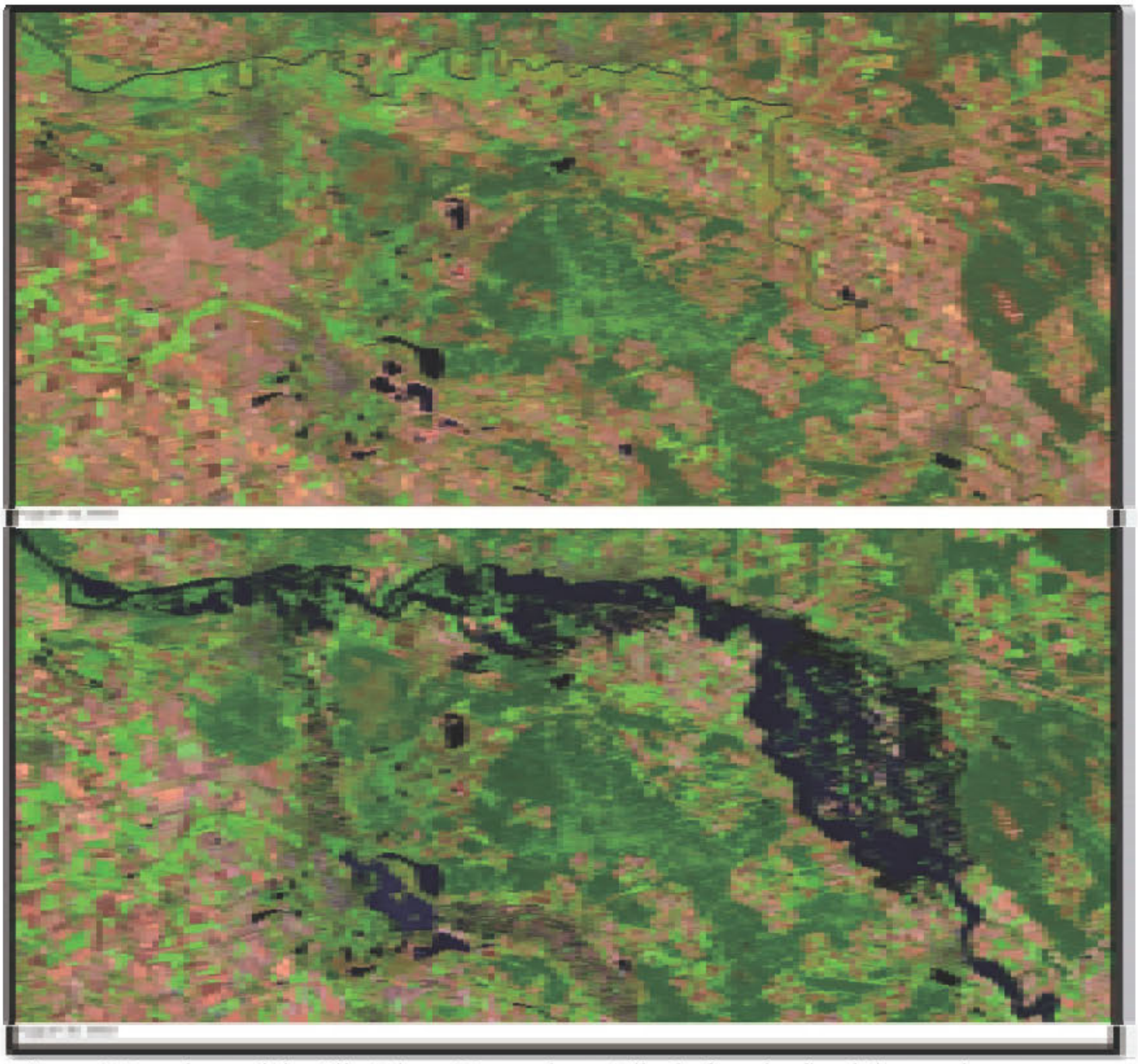


Figure 3 Dresden and the Elbe River. Upper photo: Elbe before the flood, lower picture: Dresden on August 20 2002, with flooded areas sown in dark blue.
(Source: http://visibleearth.nasa.gov/view detail.php?id=3584).

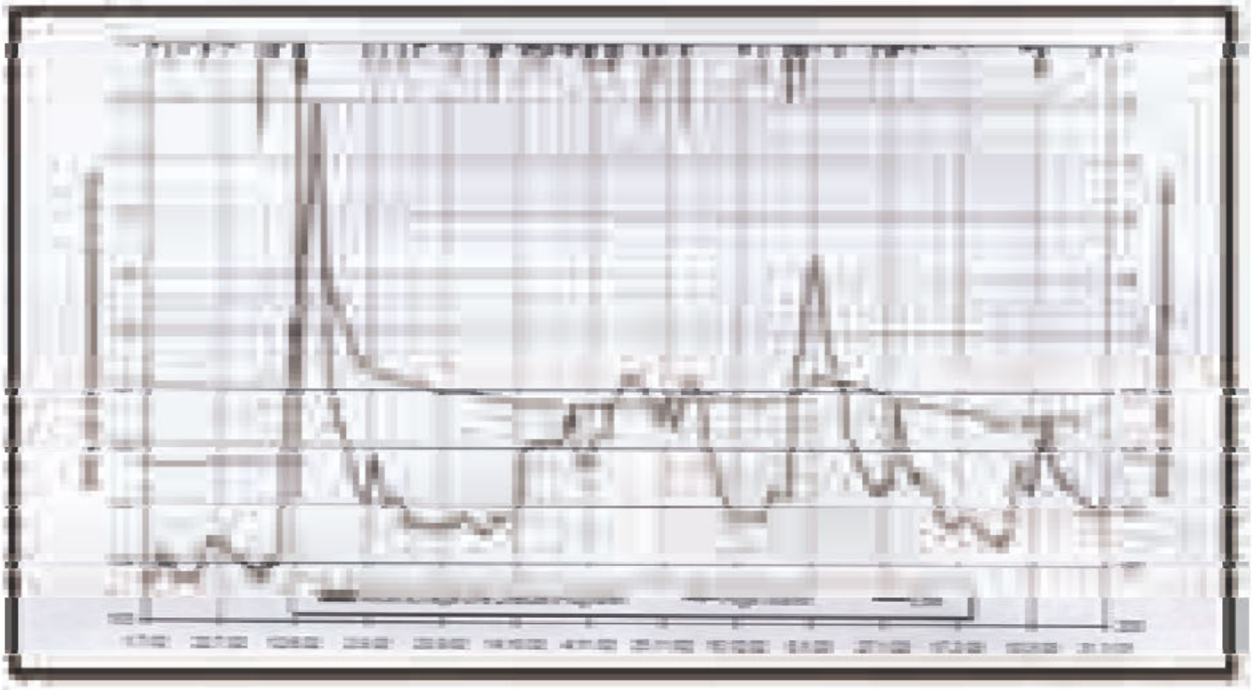


Figure 4 Groundwater level and river level at the Elbe River as function of time

2.3 Case Studies

Two case studies shall be reported, which show not only the type of disasters encountered, but also stress the man made impacts which contributed to the magnitude of the disaster. It became evident that in many cases modern concepts of land development had been implemented without giving due regard to natural conditions. In particular, regional planning had been done traditionally only from the point of view of making room for new settlements and transportation routes.

2.3.1 Case study 1: Damage in Dresden due to the Weisseritz flood.

The Weisseritz is a tributary of the Elbe River from the Ore Mountains which flows through the city of Dresden. It is formed by the confluence of Rote Weisseritz (with one reservoir in its course) and Wilde Weisseritz (with two reservoirs). In Dresden, the river had been diverted to make room for the railroad system. It had been turned to the left to flow around the west side of the old city center and into the Elbe, as shown in the city map of Fig.5. On August 12 the Weisseritz experienced a tremendous flash flood, which was only partially dampened by controlling releases over the spillways of the reservoirs. In Dresden, the flood wave overtopped the banks of the artificial canal, shown on the left of Fig.5, and rushed into its ancient bed, passed through heavily populated districts and along the west side of the old city, thereby flooding the railroad system   it travelled so fast that many trains could not be moved out of the main station. It also flooded the west part of the old city. The magnificent Dresden Opera house (Semper Oper) was partly under water, and so was the world famous art museum, in the former royal palace "Zwinger". Invaluable cultural treasures stored in the basement of the museum could only be saved by a dedicated effort of staff and many volunteers. In total, the damage average to city property of 25 €/m² in this area was much higher than in other damaged areas of the city (an average of 11 €/m²).

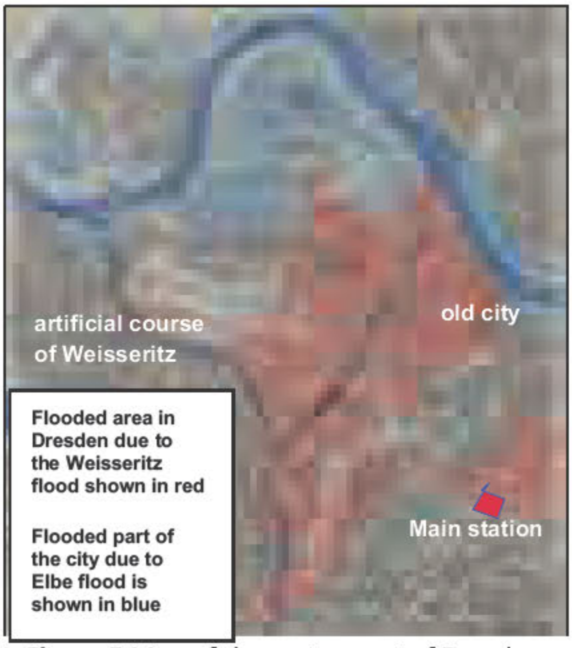


Figure 5 Map of the center part of Dresden

Because the damage in Dresden was caused by diversion of the river from its old course (the branch in Fig.5 to the right), the immediate concern was to improve the local situation at the point where the old river course is diverted into the artificial course. (The Technical University of Dresden is charged to develop a better diversion structure for this, in particular to eliminate the sharp bend in favor of a much smoother transition. The situation was studied by means of a physical model in the hydraulic laboratory of the University, and the improved design is being implemented at this time.

In order to improve flood management of the region through a "bottom up" approach, the "Weisseritz Region" action was initiated in March 2004, which offers a platform for discussion of all issues that have to do with flood management. It was created following a proposal of the Leibniz Institute for ecological regional planning (Leibniz-Institut für ökologische Raumentwicklung e.V. http://www.ioer.de) and supported by the State of Saxony. 26 communities, agencies and science institutions existing in the region got together to inform partners of local plans and discuss plans for a basin wide and coordinated flood protection system. As a first result a concept for basin wide flood protection has been prepared for a small tributary of the Weisseritz, and a brochure is published which informs people of the region about measures for flood protection and also advises on what to do in case of flood emergencies and for preparing for potential floods (see Appendix 1)

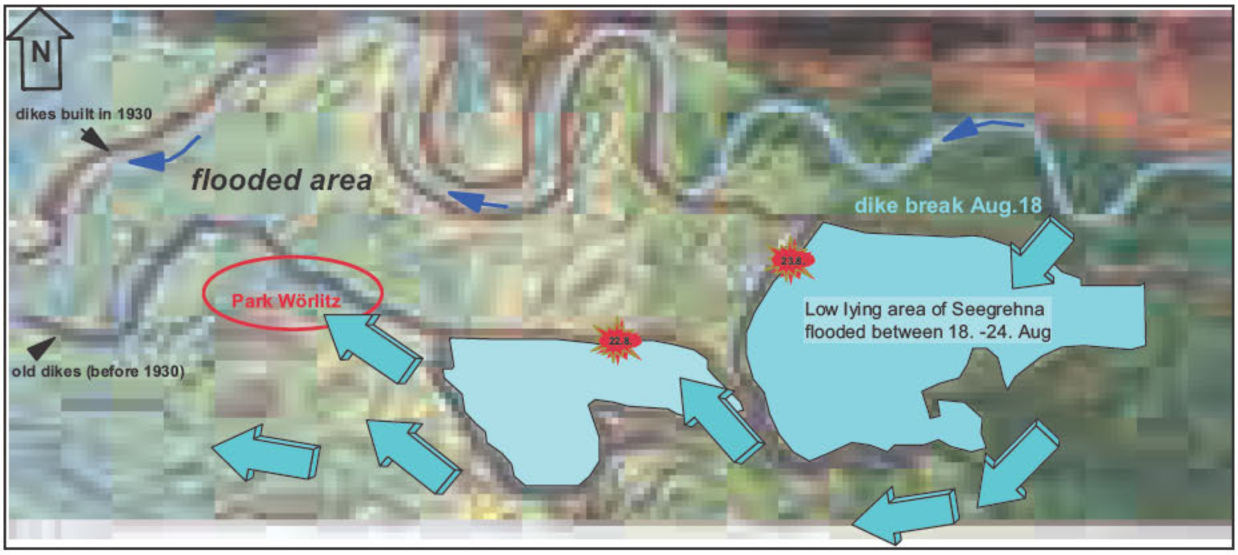


Figure 6 The Wörlitz area of the State of Saxony-Anhalt, on the Elbe River between Dessau and Wittenberg *(adapted from Niedermeyer, 2005)*

2.3.2 Case study 2: Wörlitzer Park

Among the damaged areas the UNESCO Cultural Heritage "Wörlitzer Park" located between Wittenberg and Dessau (see Fig.1) stands out. This fabulously landscaped park from the 18 and 19 century was built into what was formerly a frequently flooded wet land. By separating wetlands from the river by means of a dike, the Dukes of Dessau were able in the 19th century to create a magnificent park, with lakes and creeks formed by using the old water courses, which the gardeners crossed by numerous bridges of different design - from ancient roman bridges to modern steel structures.

The Park was flooded, due to a sequence of unfortunate circumstances. During the maximum flood on August 18 a dike about 20km upstream of the park broke, and the area shown in hatched form on the right in Fig.6 was flooded. Water flowed around the village of Seeghrena and first formed a lake around this village. When the level was high enough, the flood first overflowed the old dike north of Rensen, inundating the eastern cross hatched area, and then flooded across a small ridge to the west and reached the Wörlitz dikes from the supposed air side. Then the flood level in the Elbe River dropped, leaving the water caught in the area behind the dike. The Elbe dikes and the same ridges, which earlier had resisted flooding, prevented water to flow back when the water level subsided. To relieve the pressure of the water from the air side of the dikes, a part of the dike was blasted. First in the left cross hatched area; and when that proved inefficient, the dike north of the right retention area was blasted also, with more success. The German Technical Disaster Relief Agency (THW) and other persons worked hard for a full month (up to September 22) to get the water down and reduce damages.

The case of Wörlitz is particularly instructive as it shows clearly the disadvantages of moving dikes too close to the river. The old dike line (shown in dark) had been constructed by Dutch engineers in the late 18th and early 19th century, who avoided two important shortcomings of the new dike line constructed in 1930: first of all, they left room to the river for flooding its natural flood plain. But they also made their dikes to follow the old shore lines of ancient branches of the river, thus avoiding the problem of building on soft underground at intersections of dikes and ancient water courses, at which points during the August 2002 flood very serious weakening and breaking of the dikes occurred.

3. RELIEF AND DAMAGE ASSESSMENT

3.1 Relief Actions in Germany

The Federal Government has two semi-governmental organizations for providing help in national (or large local) emergencies. There is the THW (Technisches Hilfswerk, German Technical Disaster Relief Agency), which has a small government supported leadership, and a large number of volunteers, who are called on to give technical assistance. The second is the DRK (Deutsches Rotes Kreuz, German Red Cross), structured in the same way, for humanitarian assistance. In addition, there are numerous non-governmental organizations which raise private funds and provide local assistance. Also, hundreds of volunteers - technicians, carpenters, owners of heavy earth moving equipment with their staff - came to help from all parts of Germany. In addition, army volunteers from many neighboring and NATO countries were helping to fight the consequences of the flood, among them 400 soldiers from the United Kingdom, USA, Poland and France. The Russian Ministry of Disaster Management (EMERCOM) sent an IL-76 cargo plane with two heavy duty amphibian vehicles and 14 specialists (Freistaat Sachsen, 2003a). If it had not been for the many volunteers from many different countries and other parts of Germany, from many different professions and skills, the damage would have been even greater.

The German Technical Disaster Relief Agency (THW) had a total of more than 24000 persons in action during the flood, of these only 582 permanent, the rest temporary (usually unpaid) and well trained voluntary helpers, who worked for more than a total of 3 Million hours, at a cost of about € 50 Mio. Wherever technical knowhow was required, their competent help was gratefully accepted: pumping, defending dikes, repairing electrical lines and solving small local technical problems. They brought in heavy earth moving equipment; then provided transportation services and emergency water and electricity supplies, and also helped in evacuation and coordinated the distribution of sand bags (more than 34 Mio!). These workers were supported by a large deployment of 25,000 soldiers of the German Bundeswehr (German Armed Forces). Furthermore, the German Red Cross had more than 5000 emergency helpers in operation the largest relief operation in the history of the DRK. According to its mission, the DRK was mostly responsible for personal relief - providing medical support and medical supplies, installing and operating emergency hospitals, helping with shelters and others. A comprehensive report by the DRK (DRK, 2005) exists. THW, Bundeswehr and DRK assisted State employees in all flood endangered states. These included fire brigades and city workers, members of the Dam Administrations of the states, and Federal Officials responsible for the functioning of inland navigation. More than 400000 people in the Czech Republic, in South Germany and in East Germany had to be evacuated. It required a tremendous organizational effort, first to get the people to move out of the endangered area, and then not only to help the people but also to deploy and feed them, as well as the large numbers of non-local volunteers and helpers.

3.2 Funding of Relief Operations

Already during the disaster large quantities of money had to be made available for relief and rescue operations. In Austria relief costs are listed as 35 Mio €. For the Czech Republic, no separate determinations of total relief costs were published, although the Government lists 34 Mio € for covering the costs of rescue work and direct damage compensation. In Germany, the Federal Government spent a total of about € 260 Mio from the reconstruction fund of the European Community (which provided a total of € 444 Million) to finance its operations, which included the cost for the THW and of Federal Agencies involved in relief work (BMVBW, 2005). The additional costs for communities and states are also huge, but no cost figures are readily available at this time.

For financing its activities the German Red Cross (DRK, 2005) set up an emergency fund and asked for donations from the German public for the victims of the flood. A total of 147 Mio € from more than 1.3 Mio donors were used for relief and reconstruction operations in the flood zones. The money was distributed in 5 categories. Support to individual households and private persons, Support to small businesses, Support for rehabilitation of displaced families (sending them to vacation places to relief mental anguish and hardship), Support for medical institutions and social agencies, as well as Support for some smaller activities: among them financing the study DKKV(2003). The operation went in three phases: First was providing immediate relief consisting of help operations by DRK members, emergency monetary assistance for people in need and others. The second phase was the distribution of funds to damage repairs of private households and small businesses (if other support was not sufficient) for which a special organizational office had to be set up. The third consisted of other activities intended to assist in avoiding future disasters of the kind experienced in Dresden and other places on the Elbe River. International assistance was given by other Red Cross societies from other countries, and the German Red Cross also provided assistance to other countries on the Danube

3.3 Problems of Flood Management during and after the Flood

The large flooded area caused extensive problems in the organizational structure of the emergency handling systems in the countries. The German States were particularly vulnerable, because of two reasons. First, all of them are in East Germany, and rebuilding of East Germany after reunification of East and West Germany concentrated predominantly on improving the infrastructure required for economic development. Large investments had been made in highways, railroads, inland canals and urban renewal, and only little effort was invested in dike strengthening and maintenance. River training. if considered at all, mostly focused on river ecology and wetland restoration[1].

The second reason actually has the same root cause: during the last decade priority was given to establishing democratic administration structures in East Germany, and little or no attention had been paid to improving the organizational structure for disaster management. As a consequence administrators on all political levels were poorly prepared to handle a disaster of the magnitude experienced in August 2002. In addition, there was a general problem in all of Germany. After break down of the Russian Federation, a military threat was no longer perceived, and warning measures (such as sirens) had been abolished in most parts of Germany, and the budget for relief organizations, such as the THW had been drastically shortened.

As a consequence, there was a lot of confusion on all levels, and lack of leadership was felt everywhere, which was exacerbated by lack of reliable forecasts and warnings. A dramatic description of the initial response to flooding of small rivers from the Ore Mountains was given by the fire chief of the city of Düsseldorf, Cimolino (2003), to quote:

"The strong rains in the Ore Mountains caused small creeks to become torrents in very short time, giving no time to warning. Unprepared fire brigades had to react, and soon were no longer able to contain the floods. They asked for help from neighboring communities, which frequently could not help because they were fighting their own flood (or traffic) problems. Furthermore, the rivers eroded banks and flooded highways, which usually run alongside rivers and creeks, thusimpeding access for relief forces. Further increases in water level and velocities destroyed city streets and highways, and in many cases houses in the path of the flood wave. Local command centers - if they existed at all - requested help from outside, including service by THW and Bundeswehr (Helicopters for saving lives). These organizations were flooded with requests, and usually could react only after many hours.

Further downstream, at the confluence of creeks and rivers massive inundations occurred, cities were threatened and often flooded, many roads which were deemed safe, were no longer accessible, and relief vehicles, unless they were of off road type, had to use detours of many km.

[1] A decision had been made in the early nineties to leave the Elbe in as natural a state as possible. During the years of two Germanys, the lower Elbe had been the border between East and West Germany. The lower Elbe and the city of Hamburg were cut off from the inland canal "Mittelland Kanal" - which formerly connected (and now connects again) the city of Berlin with the Ruhr district. Downstream of the city of Magdeburg, the Elbe had been part of the inland canal system. The West Germans reconnected Hamburg with the Ruhr District by building a new canal (the "Elbe Seitenkanal") on the westside of the border parallel to the Elbe River, which connects to the Elbe River on West German territory some 50 km upstream of Hamburg. In the 40 years of two Germanys the part of the Elbe River upstream of the junction had reverted to a very natural state, and after reunification it was one of the objectives of ecological planning to keep it that way. As a consequence, not much attention was given to river improvement, and little investments had been made to improve the safety of the dikes along the Elbe River or its tributaries.

Many threatened cities abandoned official channels and fire chiefs turned for help directly to cities in other parts of Germany and to neighboring non-threatened communities.

…… The interest of the media increased exponentially with severity of floods, concentrating on some spectacular sites, either places with good accessibility (large cities) or with large pittoresc destructions, with the result, that external humanitarian assistance was concentrated on these areas (causing in some cases an oversupply of relief goods and relief personnel, which was badly needed in other areas less well covered by the media). With presence of media assured, the usual flood tourisms started. Impending national elections added to the political interest. Ministers, Prime Ministers, and finally the Chancellor appeared on the scene. Many hands were shaken, etc - requiring a disproportional deployment of local politicians, police, and relief personnel - so much so that the major of Dresden publicly complained. Among all this sensationalist coverage, there was initially no authority able to give clear status information to the media. Only after some time did Bundeswehr and THW start to provide accurate information………"

The critical assessment of Cimolino was the rather unguarded first impression of an experienced expert, which was confirmed - with less emotion - and detailed in the so called Kirchbach Report. Immediately after the flood Prime Minister Milbrand of Saxony commissioned an independent team of experts to draw conclusions from the flood disaster and to recommend measures and actions to prevent future disasters of the magnitude of the August flood. The team of experts, headed by former Army General von Kirchbach, produced a report (Kirchbach Report, 2003), in which much was listed what went wrong. The report investigated critically the three levels of flood management.

First, there is the local level, usually fire brigades and political leadership of communities or villages, where the actions for relief and rescue took place. The report stated that in general local emergency teams were understaffed, and not enough experts were at hand to support the well functioning fire brigades (whose members are voluntary and unpaid). Fire brigades usually were well equipped and well informed about their duties, but others, which were not usually involved in disaster management, were less efficient.[2] Although in many communities there were plans for flood management, the plans were not followed, or were incomplete. Locally, the responsible persons where often poorly prepared, and in many cases did not know what to do - and often did the wrong thing. For example, as is illustrated in case 2 for the Wörlitz Park, the dam for relieving flood waters was blasted at the wrong place. Second is the intermediate regional level, where a disaster management centre exists for coordinating local activities and managing the input from external sources. The third is the state level, where statewide consequences and help actions had to be assessed and state wide deployment of help actions had to be (but were not) planned.

Another comprehensive survey, which included University experts, was made by the German Committee for Disaster Prevention (DKKV), which responded immediately to the flood by installing a working group to identify weak points of the flood management strategy as applied to the Elbe flood (DKKV 2003a). The working group produced a report (DKKV, 2003a)

[2] For example, hospitals were prepared to take in patients from other hospitals, but they had no plans for evacuating their own buildings in flood prone areas. Or help that came in from all over Germany and beyond occasionally was poorly integrated into local activities. As an example (source:http://www.weisseritz.de/berichte.html), a badly needed fire brigade with 70 vehicles from Bavaria was stranded in the Dresden Airport for 48 hours without finding anybody to tell them where they could help.

in which a series of major short comings is identified, which mostly strengthened conclusions from the other reports and reinforced the conclusions of the Kirchbach Report . This team also produced recommendations for future research to clarify issues that needed scientific study. A short version of their report in English is available (DKKV, 2003b).

3.4 Damage Assessment

Reconstruction after the flood disaster started with an assessment of damages and securing funds to help people to rebuild their houses and businesses, as well as to reconstruct the damaged railroads, highways and other infrastructure measures. As is mentioned in the introduction, the total losses caused by the flood in Central Europe reached more than 13 Billion € in Germany alone. To this, one has to add losses of at least 7 Billion in Eastern Europe, so that the total damage exceeded 20 Billion €. This is the largest natural disaster ever in this region. The actual damages are not yet fully known; partly because flood damages from long term effects of the flood are revealed only much later, and partly because intensive evaluation of the disaster management agencies showed that not all claims and damage reports were justified: in many cases damages had been reported which could not unanimously be assigned to floods. This included some infrastructure projects of cities and communities, which were necessary even without floods, or damages were caused by extreme rain and not by flooding, and thus were not eligible for relief funds. A considerable organizational structure had to be set up to handle claims at different levels. For example, the highway department of Saxony had to inspect 533 sites in order to verify the justification of the claims for 533 measures. As a consequence, the final damage compensation had three different categories: claimed damages, justified damages, justified damages minus compensation through donations, insurance and self help (in this way, some of the donations by the public ultimately helped the Government, this certainly was for many of the donors not the intended use of their gifts). Most of the measures had been finished by the end of 2006, so that life has returned basically to normal.

3.4.1 Czech Republic

The damage volume exceeded 3.3 Billion €, which probably does not include indirect costs. For example, the flood heavily damaged the National Technical Museum archives in Prague. Almost 90% of the museums archives were flooded, among them the world-known Architecture Archives, which include complete heritage and documentation of the designs of the top Czech architects of the 19th and 20th centuries, but also many designs and original works by architects from all over the world.

The state budget and off-budget funds provided € 527 Mio on flood-damage removal, of which € 341 Mio was from the state budget, including a loan from the European Investment Fund. The European Union granted relief money of € 129 Mio, which was distributed as follows: 34 Mio for covering the costs of rescue work and of direct damage compensation, and € 72 for rebuilding flood damaged areas, with each region to get 3.28 pct of the overall damage it suffered. Repairing damage to state property requires € 9 Mio. Among those to draw on these funds are water and forest management companies. The use of the remaining € 14 Mio is to be decided by the government later.

3.4.2 Austria

The damage caused by the flood in Austria is estimated at roughly 3.2 Billion €. Noteworthy is the cooperative effort of the Austrian Governments Institute for the Environment (www.umweltbundesamt.at, Bundesumwelt- amt), in cooperation with the University for Rural

Development (Universität für Bodenkultur, "BoKu", www.boku.ac.at) to document and to draw lessons from the flood. This document was prepared by Professor Habersack of the BoKu right after the disaster (Habersack & Moser, 2003) and included a report on subdividing the damages into the categories shown in Table 2. The damages include estimates of indirect costs after the flood (including about 180 Mio € production losses).

Table 2: Damages in Austria of different economic categories

Categories of damages :	**Mio €**
Private property (including businesses)	1420
Infra structure	573
Long term direct and indirect damages (estimate)	687
Losses in productivity	180
Water resource damages (on rivers, canals, and mountain protection)	78
Agriculture and forestry	71
Damages to urban water supply and sewage disposal systems	41
Cost of relief and replacement of equipment	35
Damage to Government property (federal government)	29
Total:	3114

3.4.3 Germany

After the flood, a tremendous wave of solidarity with the victims set in. Donations came of many Mio € from all parts of the population. International help also arrived. For example, the Swiss Government donated 50 Mio Swiss Francs, some of which was used to help homeowners to avoid damage to the environment or remove spillage from flooded fuel tanks. But the biggest contribution came from the German Government and thus from the German public, through the enthusiastically supported commitment of the Federal Government to fully compensate everyone for incurred flood damages (BMVBW, 2005). Such a generous compensation is not usual in Germany. There was a political purpose accompanying this compensation. It was to assist in further reconstructing East Germany, where many of the damaged small businesses and homes had been built or remodeled after reunification of Germany, mostly using up all of the resources of the owners, who faced complete destruction of their livelihood after the flood, with no reserves and no credit by banks and other financial institutions. Right after the disaster and after a very preliminary assessment of the damages, the Federal Government set up an emergency fund titled “Aufbauhilfe” (reconstruction assistance), to be administered by the Kreditanstalt für Wiederaufbau (federal bank that had originally been founded after the second world war to administer reconstruction programs and foreign aid). The emergency fund had a volume of 6.5 Billion €, obtained from tax money by postponing a planned tax cut by one year, plus an extra amount of 470 Mio € of regular taxes- plus 185 Mio € of EU money. There were three categories of relief: Program "Reconstruction of infrastructures for communities"[3] (1.64 Billion €, with 845 Mio € Federal funds, for 711 communities), Program "Infrastructure reconstruction for rural areas" (730 Mio €, with 316 Mio € for water course reconstruction, 414 Mio € for rural highways), Program "Reconstruction of private homes"(923 Mio €, half federal and half state financed, for about 23000 housing units). In addition, some smaller programs were established

[3] The figures refer to expenditures until 1.1.2004 (Bundesregierung, 2004). Some later costs are still to be expected, and shall be financed through regular budgets.

for federal highways and railroads, and for buffering long term damages due to crop failures and other flood related causes. This support came in addition to insurance compensations of 1.8 Billion € (Thieken et al., 2006).

In 2003 the State of Saxony presented a report to the state assembly in which not only the course of the flood was described in great detail, but also the actions that were taken after the initial relief phase. It forms the basis of the assessment. Total damage costs for the state were estimated at 6.2 Billion €, with the breakdown of costs shown in Table 3.The report stressed that these costs are only direct costs, not included are indirect costs due to loss of working hours and missed production goals, as well as hidden costs, which are recognized only after much of the damage has been removed, such as geo-hydrological damages: landslides due to damage to agricultural lands caused by long lasting raised groundwater levels, or such as damages to buildings that became apparent long after subsidence of the flood. These hidden costs are estimated to add another 200 Mio € to the damages.

Table 3 Total damage in the state of Saxony

Damage to	**Mio €**	**Percentage**
Family dwellings	1706	27.5
Businesses	1420	22.9
Infrastructure of communes	1287	20.8
Infrastructure of state and federal government	928	15.0
Household inventories	529	8.5
Disaster relief and assistance	136	2.2
Infrastructure of others	111	1.8
Agriculture and forestry	70	1.3
Total	**6196**	**100**

More than half of the total came from damage to family dwellings and damage to a total of about 12000 small businesses with a total of more than 110000 employees. Particularly significant are losses to power companies, which reported damages of 118 Mio €. Damage to household goods reached a level of 529 Mio. €, of which about 250 Mio € was covered by insurance. This is a high percentage, which is a result of the fact that the German Democratic Republic had mandatory insurance against natural disasters provided by state insurers. After 1999 the policies had been taken over by private insurance companies, adding a clause that allowed dropping insurance against floods. Most citizens had not changed their policy, so that large insurance claims resulted.

The other half is damages to infrastructure and public installations. To be noted is the large cost of relief, with 136 Mio €, although it represented only about 2% of the total damage. The state agencies reported total damages to government installations of 928 Mio €, of which some 590 Mio€ were damages to water courses, including damage to 35 dams and 185 km of dikes. 113 Mio € were associated with damage to 170 km of highways and 466 bridges. Damage of 106 Mio € was caused to public buildings, and also Universities and other research institutions suffered losses of about 24 Mio €. The city of Dresden alone suffered losses on public goods of € 760 Mio (Korndörfer, http://www.dresden.de/index.html/?node 9827), of which 30% was caused by backwater into the sewage canals.

Figure 7 Typical damage to the railroads: Zschopau river (branch of Mulde)

The distribution of damage costs is typical for all states in Germany, none of which had to suffer damages of the same magnitude as Saxony. Not included in these figures are damages to institutions and public carriers, such as the Federal railway system, the postal service and others. Typical damages to the railway system included erosion below railroad tracks, as shown in Fig.7 and the partial of complete destruction of bridges, as shown in Fig.8 (The pictures were taken on the Zschopau river, near the city of Chemnitz (see map Fig.1) which is one of the main tributaries to the Mulde river). Hundreds of pictures were taken which showed the extent of the damage to the public, which was also treated to miles of footage of flood films from many different sources. Photos were taken by officials for documentation, by news services from all over the world, as well as by literally thousands of tourists or amateurs who came to look (and in some cases were in the way of relief measures.

A further breakdown of costs and damages showed large variations from household to house household. A telephone survey of about 1700 households by Thieken et al. (2005) yielded some good statistical values to show the large losses encountered, but also revealed the large range of values of damaged houses and of the damages suffered. It was found that the average value of a single family house was 319,000 €, and of a multi-family dwellings 607000 €. Damage to houses ranged from less than 1000 € to more than 60000 €, with an average value of 42100 €. The average value of the household goods was estimated to 58000 € as mean value, with a range from 28000 € to 500000 €, with flood damage to household goods due to the flood ranging from less than 2500 € to more than 25000 €, with a mean value of 16300 €. In a series of studies, Thieken et al. (2005) further subdivided the total costs into different social and damage classes. Reference is made to the original papers (Thieken et al., 2005, Kreibich et al., 2005).

3.4.4 Water quality issues

The largest damage factor associated with pollutants was the spillage of oil and other substances in domestic households. Heating in Germany is largely based on oil as fuel, with most oil containers buried in gardens or stationed in basements. Consequently, spillage was an important factor in the losses. Thieken et al., (2005) indicate the important increase of damage due to such spills in all classes of flood damaged buildings. Whereas these factors significantly increased damage to housing they did not contribute significantly to water quality of ground or surface waters. The most important pollution occurred due to flooding of numerous sewage disposal plants along the rivers Mulde and Elbe. There were a series of episodes of very low water quality - expressed through the oxygen content of the river. The first wave of oxygen level below the critical value of 4 mg/l occurred directly during the flood, when the river waters carried the sewage load and fertilizer effluents from the fields. Other oxygen depleted periods followed, when the flood waters from the fields and polders started to run off. A systematic and careful investigation of the water quality of the sediment deposits on the flooded parts of the catchment (Niedermeyer, 2005) did not show any significant increase of toxic material in the deposits. Elevated concentrations of Cadmium Cd and arsenic As were found throughout the riparian borderlands. However, they were attributable to agricultural practice, and had nothing to do with the flood.

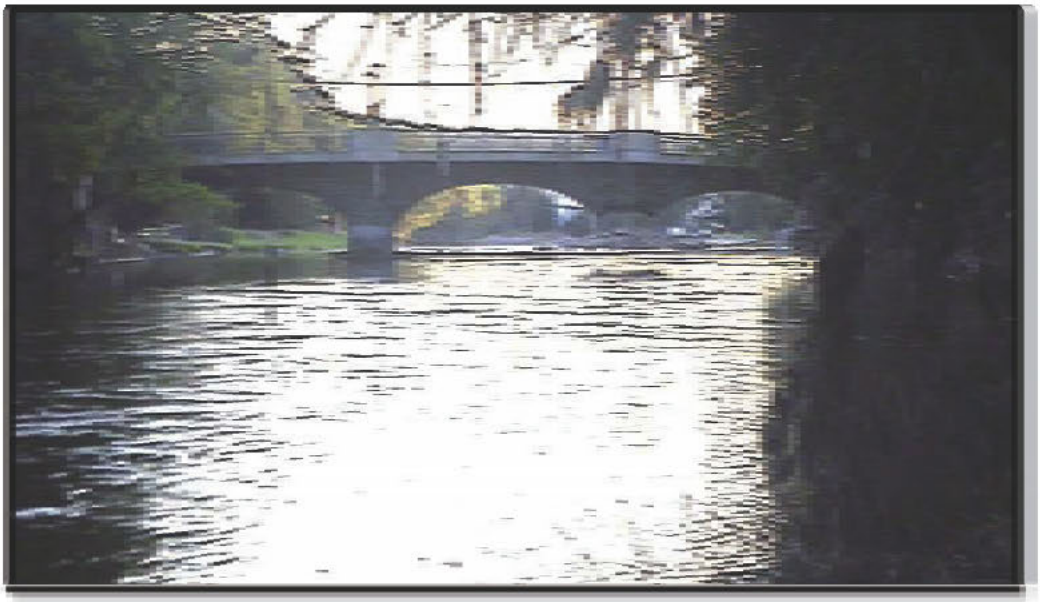


Figure 8 Bridge pier destroyed (near Flöha, on the Zschopau)

4. RECOVERY AND RECONSTRUCTION

The reports of the Kirchbach Commission (2003) the DKKV (2003a) and others led to political actions on all levels. The recommendations of the Kirchbach Report formed the blueprint for actions for the state of Saxony, but it also gave directions to other states which suffered from the flood. Governments and States prepared extensive reports. In Germany, each of the flood affected States made an assessment of flood damage, usually on the level of State Government, prepared by Government staff (examples are the two reports of the Freistaat Sachsen (2003 a & b)). State Government agencies in Saxony had to relate all their activities for future prevention of flood disasters against this report, as was done in the Government Report Freistaat Sachsen (2003a).

Public indignation is one of the driving forces for reconstruction and recovery. It is usual that after a disaster the public demands actions from administration and politicians, blaming the disaster on failures of structures and organizations rather than blaming themselves for living in a flood prone area. Victims will strive to reestablish the status quo ante, houses will mostly be rebuilt as they were before the disaster, and people demand actions for improving their safety without affecting them directly. On the other hand, after a disaster there is the window of opportunity for improving the safety on a large scale. These two opposing strands have to be reconciled. This is also a problem of the Elbe disaster. The least controversial is improvement of the administrations in order to overcome the problems identified by Cimolino (2003). He identified, among others, the following major shortcomings, which will have to be overcome if similar disasters are to be avoided in the future:

1. Early warning was deficient: the warning methods available (sirens, radio communication, cell phones) proved insufficient, because supporting infra-structures were not functioning (i.e. jamming of telephone lines, power failure)
2. Reactions of staff and emergency centers were too slow (no round the clock emergency alert, lack of telephone connections, wrong telephone numbers, not enough personnel for 24 hour service)
3. Lack of clear distributions of responsibilities between federal, state, and local agencies. (Fire chiefs not trained for large scale emergencies)
4. Lack of authority to implement large scale measures which might be locally harmful, but improve the overall situation. (Needed is proper reaction to theft of sandbags etc, no unauthorized local actions should be permitted etc.)
5. Number of emergency response centers is not optimized. (There were too many local centers and too few regional centers).
6. Deficits in communication. (Inappropriate concepts of vertical communication, lack of uniformity of materiel and equipment across German state borders)
7. Lack of training of responsible persons, not enough staff for 24 hour service.
8. Lack of experts (or addresses of expert) for special problems (collapsed buildings, chemical releases)
9. Lack of trust in competence of others, so that no well defined cooperation is planned or takes place,
10. State officials lack logistic experience with large scale operations: such as feeding and housing large groups of emergency helpers, providing service and fuel for vehicles etc (as exists in the Bundeswehr)

Consequently, all recommendations focused on two aspects, as has already been mentioned: administrative problems in handling the disaster, and technical aspects of improving safety of flood protection structures. The most apparent problem was the lack of coordination between different levels of Government - local, county, and state as well as among neighboring communities and states, and between water resources agencies in different states, so that downstream states heard too late what kind of flood to expect. Therefore, a first initiative of the different agencies and administrative units was drawing up action plans for immediate action (reported in Freistaat Sachsen 2003a & b). Among others, the Kirchbach report recommends that a clear chain of command be established basin wide in every river basin. Furthermore, the DKKV report stresses the need for unified equipment, so that parts and components can be exchanged between different organizations.

4.1 Government Response in Germany to the August 2002 Flood.

4.1.1 Reorganizing flood management responsibility.

Floods and flood management is, according to the Constitution of Germany (Grundgesetz) responsibility of the States (Länder). Germany is a Federal Republic of States with a Federal Government. The Federal Government is responsible for all matters that are not local, for example for Foreign Politics, Defense, National and Social Security. All tasks that can be handled locally are generally done by the States. In the field of water resources management, the federal government has responsibility to set general standards, which are to be implemented by the states through state laws and directives. Because of different state laws the assignment of responsibilities within the States is not everywhere the same. Usually, water resources management including flood protection is assigned to the Ministry of Environment (or better, environmental protection) or the Ministry of Agriculture. Flood forecasting for the States is a task assigned to State Institutes responsible for water quality and monitoring (Institutes of Environment).

The discussion after the flood involved many different aspects, and involved many different ministries, both on the federal level and in the states. A primary issue was to distribute tasks among the actors: Who is responsible for flood management? Who has the function to outline flood risk areas? In Germany, spatial planning is a special branch of Regional Development Planning, which is strongly focused on industrial and urban development, transportation systems and supply lines, as seen from the spatial development perspective. On the other hand, planning flood protection is part of Water Resources Planning, and involves hydraulic and other civil engineers in cooperation with civil protection organizations, such as fire brigades and Red Cross. After lengthy discussions, a compromise was established: water resources experts would outline the different zones of flood protection - against the 30 year flood and the 100 year flood, as for example in Austria, and spatial planners would shoulder the tasks of converting these water resources plans into legal documents and operational instructions for city management and the like.

4.1.2 Flood protection strategy of the Federal Government

On September 15, immediately after the August flood disaster, officials of the Federal Government formulated a five point program (as listed for example in BMVBW, 2005), which identified major political actions for improvement of flood protection. These points are:

1. Flood laws and regulations of federal government and states are to be combined into a common flood protection program of states and federal government, which include the following principles for future flood protection actions:

- To give more room to the rivers (generate polders, move dikes away from the main river, improve or generate flood forecasting and warning systems),
- to retain flood waters on the land of the basin (restore riparian forested areas, wetland restoration),
- change straightened creeks and rivers back to natural courses, more extensive use of reservoirs for flood control,
- improve infiltration capacity of rural and urban areas, adjust land use to natural local conditions (protect against surface erosion),
- To control regional and urban development.

2. Flood protection measures shall be planned and implemented basin wide, across state and international borders

3. International cooperation in Europe in common river basins is to be intensified through common projects
4. The functionality of existing and planned river training measures is to be reinvestigated in view of flood protection, and further development of inland navigation should be done in accordance with environmental requirements.
5. Immediate action is to be co-funded by Government and States to overcome flood damages.

These principles were discussed by the State Ministers of the Environment in their regular meeting on November 7 and 8 2002- who concentrated on asserting the responsibility of the States for flood protection. The (revised) report of the States on flood protection of 1995 (LAWA, 2004) for the first time identified conflicts among all agencies which are touched by flood protection activities - Regional Planning, Water Resources Management, Agriculture, Urban development, Disaster management etc. Conflicts which arose during the flood of 2002 served as examples, and these experiences are used for planning improved legal structures for future coordination.

Experience from the flood of 2002 was also considered by experts of the Federal Government, who were charged to produce the draft of an "Act to Improve Preventive Flood Control" as amendment to the Federal Water Act (which regulates distribution of water related responsibilities among states and the Federal Government). These activities profited also from recent floods on Oder and Rhine, and drew heavily on the LAWA recommendations. The result is a federal law (Hochwasserschutzgesetz Flood Protection Law), which was put into effect on May 9, 2005 by the German Parliament (Bundestag) and by the Council of the States (Bundesrat).[4]

The most important aspects of the law are:

a. flood protection should start in the river basin: it requires avoidance of sealing of soils, adjusting agricultural practices for reducing runoff from fields, etc.
b. flood plains should be identified: the law states that flooded areas from the maximum flood observed during the last 100 year should be used for flood proofing: no new building permits for private dwellings or industrial sites should be allowed in this flood plain. On the Elbe River, the maximum flood clearly was the flood of 2002, although a flood of similar magnitude had occurred in 1954. The law requires the states to list these areas within the next 5 to 7 years.
c. Regional planning has to take cognizance of flooding. (Up to now, city and urban planning did not consider threats due to floods - previously a serious omission and a constant source of dispute between city planners and water resources administrations).
d. Rivers and creeks are no more to be straightened, natural measures are to be given preference before technical measures
e. States are required to pass their own flood protection laws, in which details for developing Flood Action Plans (such as already exist on the Rhine) are spelled out.

The principles of the Federal law are being implemented at this time by detailed laws of the States, which basically repeat the principles and identify steps to be taken locally for improving flood protection. The 5 points were made operational by conversion into recommendations for action by the water administrations of the Federal States (LAWA, 2004). These were further detailed and adapted to local conditions in the form of flood action plans by the different states.

[4] Although the Hochwasserschutzgesetz is a federal law, it needs approval by the States, as it touches State matters, i.e. the constitutional responsibility of the states for flood protection.

Based upon these reports, a flood action plan for the whole Elbe River was prepared by the International Commission for the Protection of the Elbe (IKSE, 2005).

The Kirchbach Report and the DKKV Recommendations after the flood (DKKV, 2003) also recommend: to work towards a Federal Law which unifies disaster management and defines a clear hierarchical setup, which clearly identifies tasks and responsibilities of the actors on all levels. And as a consequence of the flood a discussion among States and Federal Government was started immediately on the best way of creating and structuring a common center for handling emergencies such as the extreme flood of August 2002. (These plans have not yet been realized)

4.2 International and Trans-Boundary Responses

The flood of 2002 has strengthened the role of international bodies which originally had been set up for managing the water quality of the rivers, and which later on have been charged also with planning and coordinating flood issues. Benchmark is the International Commission for the Protection of the Rhine (Internationale Kommission zum Schutz des Rheins IKSR). This commission includes federal and state representatives from all Rhine countries: Swiss, French, German and Dutch authorities. It was originally created for improving the water quality of the Rhine and had started off with formulating programs for cleaning up the river, such as "Salmon in the Rhine by 2000", which was put into action by the member states, with considerable success. In the aftermath of the floods on the Rhine in 1993 and 1995 the commission was charged to develop a "Flood Action Plan" for the Rhine, which is a blue print for future flood protection measures along the Rhine. This plan is gradually converted into projects. Its major component is the already far advanced "Integrated Rhine Project" of the States on the upper Rhine, as well as coordinated efforts for flood alleviation on the lower Rhine in the Netherlands and the German State of Rhineland Westphalia. Such a commission also existed for the Elbe, the commission for the protection of the Elbe (IKSE Internationale Kommission zum Schutz der Elbe). This commission was also created for common water quality issues of Germany and the Czech Republic, and just like the IKSR was entrusted in the aftermath of an extreme flood with coordinating flood protection measures after the August 2002 flood. The IKSE produced a flood action plan for the Elbe (IKSE 2002), and continuously assesses and documents its implementation (IKSE, 2005). It serves also as a platform for discussion of international and inter-state activities and for preparing concepts for improving the flood safety along the Elbe, using local and international experiences with handling previous floods.[5] As with the Rhine Action Plan, this plan is not legally binding. It rather serves as a set of recommendations, which shall be discussed and implemented locally

Large European rivers like Rhine and Elbe are crossing national borders, and regulations for flood protection on these rivers thus are to some extent subject to jurisdiction of the European Community. An initiative started by Germany and other countries taken up by the Commission of the European Communities. On Jan 18 2006 the commission proposed a "Directive of the European Parliament and of the Council of Europe on the assessment and management of

[5] It is interesting to note that the flood of 2002 was caused by the same weather pattern (Vb pattern according to Hess & Brekowski (Gerstengarbe & Werner, 1993)) as the Rhine flood , except that for the Rhine floods the weather center was shifted west. The floods of 1998 and again in 2003 were caused by a shift of the same weather pattern to the east, causing heavy floodings mostly in Poland.

floods", which has been amended and passed by the European Parliament and Council in December 2006 and will become law in 2007. The directive at this time is restricted to flood risk mapping, requiring first an inventory: list all previous extreme floods and the flooded areas, identify flood prone areas, describe the processes that cause flooding, and list all actions that have been taken for flood protection against previous floods. Furthermore, damage potential should be determined within flood plains. From these, flood risk maps (see 5.3.1 below) are to be developed for all flood plains.

4.3 Improving Preparedness Activities

An important emphasis given after the flood of 2002 was to improve the state of preparedness of the population. According to Kreibich et al. (2005), preparedness consists of three parts: preparative, preventive, and precautionary measures. Preparative measures are all activities taken to be prepared for the flood, such as improving the legal base for flood protection, including hazard and risk mapping, as well as preparing escape routes and instructions for the public on what to do in case of floods. Preventive measures are technical or non technical means of protection, such as dams and dikes, as well as land use changes. This includes the effect of structures on the rivers which had no function for flood protection.[6] Included in this part is also the setting up of forecast centers. Precautionary measures are private flood proofing measures, such as flood proofing of houses and basements, and preparing for floods by moving heating units and boilers to higher levels in flood prone houses.

For all these activities many of the necessary ingredients of organized flood management were missing, as was pointed out above. Therefore, emphasis of the reconstruction period was not only on rebuilding of destroyed buildings and damaged infrastructure, but also on improving administrative processes and structures.

4.3.1 Inundation maps, Hazard maps, Hazard Indicator Maps and Risk maps.

One of the most promoted activities is the production of maps, to show the degree of danger for households and industry in different ways and with different degrees of accuracy. Although the terms are not generally used in the same way, typical maps are defined as follows (IKSE, 2005) Inundation maps (Überschwemmungskarten) are maps showing for a certain location and for a flood of certain frequency, (usually HQ_{100}, which is the flood with recurrence interval once in 100 years) the depth of inundation. Hazard Maps (Gefahrenkarten) are maps in which flooded areas are indicated, and the depth of inundation and the local velocity of the water is combined into a hazard. In agreement with the European Directive, the State of Saxony and other States have developed primarily so called "Gefahrenhinweiskarten Sachsen" (flood risk indicator maps Saxony). Hazard Indicator Maps (Gefährdungshinweiskarten) are maps showing the flooded area, usually for HQ_{100}, (sometimes including the threatened houses, industrial areas and public

[6] In Germany, federal institutes (BAW and BfG) were requested after the flood of 2002 to investigate how all ongoing federally funded projects on the rivers affect or are affected by floods of extreme magnitude. All projects that were in the preliminary stage of execution were stopped until this study had been completed. It was found that none of the projects was having negative effects on the flooding situation (an example for the Elbe River is cited in BAW (2003), where erosion control is planned for the middle reach of the river. To prevent future destabilization of shore protection works, sediment is to be controlled through feeding of sediment into the Elbe River - a practice which is successfully applied to the river barrages of the Upper Rhine).

buildings), without regard to technical flood protection measures, i.e. inundations and inundation depth identified solely on the basis of topographic maps. By adding the qualifier "indicator" (Hinweis) it is assured that these maps are not considered legally binding; rather, they are intended to warn people. Typically, such maps have 3 zones of flooded areas: most endangered area (flooded for more frequent floods than the 20 year flood), medium dangerous floods (between 20 year floods and 100 year flood), and barely flood endangered areas (flooded by floods between 100 year flood and the maximum observed flood, but at least the 300 year flood). Shown usually is one map each for each recurrence interval.

For creating flood risk maps hazard maps are combined with value estimates for the buildings at risk in these areas, so that they represent the local estimated risk (http://www.umwelt sachsen.de) showing the expected value of the damage at each point, or for each building in the area under investigation. In order to simplify risk map construction, in many cases fixed values K of damage are used without considering depth of inundation, and the risk is calculated as product of K and exceedance probability. In other types of risk maps risk zones are defined as zones of high hazard (product of velocity v and depth of flow h : $h \circ v > 2\ m^3/s$, or depth $h > 2$ m) medium ($0.5\ m^3/s < h \circ v < 2\ m^3/s$ or $0.5\ m < h \circ v < 2$ m) and low ($h \circ v < 0.5\ m^3/s$ or $h < 0.5$ m). A more refined analysis for risk maps uses also curves showing dependency of damage on flood level, for which the German Association for Water and Sewage has derived damage functions that are published by the Bavarian Water Resources Administration in a data bank called HOWAS. (Merz & Gocht, 2003): The scales of different maps range from 1:5000 to 1:100000 typically, the more detail the larger the scale: for example, for the State of Saxony Hazard Indicator Maps are on a scale of 1:100000, whereas typical risk maps show isolines of the limit of inundation due to floods of different recurrence intervals at a scale of 1:5000.

4.3.2 Improvement of flood forecasting:

Flood forecasting in Germany is a task shared between the Federal Government and the States, according to their respective responsibilities as specified in the German Constitution. Inland navigation on the large rivers of Germany (and coastal defense, including ports and harbors) is under the control of the Federal Government, whereas flood protection on all rivers is responsibility of the States. Because flood protection and navigation interact, the Federal Government is involved also in flood protection on navigable rivers. In particular, flood forecasting is a task of the same agency which is also providing low flow forecasts, because extremes require that shipping on the rivers is restricted, for high water as well as for low flows in the rivers. Inland navigation and coastal protection within the Federal Government are assigned to the Ministry of Transport, Building and Urban Affairs, which has two Applied Research Institutes: the Federal Institute for Hydraulic Engineering (BAW Bundesanstalt für Wasserbau), where engineering projects for inland navigation and coastal protection are researched, and the Federal Institute of Hydrology (BfG Bundesanstalt für Gewässerkunde), where Hydrological questions associated with inland navigation, including water quality issues are investigated.

Among the tasks of the BfG is development of river stage forecasting for navigable rivers. Because of overlapping interests, the BfG works closely with State institutes for flood forecasting. For the Rhine a well developed forecasting system exists, consisting of a central coordinating institute (the Federal Institute of Hydrology, in Koblenz), and local forecasting centers in all States, for example in Karlsruhe, for the State of Baden-Württemberg.

A network of forecasting centers is also planned for the Elbe River. For example, directly after the flood the State of Saxony combined the existing 4 regional flood centers of the State into one Flood Management Center, (Landeshoch-wasserzentrum) which has started to operate in 2004 (DKKV, 2003). This center has a flood forecasting team (Büttner, 2006), which has collected all existing models for the tributaries of the Elbe and cooperates in the forecasting project RIMAX (see 6.3) in developing more advanced hydraulic modeling capacity - with the ultimate goal to provide forecast scenarios for all rivers which permit forecasts of expected values and of probability distributions of possible forecast outcomes. The forecasts and warning issued from this center will be the official forecast and warning for the state and the basis for actions of state employees.

4.3.3 Improvement of flood disaster management

There is no doubt that every village, community, city and state is shocked into planning improved command structures for the handling of large disasters. However, many feel that the flood of 2002 was a singular event, and is not likely to happen again soon. Therefore, most states in Germany continue their plans of reducing civil service jobs, and to hire outside consultants for advising on flood proofing measures. On the other hand, most states also are engaged in remedying deficiencies of the organizational structure. The federal water law requires that states prepare plans for managing floods, but there is no direct reference in the laws for improving the com command structure and for avoiding the shortcomings indicated by Cimolino (2003). In addition, efforts are made to get the public involved, by increasing awareness, and by supporting the organization of self help groups. A good example is the self help group of the Weisseritz region, already mentioned in chapter 2.3.1, whose principles are well suited for generalization. They are reproduced in Appendix 1 for this report.

4.3.4 Improvement of operation rules for reservoirs.

There are numerous reservoirs in the catchment of the Moldava in Czech Republic which could have retained a large amount of the waters in the Moldava/Vituva catchment and could have prevented much of the damage in Prague and below. Unfortunately no flood waters were released for additional flood storage, so that the reservoirs could not retain much of the flood waters. In South Germany, the large effect of the Silvenstein reservoir, upstream of Munich, was already mentioned. In contrast, the reservoirs on the small Elbe tributaries (described by Horlacher et. al (2006), upstream of Dresden, were practically filled already early after the beginning of the strong rainfalls. Their capacity, however, is too small to retain all the flood waters, although more than half of the floods from upstream of the reservoirs were retained. In Austria, much discussion is going on if an improvement could have been had from reservoirs. It was concluded that all reservoirs were operated according to existing operation rules, but that research is needed to optimize operation during extreme floods.

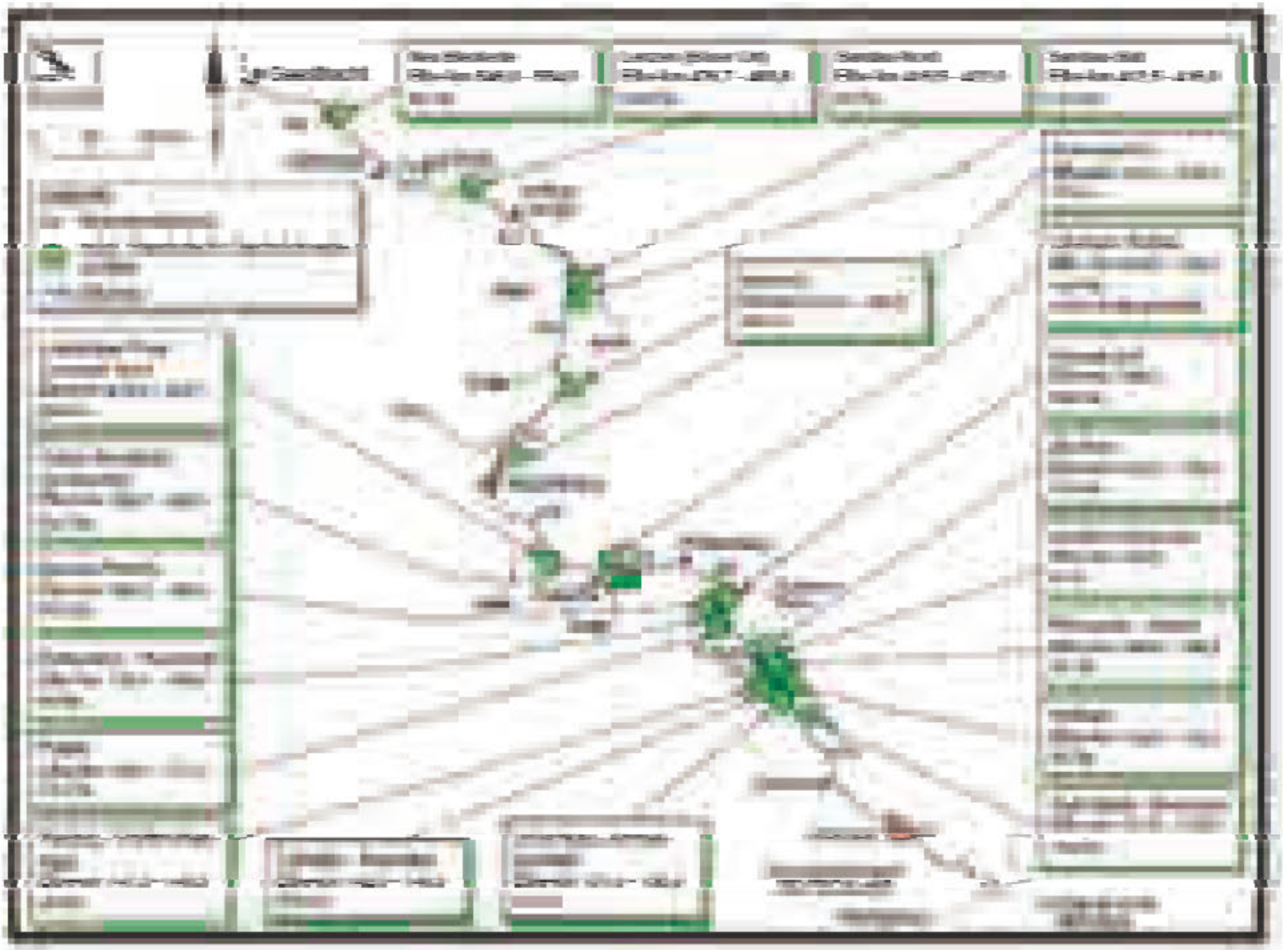


Figure 9 Potential areas for polders or dike relocations along the Elbe River downstream of the Czech – German Border. The locations are identified by the distance along the Elbe starting from the Czech border, and the areas for potential flooding are given in ha. *(Source: IKSE, 2006)*

4.3.5 Moving of dike lines.

One of the most controversial measures promoted in particular by environmentalists is the removal of dikes and building new protection dikes further inland in order to leave more room for the rivers. Environmentalists claim that this measure would reduce flood levels due to the increased width of the flood channel, whereas hydraulic engineers tend to think that a natural and forested flood plain may contribute to retention of flood waters, but will not influence flood levels very much, due to high roughness of such a flood plain (Helms et al. 2002). Nevertheless, after the flood of the Elbe River the Czech Republic, the European Union and Germany agreed to a comprehensive plan to stem future flood damage. The two neighboring countries, with support of the EU, plan to widen the Elbe by 2015 by pushing back dikes at 15 sites in Germany and to create polders for excess river water under the auspices of the International Commission for the Protection of the Elbe (IKSE). In order to investigate the feasibility of such a strategy, a water quality committee has identified 21 potential locations (see Fig.9) for polder or dike removal, to gain a total of about 40 km² of retention space (IKSE, 2006). At this time, these areas have only been identified and only one of them has been developed. .The EU Commission has earmarked € 560 Mio for this purpose, (which includes funds for improving the early warning system for the river).

4.3.6 Resettlement out of the flood plain.

Among the most effective measures of flood protection is to permanently remove buildings and other endangered objects from the flood plain. A spectacular case of this measure is the case of Röderau Süd. The Government of Saxony decided in November 2002, that this housing development should be removed and the population resettled. The Federal Government made the money available, and today the resettlement process is ongoing, the Saxony Reconstruction Bank (SAB Sächsische Aufbaubank) in its report for the year 2003 informed that 185 measures with a total cost of 37.8 Mio € had been initiated. The resettlement program was well organized and required to solve three types of problems. First were legal problems - the result was that three alternatives were offered to the people affected: a. to get cash for the property at an adequate level, b. to obtain property of equal value elsewhere, and c. to build a new home of equal value as the one to be destroyed. The second problem was to make people accept the offer of resettlement, which was solved by a campaign of persuasion by a leading government official, who spoke with more than 200 individuals. The third problem was to reconcile differing interests within the state: the Government of Saxony, the community of which Röderau was a part, the concerned citizens, and professionals: engineers and lawyers etc. (Freistaat Sachsen, 2003c, where a detailed report on this action is given)

4.3.7 Role of Insurance

The flood of 2002 also has brought up the discussion of damage flood insurance. Some recommend a mandatory flood insurance, which covers all natural causes (earthquake, flood, wind storms, hail and ice damage, etc.). Mandatory flat-rate insurance for all natural cause damages did exist in some parts of Germany until about 1980. Due to EU regulation this was cancelled in the 80-th in favor of free choice of insurers. Insurance companies responded by no longer insuring against extreme floods and storm surges. Under the influence of the floods on Rhine in 1993 and 1995, on the Oder in 1997 and Elbe 2002 the issue was picked up again, and in Germany the discussion has started on how to reduce Government involvement in favor of insurance coverage. Advocates of flat rate insurance face opposition from others in favor of voluntary flood damage insurance who claim that it does not seem reasonable to let people or (tax payers!) everywhere cover damages which are happening because people do not give due regards to natural environmental conditions. In Germany the insurance industry is preparing its members for the day that flood insurance is required by law. As a basis they have financed a system of flood inundation maps for the whole of Germany, under program "ZÜRS". (This program provides to insurers recommendations for potential flooding zones along every river zones, although it is up to the insurance agent to adhere to these maps).

Public private partnership concepts are being developed, in which proactive preparedness by the property owners is rewarded in some way. However, at present, the insurance industry is not very interested in special actions of reducing losses through incentives, such as deductibles or special rates for people who invest in precautionary measures. Likewise the people at risk do not seem to be very interested in insurance, as was found by Thieken et al., (2006), who questioned more than 1000 flood victims after the flood.

The discussion brought out novel concepts for the role of insurance. In Habersack et al. (2004) a model is proposed which is based on setting up a fund for flood compensation which consists of two parts: a Damage Compensation Fund for ordinary flood damages, and a Disaster Prevention Fund. Damage compensation for ordinary cases is to be covered fully by insurance; the Damage Prevention Fund covers extreme damages, and can be supported by credit from the

Government. Insurance premiums would be split into two parts, one for each fund. Obviously, the role of the Damage Prevention Fund can also be taken up by the Re-insurance industry.

5. RESEARCH PROGRAMS IN THE AFTERMATH OF THE AUGUST FLOOD

The report shall be closed with a short review of research activities which have been initiated after the flood. They usual were already in the planning stage, due to previous flood disasters, but because of the immense dimension of the August 2002 Central European Flood, they have increased in funding and have drawn other groups of researchers into the scene. For example, many researchers who are involved in climate change research were looking into the connection between climate change and floods, although a recent study by Grünewald and Schumann et al. al (2001) showed by means of an example of the upper Danube that the variability of natural conditions in Central Europe does not permit to obtain a reasonably statistically significant influence of climate change even with a hypothetical increase in rainfall intensity and frequency as predicted by climate models..

5.1 International research programs

The European Community, Austria and Germany initiated extensive research programs for improving management of floods in the Elbe River, and by extension in all European rivers. An overview over the many projects was given in a recent European Symposium on Flood Risk Management Research (Schanze, Ed, 2007). Typical is the program FloodSite (http://www.floodsite.net/html) of the European Community, funded under the 6-th Research Framework Program of the EU. The program is arranged according to the following themes:

1. Risk analysis - hazard sources, pathways and vulnerability of receptors
2. Risk management - pre-flood measures and flood emergency management
3. Technological integration - decision support and uncertainty
4. Pilot applications - for rivers, estuaries and coastal sites
5. Training and knowledge uptake - guidance for professionals, public information and educational material
6. Networking, review and assessment
7. Coordination and management.

There are thirty projects funded under this program from all European countries. Typical for the type of research funded under this program is the project VERIS-Elbe. This project has as objective to anticipate and be prepared for long term flood risk changes, taking account of climate and social changes. An overview of the model is shown in Fig. 10 (from Schanze, 2007). The concept is to develop scenarios of climate change, yielding statistical distributions of future rainfall events, to be used as inputs into hydraulic models: a coarse 1-D model for the full river, and detailed 2-D models (SMS) for design of structures (polders) and for developing flood models for urban areas. Water level outputs are to be analyses statistically for use in decision models.

A second important EU initiative is the development of a European Flood Alert System EFAS, (http://efas.jrc.it) under development since 2003 at the Joint Research Center (JRC) of the European Union in Ispra, Italy, (which is intended to supplement national forecasting, not to supplant them. A prototype based on the European Flood Forecasting System EFFS (Goweleeuw, et al., 2004) is at present being developed in cooperation with agencies from different European countries. The benefit of this system is to be twofold: First, EFAS should provide the European Community useful information for providing and management of aid during a flood crisis. Second, national water authorities should benefit from additional medium range flood information that might contribute to increased preparedness in an upcoming flood event.

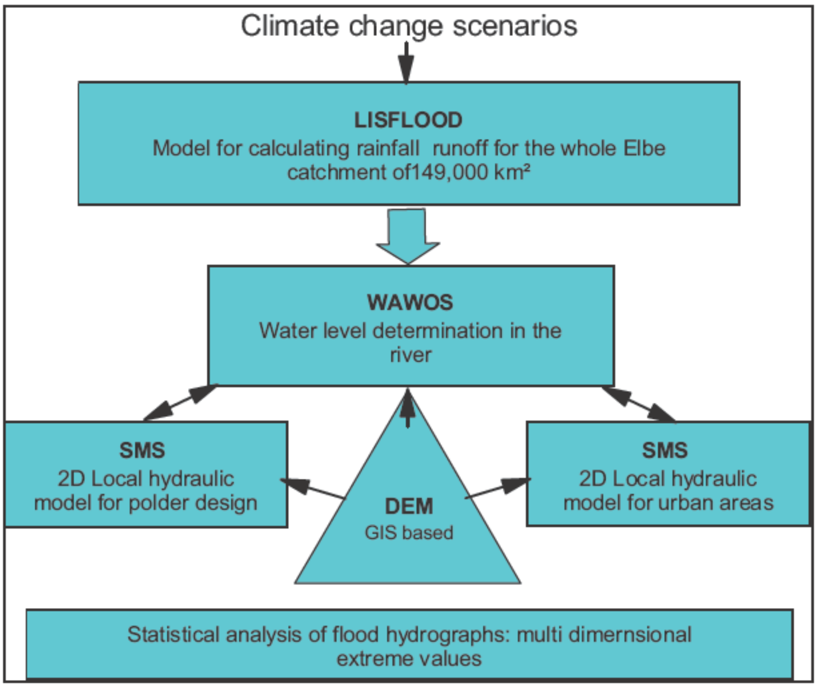


Figure 10 Structure of VERIS Elbe project (*from Schanze, 2007*)

A third international program supported by the European Community and member states is Program ELLA, which focuses on regional planning. This is a trans-boundary coordination program of € 2.56 Mio for the years 2003 -2006. (ELbe Labe, the German and Czech names for the river Elbe) with the purpose of coordinating regional planning issues within the two states involved, but with the additional purpose of deriving standards that could be applied to all States in the European Community. Its objectives are:

1. Creation of a transnational network of regional planning and water resources management authorities, make available data from trans-boundary regions.
2. Development of a set of transnational agreed on regional planning concepts for spatial flood protection
3. Preparation of inundation maps showing potential flood risks and devise ways of integrating these maps into regional development plans
4. Applications and improvement of existing regional planning instruments in the Elbe/Labe river basin in pilot projects.

The program is conducted in cooperation of States, with support from State and European Union funds (through the European Regional Development Fund) and enables the funding of working groups on appropriate topics and of the required numerous work group sessions, in which mutual problems are discussed and consensus is achieved on trans-boundary planning. Nine pilot projects are conducted to investigate the applicability of the developed concepts in different regions of the Elbe basin. Progress on the projects is reported in ELLA Newsletters, which appear in irregular intervals. (www.ella-interreg.org, see also IKSE, 2005).

5.2 Austria

The report by Habersack & Moser (2003) mentioned above convinced the Austrian Government to fund and establish an applied research and development program to study cause and effects of the floods, to investigate the performance of the individual actors, and to draw conclusions for further actions. It was coordinated by Prof. Habersack, of the BoKu. The final report (Habersack et al., 2004) is a summary of all activities that are ongoing in research and development along the Danube and her tributaries, and has become a Government endorsed blueprint for future actions. A particularly impressive feat of the Austrian group was that it brought together interested persons from all domains: private companies, Governmental and University Research Institutes, and Government Agencies, involving actors from all levels of risk management: legal, socio-economic, and the natural sciences based process level. Objective was to obtain a common framework for future integrated measures from regional planning, engineering, and administration. It ended with numerous recommendations, which are now being considered for realization by the responsible regional and national governments.

5.3 Germany

In Germany federal and state institutes are strictly application oriented; it is common practice to leave water research to research institutes and Universities, which are primarily funded by states, usually with substantial federal support for research. Fully federally funded are research institutes of the Helmholtz Gesellschaft (Helmholtz Association), which include in the field of flood research the Geoforschungszentrum in Potsdam (GFZ) and the Forschungszentrum Karlsruhe (FZK).

After the flood many new activities in flood research have been initiated in Germany. In most states, research for local studies was financed, and risk management studies are being conducted nationwide, and also the Government supports research on floods. Not all of these programs can be described. Typical are trans-boundary programs such as ELLA, which has already been described. The Ministry of Education and Research (BMBF) of the Federal Government of Germany made available 20 Mio € for a research program with the objective: to study what went wrong during the flood, to develop concepts for improving local situations, and to improve the scientific base of flood related activities. This program is called RIMAX and is coordinated by the Geoforschungszentrum (GFZ) in Potsdam. Objective of the program is:

- to contribute to the implementation of the 5 point program of the German Government,
- to close gaps in flood related knowledge in the areas of natural and social, as well as engineering sciences
- to improve methods for analysis, evaluation and management of flood risks, and to integrate flood disaster management into general water resources management of basins
- to develop integrative concepts for flood preparedness and flood mitigation
- to initiate innovative approaches for technical flood protection
- to contribute towards risk awareness of society

A total of 155 proposals were submitted, of which 35 were selected for funding. Typical projects are devoted to uncertainty analysis in order to better analyze potential risks (HORIX Development of an operational Expert System for Flood Risk Management considering predictor uncertainty), projects for improvement of the reservoir operation based on improved forecasts of rainfall (Typical: project "Development of integrative solutions for operational management of floods, example Mulde River") and projects for identifying dike weaknesses and improving dike construction.

6. FINAL REMARKS

The flood of August 2002 has caused such large damage costs that a rethinking of existing practices of flood management was absolutely necessary, although it is well known that pressure to do something on political and other levels diminishes with time. Major legal, administrative, and technical efforts are being made to prevent future flood disasters of the type experienced in 2002. Comprehensive flood risk management along the principles set forth by the 5 points of the German Government is extensively planned. In reviewing the damage of the flood and the performance of the individual actors, Prof. Pasche of the Technical University Hamburg Harburg formulated a number of theses (Pasche, 2003a), which nicely summarize the most important needs for improvement of the existing technical and non-technical measures, and it is useful to conclude this report by listing his theses:

1. Thesis: Flood preparedness should extend to regions protected by technical measures, to be prepared for dike breaks and overtopping. For this, models are needed that can be used to develop disaster management plans.
2. Thesis: People should be motivated to invest into precautionary measures. Tax incentives or insurance instruments should be offered to increase motivation.

3 Thesis: Better coordination of the planning instruments of Federal Government, States, and Communities. In particular, it should be assured that the right of communities to develop into flood plains should be subject to review by State and Federal Agencies to make sure that measures developed in comprehensive and basin wide framework plans are kept, with veto power of these agencies.

4 Thesis: The present fights among different agencies about who is responsible should stop, and willingness to reach an optimum compromise should be improved by developing dialog capability of the different players, who should learn to respect and try to understand different views of different experts and non-experts.

5 Thesis: Assessment of different influences of human interferences into the natural course of rivers should be supported by state of the art hydrological and hydraulic computer models based on solid hydrological and land use data

6 Thesis: States and Federal Government should improve the data base for future hydrological studies. This requires that a thorough assessment of data needs for all purposes be made and data collection services for obtaining these data be strengthened instead of being reduced (as is the present trend in Germany)

7 Thesis: States and Government should improve the professional competence of their staff, by continuous training and continuing education. A close interaction of Universities and Agencies is part of this process.

To these, one should add the requirements on preparedness, as postulated earlier:

8. Early warning capabilities should be strengthened and the warning process be practiced across all levels, including familiarizing the population with warning strategies.
9. A clear command structure should be set up within and across all three levels of government, from local administrations to regional and state command centers.
10. An effort should be made on local and regional level, and among government and non-government players in disaster management, to coordinate their cooperation structures and to unify their equipment.

Floods are to be expected again, in particular if the predictions of climate change research become true. We hope that the countries of central Europe have learned the lessons from the floods. If they heed the 10 points of advice, improve their protection systems, in a mixture of administrative acts, practical improvement of technical and non-technical protection measures, and good object-oriented research, they will be better prepared next time.

APPENDIX 1: WEISSERITZ RECOMMENDATIONS

Preparation of a web site for people preparedness (http://www.weisseritz.de/verhalten.html):

a. prepare for the flood ahead of time:

- Obtain a portable radio and batteries
- Obtain a supply of candles
- Obtain flash lights and batteries
- Store your valuable papers and valuables where you can find them quickly
- Be able to quickly locate the points in your house where to shut off gas, electricity and water
- Obtain a supply of food, which can last for a few days and can be eaten cold.
- Get water containers for obtaining a supply of water in emergencies
- Get shots against Tetanus

b. what to do during the flood

- Keep your cool and do not panic!
- To prevent your house from groundwater uplift, do not protect your basements with sand bags! (Important for Dresden, because of high groundwater levels)
- If warned early enough:
- Stack sandbags in some distance from your house; protect doors and windows by means of plywood sheets, move furniture and valuables to higher levels in the house.
- Prepare a supply of drinking water
- Locate important papers and medicines
- Disconnect all electrical devices, shut down main fuse of the house
- Disconnect gas and water supplies.
- Start your radio
- Use telephone and cell phone only when absolutely necessary
- Follow instructions of officials when ordered to evacuate

c. what to do during the flood

- If enclosed by water, move to higher floors and eventually on to the roof of your house and wait to be rescued
- Do not dwell in underground garages or basements (danger of drowning)
- Do not enter flooded basements (danger of electrical shocks- main electricity cable may still be alive)
- Do not leave the house and into the water (unless so ordered for evacuation). You may underestimate the currents, and once caught by them you are very likely lost)

d. what to do after the flood

- Do not create or spread rumors!
- Enter houses only after official clearance; if houses are damaged do not enter until an expert has checked the safety
- Do not enter basements unless you know for sure that there is no live electricity.
- Pump out the water from basements only when you are sure that the groundwater level has been lowered enough.

Have electrical appliances and electrical connections and fuses checked by experts
Destroy food, from refrigerators and other storages, that has been in the water.
Boil water from the water supply system
Remove soil deposits in apartments and basements as quickly as possible (as sediment deposits will harden when dry) but watch out: the deposit may be contaminated by bacteria or chemically. Use gloves and rubber boots!

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Chapter 4

Hurricane Katrina: Key US Task Force Findings and Measures

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EXECUTIVE SUMMARY
It has been six years since Hurricane Katrina devastated the Gulf Coast of the United States and changed our understanding of the overall effects of large tropical storms and the protection systems we devise to minimize their impacts. Since that time the US has made significant strides in a large number of areas related to hazard and disaster management. This paper describes the results of two significant task forces that were formed in the aftermath of Hurricane Katrina the Interagency Performance Evaluation Task Force (IPET) and Task Force Hope. The former was established to determine what went wrong with the regional hurricane protection system and suggest changes, while the latter was established to repair the actual damages and create a more sustainable protection system for Greater New Orleans.

The US has learned a great deal from Hurricane Katrina, and the New Orleans area is clearly now in a far better position to cope with future hurricane events. It should be noted, however, that hazard risk management is a true work in progress. The IPET findings and lessons learned are based on the experience of a past event, Katrina, but they are also an important lens into the future.

Understanding risk is a powerful tool in helping both individuals and government agencies to make consistent and conscientious decisions concerning natural hazard risk management. The ability to quantify risk for large geographical areas and complex engineered systems is slowly emerging in the US through the work in New Orleans and central California. Risk provides a much richer body of knowledge to understand and manage vulnerability to hazards as well as providing a clear common picture of the situation to all. Risk methods for regional infrastructure, if fully developed, will not only allow assessment of multiple hazards, but also allow collective consideration of life safety, direct and indirect economics and social-cultural issues, enabling customization of solutions to situations. But the evolution and application of risk to support decision making must be enabled by policy which currently does not exist. We have yet to demonstrate the public and the political will to adopt these more rigorous guidelines for risk management and mitigation. It must also be noted that our current policy and practice does not deal well with change. We must be much more anticipatory and adaptive as changes occur in the hazard, the system or the potential consequences.

1. INTRODUCTION: PERFORMANCE EVALUATION

Shortly after the disaster the Interagency Performance Evaluation Task Force (IPET) was formed by the US Army Corps of Engineers to determine the facts concerning the performance of the Hurricane Protection System (HPS) in New Orleans and Southeast Louisiana during Hurricane Katrina. The analyses conducted by the IPET were designed to answer the following five principal questions:

1. The System: What were the pre-Katrina characteristics of the HPS components; how did they compare to the original design intent?
2. The Storm: What was the surge and wave environment created by Katrina and the forces incident on the levees and floodwalls?
3. The Performance: How did the levees and floodwalls perform, what insights can be gained for the effective repair of the system, and what is the residual capability of the undamaged portions? What was the performance of the interior drainage system and pump stations and their role in flooding and unwatering of the area?
4. The Consequences: What were the societal-related consequences of the flooding from Katrina (including economic, life and safety, environmental, and historical and cultural losses)?
5. The Risk: What were the risk and reliability of the HPS prior to Katrina, and what will they be following the planned repairs and improvements?

The knowledge gained in answering these questions: 1) was applied directly to the design and construction of immediate and longer term repairs, 2) was used to assess the integrity of and plan remedial actions for the sections of the HPS not severely damaged, 3) is being used in the ongoing efforts to enhance the capabilities of the system to achieve 100-year levels of protection, and 4) provides analytical methods and a body of knowledge to assist in planning and designing more effective risk reduction and management measures in the future. The IPET analytical tools and information bases are being transitioned to the Corps of Engineers and other agencies to assist in developing more effective approaches for reducing risk from extreme events.

The nine volumes of the final report provide a detailed documentation of a broad, multidisciplinary analysis of the HPS and its performance during Hurricane Katrina. The frequent professional interaction and review comments provided by the American Society of Civil Engineers (ASCE) External Review Panel (ERP) and the strategic oversight of the National Research Council (NRC) Committee on New Orleans Regional Hurricane Protection Projects made substantial contributions to the conduct of the analysis and development of the results described in this report. The complete IPET report and all other IPET-produced documents are available on the IPET Web site: *https://IPET.wes.army.mil*.

It should be noted that IPET did not examine organizational and jurisdictional issues that impacted the effectiveness of the physical hurricane protection system. These issues were examined by a separate team and are reported in “Decision Making Chronology for the Lake Pontchartrain and Vicinity Hurricane Protection Project”, which was published in March of 2008. That study is available on the U.S. Army Corps of Engineers web page at the following address: *http://www.IWR.USACE.army.mil/inside/products/pub/hpdc/hpdc.cfm*.

2. SUMMARY OF FINDINGS

The protection system did not perform as a system. In some areas it was not completed, and in others, datum misinterpretation and subsidence reduced its intended protective elevation.

The initial 1960s-based design criteria, the Standard Project Hurricane, was redefined during the design and construction phase, but the system component designs were not altered to address those changes. The capacity for protection varied because of some structures that provided no reliable protection above their design elevations and others that had inadequate designs, leaving them vulnerable at water elevations significantly below the design intent. The many pump stations around New Orleans were also not an integral part of hurricane protection, focused mainly on removing rain and ground water from the protected areas. The structures along the outfall canals were particularly inadequate. A series of incremental decisions, extending from the original "barrier" plan to the "parallel protection" structures ultimately constructed, systematically increased the inherent risk in the system without recognition or acknowledgment.

Hurricane Katrina created record surge and wave conditions along the east side of New Orleans and the coast of Mississippi. Peak water levels along the Plaquemines and St. Bernard levees and within the Inner Harbor Navigation Canal (IHNC) were significantly higher than the structures, leading to massive overtopping and eventually breaching. Wave heights during the hurricane were typically similar to those assumed for the design of the structures, except for Plaquemines Parish where they were higher than the design assumptions. Wave periods, however, were three times longer than the design assumptions, particularly along the east side of St. Bernard and Plaquemines Parishes. The longer period, more energetic waves created much greater potential for run-up and overtopping. Conditions within Lake Pontchartrain were roughly equal to the design criteria for the shoreline structures. The Mississippi River Gulf Outlet (MRGO) channel, presumed to be a major factor in propagating storm surge into the IHNC, was demonstrated to have little impact on storm water levels for large storms.

Hurricane Katrina resulted in 50 major breaches. With the exception of four levee-flood wall foundation design failures, all of the major breaches (a total of 46) were caused by overtopping and subsequent erosion. Protective elevations that were below those required by the design caused an increase in the amount of overtopping, erosion, and subsequent flooding, particularly in Orleans East. Ironically, the structures that ultimately breached performed as designed, providing protection until overtopping occurred and then becoming vulnerable to catastrophic breaching. The lack of resilience to overtopping significantly increased flooding and resultant losses. The levee-floodwall designs for the 17th Street and London Avenue Outfall Canals and the IHNC were inadequate. In four cases the structures failed catastrophically prior to water reaching design elevations. A significant number of structures that were subjected to water levels beyond their design limits performed well. Typically, in the case of floodwalls, they represented more conservative design assumptions and, for levees, use of higher quality, less erodible materials. The pump stations were largely inoperable during Katrina due to lack of resilience in their power supplies and safe havens for operators.

Consequently, approximately 80% of New Orleans was flooded, in many areas with depth of flooding exceeding 15 ft. The majority, approximately two-thirds overall in areas such as Orleans East Bank and St. Bernard, of the flooding and half of the economic losses can be attributed to water flowing through breaches in floodwalls and levees. In December 2005, the National Hurricane Center reported that there were approximately 1300 fatalities in Louisiana directly related to the forces of Katrina, a significant majority within New Orleans. Over 70% of the fatalities were people over age 70. The poor, elderly, and disabled, the groups least likely to be able to evacuate without assistance, were disproportionately impacted. Direct property losses exceeded $20 billion, and 78% of those losses were in residential areas. There was an additional loss of over $7 billion in public structures and utilities. The indirect consequences were equally disastrous. The breakdown in New Orleans' social structure, loss of cultural heritage, and dramatically altered physical, economic, political, social, and psychological character of the area are unprecedented in the United States. In themselves, these create a formidable barrier to full recovery.

3. SUMMARY OF LESSONS LEARNED

The first key IPET finding is that all future planning and design methods need to be system-based, allowing for a more in-depth analysis of how a combination of structures and measures will perform together. These methods need to be able to consider the performance of the system beyond the design criteria, including the life-cycle value of resilience and redundancy in the design. They should also allow examination of what is considered a system at one scale as a component of a larger, regional system. Dynamic factors such as subsidence and changing hazard levels must be included. This requires an ability to develop and evaluate adaptive designs, protective concepts that allow planned augmentation to deal with expected changes, as well as some ability to accommodate the unexpected. An accurate reference datum and monitoring of structure elevations, as well as the effective operation and maintenance of the HPS, are essential parts of this process. All assets that factor in the capability to provide protection, such as pump plants and closure structures, must be included in the overall analyses. With rapid changes in knowledge and engineering practice, it is essential to continuously review and update technical guidance used in planning and design as well as providing an effective mechanism for the engineering community to adopt and mature new methods. The standard project hurricane (SPH) methodology used to develop design criteria for the original system is outdated and should no longer be used. More flexible and robust probability-based methods are available that will provide better definition of the future hazard faced by protective structures.

A second finding is that sophisticated models that incorporate high-resolution spatial data and high quality wind fields are essential to accurately characterize storm surge and waves. This is particularly true in an area such as New Orleans with complex shoreline comprised of both natural (marshes and ridges) and man-made barriers (levees and transportation corridors). These models need increased capabilities to accurately simulate the impact of barrier islands, marsh, and wetlands on surge and wave conditions. The interaction of the surge and wave conditions with structures such as levees and floodwalls requires special detailed modeling to accurately account for wave run-up and overtopping, and to examine levee/wall response to dynamic loadings. Typically, very few measurements of waves and surge are made along the entire periphery of a HPS as part of a monitoring program. That was the case for this HPS. Large storms such as Katrina can cause failure of instrumentation intended to record the surge and wave environments created by the storm; Katrina did so in this case. This creates a difficult problem for conducting analyses of a storm and its impacts. High-water marks were the only reference information reasonably available around the region for calibrating and validating surge modeling. Only a relatively small percentage of these marks (15%) were considered accurate enough for use, pointing to the need for more robust instrumentation that can survive storms as well as rigorous standards for evaluating the quality of high-water marks.

Overall system performance is a third key finding for consideration. Hurricane protection structures need to be designed as a part of a complete system-based approach to protection, providing balanced and uniform levels of protection from the perspectives of time, level of hazard, and reliability. Designs need to be conservative enough to accommodate unknowns. Designs need to consider dynamic wave loadings in situations where waves are present. The unanticipated failure mode defined in the IPET analysis for the outfall canal floodwalls is not the only potential failure mode for these structures not considered in the original designs. With the rapid expansion of knowledge and practice, it is necessary to frequently review the adequacy of existing infrastructure in the context of that new knowledge and have processes in place to respond expeditiously to any performance limitations that arise. Resilience should be factored in to all designs to prevent catastrophic failures and to protect the integrity of the Hurricane Protection System (HPS) itself. The maintained condition of the levees is an important factor in their overall performance and should be monitored more rigorously and through evaluations that extend beyond visual inspections.

Fourth, even without the significant catastrophic breaching that occurred, the flooding and direct losses from Katrina would have been the worst in the history of the region. However, at least half of the direct losses may have been averted if catastrophic breaching had not occurred. This reduction in direct losses would likely have dramatically reduced the indirect consequences of the event as well. Together, this may have enabled a more rapid and systematic recovery. Resilience in the HPS would have provided that advantage. It is also clear that emergency response planning must focus more attention on providing necessary assistance to those unable to self-evacuate. Mapping the economic and human health and safety consequences of Katrina has created a powerful information base from which risk assessments and future planning priorities can be informed. Estimating the future distributions of population and property in the uncertain recovery and redevelopment environment proved very difficult. The scenario development accomplished to provide some insights into possible consequences of future hurricane events proved a feasible and valuable approach. Environmental losses were an essential component to the overall assessment of consequences, but they proved to be difficult to characterize beyond the short term, in part because of the already significant levels of contamination existing in the region. Not nearly enough information is available on the long-term impacts of saltwater intrusion and flooding on freshwater marshes, or the conditions and rates of recovery that can be expected.

Lastly, risk assessment provides a new and more comprehensive method to understand the inherent vulnerability of areas protected by complex protection systems and subjected to uncertain natural hazards. It provides a direct view into the sources of vulnerability, providing a valuable tool for public officials at all levels to focus resources and attention on the most serious problems and to seek solutions that reduce risk through both strengthening physical structures and reducing exposure of people and property to losses by non-structural means. Given a relatively uniform level of reliability of the protection system, the relative risk values are largely related to elevation (below sea level) and the value of property or number of people who occupy those areas. The emergency response preparedness and efficiency of evacuation prior to a storm is a key component to reducing risk to life and human safety. This is especially important for those who need assistance to evacuate. Communicating risk is a difficult task that can only be achieved through a spectrum of coordinated efforts. Key among these efforts is having relatively simple graphical representations of the vulnerability to flooding and risk. Also essential is repeated direct person to person contact with constituents. Since risk is a broadly used term, the development of a common understanding of the content and context of the information available and its appropriate (and inappropriate) uses are essential to effective communication and application of the risk information. Assistance of local and national media, as well as the Internet, is an essential component to make the information available to the broadest possible audience. The risk information is a powerful means to create a common understanding of a situation and the relative benefits of alternative approaches to manage or reduce risk. Quantitative estimates of vulnerability to flooding and potential losses (risk) are a powerful tool to convey situational awareness to the public and to provide a common picture to stakeholders at all levels. It allows the public to make individual decisions that are within their purview, provides more knowledgeable input to dialogue with public officials, and facilitates more focused discussions and collaboration among government agencies at all levels.

Understanding life-safety and economic loss potentials also provides a more comprehensive and system-wide body of knowledge to evaluate alternative approaches for managing risk.

4. TASK FORCE HOPE

Task Force Hope was established by the US Army Corps of Engineers in the aftermath of Hurricane Katrina to oversee the entire suite of recovery and improvement tasks for the Greater New Orleans area. Immediately following the 2005 hurricane, the US Congress and Administration gave the Corps authorization and funding totaling nearly $15 billion through seven Emergency Supplemental Appropriations acts. That granted the Corps the needed approval for and requisite funding to design and construct a substantial perimeter storm surge defense system for the Greater New Orleans area. The system - the Hurricane and Storm Damage Risk Reduction System (HSDRRS) - is comprised of 350 miles of levees, floodwalls, pumps and gates across a five parish area along the Louisiana Gulf Coast. HSDRRS vastly improves the fractured system that existed prior to Katrina's landfall.

The Corps established the goal of completing the work within a six year time-frame, which is particularly aggressive for an Army Civil Works program. This new perimeter defense system is designed to defend the Greater New Orleans area against a storm surge that has a 1% annual probability of occurrence the 100-year storm. Katrina was one storm along one track. It was a nearly 400-year storm with a surge of as much as 32 feet along the Louisiana/Mississippi coasts. If the US experiences a Katrina-like storm along the same track, the hurricane system will most likely be overtopped once again. The difference is that it is designed to withstand the storm effects. The interior areas will experience flooding, but with storm proofed pump stations that will have the ability to operate during the storm so that flooded areas would be pumped out more quickly. Also, the features of the new system contain armoring of the levees, and once built, will prevent breaching of the levees from overtopping. As a result, the Greater New Orleans area can now boast the best perimeter defense in its history.

Prior to Katrina, the Corps designed to what was referred to as the "maximum probable storm". The storm brought by Katrina was largely unanticipated. It was a Category 3 event at landfall, but the surge it brought was far larger than the previous one-storm design. Based on IPET findings, HSDRRS has been designed for a suite of over 150 storms that have numerous tracks - anywhere from a 25-year to a 5,000-year frequency. The effects of these various storms and their possible paths are taken into account as they make landfall, and estimates are derived on the consequences of a storm that has a one percent risk of occurring in any given year. So, there is no comparison of the previous system to the current system that is nearing completion. Simply put, it is a dramatically different and a dramatically better system.

5. THE HURRICANE AND STORM DAMAGE RISK REDUCTION SYSTEM (HSDRRS)

Through several Congressional appropriations, Task Force Hope oversees the construction of several large-scale projects that have been constructed at an unusually fast pace. A map of the Hurricane and Storm Damage Risk Reduction System (HSDRRS) is provided in Figure 1, along with snapshots of its major projects. What follows is a short summary of the large-scale projects that help define the new system that will provide a 100-year level of protection.

6.1 Inner Harbor Navigation Canal (IHNC) Surge Barrier Wall

During Hurricane Katrina, storm surges up to 18 feet high were funneled into the Gulf Intercoastal Water Way and the Inner Harbor Navigation Canal. The tremendous power of this surge caused some of the worst damage during Katrina, making neighborhoods like the Lower Ninth Ward household names. To ensure that surge of this magnitude would never again be experienced, the Corps built the Inner Harbor Navigation Canal Surge Barrier, the largest design-build civil works project in our history.

The Inner Harbor Navigation Canal Surge Barrier is a $1.3 billion project that is part of a $14.6 billion system that was constructed to defend against a 100-year storm surge event in less than six years. Prior to Katrina, the IHNC floodwalls were the first line of defense. However, by placing the IHNC Surge Barrier at the confluence of the GIWW and Mississippi River-Gulf Outlet these walls, though themselves stronger and more robust than before, are now secondary levels of protection. There are similar instances throughout the HSDRRS, such as at the outfall canals or floodwalls along Harvey Canal.

The surge barrier can be likened to an iceberg, in that what is visible is only a small portion of the overall project. To defend against surge overtopping, the barrier reaches 25-26 feet above sea level. To withstand the tremendous battering of surge this size, the concrete piles have been driven 130 feet into the ground. The batter piles have been driven in excess of 200 feet.

To close the system, the IHNC is tied in to the system in the north by an 850 foot T-wall, extending 1.8 miles across the GIWW, the Golden Triangle Marsh, and the Mississippi River Gulf Outlet, connecting to the southern system with a 500-foot long T-wall.

6.2 The West Closure Complex

The Gulf Intracoastal Waterway - West Closure Complex is located approximately one half mile south of the confluence of the Harvey and Algiers canals on the Gulf Intracoastal Waterway. This risk reduction feature reduces risk to residences and businesses in three parishes on the west bank of the Mississippi River: Orleans, Jefferson, and Plaquemines parishes.

The structural features of the project reduce the risk associated with a storm surge event that has a one percent chance of occurring in any given year, or a 100-year storm surge. The total construction value for the West Closure Complex is an estimated $1 billion.

The GIWW - West Closure Complex consists of a navigable floodgate, a pumping station, floodwalls, water control structures, foreshore protection and an earthen levee. The project also required the dredging of Algiers Canal, as well as the realignment of Bayou Road.

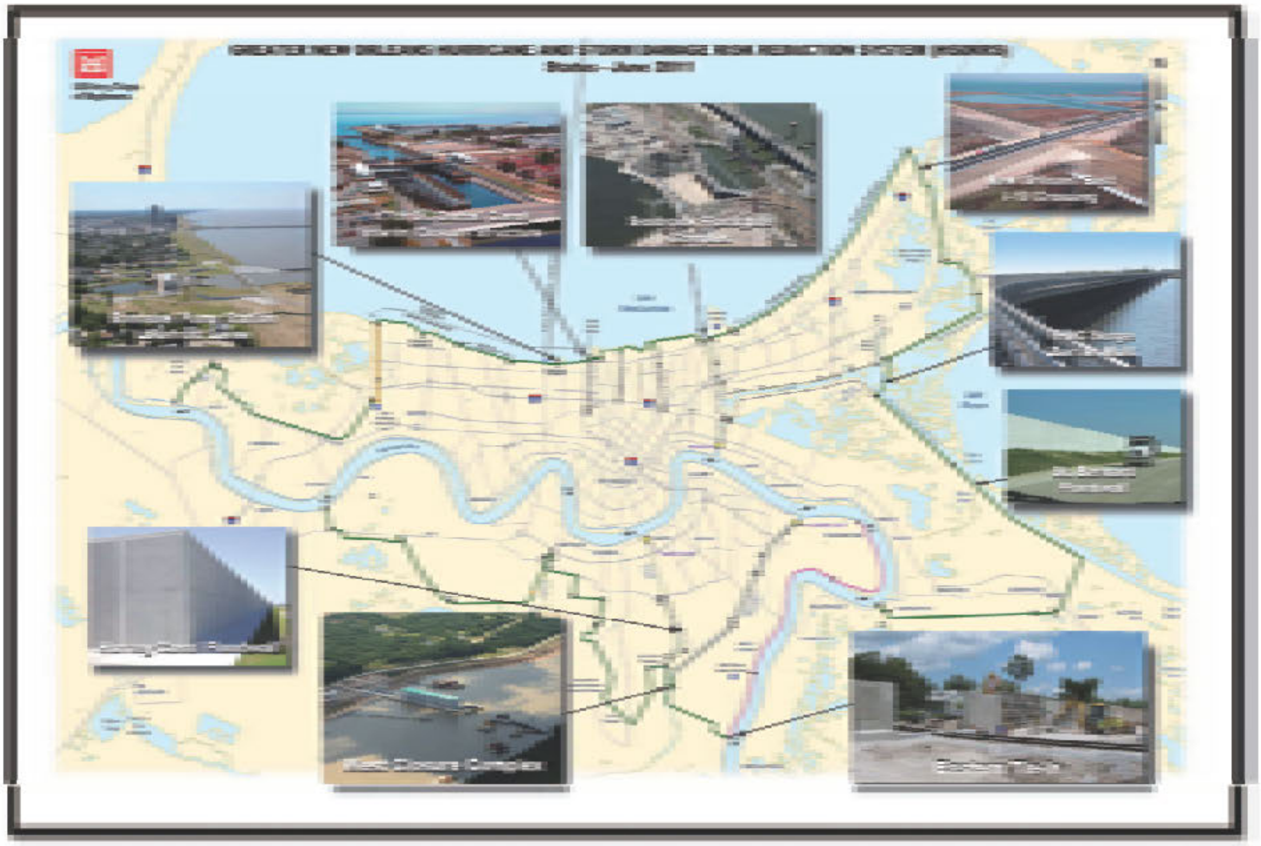

Figure 1 Map of Greater New Orleans Hurricane and Storm Damage Risk Reduction System

Project challenges include maintaining navigation traffic on the GIWW (a Federal navigation channel with heavy commercial barge traffic) and the location of the complex in relationship to the Environmental Protection Agency's Bayou aux Carpes Clean Water Act (CWA) 404(c) area, a wetland area of national significance.

The complex significantly reduces the risk to a large area of the west bank by removing 26 miles of levees, floodwalls, a gate, and pumping stations along the Harvey and Algiers canals from the direct impacts of storm surge. Construction of this risk reduction feature began in August 2009 and is approximately 87% complete as of August 2011. All 100-year risk reduction features are ready to defend against a 100-year storm; however construction will continue through 2012.

6.3 The Harvey Canal Floodwall

The Harvey Canal floodwall project was designed to reduce the risk of impacts to residents and businesses in the project area from a storm event that has a 1 percent chance of occurring in any given year. These floodwalls along Peters Road, nearly completed, provide federal risk reduction where no federal protection existed previously. Public safety is the Corps' number one priority and it is committed to completing the Greater New Orleans Hurricane and Storm Damage Risk Reduction System as authorized by Congress.

The project is located on the west bank of the Mississippi River in Jefferson Parish. The floodwall construction project reduces risk to residents and businesses in the area of the Harvey Canal. The project area is high-density residential and commercial development, with businesses and residents that require access to the surrounding waterways. Much of the area is subject to flooding during moderate tropical storms. The Harvey Canal project area extends from the Harvey Canal Sector Gate at Lapalco Blvd down the east bank of the Harvey Canal to the confluence of the Harvey and Algiers canals. The Harvey Canal Floodwall Project consists of approximately 3.5 miles of "T-wall" floodwall to an elevation of +14 feet founded on 130 foot long H-piles. These structures incorporate several vehicle gates to allow for access to businesses

Figure 2 West Bank and Vicinity Closure

Of the 5 contract reaches that make up the Harvey Canal Floodwall project, and which were awarded for $340 Million, construction is substantially complete for 3 of those reaches. Substantial completion of the other 2 reaches is expected in May 2011. 100-year level of risk reduction has already been achieved from the Harvey Canal sector gate to the Hero Pump Station.

6.4 The Inner Harbor Navigation Canal (IHNC) Seabrook Floodgate Complex

The Inner Harbor Navigation Canal (IHNC) Seabrook Floodgate Complex was authorized by Congress in 2006 and will operate in tandem with the IHNC-Lake Borgne Surge Barrier to reduce the risk of storm damage to some of the region's most vulnerable areas New Orleans East, metro New Orleans, the Ninth Ward, Gentilly and St. Bernard Parish. The Seabrook Floodgate Complex will reduce risk from storm surge generated through Lake Pontchartrain.

The Seabrook Floodgate Complex will consist of a 95-foot-wide sector gate and two 50-foot-wide vertical lift gates approximately 540 feet south of the Ted Hickey Bridge with floodwall tie-ins on the east and west sides. Other components of the Seabrook Floodgate Complex include upgrading the Alabama Great Southern Railroad gate to 100-year heights, constructing new T-walls that will tie into the lakefront risk reduction system and raising the

Hayne Boulevard ramp. When complete, the Seabrook complex will close the only remaining gap along the lakefront in Orleans Parish.

Figure 3 Floodwall at Harvey Canal

Construction is under way and will continue into 2012; however, the 100-year level of risk reduction will be achieved in June 2011 with the completion of the Seabrook Interim Closure Structure, a cofferdam inside which the floodgates will be built. During construction of the Seabrook Floodgate Complex, residents in the area may experience inconveniences; however, the Corps and its contractors are making efforts to minimize these impacts. The Seabrook area is currently closed to all navigation. Marine traffic is prohibited in the Inner Harbor Navigation Canal (also known as the Industrial Canal) from the north end of Slip 6 to the Senator Ted Hickey Bridge. The channel is scheduled to be re-opened in fall 2011.

6.5 The Outfall Canal Interim Closure Structures

During hurricanes and tropical storms, three outfall canals drain water from portions of New Orleans northward into Lake Pontchartrain. These outfall canals are critical elements in New Orleans' flood control system. Levees line the sides of the canals, and floodwalls are situated on the top of each levee.

Figure 4 17th Street Outfall Canal

The 17th Street Canal extends 2.4 miles north from Pump Station #6 to Lake Pontchartrain along the boundary between Orleans and Jefferson parishes.

The Orleans Avenue Canal, between the 17th Street and London Avenue Canals, runs from Pump Station #7 to Lake Pontchartrain.

The London Avenue Canal extends 4 miles north from Pump Station #3 to Lake Pontchartrain about halfway between the Orleans Avenue Canal and the Inner Harbor Navigation Canal (also known locally as the Industrial Canal).

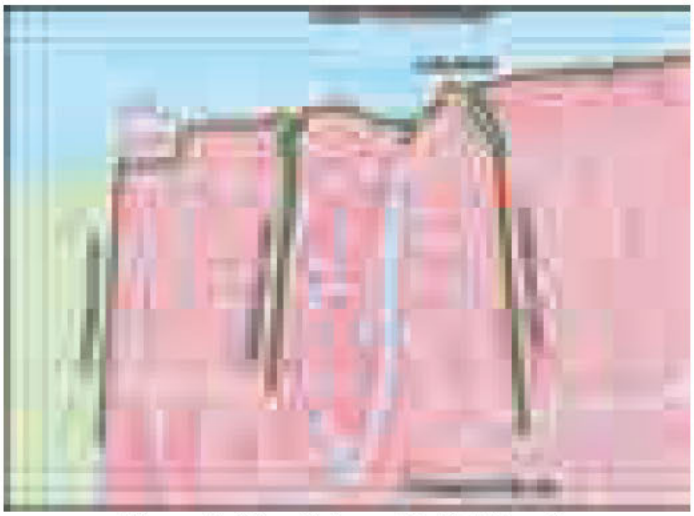

Figure 5 New Orleans Outfall Canals

During Hurricane Katrina, breaches occurred at the 17th Street and London Avenue Canals when water and waves pushing against the outside (water side) of the floodwalls (I-walls) caused the walls to shift, essentially splitting each levee into two pieces. Material on the protected side of the levee was unable to withstand the pressure from the forces opposite the floodwall and gave way, allowing water, intensified by the force of the waves, to spill into the protected areas.

The Corps repaired and improved all three canals beyond pre-Katrina risk reduction levels before the start of the 2006 hurricane season.

In addition to repairing and improving the canal walls, temporary gated closure structures were built at the mouths of the three outfall canals prior to the start of the 2006 hurricane season. These gated structures stay open during normal, non-tropical conditions.

When storm surge threatens to exceed the maximum operating water level of a canal, the Corps will close the gates and turn on the pumps. Pumps push rainwater around the closed gates and into Lake Pontchartrain. The closed gates prevent storm surge from entering the canals and going back into the city. When the surge recedes, the Corps will reopen the gates and normal drainage will resume.

These structures were built with a limited design life, and they will be replaced with permanent canal closures and pumps.

6.5 The Eastern Tie-In

The Eastern Tie-In project, located on the west bank of the Mississippi River in the vicinity of the town of Oakville in Plaquemines Parish, will tie into the existing Hero Canal levee, cross Hwy 23, and link to the Mississippi River Levee system. The total construction value for the Eastern Tie-In projects is an estimated $67 million.

For the Eastern Tie-In projects, the Corps will connect with the existing Hero Canal Levee and provide a navigable stop-log gate across the Hero Canal. These features will link to a levee, a pump station, an additional levee, a floodwall, a floodgate across Hwy 23, a railroad gate and a levee that ties into the Mississippi River Levees. To cross Highway 23, the Corps has determined that a double swing gate system is the most reliable way to close the system.

Earlier in the process, other alternatives were considered. However, the Swing Gate was selected as the approved plan because it is a proven reliable risk reduction feature. It requires minimal training and advanced preparation; it can be closed in four hours or less, allowing travel lanes to be quickly opened and closed in the event of a storm. The gate will prevent storm surge from reaching Highway 23, the only evacuation route for the areas south of Oakville in Plaquemines Parish. An emergency by-pass road will be available for authorized vehicles once the gate is closed.

6.6 Pump Station Repairs and Storm-Proofing

There are 78 Federal and non-Federal pump stations in Orleans, Jefferson, St. Bernard and Plaquemines parishes. Following the devastation of Hurricane Katrina, Congress authorized the Corps of Engineers to repair 61 pump stations in the four-parish area. These pump station repairs are complete. In addition, the Corps was authorized to storm-proof up to 49 pump stations in Orleans and Jefferson parishes in order to ensure the operability of the pump stations during and after tropical events, as well as to provide a safe haven for operators at some stations. The Corps divided the storm-proofing work into 34 separate projects. Upon completion of the repair and storm-proofing projects, local or state agencies (depending on the parish) resume daily operation and maintenance of the pump stations.

Jefferson Parish

There are 25 pump stations divided into 16 individual storm-proofing construction projects in Jefferson Parish, for a combined total of $136 million. Construction includes providing safe rooms, automating pumps and ancillary systems, installing climber screens, hardening building structures (frames, walls, doors, roofs), installing additional wells to backup Non-Potable Water Systems, elevating electrical equipment, adding fuel capacity and installing standby generators. When storm-proofing is complete, the pumps will be operated and maintained by the Jefferson Parish Drainage Department.

Figure 6 Storm-proofing

Orleans Parish

There are 24 pump stations divided into 18 individual storm-proofing construction projects in Orleans Parish, for a combined total of $204 million. Construction includes providing a 15 megawatt generator, installing a 60 hertz underground feeder, adding perimeter floodwall and berm construction around the Carrollton Water Treatment & Power Plant, hardening of buildings, enhancing water protection, installing emergency generators, adding new pumps, installing wells to backup Non-Potable Water Systems, elevating electrical equipment and adding fuel capacity. When storm-proofing is complete, the pumps will be operated and maintained by the New Orleans Sewerage and Water Board.

It should be noted that the Corps is constructing the Hurricane and Storm Damage Risk Reduction System (HSDRRS) in partnership with several other federal, state and local stakeholders. For instance, it collaborates with the Coast Guard to ensure public safety during the event of hurricanes in the Greater New Orleans area. The Coast Guard, to further ensure safety and security of the maritime infrastructure, requires marine facilities to have "Heavy Weather Action Plans" for use during hurricane conditions. The plans describe what actions will be taken when a hurricane approaches and threatens landfall in southeast Louisiana. The plans were effective in aiding the Port of New Orleans to reestablish operations and enable maritime commerce to proceed along the Mississippi River and in the port after the 2008 landfall of Hurricane Gustav.

Figure 7 Map of Pumping Stations

6. NEW METHODOLOGIES APPLIED TO THE HSDRRS

Task Force Hope is utilizing many new and innovative techniques in the HSDRRS construction process, many of which stem from IPET recommendations. Some of the prime examples that are discussed in this section include innovative levee design, fronting protection, the compilation of new risk-based maps and alternative environmental arrangements.

6.1 Innovative Levee Design

As a result of lessons learned from IPET, the Corps now uses much more rigorous methods in the design and construction of its levees. The requirements for soils used for levee construction are far more stringent now than they were prior to Hurricane Katrina. For instance, the clay soils used must now have a lower percentage of organic content and a higher level of plasticity to ensure needed strength. Any material not meeting those specifications is discarded. The Corps follows a four phase soil testing program: borrow pit investigation, quality control during excavation, in-place embankment testing, and post construction borings. Testing during these phases consists of soil classification, moisture content analysis, organic content analysis, in-place density, and sand content measurements.

The evaluation process begins at borrow pit sites. Before a site is used as a soil source, an aggressive sampling and testing program is implemented to ensure that the soil meets specifications for levee construction. Only when soils meet strict criteria at a borrow site is an excavation plan developed to establish portions of the pit where the soil is suitable for levee construction. Soils are sampled by taking borings. A series of borings are spaced every 500 feet in the pit to accurately represent all soil in that particular pit. Boring samples are tested at inspected laboratories that meet high standards for testing and storage. Labs test the soil for type, moisture and organic content, as well as amount of sand. Contractor partners who are responsible for borrow projects perform visual inspections and sample testing to ensure that materials from designated pit locations conform to contract specifications. Once soil is placed and compacted within a levee section, samples are taken by the contractor and the Corps, each set is sent to different labs for another round of testing, including an analysis of in-place density. Once a levee or section of one is completed, additional borings are taken to verify adherence to established standards for proper soil type, proper compaction and soil shear strength. Borings are also used in the design of any subsequent levee lifts.

The new engineering criteria is applied to the borrow material mandating a higher clay content in the dirt that is used to build the levees. The floodwalls are now supported by steel piles which are now as much as 200 feet in depth. These massive surge barriers, as previously described, are built across the Inner Harbor Navigation Canal on the east side of the river, and across the Gulf Intracoastal Waterway on the west side. This is all entirely new construction. In some areas stabilization techniques have been added to the soil, such as drainage blankets, which reduce some of the water in the soil to allow for construction. Deep soil mixing also adds concrete to the soil to provide a stronger base for levees.

Never before in the history of the Corps has so much levee material (borrow) been required to complete a project, much less a system on the scale of HSDRRS. The Corps and its partners required 100+ million cubic yards of borrow to complete the HSDRRS. The Corps collaborated with industry, private landowners and local governments in its effort to obtain the necessary borrow. Prior to Katrina, borrow material was usually obtained in close proximity to the levee where it was needed. Due to the unprecedented need, three options for borrow were established to obtain the needed material. In addition to government-furnished, there are contractor site and supply contract site options. The Corps explored several potential sites and possibilities, not only in the five parishes that include the HSDRRS, but nation-wide. This process was entirely new for any Corps project in the US.

The overtopping of surge waters from Hurricane Katrina caused scouring of many levees in the system. Armoring adds resiliency to a levee and can reduce erosion and scouring by protecting levee back-slopes against wave overtopping. Since Katrina, the Corps has undertaken a concerted effort to improve standard armoring methods and to develop new uses for traditional erosion control materials and new techniques for armoring levees. The universe of armoring materials evaluated by the Corps and academia for use in the system included grass, geotextile materials, and more substantial means like stone and paving materials.

It should be noted that the Corps of Engineers serves as one of the nation's largest infrastructure stewards with oversight authority for approximately 2,000 levees across the country. There exists a perception that the Corps has universal responsibility for all our nation's levees when, in fact, there is no single agency with levee oversight nationwide. Thousands of miles of levees are owned and controlled by local governments and private landowners, while certification of levees for FEMA's National Flood Insurance Program is the responsibility of the local levee owner or sponsor. Regardless of levee ownership, the Corps works closely with state and local managers to inspect, advise and assist communities with professional engineering expertise and material during flood fights.

6.2 Fronting Protection

Fronting Protection describes defensive measures placed in front of pump stations located on shore lines to reduce the possible damaging effects of storm surge to the pump stations. These defensive measures can include floodwalls, closure gates and other features. Four pump stations located along Lake Pontchartrain in Jefferson Parish provide roughly 95% of the drainage capacity for East Jefferson. These facilities pump water from adjacent drainage canals into Lake Pontchartrain. Hurricane Katrina led to a revision of design standards for strength and functional reliability for these important facilities. Fronting Protection construction brings the lakefront pump stations into compliance with these new standards and prepares them to better resist hurricane related storm surge. T-walls were constructed in front of pump stations and tied into the existing levees on either side. The pump discharge tubes were extended through the floodwall, and valves or gates were also constructed to prevent any water from back-flowing through the pumps.

6.3 Risk & Reliability Maps

New Orleans is the first city in the US to have Risk and Reliability Maps that provide a comprehensive system assessment of the area's flooding risk. These maps, an IPET-derived product, are part of the Corps' goal of communicating risk and assisting the public with risk-informed decision making. In August 2007, the Corps of Engineers released the 100-year set of risk maps. These products represent the depth of flooding (or lack thereof) that could be experienced after the Corps of Engineers completes the 100-year level of protection for the Hurricane Protection System, which is designed to prevent overtopping from the water levels (surge and waves) that New Orleans has a 1% chance of experiencing each year, produced by a variety of hurricanes. The risk assessment that went into the compilation of these maps was fairly complex. The end product provides a critical piece of information that the citizens in the New Orleans area need to help them make well informed decisions about where and how they choose to live and work. Two sets of flood risk maps are shown in Figure 8. The first shows pre-Katrina 1% chance conditions before the 100-year level of protection, while the second shows the same conditions after the 100-year level of protection and assumes a 50% pumping capacity. Armed with these maps citizens now have the ability to make informed decisions regarding their own particular set of conditions.

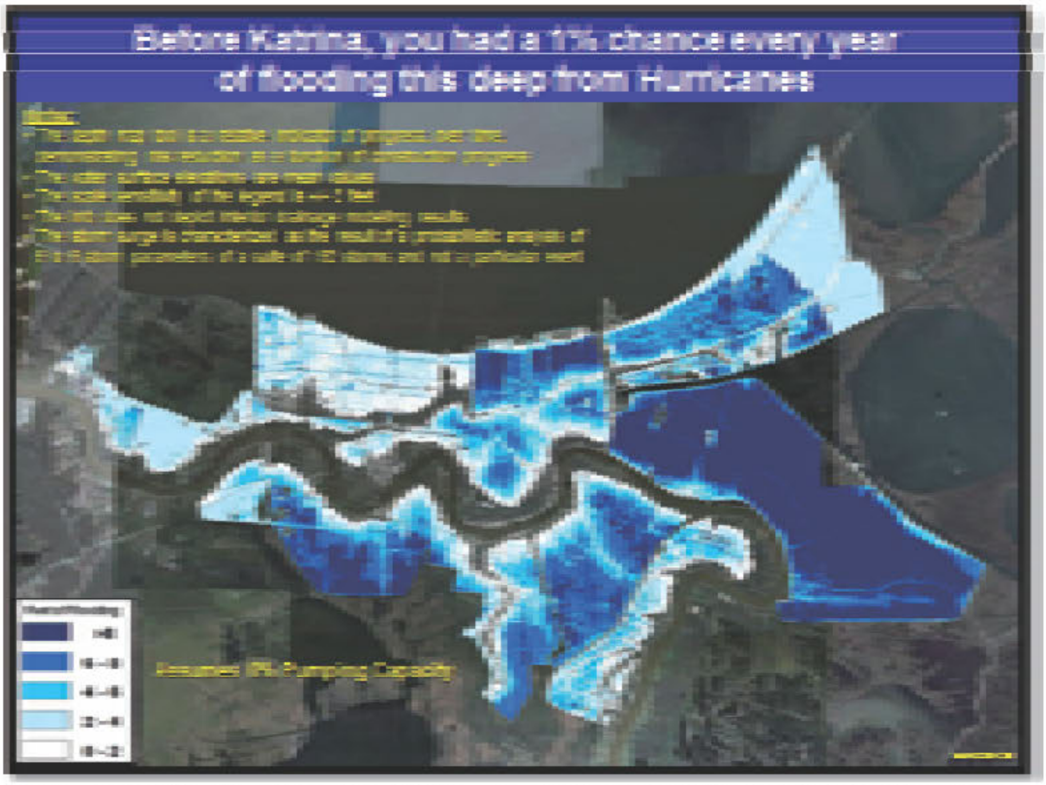

Figure 8a Risk Map Showing 1% Chance of Flooding With Pre-Katrina Conditions

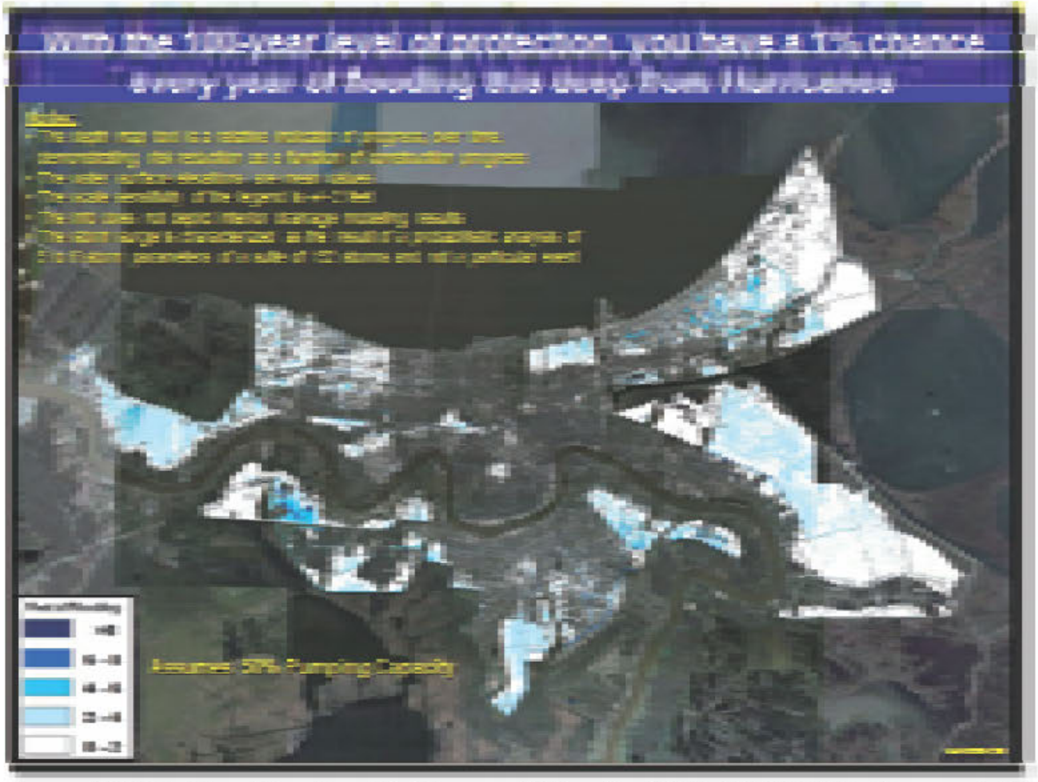

Figure 8b Risk Map Showing 1% Chance of Flooding With HSDRRS in Place and 50% Pumping Capacity

6.4 Alternative Environmental Arrangements

The overall effects on the environment have also been taken into account with HSDRRS. The 1960s ushered in a wave of new US laws and procedures designed to protect the environment. Accordingly, since 1970 all federal projects have been required to meet National Environmental Protection Act (NEPA) compliance requirements. The NEPA compliance process for a single project, which involves detailed environmental studies, often takes five to ten years to complete. Since the HSDRRS involves hundreds of construction projects, coordination of the environmental impacts into traditional Environmental Impact Statements presented a significant challenge. In an effort to achieve its timely mission, the Corps sought a way to expedite the NEPA process while remaining in compliance with all environmental laws and regulations. The Corps' environmental team working with concurrence from the White House's Council on Environmental Quality, the Department of the Army, federal and state resource agencies, and Corps stakeholders achieved compliance in part with a unique method called "Alternative Arrangements." Through Alternative Arrangements, proposed construction projects were identified and evaluated by basins within the system. These Alternative NEPA Arrangements allowed for system-wide environmental studies to be completed, while still moving segments ahead to construction at a pace fitting the emergency nature of the work at hand.

7. MOVING FORWARD

The US has learned a great deal from Hurricane Katrina, and the New Orleans area is clearly now in a far better position to cope with future hurricane events. It should be noted, however, that hazard risk management is a true work in progress. The IPET findings and lessons learned are based on the experience of a past event, Katrina, but they are also an important lens into the future. The following are strategic messages from Katrina that need to be considered in both policy and practice.

First and foremost, the US lacks a coherent and comprehensive strategy for water resources. Consequently, levels of protection are marginal with respect to levels of risk and investments too often are local in scope, short-term in nature, cost-benefit based, and focused on taming rather than working with natural processes. Integrating risk reduction with other critical functions such as water quality, sustainability and commerce remain an idealistic goal. It is, therefore, time for a new national emphasis on holistic water policy where public safety is a mandatory component.

The hurricane protection measures in New Orleans were clearly overwhelmed by a major and rare event, but they were also below current standards in their performance. The system in place before Katrina was compromised by a long series of decisions driven by competing priorities, incremental decision making and funding, inadequate consideration of change and de-facto standards far too low to deal with the realities of modern natural hazards. The HPS could not and did not perform as a system because of these and other factors. Future projects, as demonstrated by HSDRRS, must be designed, constructed, and maintained as systems. The promise or perception of a system when it does not exist is perhaps more dangerous than no system at all.

As a nation we lack clear standards for planning, design, and development of major public infrastructure for water resources. New knowledge is often too slow to be incorporated into engineering guidance, and we too often optimize based on immediate cost and accept short-term gains instead of long-term solutions. This is a national cultural malady that can only be reversed if the public demands a change in policy. Life-cycle solutions are important to our future, and we can only get there through the election cycle. The 100-year de-facto standard is far too risky for the continued vitality of our economy that is highly dependent on the viability of the public infrastructure and the continuity of the economy. The nation must go to more comprehensive risk-based standards that provide longer term solutions that combine benefits of both built and natural measures.

Further, man-made measures alone cannot sufficiently reduce risk for vulnerable areas such as New Orleans. Natural processes and attributes such as marshes, mangroves, and barrier islands need to be integral to a systems strategy for risk reduction. In combination with traditional structures and aggressive emergency management planning and execution, an enhanced natural environment would be a major component to a sustainable and effective long-term strategy to deal with the dynamics of climate, demographics, and social and economic wellbeing.

Risk is increasing significantly along the nation's coastlines, in part because natural hazards such as hurricanes appear to be more severe, but even more so because increasing numbers of people and property are being allowed to reside in harm's way. There is little that governments or individuals can do about the changing hazard, but there is much that can be done to manage risk by reducing exposure to the hazard. For populated flood-prone areas, compartmentalization of basins, raising first floor elevations, and flood-proofing structures can reduce exposure to losses. The simplest approach in principle is managing land use to avoid placing more people and property in areas vulnerable to hazards. While simple in principle, the dichotomy of land-use authorities between levels of government, lack of adequate standards, and the dependence on continued development has made this the correct path seldom taken. Many individuals are drawn into this web by ignorance or lack of clear information, an issue that must be addressed by all public officials.

Understanding risk is a powerful tool in helping both individuals and government agencies to make consistent and conscientious decisions concerning natural hazard risk management.

The ability to quantify risk for large geographical areas and complex engineered systems is slowly emerging in the US through the work in New Orleans and central California. Risk provides a much richer body of knowledge to understand and manage vulnerability to hazards as well as providing a clear common picture of the situation to all. Risk methods for regional infrastructure, if fully developed, will not only allow assessment of multiple hazards, but also allow collective consideration of life safety, direct and indirect economics and social-cultural issues, enabling customization of solutions to situations. But the evolution and application of risk to support decision making must be enabled by policy which currently does not exist. We have yet to demonstrate the public and the political will to adopt these more rigorous guidelines for risk management and mitigation.

There is clearly much more to learn. If we as a nation hope to manage risk from the most severe hazards, we need to learn how to work with rather than control nature. Research is needed to better define the actual role of natural environments in managing surge and waves; rules of thumb are just too inaccurate. Given the challenges of continued sea level rise and subsidence and the potential for more intense storms, the art of building and sustaining the natural environment is especially important. The vulnerability of natural features to large storms is a particular challenge if we are to rely on them for long-term risk reduction. The fact that there are not enough high quality natural materials to build traditional structures demands that we seek innovative alternatives. The ability to routinely monitor conditions and residual risk on a system-wide and regional basis will require much more effective sensing and analysis, particularly concerning geotechnical issues.

It must also be noted that our current policy and practice does not deal well with change. We must be much more anticipatory and adaptive as changes occur in the hazard, the system or the potential consequences.

In summary, the key findings and recommendations that stem from the Interagency Performance Evaluation Task Force suggest that the US has a far from perfect system for managing its vast "hazard-scape". Our ability to minimize the impact of disasters of the magnitude of Hurricane Katrina is a daunting task, and we must continue to strive for new and innovative strategies such as those now being demonstrated in Greater New Orleans. In the aftermath of Hurricane Katrina the future of that city was in doubt. The recovery efforts that have been spearheaded by Task Force Hope have vastly improved a once-fractured system and have put that entire region on a much more sustainable path.

Sources for this paper were derived from the archives of the Interagency Performance Evaluation Task Force and material provided by Task Force Hope.

Chapter 5

Report on Damages by Recent Cyclonic Floods (2007-2009) in Bangladesh

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EXECUTIVE SUMMARY

Bangladesh is a disaster-prone country. Of natural disasters, river floods and cyclone-driven tidal floods are the most notorious. In Bangladesh, most of the losses of lives and wealth were caused by flood disasters. Flood events cause land to submerge. However, submergence of land by river floods is beneficial because silt deposition elevates land, making it fit for cultivation of fruits and vegetables and planting trees. It is also important for human settlement. Annual submergence of land by river water enhances soil fertility and replenishes ground water with direct benefit of increasing agricultural production of crops. With so many positive impacts of land inundation by river water, floods can be considered good. The land mass of Bangladesh is the biggest delta on the planet earth. It was formed with sand and silt deposited by river floods.

Bangladesh's rivers annually receive about one billion ton of sand and silt that are carried by floodwaters mostly from outside the country in the monsoon period. Sand and silt continue to deposit in the rivers' bed every year. This phenomenon has resulted in filling and elevating of the rivers' bed. As a result, the rivers frequently show a tendency to shift their courses. Shifting river courses causes bank erosion engulfing homesteads. People become victims of land losses, some of them repeatedly, and thus the poverty level of the victims goes up. At the same time the conveyance capacity of the rivers reduces drastically disrupting river navigation and destroying fish habitats in the rivers. Monsoon floods, due to a high flow velocity in the rivers, frequently cause bank erosion. In the receding stage of floods, again bank erosion takes place. The phenomenon gives rise to disaster event(s) (for BWDB) when a segment of flood embankment bursts open or is overtopped by spilling water or erosion engulfs embankments, revetments, spurs, or groins (i.e., river training works). As there is no perfect way to control bank erosion completely, it is highly recommended to keep a free buffer zone for future development plans in river banks and avoid establishing any utility infrastructure close to eroded banks

Very recently, two extreme events of natural disaster one caused by Cyclone Sidr on 15-16 November 2007 and another by Cyclone Aila on 25-26 May 2009 swept over the south and south-west regions of Bangladesh. In case of Sidr, there were forecasts and warnings by the Met Office and broadcast over TV and Radio for five days about the grave severity of danger that could be inflicted by the blowing wind and flood. In case of Aila, there were forecasts and warnings for three days. Highest warning signal No.10 was issued to prepare for Sidr and danger signal No.6 to prepare for Aila. Although the warnings helped keep the death tolls low, they were not necessarily effective to avoid casualties. In this report main cause of damage and strategy to reduce them will be discussed.

1. INTRODUCTION

Bangladesh, a South Asian country, is located on the north of the Bay of Bengal. Her geographical location is $20^{0}34'$N to $26^{0}38'$N and $88^{0}01'$E to $92^{0}41'$E. The country is surrounded by India in the west, north and east, and by Myanmar in the south-east (Map 1). The country occupies an area of 147,570 sq. km and her coast is stretched towards the south in the Bay of Bengal. According to the 2001 census, the population of the country was 129.25 million (density: 834 persons in one sq. km), but the population is estimated 159 million (2011 estimation). The country's climate is sub-tropical; the temperature in winter ranges from 7 to 31 deg. C while in summer the mean temperature is about 30 deg. C and sometimes rises up to 40 deg. C. Two distinct weather seasons dominate in a year: the dry season from November to May and the wet season (monsoon) from June to October. The annual precipitation varies from 1200 mm in the north-west to 5500 mm in the north-east.

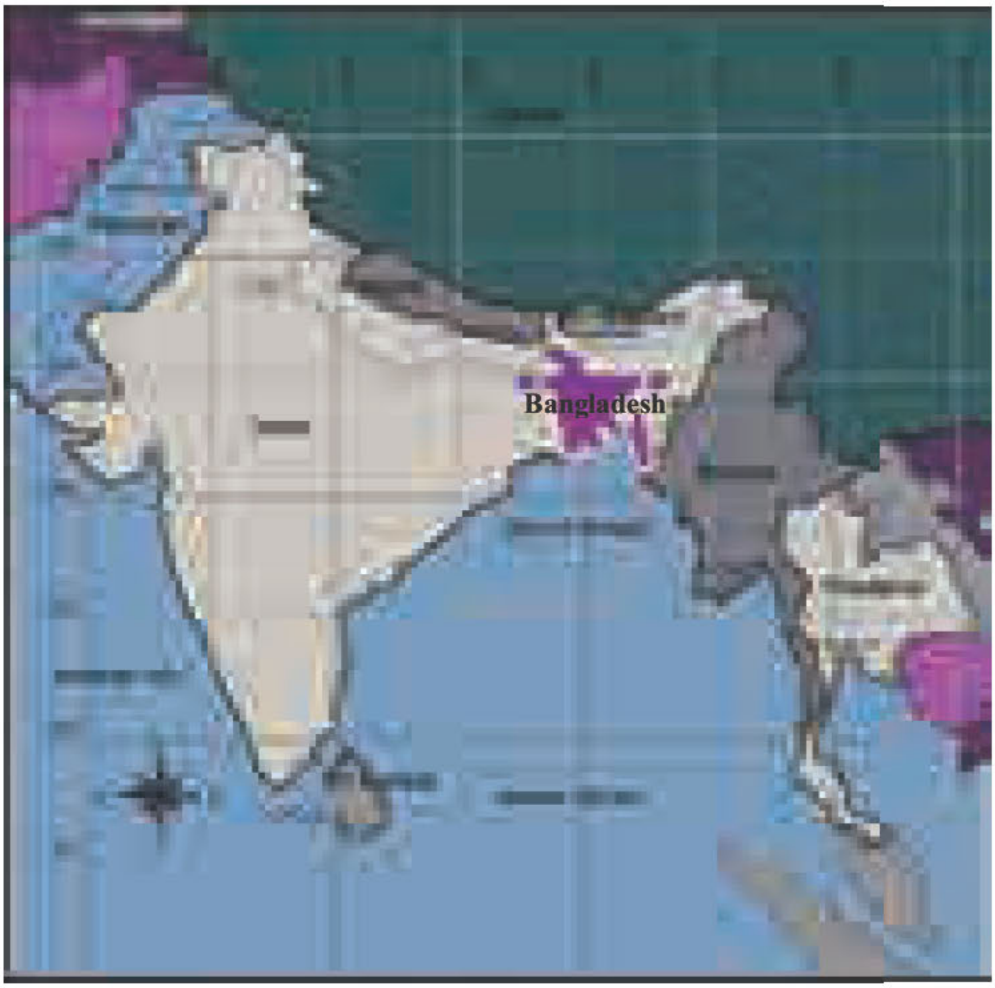

Figure 1 Bangladesh and its neighboring countries

2. NATURAL DISASTERS IN BANGLADESH

Bangladesh is a disaster-prone country. Of natural disasters, river floods and cyclone-driven tidal floods are the most notorious. In Bangladesh, most of the losses of lives and wealth were caused by flood disasters.

Flood events cause land to submerge. However, submergence of land by river floods is beneficial because silt deposition elevates land, making it fit for cultivation of fruits and vegetables and planting trees. It is also important for human settlement. Annual submergence of land by river water enhances soil fertility and replenishes ground water with direct benefit of increasing agricultural production of crops. With so many positive impacts of land inundation by river water, floods can be considered good. The land mass of Bangladesh is the biggest delta on the planet earth. It was formed with sand and silt deposited by river floods.

Sea water of the Bay of Bengal also causes inundation of land by every tide; sea water covers a vast area of the country twice a day. An estimated about 20% of Bangladesh's land is merely (+) 2 meters above mean sea level (MSL) in the south along the Bay of Bengal. Thus tidal inundation was a regular phenomenon in the past in the south region (and is still so in off-shore islands). The tide of the sea water travels towards the north, i.e., in the interior of the country, in the opposite direction of the upland river current, which causes 'tide lockage' and thus enhances the land building process by deposition of sand and silt. In the south of the country, people used to harvest salt brought in by sea water over flat land, which now occurs only in limited areas during the summer. In fact, land formation in the south by the process of alternate drying and flooding from the sea raised land elevation (islands formed) and ultimately led to development of human settlements.

However, the phenomena of flooding in extreme cases are a curse for people. Although water is one of the most important and essential elements of human lives (and lives of all living creatures), excess water mainly deep water on land, which is called floods is detrimental to human, habitat and property. Floods can damage everything from standing crops to homesteads and to all infrastructures, if it exceeds certain depth and also stays beyond a threshold time limit. Floods lead to disaster when they claim human lives while passing at high velocity and erode riverbanks and wash out households, a huge area of cultivable land, and crops. Coastal land subjected to flooding by sea water is always unsuitable to crop production due to excess salinity brought in by sea water. In the past, there was no excessive concentration of population in the coastal areas along the Bay of Bengal; that condition underwent gradual change from the beginning of the twentieth century with the population increase in the country. People from the north and the central areas of the country continued to move towards the south along the coast to earn basic elements of life. Means of living for most of the inhabitants in the coastal region are fishing and salt trading.

The northern and the central areas of the country experience floods almost every year. In general, floods are mild and do not cause any harm to crops or human habitat. However, floods in the northern and central regions of the country can be extremely severe both in depth and duration in some cases. In 1998, an estimated 68% area of the country experienced severe floods. In the central area around the capital Dhaka, a flood event sustained as long as 58 days. In the recent history of the country, this was the most severe deluge event caused by precipitation and upland river flow. At that time, a lot of infrastructures were damaged; roads were submerged, schools were shut, food depots were rendered unusable by water, and food grains could not be transported to flood victims by land transport. It was a very difficult task to keep a huge number of flood victims in temporary shelters. Schools and other educational institutions in affected rural areas were converted to flood shelters (and this in effect disrupted education of children). It was a very chaotic situation. On the one hand, victims had to be provided with food, drinking water, clothes, medicine; on the other hand flood defence infrastructures had to be saved as much as possible by fighting the flood. Engineers of the Bangladesh Water Development Board (BWDB) under the Ministry of Water Resources worked round the clock to avoid the failure of flood defence measures by flood fighting. At the same time the personnel of the armed forces used helicopters to transport relief materials to rural areas. Water vessels were used all the time to ferry relief goods and rescue people from low lying areas. The flood-prone area map prepared for the BWDB by the Institute of Water Modeling (IWM) may have been consulted to get an idea about the magnitude of the problem (Map 2).

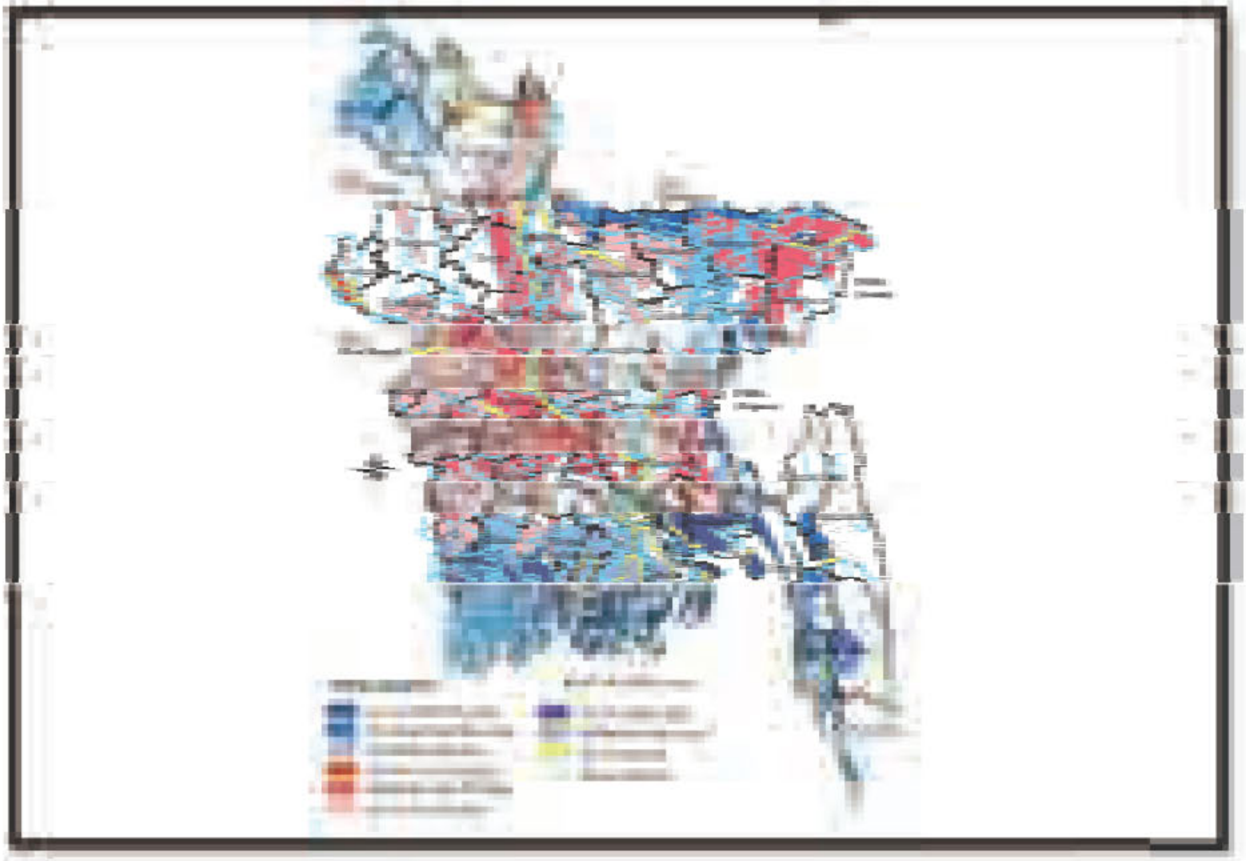

Figure 2 Flood Prone Areas of Bangladesh

In fact, as mentioned above, floods are a recurring natural phenomenon in Bangladesh, and the people of Bangladesh are used to live with floods for many years. In the north-eastern hilly part of the country bordering India, the annual rainfall is high (about 5500mm/year). The intensity of rainfall is also high. When a very high intensity rainfall occurs in the hilly area, the accumulated water rushes downstream through steep rivers. When the water reaches a flat land, flooding will take place within a very short span of time with many things submerged. This type of flooding phenomenon is also prevalent in the south-eastern region of the country for the same reason (hilly area with steep rivers). However, the north-eastern region, where many "haors" are located (haors, or more commonly known as backswanps, are saucer-shaped shallow depression, where only one crop of high yielding paddy can be cultivated with irrigation from January to May), is extremely vulnerable to flash floods in the April-May period of the year. In the worst case, they wash out ripe paddies. (However, the BWDB built an about 1800 km dwarf dyke around some of the haors to save crops from flash floods. Though the dyke has been proved effective, more interventions should be applied to find out a sustainable mitigation measure.)

Upstream floods, i.e., floods in the northern and central regions of the country, are attributed to a huge volume of water that rushes into Bangladesh through international rivers from neighbouring India. Bangladesh is the drainage route of water in the monsoon into the Bay of Bengal. The three mightiest rivers of the world, the Ganges, Brahmaputra and Meghna River systems, run through the country. Out of the 1.72 million sq. km combined drainage area, 93% is estimated to be located outside Bangladesh (Map 3). The estimated average flow of these huge river systems is about 1,250 billion cubic meter (BCM) annually, of which about 250 BCM are generated inside the country. About 80% of the water flow is generated in the monsoon (from July to September). During this period, the elevation of the water surface in the sea on the south also remains at a high stage. For this reason, water cannot drain out rapidly through the rivers due to the low energy gradient towards the sea. As a matter of fact, as all the big rivers come from the hilly areas of the great Himalayan Range, the rivers have steep slope outside Bangladesh's border and an estimated one billion tons of sand and silt are carried by the rivers into Bangladesh. The country has currently 310 rivers in total with a route length of about 24,000 km. Most of these rivers have accumulated a huge volume of silt in their beds and that reduced dead storage capacity of the rivers, which is in turn attributed to mild gradient of bed slope. Such a complex morphology of the rivers has put Bangladesh in a very vulnerable condition for flood events in the monsoon. But the most delicate situation lies with the variability of precipitation in the catchment areas of the three individual river systems. The country faces mild floods if only one big river system remains in a flooding condition with a high peak flow. In such a situation, the main drainage route (the Meghna River) into the Bay of Bengal from the meeting point of the Meghna and the Padma (about 25 km upstream of Chandpur) still can accommodate the flood flow without causing very much trouble and damage. But if flood peaks in more than one river systems synchronize and if the volume of water is also high, a serve flood is simply inevitable. Bangladesh experienced such a situation on many occasions in the past. and with possible change in rainfall pattern, amount and intensity due to anticipated climate change, it may suffer severe floods more frequently in the future.

Another problem that Bangladesh frequently faces is regional floods due to localized high-intensity precipitation. From April till even December, many low depressions some of them even turn to cyclones form in the Bay of Bengal. Due to the influence of the low depressions, localized high-intensity rainfall occurs in various regions, mostly in the south and south-east regions of the country. As mentioned earlier, due to either reduced conveyance capacity of the rivers by silt deposition in the beds or "tide lockage" in the rivers under the swelling-sea condition at the time of low depressions, recession of water towards the sea takes longer than usual. This type of situation attributes to inundation of land for a few days destroying standing crops.

Figure 3 catchment areas of three major rivers of Indian sub-continent

In the year 1998, the most severe flood in the recent history lasted for a long period of 58 days. During this period, the water level in the central part of the country showed few signs of recession. But with some gaps of time, the water level registered a trend of rise. In some important flood control, drainage and irrigation projects around the capital city of Dhaka (where a huge area of human habitation grew), the floodwaters overtopped the top of the existing flood defence dykes at regular intervals of 4-5 days, at which each time flood waves moved from the north to the south (from the upstream to downstream direction). This type of menace was addressed by putting sand-filled bags (synthetic/jute made bags) on the crest of the embankment. One devastating phenomenon was noticed at this period of the flood event. Across the embankment, a huge number of seepage points developed underneath the flood defence embankment from the river side towards the country side (project side); as time passed by, the number of seepage points continued increasing. At the later part of the event, sliding of embankment segments on the country side took place by “slip circle failure” in the slope which was extremely difficult to repair in the raining period. Later on, when the flood water started receding in mid September that year, some researchers were telling that a “El Nino, La Nina” condition prevailed in the Bay of Bengal, in which the sea water level remained at a high stage for a long period impeding the normal drainage of the river water into the sea. They said that was the main reason of prolonged floods in the country in that year. (Unfortunately, no further systematic studies were carried out at that period to make a documentation for the future.) Such type of prolonged flood events had a characteristic that the river side of the dyke was subjected to continuous pressure of water column while the country side was dry. Due to a huge head difference of energy, water from the river side gets passage towards the country side through the dyke in the process of seepage. At the later stage of the flood event, it was noticed that the embankment soil was also rendered soft in the core area. The situation was so dangerous that the entire embankment could have breached at anytime without allowing any chance to take any further defensive/mitigation measures. In a respect, the danger posed by long-standing flood water against a dyke is unique, but Bangladesh faced such serious hazards in the recent past. In the future, with the impact of climate change, it will be very difficult for Bangladesh to counter a more severe flood event than that occurred in 1998.

The southern part of the country, in the past, was subjected to occasional extreme cyclone-driven floods of the sea. Most cyclones originated in the “Andaman Sea” at around 6 to 10 deg. N latitude. In severe events of cyclone-driven floods, people were killed in thousands. In fact, according to available data, the first river flood in 1644 and the first cyclone-driven tidal flood in 1797 were the first events in the country whose death tolls were recorded by the type of events. As of 2009, over 1,058,178 humans were killed by river or cyclonic floods in Bangladesh, according to records available.

In 1901, the population of the country was only 28.93 million persons. But in 1951, the population increased to 44.17 million and in 1961 to 55.22 million. With the passing of time, the population increased and the need for food also increased. In 1954 and 1955, there were consecutive severe floods in Bangladesh, which caused huge damage to properties especially to crops, and there was severe shortage of food. Consequently, starvation resulted, which shocked the nation for the first time in years.

3. FLOOD MITIGATION MEASURES

In 1959, the then EPWAPDA (East Pakistan Water And Power Development Authority; till 1970 Bangladesh was known as East Pakistan which was a part of Pakistan, now bordered by India and Afghanistan in Asia) was established to formulate, develop and manage plans and works of the water resource and energy sectors of the country. Later on when Bangladesh won independence from Pakistan after a war in 1971, the EPWAPDA was bifurcated into the “Bangladesh Water Development Board (BWDB)” and the “Bangladesh Power Development Board (BPDB)” in 1972. The BWDB, which was previously the “Water Wing” of the EPWAPDA, is mandated to plan, develop, manage and implement water sector projects in the following manner:

- *Structural Measures*
- *Non-Structural Measures*

However, both types of interventions are required to be formulated and approved by the government when the fund is to be spent from the state exchequer. Approval of the BWDB sponsored projects passes through identification, pre-feasibility study, feasibility study, formulation of Development Project Proforma (DPP), detail engineering design, examination at various stages/levels.

3.1 Structural Measures:

- Control and development of River and River Catchment
- Flood control
- Water drainage improvement
- Irrigation development
- Construction of reservoir, barrage, embankment, regulator, or any other structures with the aim of mitigation of drought
- Re-excavation of water routes, canals, rivers, beels (flat field) in order to divert or improve water drainage routes
- Development of water flow in order to provide facilities and improve irrigation, fisheries, navigation, forestation, preservation of wildlife and overall conservation of environment

- Land conservation, land development, and land reclamation, and control of river confluence
- Protection of river bank
- Protection of towns, markets, places of historical and national importance from probable erosion by rivers
- Construction and protection of coastal embankment
- Prevention of intrusion of saline waters in the mainland
- Reduction of desertification
- Collection of rain waters for irrigation, conservation of the environment, and drinking and potable water

3.2 Non-Structural Measures:

- Forecasting and warning of floods and droughts
- Investigation in respect of hydrology and collection, preservation and dissemination of data and information
- Plantation of trees in the private-owned land with the assistance of other departments to conserve and improve the environment
- Implementation of fisheries projects in departmental land and construction of road on the embankment
- Fundamental and applied research studies on activities and projects of the BWDB
- Organization of the stakeholders of projects (implemented by the BWDB) to distribute benefits among them without being uninterrupted
- Active participation in the projects
- Development of ways, means, methods and techniques to recover operation and maintenance costs and project investment costs
- Development of various techniques and institutional approaches for project implementation and operation

From 1959 and onwards, the concept of saving land and lives from floods became a serious issue and priority of the nation. The first programme of the organization was to protect coastal land from sea-tide floods in order to develop a congenial environment for crop production and secure human settlement. The engineering approach of the plan was to build dykes encircling raised land. Natural drainage channels were closed by dams to make the area flood-proof while sluices and regulators were built across dykes for drainage by gravitational force. The dykes facing the sea, 4.27 meter (14 ft.) crest width, 1:7 sea side and 1:3 country side slopes, were built with local soil materials by human labour force. The sea-dykes were provided with 1.52 m (5 ft.) freeboard above the design highest flood level of the sea.

While building sea-dykes in the coastal areas under the Coastal Embankment Project (CEP) since the 1960s, the focus was also directed to build embankments alongside the major rivers of the country to protect land and property from monsoon floods (caused by cross-boundary water flows). By June 2009, the BWDB made the following achievements:

1. Sea-dyke: 4,530 km (in 125 polder projects in the coastal areas)
2. Embankment : 5,696 km (other projects)
3. Irrigation canal : 5,173 km
4. Drainage canal : 3,977 km
5. Hydraulic structure: 14,126 Nos.
6. Pumping station: 19 Nos.
7. Barrage: 04 Nos.
8. River closure dams: 1,303 Nos.

4. VULNERABILITY TO FLOOD DISASTERS

Of the total 147,570 sq. km area of Bangladesh, the cultivable land in the country is estimated at 82,000 sq. km. About 117,000 sq km (78%) is estimated to be flood prone, out of which 59,000 sq. km is under the BWDB projects of the Flood Control and Drainage (FCD) or the Flood Control Drainage and Irrigation (FCDI). The irrigation facilities provided by BWBD cover over 14,140 sq. km of the land to protect it from floods.

On average, about 22% of Bangladesh experiences floods annually. Floods are categorized into mild, severe and very severe, depending upon the depth of inundation, duration and also the extent of area inundated. As stated earlier, in 1998, as large as 68% of the country was inundated by floods, the event lasted for 58 consecutive days in Dhaka and adjoining areas. It was a catastrophic event in the recent history. However, floods due to erosion of banks or breach of embankments by river water in the monsoon is less devastating in respect of human death toll, though damage of crops may be enormous.

But floods caused by cyclone-driven sea waves in the southern part of the country are totally different in nature, scale and damage. Sea wave(s) driven by cyclonic storms with very high wind speeds move towards the coast at very high speeds and hit the land with tremendous force. Houses are blown away, trees are knocked down, crops are submerged by water, people are killed in the worst affected areas under fallen houses or trees but mostly by water. This type of disaster can sweep an area in just an hour's time, and the fury is gone as soon as the cyclone eye crosses the main land. About 20% of the country in the south along the Bay of Bengal is highly vulnerable to cyclonic floods. The area most vulnerable to cyclonic floods is shown in Map 4.

Figure 4 Cyclonic-flood vulnerable areas of Bangladesh

In fact, a huge number of human lives (511,240 Nos.) were claimed by cyclonic floods from 1960 to 2009 in Bangladesh as given in Table 1.

Table 1 Death Tolls in Recent Years by Cyclonic Floods in Bangladesh (40 yrs, 1960-2009.)

Date of occurrence	Max. Wind speed, (km/hr)	Predicted Storm Surge Height, (m)	Human Deaths, (Nos.)
1	2	3	4
09/10/1960	160	3	3,000
30/10/1960	208	4-6	5,149
09/05/1961	144	2-3	11,466
28/05/1963	200	4-5	11,520
11/05/1965	160	3-4	19,279
14/12/1965	208	5-6	873
01/10/1966	144	5-6	850
12/11/1970	224	6-8 (Gorki)	300,000
25/05/1985	152	3-5	11,069
29/11/1988	160	2-3	5,708
21/04/1991	225	4-5	138,868
15/11/2007	225	4-5 (Sidr)	3,268
25/05/2009	-	3-4 (Aila)	190

5. DAMAGES BY RECENT CYCLONIC FLOODS

Very recently, two extreme events of natural disaster one caused by Cyclone Sidr on 15-16 November 2007 and another by Cyclone Aila on 25-26 May 2009 swept over the south and south-west regions of Bangladesh. In case of Sidr, there were forecasts and warnings by the Met Office and broadcast over TV and Radio for five days about the grave severity of danger that could be inflicted by the blowing wind and flood. In case of Aila, there were forecasts and warnings for three days. Highest warning signal No.10 was issued to prepare for Sidr and danger signal No.6 to prepare for Aila. Although the warnings helped keep the death tolls low, they were not necessarily effective to avoid casualties.

The damage caused by sea floods at the time of Sidr and Aila in the southern coast of Bangladesh is compared in Table 2 and Table 3.

6. IMPACT OF RECENT FLOOD DAMAGES

It is quite clear from Table 2 and Table 3 that the damage inflicted by the cyclonic floods caused by Sidr and Aila were enormous in terms of human death toll and other types of damage to various infrastructures. However, it should be noted that, in respect of damage to flood defence infrastructures, the restoration cost is USD 76.87 million in 2007 and USD 85.71 million in 2009. Hopefully, in three to four years, the infrastructures will be made fully serviceable with finance from the Bangladesh government and development partners (the process is already underway). Damage to rural roads, schools and colleges, and other community facilities will also be rehabilitated in a similar fashion. The loss due to crop damage is fully personal, so is the loss of houses. However, the government made the best effort to compensate for the losses as much as possible. As a matter of fact, due to damage of crops in 2007 by the cyclonic floods was followed by a huge crisis of food grains, mainly the staple food of rice in the region. There were no sufficient facilities existing to maintain adequate food grains under the government initiative in the coastal region of Bangladesh.

The cyclonic flood of 2007 (Sidr) struck the region in mid-November when paddy crops were almost half-ripe standing in the field. At that time, crops were submerged by cyclonic floods in the polder projects and farmers could save nothing. That was the time when most inhabitants in the region exhausted their food grains from the previous crop season and were expecting to harvest new crops (Kharif II) in a month's time. It was such a crucial time that the community did not have any resource to help one another. The after-effect was very troublesome. A huge number of people were in need of food, drinking water, medicines, clothes, houses, etc. for a long period. This event coincided with the panic of rising food price in the international market. The Bangladesh government made the utmost effort to deliver essentials including food to the survivors of the disaster from other regions within the country mobilizing all sorts of transports. The armed forces were deployed with all logistics to assist the civil administration in relief and rescue operations.

Table 2 Damage by "Sidr" Cyclonic-flood in 2007 and Aila in 2009

Damage	Sidr (2007)	Aila (2009)
Human death	3,268 persons	190 persons
Affected people	5.08 mil	3.93 million
Crops	1.24 mil ton	0.18 mil tons
Dyke (full)	308 km	237 km
Dyke (partial)	1672 km	1,557 km
Regulator (full)	321 Nos.	41 Nos.
Regulator (part)	513 Nos.	321 Nos.
Damage	Number	Number
Missing people	773 persons	14 persons
Affected family	1,509,288 Nos.	948,000 Nos.
Affected households	565, 000 (fully) 957,000 (partly)	243,000 (fully) 371,000 (partly)
Shelterless	2.44 mil persons	1.01 million persons
School/College	4,231 (full) 12,723 (partly)	445 (fully) 4,588 (partly)
Schooling lost by	1.48 mil children	0.16 million
BWDB rehab cost	BDT.5.38 billion (USD76.87 million).	BDT.6.00 billion (USD85.71 million).

At that time, Bangladesh faced the most daunting problem that some of the neighbouring countries could not manage to sell food grains to Bangladesh fearing a domestic price hike of food. On the other hand, it was extremely difficult for Bangladesh to procure food from far off countries at a short notice. Despite all these hurdles, the government could save people from a famine-like disaster. This is just one side of the story (i.e., nobody died for want of food).

Another serious side of the story as furnished in Table 2 is that as many as 3,268 persons were killed by the Sidr-induced flood and 190 more persons by the Aila-induced flood. Most of the dead people were heads of the family, and a significant number of the dead were the second earning member of the family. With the death of the family head and/or the second earning member of the family, many survivors were left with none to earn money for the family. So these families' economic erosion is very unlikely to reverse. Many women became widows and their plight had no bounds. Many children became orphans, and there is no state safety net to ensure their livelihoods, enough health care and education. This type of disasters inflicts more far-reaching negative impacts on overall development of the country. By Sidr a total of 4,231 and by Aila another 445 educational institutions were fully damaged. Yet another 17,311 institutions were partly damaged by these two events. However, there may be duplication in the figures of the damaged educational institutions due to the two consecutive disasters. Considering the first event (Sidr), the damaged 16,954 institutions were home of learning for estimated 5.93 million children. Due to damage of the institutions, the young students faced a sudden loss of school accommodation, which meant suspension of the routine schooling. Most children who come from poor families had to help their parents at the risk of schooling. In cases like these, even when schools have been rebuilt and reopened after a certain period of time, a huge number of students will never be able to return to classes. This will lengthen the list of drop-outs from schools. Drop-out rates are significantly higher in villages than in urban areas. In the ultimate result, they will be deprived of education and unable to earn an academic certificate or degree. Consequently, they will have little chance to compete for a better job. They will find themselves in the vicious circle of poverty, and their poverty level will deepen. This will always put an extra burden on Bangladesh's efforts for economic and social development. Wrong-headed people may find this a good opportunity to lay traps for school drop-outs and involve them in anti-social activities making further troubles for those who would prefer peace to trouble. Thus, in short, cyclonic flood damage in Bangladesh can cast far-reaching negative impacts on the society and overall economic development of the country.

7. BANGLADESH'S INEVITABLE DISASTERS

There are some undeniable factors of nature that keep Bangladesh vulnerable to the danger of natural disasters of floods, and it is very much certain that Bangladesh will never be able to alter any of the following two most important factors that are the major cause of flood disasters. The first one is her geographical location and the second one is the amount of cross-border water flows in the monsoon.

- Bangladesh is the drainage route of three big river systems of the Indian Sub-Continent the Ganges, the Brahmmaputra and the Meghna as stated earlier. These, along with other 54 medium- and small-sized international rivers, carry about 1000 billion cubic meters (BCM) of flow discharge into Bangladesh. Bangladesh's own contribution of flow is about 250 BCM. Altogether an enormous amount of about 1,250 BCM flow needs to pour into the Bay of Bengal in the monsoon period (from June to September) through the rivers of Bangladesh. Also stated earlier, the catchment areas of these rivers are about 1.72 million sq. km in total, of which about 93% is located outside the territory of Bangladesh. Whenever the peak water stages of two of those river systems within the Bangladesh territory synchronize in the monsoon, a severe flood is inevitable (Map 5).

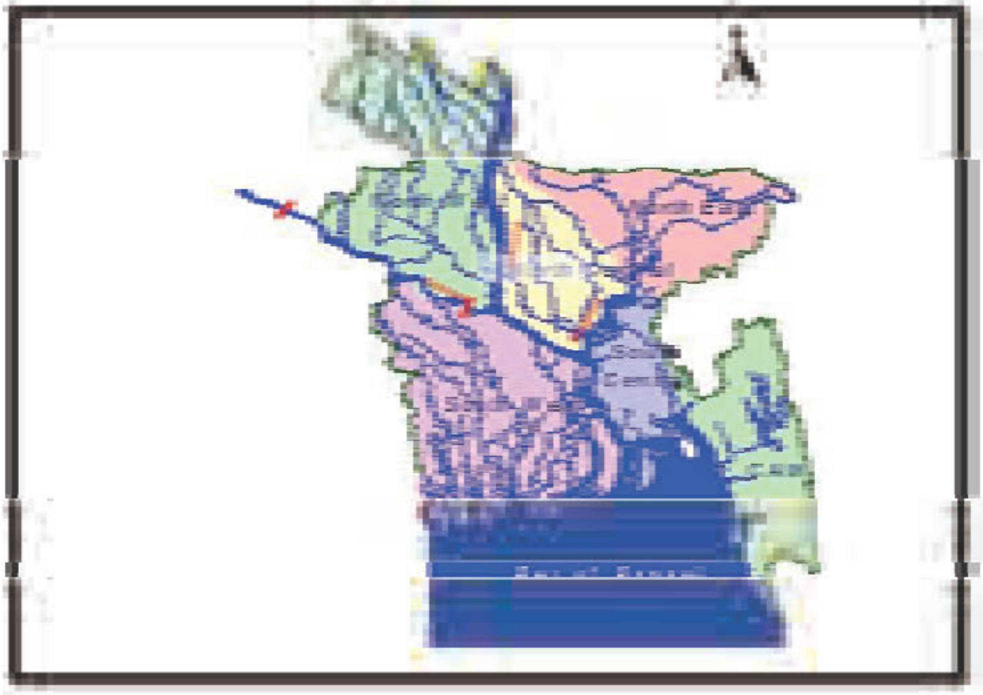

Figure 5 River-flood takes bad turn in Bangladesh, if any of two of the three major river Systems are at high flood simultaneously

- Bangladesh's rivers annually receive about one billion ton of sand and silt that are carried by floodwaters mostly from outside the country in the monsoon period. Sand and silt continue to deposit in the rivers' bed every year. This phenomenon has resulted in filling and elevating of the rivers' bed. As a result, the rivers frequently show a tendency to shift their courses. Shifting river courses causes bank erosion engulfing homesteads. People become victims of land losses, some of them repeatedly, and thus the poverty level of the victims goes up. At the same time the conveyance capacity of the rivers reduces drastically disrupting river navigation and destroying fish habitats in the rivers. Monsoon floods, due to a high flow velocity in the rivers, frequently cause bank erosion. In the receding stage of floods, again bank erosion takes place. The phenomenon gives rise to disaster event(s) (for BWDB) when a segment of flood embankment bursts open or is overtopped by spilling water or erosion engulfs embankments, revetments, spurs, or groins (i.e., river training works). As there is no perfect way to control bank erosion completely, it is highly recommended to keep a free buffer zone for future development plans in river banks and avoid establishing any utility infrastructure close to eroded banks.
- In the southern region of the country, sea dykes and river embankments (being part of Polder projects) are occasionally breached by severe cyclonic floods. In the most severe event(s), cyclone-driven floods overtop dykes and embankments, and saline water spills inside a polder project submerging crops, homesteads and infrastructures. Otherwise, a segment of the dykes and embankments may give in to the onslaught of floods developing a breach through which water rushes inside with tremendous force. Anything standing in front of such a water column including humans can be crushed in moments. There is little chance to pass down the horror of the calamity because it is almost

impossible to survive this disaster. If so happens (it indeed happened in 1970, 1985, 1991, 2007 and 2009 in large magnitude in the coast of Bangladesh), the human death toll would be enormous.

- Any cyclonic storm that develops in the sea from 6 deg. North latitude or at a distance further north from the equator and in between 86 to 93 deg. East longitude is almost bound to hit the Bangladesh coast for the inherent rule of nature, i.e., for earth's rotation. About 20% area of Bangladesh along the shore of the Bay of Bengal is identified from the past records to be vulnerable to cyclonic floods (Map 4). Bangladesh can escape a severe hit and submergence by cyclonic floods as she did in 2008 when Cyclone Nargis took a turn towards Myanmar and caused extreme damage there killing a huge number of humans. In 2009, Cyclone Aila made a direct hit to the West Bengal of India where Bangladesh's nearby coast was protected by the Sundarbans, the world's biggest mangrove forest spreading partly in Bangladesh and partly in India. However, still 190 people were killed in Bangladesh and the waves of the event caused massive flooding in the coastal polder projects.

8. RECOMMENDATIONS:

- Components of water resource projects (FCD/FCDI/River Training works) should always be maintained to the "Designed Status".
- Preventive maintenance of flood mitigation structures should be carried out in full scale at an appropriate time.
- Afforestation in the foreshore of sea dykes should be an integral part of the project plan to reduce risk of damage to flood defence structures in the coast by cyclone-driven sea surges.
- It is essential to arrange efforts for mechanical compaction of dykes and embankments in the polder projects for consolidation (and make it more resistant to attack by floods and cyclonic floods).
- Construction of cyclone shelters and ramparts in the coastal region for emergency refuge should also be in the disaster management plan as life saving measures.

Chapter 6

Disasters Caused by Cyclone Nargis and Their Underlying Causes

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EXECUTIVE SUMMARY

An extremely devastating cyclone, NARGIS, struck the Myanmar coast on the evening of 2 May 2008. Before Nargis, Myanmar was not on the list of the "Deadliest Tropical Cyclone" zones in the tropical regions. With a death toll of 138 000 human lives, Nargis became the eighth deadliest tropical cyclone. Myanmar's death toll increased from 0.09% to 6.8 % of the total death toll in the Bay of Bengal after Nargis. Nargis gave a huge socio-economic impact on the country with the damage cost mounting over 11 trillion kyats.

There is clear evidence that a footprint of climate change was observed in Nargis, especially, in its track. According to a study made by Lwin (2008), the latitude of bay-storm curvatures in the pre-monsoon season has shifted southwards from the latitude of Bangladesh (> 20 deg. North) to the latitude of Myanmar delta area (around 16 deg. North). The shift has been clearly seen since the 1980s in the decadal average of both 850 hPa winds. In addition, the decadal mean sea surface temperatures anomalies (SSTA) shows clearly that the decadal average SSTAs in the Bay of Bengal for the pre-monsoon periods has changed from negative to positive starting from 1980 onwards. Moreover, a maximum positive SSTA centre is observed in the vicinity of Preparis Island in the Andman Islands. Most storms originating in this area normally end up making landfall on the Myanmar coast.

One of the key factors for the high loss (human lives and property) caused by Nargis is a high vulnerability of the Delta Area itself. The risks in association with the area's vulnerability are found changing due to both climatic and non-climatic causes. The underlying causes of these risk changes have been discussed in details but need further investigation as the priority issue. Without doing so, disaster management in the country may not be successful in the future.

1. INTRODUCTION

Myanmar is the largest country in the southeast Asia. Its coastline is about 2,400 kilometers long and covers almost the whole east coast of the Bay of Bengal. It has a total area of 676,578 square kilometers and has a population of 51.5 million. Comparing with neighboring countries like Bangladesh, India and Thailand, Myanmar suffers less impact from natural hazards. However, climate change has caused the risk of natural disasters to increase during the last three decades. The national statistics on the occurrence of natural disasters in Myanmar names fires as the most disastrous disasters accounting for 70% of the total disaster events. Floods stand at 12%, followed by storms at 10%. The remaining ones such as earthquakes, landslides, tornadoes, thunderstorms and droughts account for 7% in total.

2. CYCLONES IN MYANMAR

Myanmar is situated in the western most part of the southeast Asia, between latitude 10-29.5 deg. N and longitude 92-100.5 deg. E. The country is bordering the Bay of Bengal and the Andaman Sea with its 2,400 km long coast line. Therefore the country is potentially rich in marine natural resources and also potentially threatened by waves, cyclones and associated weather. Fifty-one million people of the country have to share all the benefits and withstand all the hardships of the marine origin. As a tropical agricultural country, the majority of the people live in fertile plain land, which is often inundated by river floods, and coastal areas, which are exposed to stormy weather but offer safety for their livelihoods.

The Bay of Bengal of the North Indian Ocean is located in the tropical region, stretching northwards from the equator to the river mouths of Bramaputra, Ganges and Magna and eastward from the Madras coast of India to the Myanmar coast. The life span of a cyclone is rather short, less than a week. Once a cyclone is generated, it moves generally westward heading to India. If there is a slight curvature, the cyclone heads towards Bangladesh. If the curvature is sudden, the cyclone moves towards the Myanmar coast. The more drastic the curvature is, the higher the tendency to cross Myanmar coast at lower latitudes. So once there formed a cyclone, at least one nation is sure to suffer unless it fills up in the open sea, which has been a case seldom found.

The cyclone is accompanied by three destructive forces such as strong winds, heavy rain and storm surges. Strong winds are as high as 120-140 mph, heavy rains of 5-10 inches may be collected in 24 hours, waves higher than 10-12 feet may be experienced due to a landfall cyclone. Extent of damage is mainly due to storm surges, depending on the vulnerability of the place of landfall.

Annually there are about ten tropical storms in the Bay of Bengal from April to December. Severe cyclones occur during the pre-monsoon season from mid-April to mid-May and the post-monsoon period from October to December. Tropical storms that form during the monsoon period from June to September become weak and disappear mainly over the Indian coast before they make landfall. In the post-monsoon periods, remnants of typhoons in the South China Sea regenerate into storms as they enter into the Bay of Bengal and the Andaman Sea. So the Bay of Bengal has two cyclone seasons annually about a month before the southwest monsoon season (pre-monsoon period) and three months after the southwest monsoon season (post monsoon period). During the monsoon season, most disturbances are so called monsoon depressions.

3. STORM HAZARDS IN MYANMAR

Storms are one of the most devastating natural disasters in Myanmar. Frequency of cyclones that make landfall on Myanmar coast was just once in about three years. However, starting from 2000 onwards cyclones started crossing the Myanmar coast at an increased rate of two in three years on average. Since 2006 cyclones have crossed Myanmar coast in almost every year.

3.1 Frequency and Extent

During the period from 1877 to 2009, 1,303 tropical storms formed in the Bay of Bengal. Eighty-three of them made landfall over Myanmar coast, which is 6.3% of the total Bay storms in the period. Among the cyclones that made landfall on Myanmar coast, 27 (33.0%) were in May and 15 (18%) were in April, and 14 (17%) were in October and November and 9 (11%) were in December, respectively. Obviously, the statistical record clearly indicates that the month May is the highest possible month for the Bay cyclones to make landfall on Myanmar coast. Climatologically, the pre-monsoon period (April and May) accounts for 42 storms (51.0%) and the post-monsoon period (October and November) and the early winter month, December, accounts for 37 storms (45%) for landfall storms in Myanmar. Therefore, there exists two clear storm seasons for Myanmar: the pre- and post-monsoon periods.

Out of the 1,303 Bay storms during the 133-year period, only 83 storms crossed Myanmar coast. Statistically, this is equivalent to say that only 6.3 % of Bay storms crossed Myanmar coast. The annual average frequency of storms potentially crossing Myanmar coast is 0.62. It is again equivalent to say that two storms crossed Myanmar coast in every three years.

During the last six decades from 1947 to 2009, a total of 36 cyclones crossed Myanmar coast in the country's cyclone history. Loss of human lives was observed with eleven cyclone incidents mainly due to storm surges. The maximum death toll was 138,373 with Cyclone Nargis in May 2008, 1037 with Cyclone Sittwe in May 1968, 304 with Cyclone Pathe in May of 1975, 37 with Cyclone Mala of May 2006. The record shows clearly that in association with storms, the most deadliest month is May and the most deadliest area is the deltaic plain in Myanmar.

3.2 Vulnerability assessment by post-storm survey teams

There are usually three components of destructions associated with cyclones crossing the land: extremely violent winds of more than hurricane force, torrential rain and storm surges. Winds of 120-140 mph are common in most cyclones. A 20 inches of 24-hour storm rain was recorded in some cases, but 10-12 inches of storm rain within 24 hours are very common. Storms with the maximum wind speed exceeding 100 mph usually generate storm surges on entering the coast. A maximum surge height of 4.57 meters was observed in Cyclone Mala of May 2006 in association with the 140-mph sustained maximum wind on entering Rakhine coast. However, the same maximum sustained wind speed of 140 mph generated the maximum surge height of 7.02 meters when Nargis entered Deltaic coast. It is evident that when storms generate the maximum surge height, the characteristics of Deltaic coast are somewhat different from Rakhine coast. As a result, the vulnerability during storms is much higher in Deltaic coast than Rakhine coast.

Apart from topographic differences between Rakhine and Deltaic coasts, Lwin (2008) identified the vulnerable factors of Deltaic coast as (1) very low-lying area, (2) densely populated, (3) no high ground and shelters, (4) no risk knowledge and risk education, (5) poor mobility, (6) complicated river systems with seven estuaries, (7) non-linear interaction factors, (8) deforestation of mangroves, (9) no hazard and risk assessments and (10) no past experiences.

3.3 Storm surge Vulnerable Locations in Myanmar

Myanmar has a coastline of 2,400 kilometers long having Rakhine, Deltaic and Mon-Tanintharyi as three major segments.

Northern Rakhine coast, adjacent to the most storm-surge vulnerable area of Bangladesh coast, consists of some large offshore islands, intervening areas between these, and the coastline are marshy and partly covered with mangrove forests. This setting therefore provides partial protection from surge waves. However, its flat nature and very gentle slope with numerous streamlets reinforce the vulnerability of the region. Southern Rakhine coast generally is rocky and sandy with three popular resort areas. Thus, this part is comparatively more vulnerable to the storm-surge hazard.

The Ayeyarwaddy Delta is a large delta with wetlands and mangrove forests, thus providing partial protection from storm waves. The delta front is wide with shoals in some places, thus slowing down the speed of incoming waves (e.g. tsunami waves). However, the most part is open to storm surges. Immediately to the east lies the river mouth of Sittaung, which is a wide estuary that is wider southwards to form the Gulf of Mottama. Owing to the lowest altitudes of the area, a high water volume due to numerous tributaries, several open or bell-shaped river mouths, a very shallow slope, and dense population, the Ayeyarwaddy delta has the highest vulnerability in Myanmar to storm surges.

Tanintharyi coast consists of more than 800 islands which are sparsely populated with human settlements mainly on the east coasts. Compared with Rakhine and Deltaic coasts, Tanintharyi coast has lower latitudes and therefore has less possibility for storms.

4. THE KILLER CYCLONE NARGIS OF 2008

Myanmar is geographically exposed to the threat of cyclones and associated severe weather phenomena and sea waves. The frequency of cyclones that made landfall on Myanmar coast was just once in three years, but after 1978, cyclones crossed Myanmar coast twice in three years. Starting from 2006 cyclones crossed Myanmar coast every year. Cyclone tracks are unprecedented with respect to the latitude and pattern of curvature. The latitude of curvature becomes lower year after year and a drastic course change can take place within a few hours. In the case of Cyclone Nargis, the cyclone impact was extremely large.

It is due to an extremely high vulnerability of the Delta region. Enhancement of coordination among responsible agencies, community participation and capacity building need to be expanded in the context of disaster reduction in Myanmar.

Category 3 Cyclone Nargis struck Myanmar on 2-3 May 2008, making landfall in the Ayeyarwady Division, approximately 250 km southwest of Yangon, and affecting more than 50 townships mainly in the Yangon and Ayeyarwady Divisions, including Yangon, the country's largest city.

With wind speeds of up to 200 km/h accompanied by heavy rain, the damage was the severest that had ever been experienced in the Delta region, where the impacts of the extreme winds were accompanied by 12-foot (3.6 metres) storm surges. According to field survey reports, at places the peak surge was measured as high as 7.01 meters (23 feet).

Nargis was the worst natural disaster in the history of Myanmar, and the most devastating cyclone to strike Asia since 1991. The following is Maynamr Nargis damage and casualties. The map shows the track of cyclonic storm (Figure 1, 2 &3).

[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
Injured	[illegible]
[illegible]	[illegible]
[illegible]	
Buffaloes, household animals	155,248 above
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
Private Sector Loss	8.3800 trillion kyats
National Sector Loss	3.3547 trillion kyats

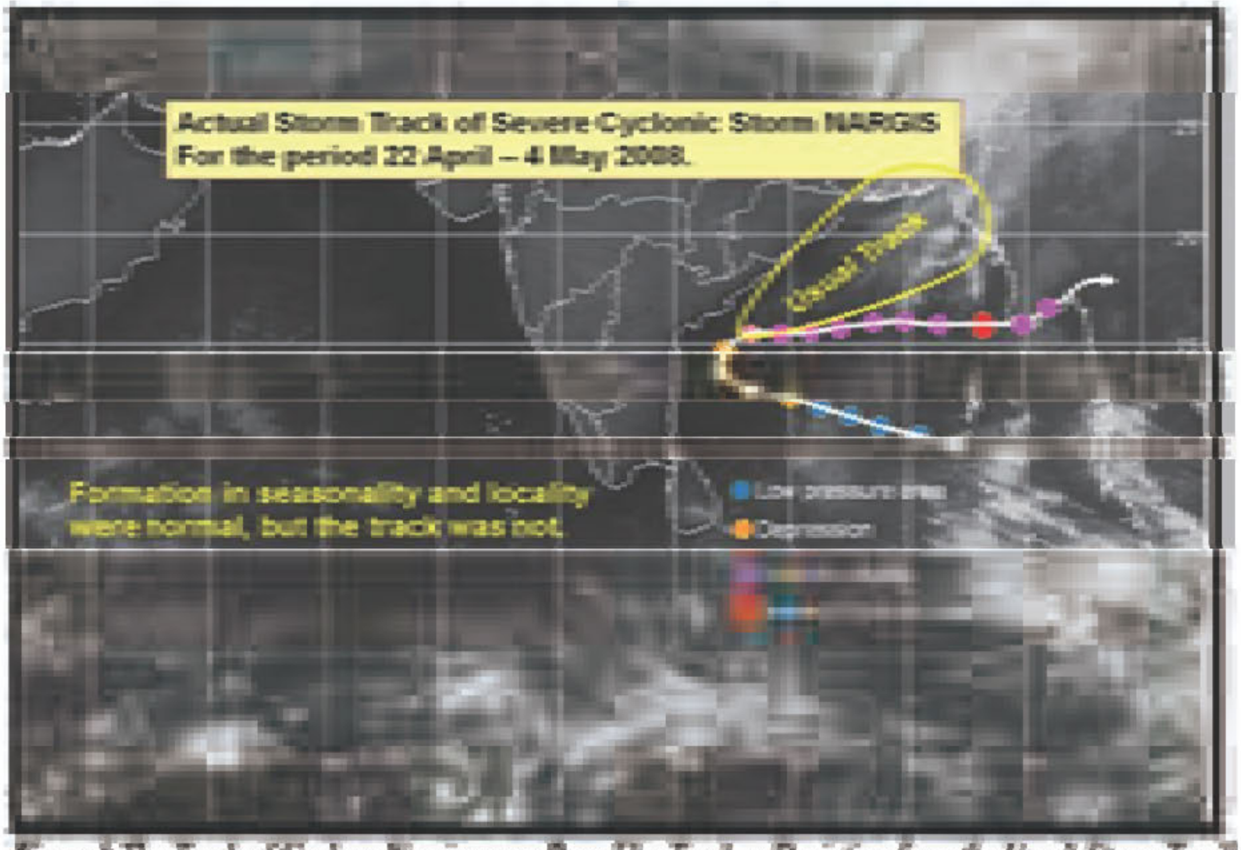

Figure1 The Track of Cyclone Nargis was a Precuiliar Track, a Deviation from the Usual Storm Tracks

Figure 2 Nargis Track from 27 April to 4 May

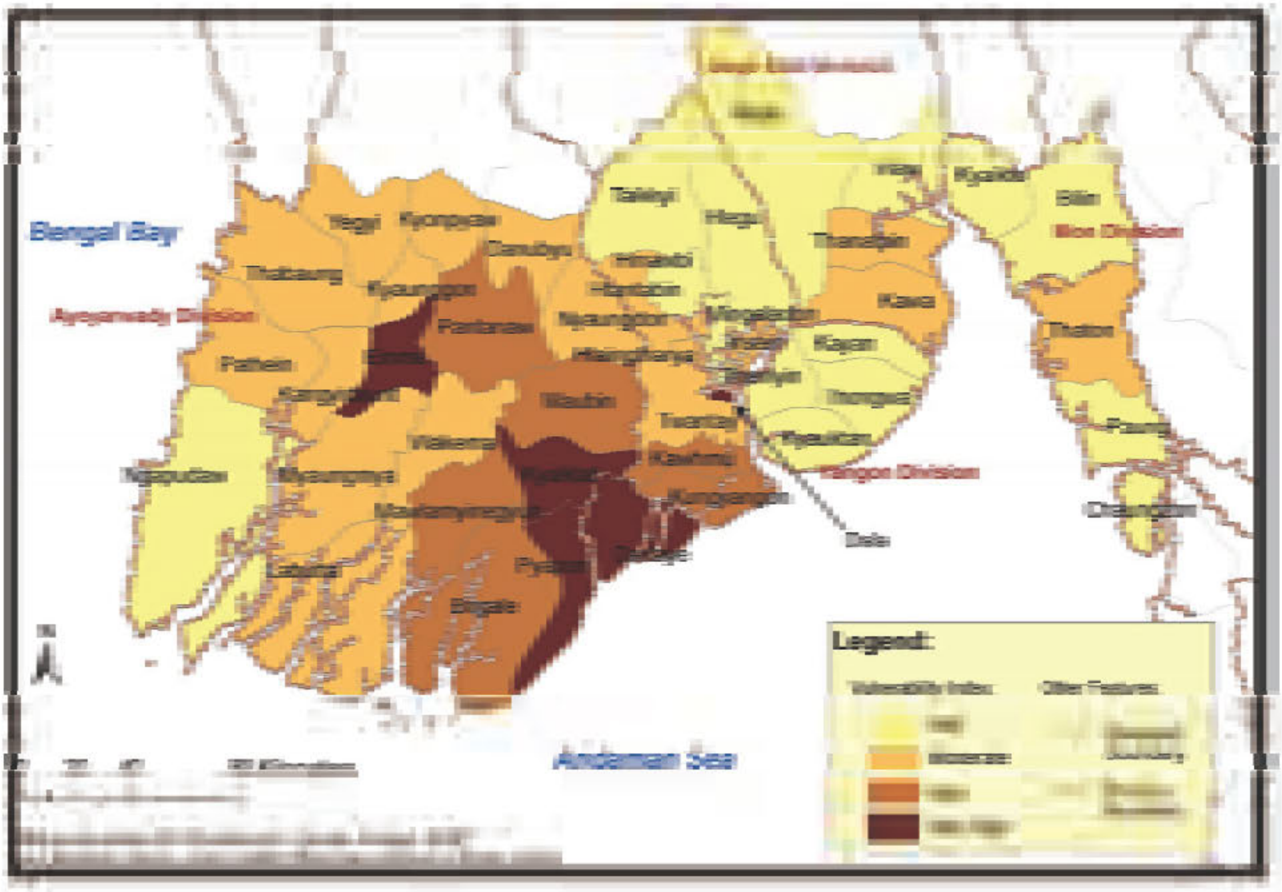

Figure 3 Cyclone Nargis: Most Affected Areas by % of Population and Area

5. CYCLONE NARGIS RISK FACTOR DISCUSSIONS

The Severe Cyclone ”NARGIS” (01B08) was a very peculiar storm as the death toll of NARGIS was the highest in the historical record of Myanmar.
The Elements of Hazard in Nargis are of significant because:
(1) It crossed southern Ayeyarwady at its severe stage,
(2) It moved straight eastwards along the coastline,
(3) It was almost stationary for about four hours on landfall, and
(4) It was phenomenal in the sense that the intensity and course had never been experienced before in the Deltaic area.

The Elements of Vulnerability of the Deltaic area are also high because:
(1) It is a very low lying area,
(2) It is the most populous area of the country,
(3) Many tributaries are in the Deltaic area (seven river mouths),
(4) No storm shelters and higher ground exist in the area,
(5) No hazard mapping and risk assessment had done yet,
(6) It has no past experience of a cyclone like Nargis, and it is extremely hard to convince local people of what is supposed to be done,
(7) Local people know little about disaster risk, especially about that of storm surges,
(8) Local people have poor mobility, mostly using waterways along small canals by boats
(9) Cyclon Nargis caused high waves that smashed low-lying coastal areas at a high-tide time.
(10) Mangrove forests are disappearing extensively.

As a result, Nargis's intensity of hazard is categorized as high. Also, the potential of vulnerability is very high. Consequently, the level of disaster, which is normally defined as the product of hazard and vulnerability, can be considered to be extremely high. The following graph shows available food in the affected areas (Figure 4). Figure 5 shows damaged shelters in the affected ares.

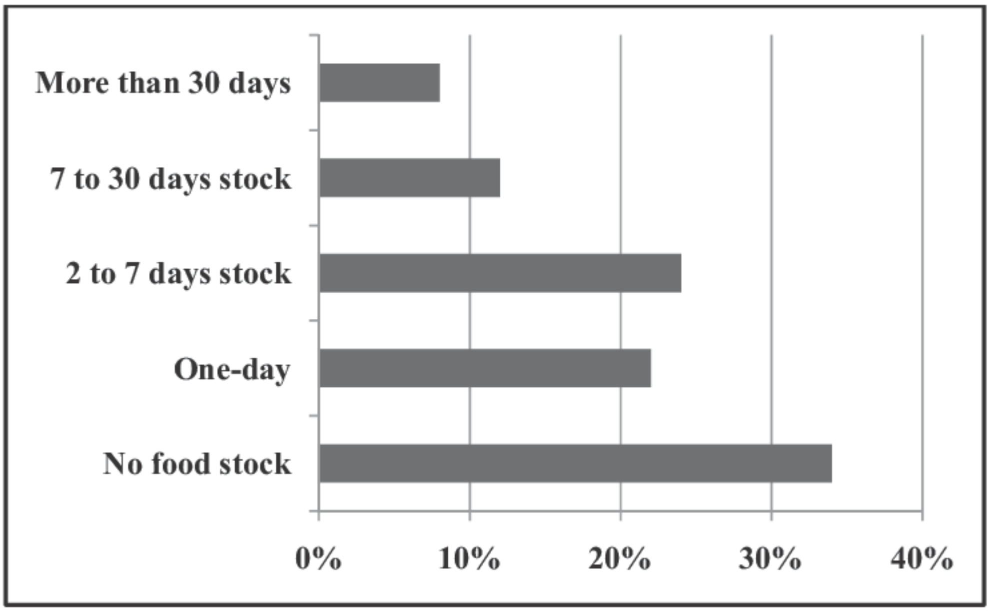

Figure 4 Nutrition and Food Security after Nargis (Availability of food stock as reported by households in the Delta)

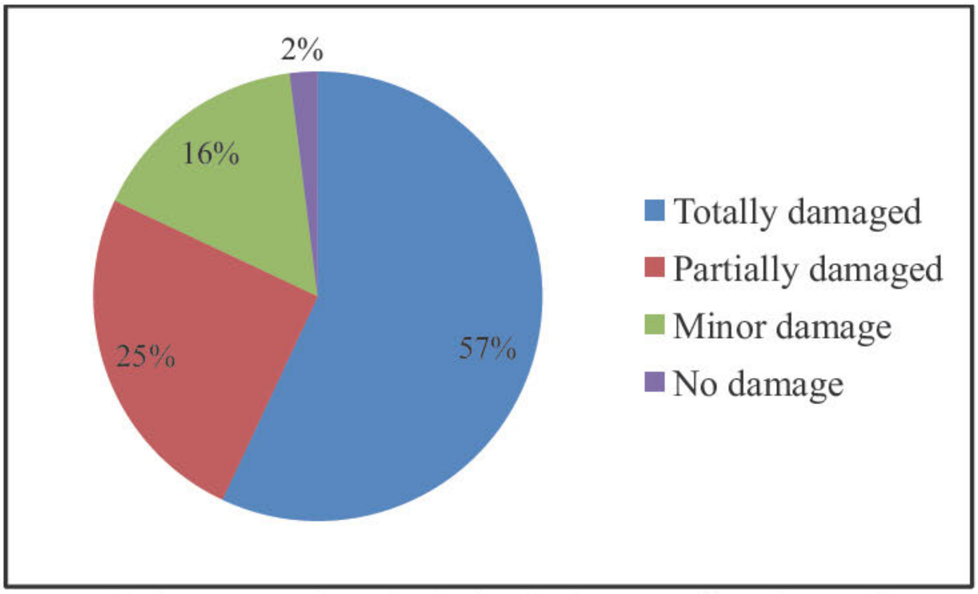

Figure 5 Shelter Damage due to the Cyclone in the Most Affected Townships

6. CHANGING RISKS OF NATURAL DISASTERS

Risks posed by natural disasters can be affected by both climate and non-climate factors. Disaster education, public awareness and disaster management are found as key factors to influence such risks.

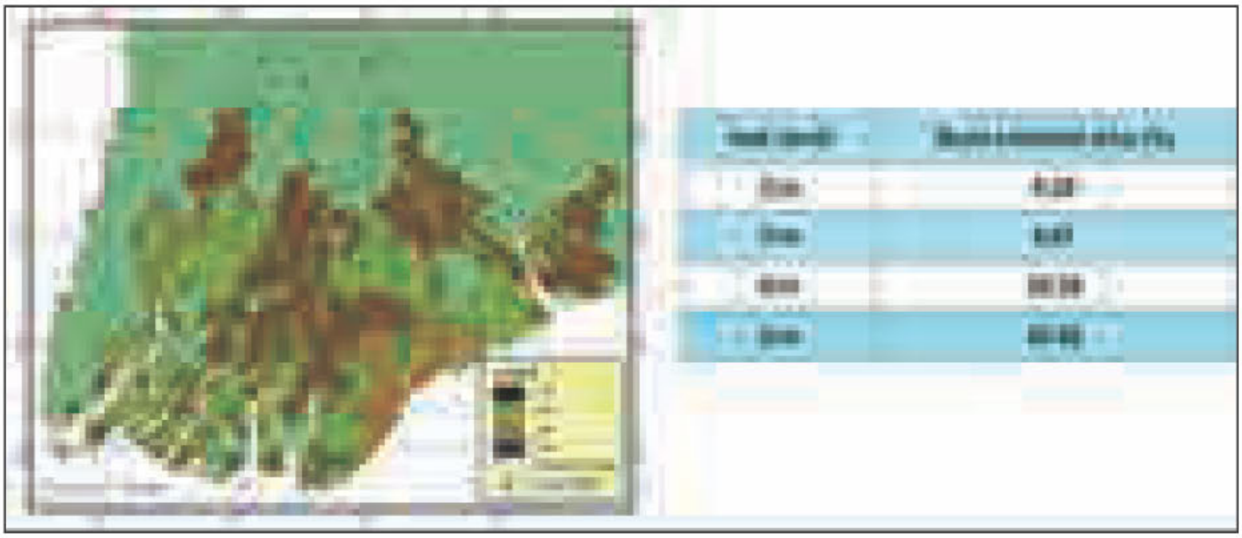

Figure7 Low lying area

6.1 Risk Changes due to Climatic Factors

6.1.1 Climate Change as an Emerging Threat

Climate change is a growing threat to natural resources, which people depend on for their livelihoods. Prior to Nargis, incremental changes to the local environment in terms of the salinisation of soil due to seawater rise had already been observed. As a result of increased salinity in soil, villagers converted areas that were no longer viable for rice production into salt farms, which has implications for household food production and security. Moreover, a recurring problem in recent years has been the contamination of groundwater sources (e.g. ponds and wells) during the dry season. Due to the salinisation of groundwater, which is an important source of drinking water, villages in the Delta have increasingly resorted to importing fresh water from other villages. Limited access to drinking water is now a common problem in many of the coastal villages of Labutta and Bogale townships, especially during the dry season (from November to May). Given limited household incomes for purchasing potable water, there is added pressure to generate cash which can only be sourced by further depleting the natural resource base.

In addition, the region is increasingly vulnerable to a greater incidence and scale of hazardous events, such as cyclones and prolonged droughts, as a result of climate change. There are also indications that patterns of storm paths may be changing. For example, of the 11 tropical storms to hit Myanmar over the last 60 years, only two made landfall in the Delta, and both of them in recent times: Cyclone Mala in 2006 and Cyclone Nargis in 2008. The increased vulnerability to severe storms is likely to be a consequence of climate change.

Climate change not only heightens disaster risks but also reduces local resilience to disaster impacts by degrading water and soil resources and diminishing agricultural production. As a result, climate change will likely aggravate existing vulnerabilities (i.e. declining natural resources and poverty). A strategic approach to disaster risk reduction (DRR) in the region is therefore needed to minimise future disaster impacts but also build response capacities and resilience.

6.1.2 Changes in Sea Surface Temperatures Anomalies

Lwin and Oo (2009) carried out a study on the sea-surface temperature anomalies (SSTA) over the Bay of Bengal for the first storm season of Myanmar (from 20 April to 10 May) over the 10-year periods of 1960-1969, 1970-1979, 1980-1989, 1990-1999 and 2000-2008. The study clearly indicated that negative SSTAs were observed for the decades of 1960-1969 and 1970-1979. However, starting from 1980-1989, SSTAs changed to positive with a maximum positive SSTA centre near the Andaman islands of the Andaman Sea. The same trend of positive SSTAs were observed throughout the whole periods of 1990-1999 and 2000-2009.

High sea-surface temperatures are a condition required for the cyclogenesis process. The minimum threshold temperature of 26.5 deg. Celsius is required for the formation of tropical depressions. The fact that the SSTAs were negative during the period prior to 1980 indicates that the potentials of storm formation were less in the Bay of Bengal before 1980. However, starting from 1980, the SSTAs became positive indicating that the potentials for storm formation in the Bay of Bengal increased. Ta and Kyaw (1970) had made a statistical analysis on historical record of Bay storms over a hundred years. They found that every storm originating near the Pre-paris Island made landfall over the coast of Myanmar. The analysis on the SSTAs showed highly positive SSTAs were observed in the vicinity of Pre-paris Island starting from 1980 onwards. It suggests that the threat of storm for crossing over Myanmar coast has increased since 1980.

6.1.3 Extended Pre- and Post-monsoon Periods.

Lwin (2002) had investigated changing climate over Myanmar for the 50-year period from 1950 to 2000. He showed that from 1978 on, the onset of monsoon became later and the withdrawal of monsoon became earlier than the normal dates. The findings contributed to the following changes in monsoon climatology:

(1) The normal pre-monsoon period is defined as the period from 15 April to the onset date of monsoon over Myanmar. Since the onset has started coming later since 1978, the pre-monsoon period has become longer since that year.

(2) The post-monsoon period is defined as the period from the date of monsoon withdrawal to 30 November. Since the withdrawal date has started coming earlier since 1978, the post-monsoon period has become longer since that year.

(3) Due to the later onset and the earlier withdrawal of monsoon, the duration of the monsoon season has become shorter since 1978.

The statistical analysis on historical storms in the Bay of Bengal showed that there were a total of 1303 storms formed in the Bay of Bengal during the period from 1877 to 2009, out of which only 83 storms (6% of the Bay storms) crossed Myanmar coast. The statistical results show that 51% of Myanmar storms occurred in the pre-monsoon period and 45% occurred in the post-monsoon period. Therefore, the pre- and post-monsoon seasons are regarded as the storm seasons of Myanmar. The fact that the periods of the pre- and post-monsoon seasons have extended since 1978 clearly indicates that the threat of storms for Myanmar coast have increased since 1978.

Moreover, the pre- and post-monsoon periods are the periods during which unstable weather conditions prevail. During these periods, a series of thunderstorm clouds (Cb-cumulonimbus clouds) of free convection are formed extensively. Extreme local weather such as tornadoes, thunder strikes, torrential rains, hails, downbursts are normally accompanied by those towering clouds. Flash floods and land erosion are occasionally accompanied with heavy rain especially in hilly areas.

The longer pre- and post-monsoon periods after 1978 thus lead to more chances for the formation of Cb clouds in the country. Therefore, more tornadoes, land erosion, flash floods, thunder strikes has been observed in the country since 1978, especially during the period from 2006 to 2009. Thus the risk of life and property loss due to such natural hazards has increased dramatically during the last couple of years notably since 2006.

One study made by DMH shows that the monsoon rainfall has increased during the monsoon season since 2001. The rainfall increase in the shorter rainy season leads to an increase in rainfall intensity during the rainy season. This does not help in agriculture generally because the higher intensity of rainfall does not help soil water storage for plantations. Moreover, the high rainfall intensity generally leads to soil degradation, land erosion and flash floods.

6. 2 Risk Changes due to Non-climatic Factors

6.2.1 Lack of Awareness and Knowledge

Communities lack awareness and knowledge about the importance of sound natural-resource management practices, which are essential for ensuring the sustainability of their livelihoods. Prior to Cyclone Nargis, most communities in the Ayeyarwady Delta have had little or no access to training or awareness-raising activities on sustainable resource management. Government extension services in forestry, agriculture and fisheries have remained insufficient, as there has been a serious lack of human and financial resources. The shortage of civil society organizations also means that very few non-governmental organizations (NGOs) are available to fill the gap in capacity building needs.

Limited community awareness is compounded by poverty and the lack of alternative livelihoods, which are driving causes of the over-exploitation of forest resources, fisheries and agricultural land. One positive outcome of Cyclone Nargis is that NGOs now have access to donor funding and technical assistance that will enable them to provide capacity building activities to improve resource management practices

6.2.2 Extent of Environmental Degradation

Poverty, unsustainable land use, lack of knowledge and awareness of improved resource management techniques, as well as land tenure insecurity have all contributed to widespread environmental degradation which had prevailed even before the impact of Nargis. The serious deterioration of natural resources in the Ayeyarwady and Yangon Divisions has subsequently imposed a limitation on local livelihoods and development, which has in turn contributed to increasing disaster risks. The fragility of ecosystems in Nargis-affected areas means that communities lost a significant portion of their remaining natural capital as a result of the cyclone, thus further compromising people's capacities to effectively recover from this major disaster. The high level of poverty in the area signifies that most households have little or no economic capital in reserve to cope with the cyclone's aftermath.

6.2.3 Deforestation and Over-exploitation of Forest Resources

The destruction of mangrove forests is an illustrative example of how the loss of this valuable resource can deprive communities of maximising their potential environmental, economic and risk-reduction benefits. Over the last 80 years, nearly 75 percent of mangroves in the Ayeyarwady Delta have been lost mainly as a result of human activities (Figure 1).Data show that from a peak of about 260,000 ha (625,222 acres) in 1924, mangrove forests had declined to 67,000 ha (160,930 acres) by 2007. Nearly a half of the decrease in mangroves took place over the last 15 years, especially after 2001. The main reason for mangrove deforestation is the harvesting of timber for firewood and charcoal for home consumption as well as income generation.

Other driving factors include conversion of mangrove forests to paddy fields, salt farms, shrimp ponds and settlement areas. Mangrove deforestation has taken place in communal land and land leased by individuals from the government, as well as in reserved and protected forests. The loss of mangroves means that these natural habitats which serve as breeding grounds for a number of fish species can no longer provide communities with a sustainable source of income. Moreover, the reduction in fish catches has also impaired food security. In addition to their socioeconomic benefits, mangroves play an essential role in coastal protection. Their loss has not only undermined livelihood sustainability in the Delta but also aggravated the catastrophic impact caused by Cyclone Nargis. Deforestation of other forest resources other than mangroves has become a common practice in Nargis-affected areas. Trees are cleared for direct use (i.e. firewood/charcoal, building materials, fence posts, boats, and thatching for houses) or for other income-generating activities such as farming. For example, nipa palms (*Nypa fruticans*) along riversides are over-harvested for thatching, while Palmyra spp on riverbanks and around paddy fields are utilised for both thatching and timber. Moreover, households with access to land generally encroach on adjoining forested land (including mangroves) in order to raise production yields by expanding paddy fields. Forest cover loss in this region has consequently reduced natural protection against high winds and tidal surges as well as the availability of forest products.

6.3 Response to Natural Disasters

Myanmar government is responding to combat against the threat imposed by natural disasters for the safety and wellbeing of the people. Comparing with the neighbouring countries, Myanmar is less vulnerable to natural disasters in terms of frequency and intensity. Yet, Myanmar was hit by the most devastating cyclone, Nargis, in May 2008. It caused heavy loss of lives and property damage. It had a huge impact on the society and economy of the country that may linger many years to come. The livelihoods and food security of the people in the Delta area are facing difficulties even in daily life.

There was an acceptable record of disaster management at the community level in the past, and both government officials and disaster managers have done respectable work in dealing with natural disasters. Myanmar was hit by 83 storms in the past over the 130-year period. There had never been a storm in the past that killed more than 1500 (except for SIttwe Storm in 1967). In May 2006, Myanmar was hit by a severe cyclone, MALA, in Rakhine State. Not a single human life was lost in this incident. If someone makes a thorough study on impacts of storms throughout the world, this incident could be an exceptional record in disaster management in terms of saving lives. There should be no doubt that the country, both the government and people, has a good disaster management system. However, in the case of Nargis, the main cause was the high vulnerability of the Delta,

Though the country has to fill many needs and gaps and promote many new developments to modernize its disaster management, Myanmar has a mechanism of its own to response to natural disasters to save its own people’s lives and property.

Most importantly, every country in the region, probably throughout the world, may have the same fate like Myanmar if they encounter such a devastating disaster like Nargis for the first time. The main thing is that every citizen of Myanmar has an obligation to do their best not to allow it to happen for the second time in the country.

7. UNDERLYING CAUSES OF RISK CHANGES

The underlying causes of vulnerability can be grouped into three namely as:

(i) Climatic causes
(ii) Non climatic causes
(iii) Environmental governance causes

7.1 Climatic Causes

7.1.1 The Increase of Sea Surface Temperatures (SSTs) in the Bay of Bengal after 1980.

Ten-year averaged SSTs were carried out for the first storm season of Myanmar from 20 April to 10 May for five decadal periods of 1961-1970, 1971-1980, 1981-1990, 1991-2000, and 2001-2008. The averaged SSTs over the Bay of Bengal for 1961-1970 and 1971-1980 clearly showed that the sea was cold with negative SST anomalies when compared with 1960-1990 average values. However, starting from 1981 onwards, the anomalies in SST for each decadal period were positive, indicating that the sea surface temperatures were warmer after 1980. The maximum positive anomaly centre was found located near the Prepares Island of the Andaman Islands. It suggests that the most likely location for the generation of cyclone was near the Prepares Island, which had already found out statistically by Myanmar meteorologists. Storms originating near Prepares Island always made landfall in Myanmar coast.

7.1.2 Mechanism of the Storm Course Shifting Towards South in the Bay of Bengal

The 10-year averaged 850-hPa level winds for the first storm season of Myanmar (from 20 April to 10 May) are analysed for each of the five decades: 1961-1970, 1971-1980, 1981-1990, 1991-2000 and 2001-2008. The analysis clearly shows the shift of the 850- and 500-hPa level troughs in the westerlies from their normal positions, i.e., from the latitude of 20 degrees North to lower latitudes of 10 to 15 degrees North, starting from 1980 onwards. The 500-hPa trough is responsible for storms from the south Bay turning to the northeast as they encounter with this trough. When storms turn to the northeast while the trough is staying at 20 degrees North, they will move towards Bangladesh in most cases. However, with the 500-hPa trough settling down south at, say, 15 degrees North, a storm will make a turn and end up moving towards Myanmar as it encounters with the trough. This may be the reason why Myanmar was struck by three consecutive storms in 2006, 2007 and 2008.

7.2 Non-climatic Causes

7.2.1 The Shallowness of the Deltaic Coast - Bathymetric Effect

By applying an empirical formula developed by Lwin (1982), storm-surge heights were calculated for Rakhine and Deltaic coasts by using the same storm parameters such as maximum wind speed, storm speed of propagation, movement direction, etc. The results obtained clearly indicate that the peak surges obtained for Deltaic coast is almost two times higher than the maximum surge heights obtained for Rakhine coast. This is simply due to the difference in shallowness between the two coasts, where the sea water depth along Deltaic coast is markedly shallower due to the heavy deposition of seven rivers in the Delta region.

7.2.2 Estuary Effect

There have been three incidents of inland flooding due to the estuary effects of storm surges in Myanmar. These were Pathein Storm (1975), Gwa Storm (1994) and Nargis (2008). Each incident caused loss of human lives with Nargis recording the worst death toll. The Ayeyarwady delta has seven tributaries of complex river systems, along which many people are residing for waterways transportation and goods trading by boats and vessels. So the potential for human life loss due to inland flooding is high in the Delta Area.

7.2.3 CCR Cyclical Adaptive System

The Rapid Assessment 6 Report carried out by ADPC and DMH in the Nargis affected area of Yangon and Ayeyarwady Divisions indicated disaster management system in Myanmar is acceptable when encountering with Nargis. Though situations after Nargis are improved quite substantially, especially in preparedness and awareness, the situation during Nargis showed several important underlying causes of vulnerability of the coastal community resilience.

Each community should be assessed for resilience benchmarks to find out strengths, weaknesses and unknowns based on eight components. The eight components are (i) disaster recovery, (ii) emergency response and evacuation, (iii) early warning, (iv) risk knowledge and public education, (v) land use and structural design, (vi) natural resources, (vii) socio-economy and livelihoods and (viii) governance. Each component should be scored by conducting assessment through field survey within the community in a well systematic manner. Based on the scores obtained from the assessment, gaps and priorities are identified. Resources and opportunities are then evaluated in order to lay out a phased action plan for CCR. Then the action plan should be monitored and improved so that each component is developed equally for the community to cope with disaster risks they may encounter. The action plan will be then implemented in full measure so that disaster risks on the community will reduce and its resilience to disasters will increase. This is the surest way for a community to reduce disaster risks and develop disaster resilience (Figure 8).

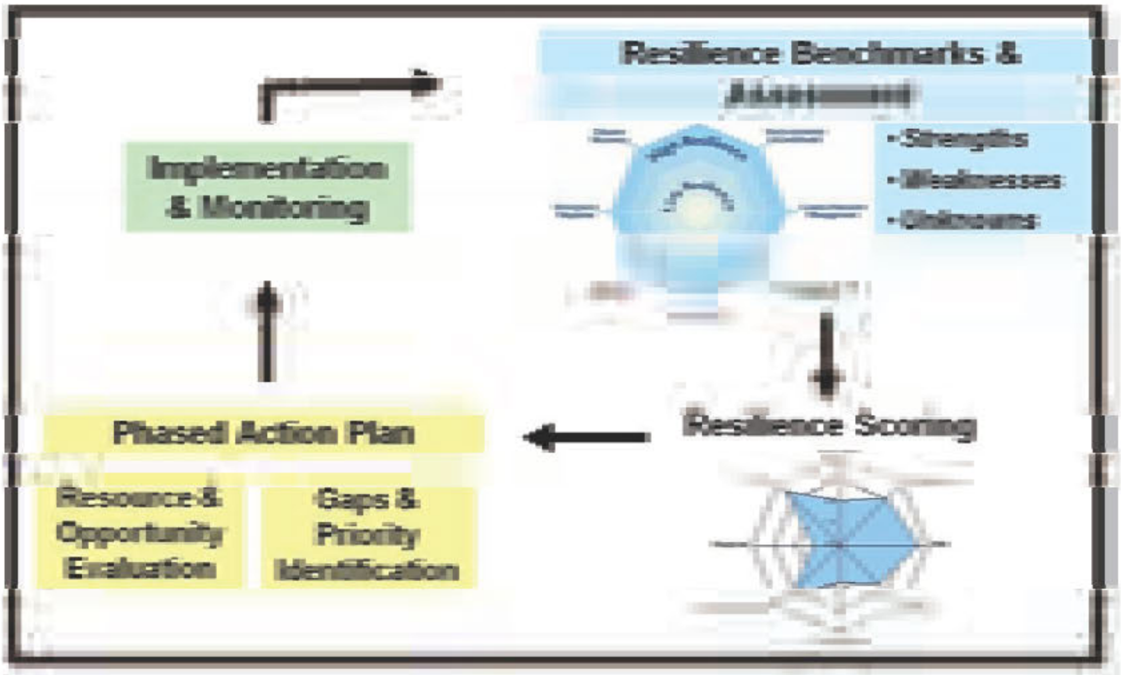

Figure8 The Coastal Community Resilience (CCR) as a cyclical adaptive system

When Myanmar was struck by Cyclone Nargis on 2-3 May 2008, coastal communities along the Ayeyarwaddy Deltaic coast were heavily devastated. It was a shocking experience for the country and the international community. A survey team composed of scientists from DMH and ADPC were sent to Nargis-affected areas in Yangon and Ayeyarwaddy divisions within a week after the storm passed over the Delta. The team made assessments on eight components by interviewing authoriies, communities, officials and UN agencies within the area. Then each component was scored in accordance with the international practice used in other countries in the region. The results obtained from the mission are shown in Figure (26).

The resilience evaluation clearly identified needs and gaps in disaster management to make coastal communities more resilient. Out of the eight components, the seven components scored under average, which clearly indicate that the community is not resilient to disasters. The only component which scored above the international average is the early warning component since warnings were issued by the Department of Meteorology and Hydrology five days in advance to the authorities and public. The gaps that requir immediate attention are disaster recovery, risk knowledge, public education and natural resources. Within the framework of MAPDRR, programs have been proposed as a national plan to fill up the gaps in those areas. However, further improvement is still needed in most of the components of CCR in order to increase the communities' resilience to natural disasters.

The survey results revealed that there are many underlying causes of high vulnerability. For example, though more than 140,000 people lost their lives due to high storm surges, the majority of the people did not know what storm surges are. Cyclone warnings were issued to local people at least 3 days ahead. However, due to lack of past experience, i.e. they had never experienced storms in the past, the majority of the people did not take the authorities' warnings with enough seriousness. The worst thing was that though the authorities tried to evacuate residents, they did not cooperate with them due to their disbelief on the impacts of storm surges. When the storm hit delta communities, there were no emergency plans instructing people on how they take shelter, evacuate the area, find life-saving places, etc. No plans were in place and ready to be executed. As a result, more than 200 small villages located along the coast were totally wiped out by large surge waves caused by Nargis.

There are more underlying causes that had made the vulnerability even higher. Risk analysis and hazard mapping had not been carried out for the Deltaic area. Therefore people were unaware of what extent of risk they were exposed to and how vulnerable their area was.

Early warning for Nargis was more than acceptable. It was timely and accurate. However, disaster management plannning was not sufficient enough as the resilient evaluation on the eight components shows. More efforts should be made in improving all those components.

7.3 Environmental Governance Causes

Several policies and their implementation have been a contributing factor to environmental degradation and therefore indirectly increased disaster vulnerability.

7.3.1 Pursuing Development Priorities over Environmental Sustainability

In the past, economic policies focused on development priorities rather than natural resource sustainability. Attention was directed towards production increase by harnessing more land area and building infrastructure such as embankments (e.g. the "Paddy I" and "Paddy II" projects in the 1980s) without fully considering environmental impacts. Established in 1990, the National Commission for Environmental Affairs (NCEA) deals mainly with policies related to multilateral environmental agreements but does not have enough staff and other resources to provide technical advice and coordinate environmental management across all line agencies. Moreover, it has limited capacity to play a significant role in environmental management at the local level. Although the NCEA has drafted environment laws, they have not yet been enacted. Hence, there are few legislative provisions to ensure that the environment is taken into account in formulating and implementing policies and plans that have impact on natural resources. In the aftermath of Cyclone Nargis, the government has committed to developing and implementing a national disaster preparedness plan. This provides opportunities for ensuring that long-term planning addresses both resource management issues as well as other prevailing risk factors in an integrated manner

7.3.2 Weakness in Implementation and Enforcement of Laws and Policies

Although many laws, regulations and policies at the national level, such as the 1995 Forestry Instructions and the Fisheries Legislation, support environmental sustainability, those responsible for their implementation do not fully comprehend the purpose of promoting sustainability or how to put these instruments in practice. As a result, these directives are often implemented in a rigid manner that does not support the spirit of the law. In addition, there is a variable interpretation of these laws, which means that their full implementation remains largely ad hoc and differs from district to district. Similarly, many laws, particularly those affecting biodiversity and the management of natural resources such as forests, fisheries and land, are poorly enforced. The lack of understanding of these laws and regulations by regional and local officials as well as by communities is made even worse by inadequate human and financial resources for law enforcement.

7.3.3 Inadequate Coordination

Another key factor contributing to environmental degradation is weak coordination between government sections at the national and sub-national levels (horizontal coordination). Each section develops and implements their own section-specific policies without consultation and consideration of their impacts on other sections. This compartmentalization is aggravated by the lack of vertical coordination between different layers of the government at the national, divisional, district and village levels. National policies tend to apply a blue print approach, which makes it difficult for local authorities to implement laws and policies effectively in their localities, especially as they strive to meet national targets for rice or timber production.

7.3.4 Needs for Improvement in Technical Capacity

Government officials across national line agencies need technical capacity building to adequately integrate environmental considerations into their sectional policies, programmes and plans. This problem also applies to sub-national levels. Local authorities in general have little awareness of how to promote sustainable natural resource management. Moreover, local staff of different line agencies (i.e. agriculture, forestry, etc.) who are charged with implementing their department's section policies are unable to address the environmental aspects of their work. They may have technical knowledge within their own discipline but with limited understanding of the environmental impacts and implications of their advice to farmers and fishers.

7.3.5Need for Upgrading Land Use Planning

The National Land Use Commission was established in 1995 with its subordinate regional and community-level land-use supervision committees. The Commission is responsible for reviewing and developing policies on land management. In addition, the 1995 Forest Policy highlighted the importance of land use planning and set out policy measures to determine programme strategies and action plans. Although the Forest Department has initiated a number of land use planning activities in the Ayeyarwady Delta, there has been little or no coordination among key stakeholders, especially between relevant government agencies. This has resulted in ineffective land use planning processes in the Delta. Consequently, land use practices remain geared towards income generation regardless of their sustainability and long-term environmental consequences. Instead, decisions are made based on short-term financial gains. For example, as discussed previously, mangrove forest areas were converted to paddy land, which then experienced creeping salinisation and thus limited rice cropping to just a few harvesting seasons. Once rice yields declined, farmers had to switch to salt farming. Financial gains were therefore short-lived, resulting in the permanent loss of a valuable resource with multiple benefits including ecological, socio-economic, and risk reduction values. The lack of land-use planning also constrains the ability of local areas to respond effectively to national government targets in the production of agricultural (paddy rice), forestry (timber) and fish products. For example, local authorities presently address national government directives to increase the production of rice or timber in their area by expanding areas under paddy cultivation or through deforestation without any consideration of their environmental impacts. However, if local authorities are able to develop coastal zone management plans or land-use plans, they could then pursue national production targets through a more rational allocation of their land and water resources. This may be a better way to take into account the environmental consequences of their decisions.

7.3.6 Inadequate Information on Natural Resources

As environmental monitoring and surveillance systems are needed in Nargis-affected areas, there is little or no reliable information at the national or local levels on which policy development or decision-making can be based. Recovery efforts to address the impacts of Cyclone Nargis have highlighted the information vacuum on environmental conditions in the Ayeyarwady Delta. There is not enough data on forest, land and fishing resources, biodiversity (ecosystems, flora and fauna) as well as water sources including drinking water. Hence, policy development and planning remains seriously hampered from the start, which undermines their effective implementation.

7.3.7 Need for More Investment

There is a lack of investment in human resources development, extension services, information management, as well as improved farming technology, which can otherwise help raise production yields sustainably. Local authorities forced to meet their production quotas are pushing farmers to extend paddy cultivation on marginal or fragile land unsuitable for farming. In addition, the lack of investment has resulted in the deterioration of tangible assets. For instance, the erosion of embankments has not only placed agricultural land under threat of seawater incursion but also increased vulnerability to natural hazards such as floods and storm surges.

8. PREDICTION OF NARGIS

The DMH monitored Cyclone Nargis since its birth on 24 April 2008. The DMH was able to make forecasts and issue warnings starting from 28 April, when the disturbance attained cyclonic intensity. Moreover, the DMH is a profound member of the RIMES (Regional Integrated Multi-hazard Early Warning System), which was able to assist the DMH in the issuance of warnings. The RIMES Centre made a perfect forecast for 120 hours (5 days in advance) that the storm would cross Myanmar coast near the Heingyi Island, Delta Region. So the DMH issued cyclone early warnings in almost every 2-3 hours for the entire 5 days. From the survey done by the DMH and others, it was found out that almost all local people knew the warnings at least 48 hours in advance.

Figure (28) shows the 120-hour Storm Animation Forecast made by the RIMES Centre in AIT, Bangkok. The forecast was issued on 28 April 2008 00 UTC, ending at 00 UTC on 3 May 2008. The landfall point on the coast was forecasted to be at Heingyi Island in the Delta region at 84 hours (12 UTC on 2 May 2008). After crossing the coast, the storm was forecasted to move eastward until 120 hours (00 UTC on 3 May 2008).

It is therefore considered the early warnings for Cyclone Nargis were more than satisfactory.

9. CONCLUSION

Just after Nargis, a WMO mission visited the DMH on 10-15 May 2008. They discussed with DMH officials, UN organizations, governmental organizations and the general public. On 22 May, WMO issued a press release entitled “Cyclone Warnings were sufficient: Deaths inevitable.” However, there is a big question still remain to answer: Why did 140,000 people have to be killed in the disaster when the warnings were good enough?

Myanmar learned a lesson from Nargis: To save human loss, the lesson that everybody should learn from Nargis is that early warning alone is not enough. This also is the answer to the question above; so many people died because early warning alone could not save them. Disaster management is a social-science issue. Science alone can not accomplish goals in disaster prevention. There are many areas in which social factors such as public participation, public education, public awareness, multi-agency cooperation, good management, rules and regulations, public drills, public information, etc. are playing vital roles in combating against the impacts of natural disasters.

Unless the basic eight components in disaster management are developed proportionately, people will still have to suffer from the impacts of disasters. This is particularly true for developing and under-developed countries.

10. ACKNOWLEDGEMENT

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Finally, the author wishes to encourage anyone to continue the work on the present assessment, especially on the climate change context and the risk change context because the time availability for this work was so limited that it should be considered as a preliminary work; therefore, more assessment work is needed naturally.

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Chapter 7

Lessons Learned from Typhoon Morakot－Typhoon Morakot's Impact on Taiwan's Disaster Prevention and Relief Strategy

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EXECUTIVE SUMMARY

The World Meteorological Organization pointed out Taiwan as one of the prone areas to natural disasters. Taiwan can never be immune to the strike of typhoons. Hurricane Katrina's ravage on New Orleans in the US should have been taken as a warning that Taiwan needs a sound mechanism of disaster prevention and response for extreme events, but obviously Taiwan did not learn the lesson. Typhoon Morakot has laid bare many existing problems in our capabilities for disaster prevention and response, leaving great room for improvement in the future. It is hoped that Taiwan has learned lessons from Morakot and will try every means possible to improve its disaster prevention and response capabilities against future disasters.

The year 2009 was a year of meteorological anomalies. Even though July is the typhoon season in Taiwan, we had to pray for rain that year to solve the drought problem. However, praying for rain in the typhoon season often brings nothing but extreme results: droughts or floods.

Typhoon Morakot has laid bare many existing problems in our disaster prevention and response mechanism, including typhoon observation and warning technology, disaster monitoring and collection systems, emergency response and mobilization capabilities and evacuation measures. To improve the problems above, future efforts will be needed in the following aspects.

The aim of this article is to illustrate emergency response in Taiwan's disaster prevention and relief efforts during Typhoon Morakot. Moreover it will outline the post-disaster recovery plan and identify the focus for future disaster prevention efforts.

1. INTRODUCTION

2009 was the 50th anniversary of the catastrophic August 7 Flood, which left inerasable and grieving memories to those in their sixties today. Before we reflected on lessons learned 50 years ago, Mother Nature yet sent another challenge, Typhoon Morakot, to remind us of those disastrous memories. Typhoon Morakot attacked Taiwan, caused more damage than its predecessor did 50 years ago and left record-setting meteorological and hydrological data. Within three days, the rainfall exceeded the annual average of 2500 mm, and in an extreme case, it recorded 3060 mm (from 00:00 hours of August 6 to 10:00 hours of the 11th) at the Alishan rainfall gauging station in Mt. Ali, Chyayi County. Such a high rainfall resulted in indescribable damage no less than that of the September 21 Ji-Ji Earthquake in 1999, which shook counties including Taitong, Pingtung, Kaohsiung, Tainan, Chyayi, Yunlin, Changhua, Nantou, Miaoli, Hsinchu, and Taoyuan, etc. The extreme rainfall caused floods, debris flows, landslides, bridge collapses, and damage to embankments, transportation infrastructure, and agriculture. According to the statistics provided by the Central Emergency Operation Center (CEOC) on August 11, Morakot killed 619 people, left 76 missing and 35 injured, damaged over 200 bridges, and caused more than 19.4 billion dollars of loss in agriculture. In addition, the amount of personal property loss and failure of flood control facilities was yet to be estimated.

2. METEOROLOGICAL ANALYSIS OF TYPHOON MORAKOT

2.1 Genesis and track of Morakot

Typhoon Morakot was the eighth typhoon that struck Taiwan in 2009. It formed at 02:00 of August 4 over the ocean 1500 kilometers east of Eluanbi (South Cape). Subject to the steer flow (east wind) from the high pressure in the north, Morakot moved at 20 kph, heading west by west-northwest. The Central Weather Bureau (CWB) announced typhoon warnings for ocean and land areas respectively at 20:00 of August 5 and 08:00 of August 6. When Morakot started to form, the wind speed read 52 to 62 kph within the 250-km radius and 88 to 103 kph within the 100-km radius. Morakot slowed down as it approached Taiwan Island. Its center touched the suburbs of Hualien City at 23:50 of August 7. After its landing, the speed was even slower, 0 to 10 kph, and continued heading north-northwest. At 11:00 of August 8, the typhoon weakened into a tropical depression and continued moving north-northwest after it exited Taiwan via Taoyuan County. At 19:00 of August 9, Morakot's radius left Taiwan Island, and both warnings for ocean and land areas were lifted Typhoon Morakot had hovered over Taiwan for 64 hours since its outer ring hit the island, and the typhoon warning for the land area lasted for 93 hours. (Figure 1)

Figure 2 shows the radar echo data of Morakot at 00:00 hours of August 7, 2009. Morakot was over the ocean east of Taiwan, and judging from the radar echo data, its outside circulation spans immensely and asymmetrically from north to south. The circulation can be divided into two parts, and there is a large front in its south. Therefore, most of Morakot's precipitation occurred in the southern part of its circulation.

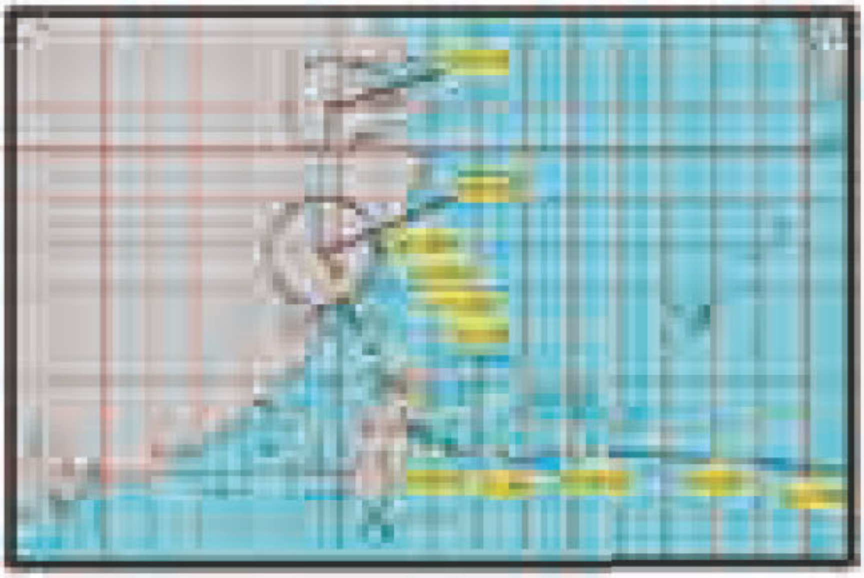

Figure 1 Typhoon Morakot's track and duration of its influence on Taiwan (From 20:00 of August 5th to 05:00 of August 10th, local time)

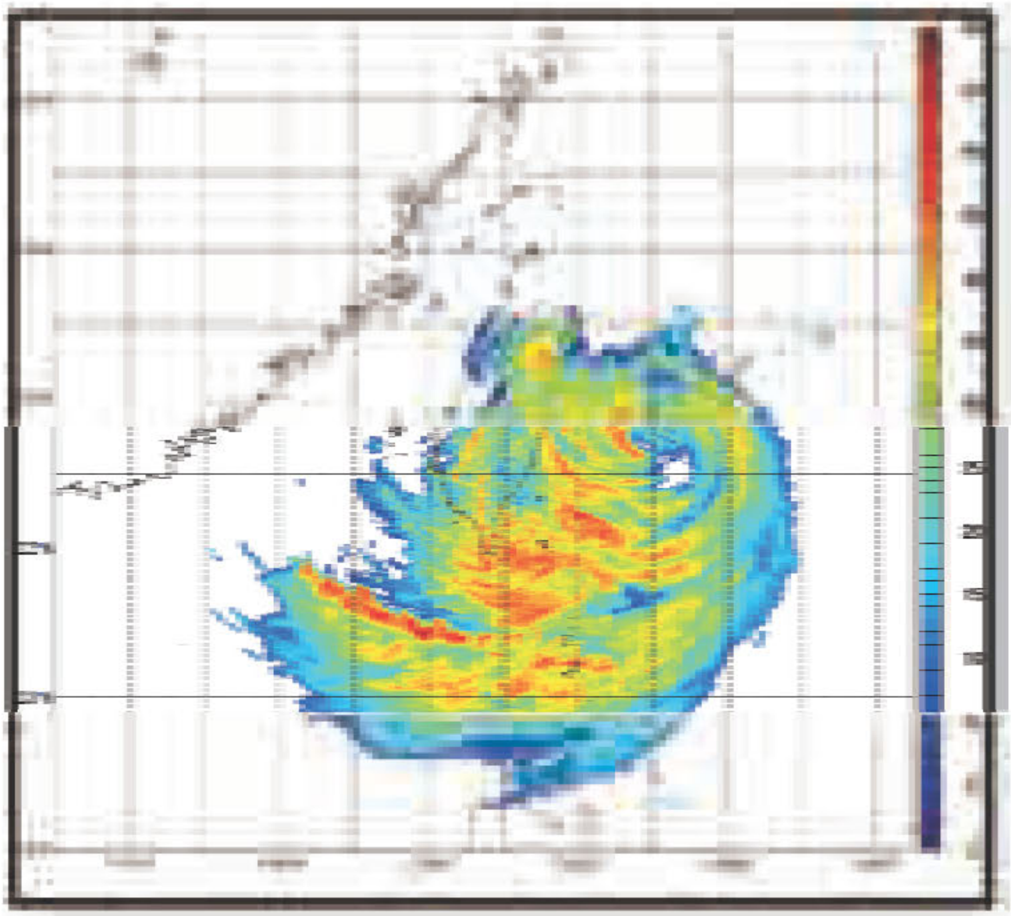

Figure 2 Morakot's Radar Echo Data as of 00:00 of August 7th, 2009(local time)

Before Morakot's radius touched Taiwan, the rainfall concentrated on the north of the island. After the radius hit the island, the rainfall shifted to the mountain area in the south. Figure 3 shows CWB's 24-hour rainfall accumulation map from August 6 to 10. On August 6, the rainfall concentrated on the mountain area in the north before it receded on the 7th. In the mean time, extremely heavy rainfall began in the mountain area in southern Taiwan (to the south of Nantou County), whose accumulative rainfall ended up being higher than that in the areas located on the track of Morakot's center. In the mountains of Chiayi, Pintung, and Kaohsiung Counties, the maximum daily rainfall exceeded 1000 mm. The rain belt moved northward as Morakot's center headed north-northwest, and a heavy rainfall began in the north of Tainan County. On August 10, the rainfall receded dramatically, but a strong southwestern flow continuously brought in rainfall in the southern mountain area with a maximum daily rainfall of nearly 300 mm. Morakot and the southwestly flow incurred a coupling effect, resulting in an additional convergence effect in the south of Taiwan Strait and creating a strong convection system. The convection system caused extremely heavy rainfall devastating central and southern Taiwan.

2.2 Cause for Extreme Torrential Rain

Typhoon Morakot had its genesis on August 4 and interacted with the Northwest Pacific Summer Monsoon Trough. The southwest monsoon in the Monsoon Trough, which incubates typhoons with abundant moisture, helped increase Morakot's magnitude to that of a typhoon. Subject to the steer flow of the east wind from the south of a high pressure, Morakot fast approached eastern Taiwan. Right after it left its birth place, another tropical low pressure rapidly developed into a typhoon, which later known as Etau. Together with Typhoon Goni in Guangdong province, these three low pressure systems formed a large low pressure belt, which enhanced the strength of the west wind belt and provided abundant moisture in the south of Morakot. Such an environment resulted in the asymmetric structure of the typhoon with a strong and growing convection system in the south.

As Morakot approached eastern Taiwan, it slowed down considerably due to the land mass and its Fujiwara effect with a typhoon coming from behind, prolonging Morakot's impact on Taiwan. As illustrated in CWB's weather chart at 08:00 hours of August 7 (Figure 4), Morakot was in the monsoon trough and joined by the southwestly flow from the south of the low pressure (as shown in Figure 5). When Morakot neared Taiwan, the enhanced southwestly flow happened to pass through southern Taiwan (mostly in Kaohsiung and Pingtung Counties). After touching down on the island, the north wind of the circulation for Morakot and the southwestly flow formed a strong convection belt, which caused continuous heavy rainfall in Kaohsiung and Pingtung Counties.

After August 9, Morakot slowly moved northward and left Taiwan thanks to the weakening high pressure. Nevertheless, the convection belt also moved northward in sync, resulting in extreme torrential rain in the Chyayi region.

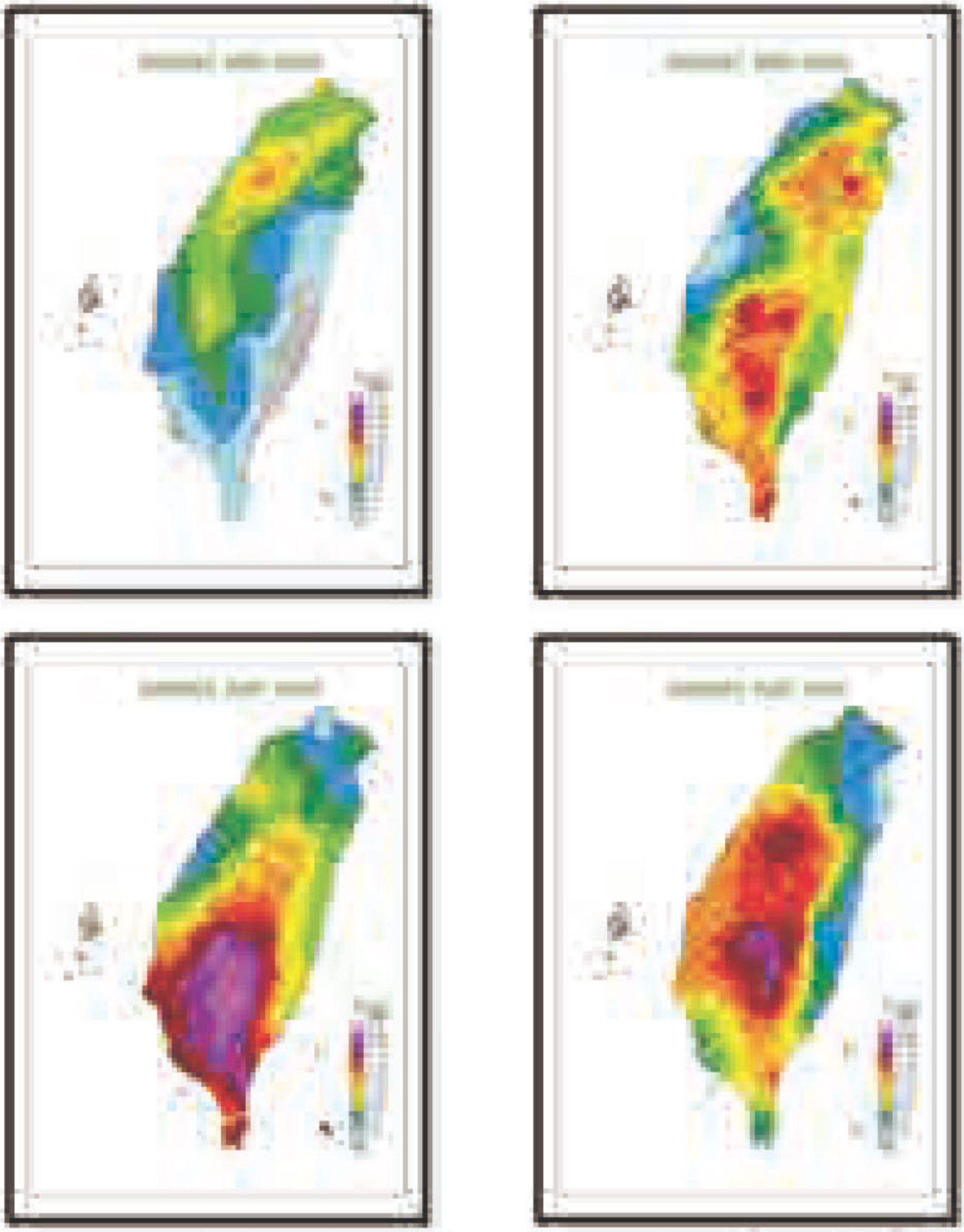

Figure 3 CWB's 24-hour (00:00~24:00) Rainfall Accumulation Map of August 6th (upper left), 7th (upper right), 8th (down left), and 9th (down right)

Figure 4 CWB's Surface Weather Chart at 08:00 hours of August 7th, 2009---Typhoon Morakot in the Large Low Pressure Belt inside the Monsoon Trough

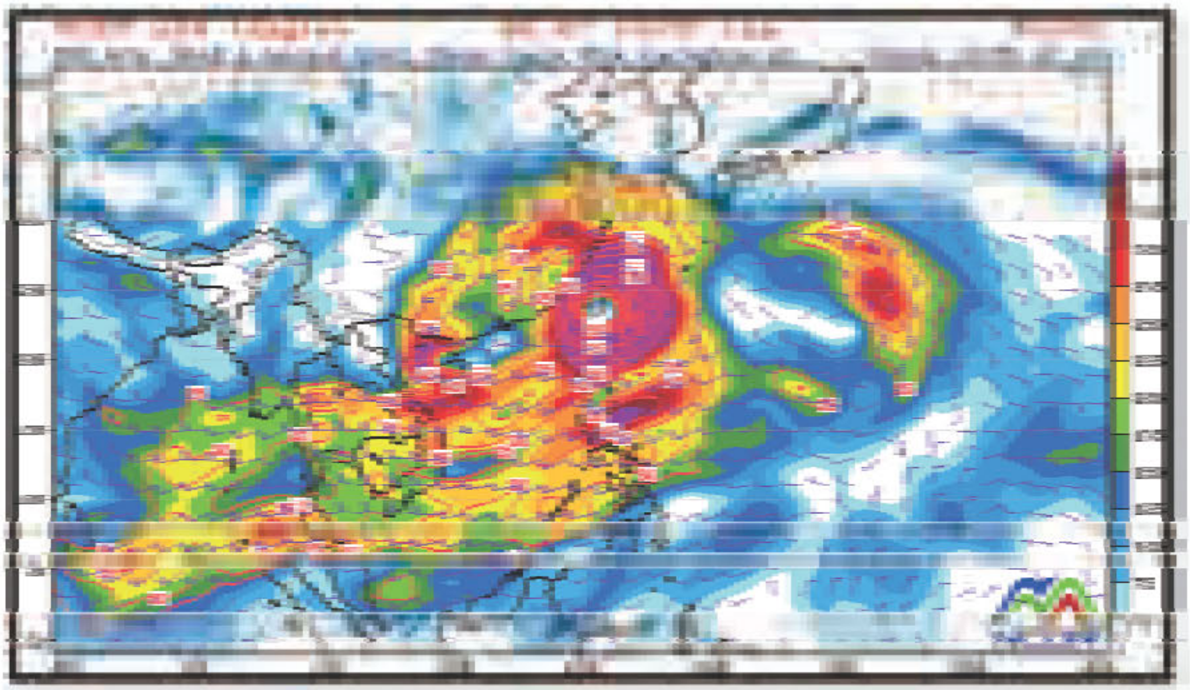

Figure 5 Convergence of typhoon Morakot and Southwestly flow from Monsoon Trough and Abundant Moisture provided by South China Sea; Wind Vector of 850hPa Wind Vane; the Colors Represents Moisture Flux

2.3 Rainfall Analysis

Figure 6 shows the five-day accumulative rainfall (8/6~8/10) caused by Typhoon Morakot. The rainfall concentrated in the mountains of Chyayi, Tainan, Kaohsiung and Pingtung Counties, among which the Alishan rainfall station recorded the highest amount of 3,060 mm (Chart 1). Table 1 lists ten townships and river basins with the highest rainfall. The rainfall on the upstream Gao-Ping River, Zengwun River, and Bajhang River all exceeded 2000 mm, gravely devastating Kaohsiung, Pingtung, Tainan, and Chyayi regions.

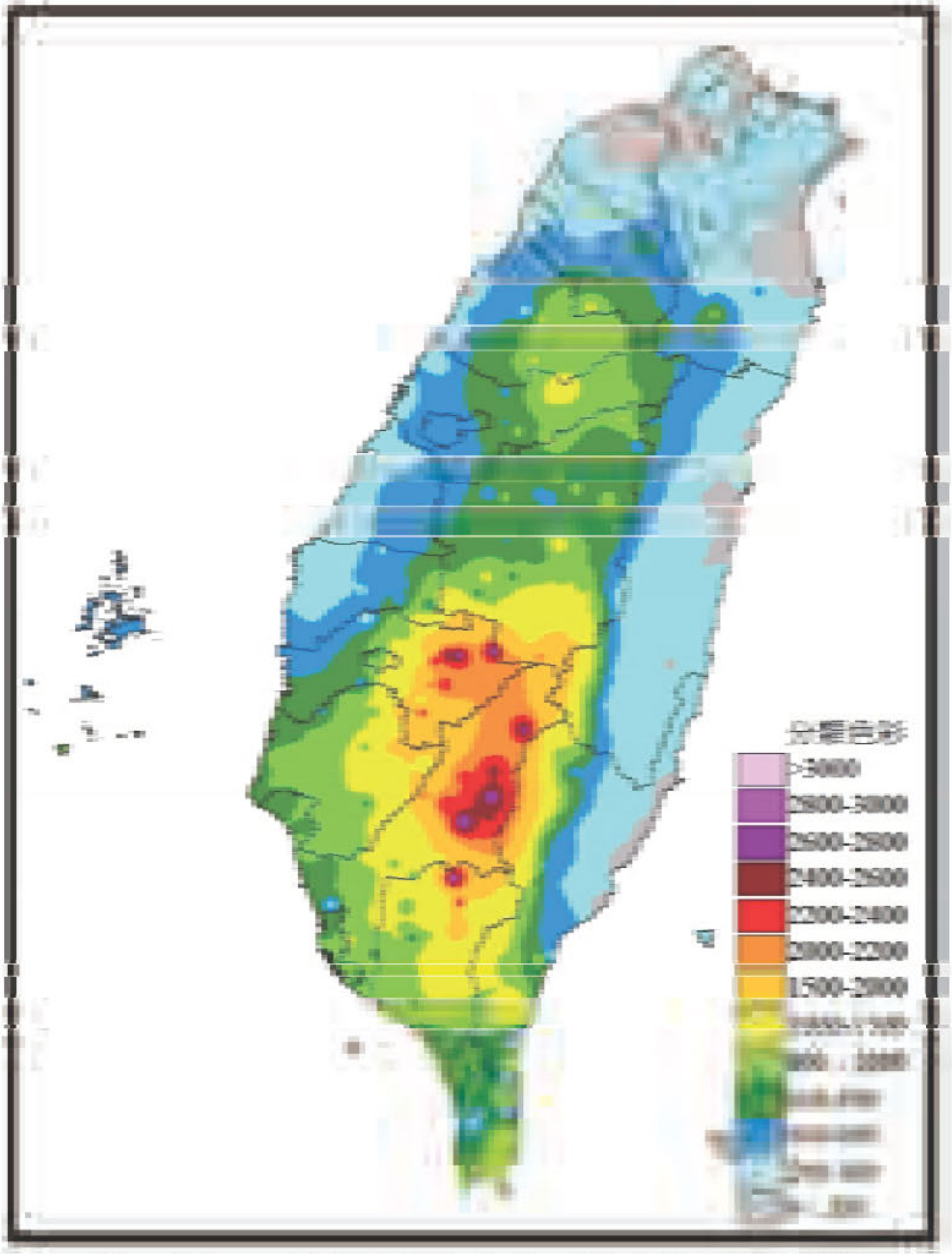

Figure 6 Accumulated Rainfall by Typhoon Morakot (mm) (8/6~8/10)

Table 1 Ten Regions with the Highest Rainfall during Typhoon Morakot (8/5~8/10)(mm)

Rainfall Station	Accumulative Rainfall	River Basin	Administrative Region
Alishan	3060	Cen-Wen River Basin	Alishan Village, Chyayi County
Weiliaoshan	2910	Kao-Ping River Basin	Sandimen Village, Pingtung County
Fenqihu	2863	Ba-Zhang River Basin	Zhu-qi Village, Chyayi County
Yuyoushan	2823	Kao-Ping River Basin	Taoyuan Village, Kaohsiung county
Xinan	2746	Kao-Ping River Basin	Taoyuan Village, Kaohsiung county
Shipanlong	2705	Ba-Zhang River Basin	Zhu-qi Village, Chyayi County
Nantianchi	2694	Kao-Ping River Basin	Taoyuan Village, Kaohsiung county
Xiaoquanshan	2485	Kao-Ping River Basin	Taoyuan Village, Kaohsiung county
Laitou	2407	Cen-Wen River Basin	Alishan Village, Chyayi County
Xinfa	2355	Kao-Ping River Basin	Liu-Gui Village, Kaohsiung County

Any one of the highest 20 24-hour or 48-hour duration rainfalls of single-event precipitation during Typhoon Morakot can be ranked in the top 20 in the past 20 years of history before Morakot (CWB first set up automatic rainfall stations in 1989). Such statistics shows Morakot, compared with other typhoons, had a higher accumulative rainfall in a wider range (Table 2). Morakot's 48-hour duration rainfall exceeded that of Herb and is ranked as No.1 in history. In addition, 31 rainfall stations recorded more than 1000 mm of precipitation during Morakot, among which 23 exceeded 1500 mm. Overall, 12 rainfall stations throughout the island recorded a rainfall of more than 2000 mm, suggesting that 9% of Taiwan's land area was ravaged by extreme torrential rain. Figure 7 shows Morakot's 24-hour and 48-hour rainfall was close to the world's extreme values.

3. DAMAGE REPORT

Typhoon Morakot's rampage caused floods, slope slides, bridge collapses, casualties, and damage to schools, transportation and utility infrastructures, and agriculture.

3.1 Floods

Based on reports issued by the Water Resources Agency of Ministry of Economy, local governments, and various survey teams, Figure 8 shows flooded areas during Typhoon Morakot. Theses areas concentrated on Taitong, Pingtung, Kaohsiung, Chyayi, Yunlin, Changhua, Taichung, and Nantou Counties, covering around 589 square kilometers with the maximum water depth of over 3 meters. The causes of the flood included the breach of embankment, land subsidence, flood discharge from reservoirs, riverbed deposition, low-lying areas along rivers, and dysfunctional urban drainage systems.

As of September 5, 2009, flood reports issued by the Water Resources Agency of Ministry of Economy and various survey teams suggested that flooded areas were mostly in Taichung City and County, Changhua County, Nantou County, Yunlin County, Chyayi City and County, Tainan City and County, Kaohsiung County, Pingtung County, and Taitong County. Among these areas, Chyayi, Tainan, Kaohsiung, and Pingtung Counties suffered most.

Table 2 Typhoon Morakot's 24-hour (lhs) and 48-hour (rhs) Maximum Accumulative Rainfall in Comparison with the Top 20 Duration Rainfalls in History (1989-2008) (mm)

Ranking	Historical 24-hour Duration Rainfall	Event	Morakot's 24-hour Duration Rainfall	Historical 48-hour Duration Rainfall	Event	Morakot's 48-hour Duration Rainfall
1	1748	Herb	1572	1986	Herb	2217
2	1345	Herb	1446	1879	Haitang	2163
3	1274	Cass	1417	1715	Haitang	2039
4	1254	Haitang	1385	1645	Herb	2012
5	1185	Nari	1341	1644	Haitang	1992
6	1180	Cass	1291	1589	Haitang	1987
7	1154	Aere	1273	1537	Aere	1976
8	1067	Herb	1232	1525	Haitang	1889
9	1065	Haitang	1221	1522	Haitang	1813
10	1063	Nari	1200	1511	Mindulle	1676
11	1043	Nanmadol	1192	1499	Mindulle	1665
12	1042	Nari	1180	1474	Haitang	1660
13	1035	Krosa	1148	1437	Mindulle	1646
14	1026	Haitang	1141	1419	Mindulle	1629
15	1015	Cass	1131	1417	Sinlaku	1623
16	1010	Haitang	1125	1416	Mindulle	1618
17	1008	Sepat	1089	1399	Sinlaku	1604
18	1003	Aere	1079	1388	Aere	1559
19	992	Haitang	1079	1371	Mindulle	1547
20	991	Sinlaku	1051	1367	Cass	1520

3.2 Landslide

According to investigation reports issued by the Soil and Water Conservation Bureau (SWCB) of the Council of Agriculture and the Directorate General of Highways of the Ministry of Transportation and Communication (MTC), Typhoon Morakot caused 1,690 landslides and road blocks caused by rock slides in the mountains. These landslide incidents were in Nantou, Yunlin, Chyayi, Tainan, Kaohsiung, Pingtung, and Taitong Counties. The two most grieving landslide incidents occurred in Kaohsiung County: one in Xiaolin Village of Jiaxian Town with over 400 people dead or missing (Figure 9) and the other in Xinfa village of Liugui Town with nearly 30 people dead and missing (Figure 10).

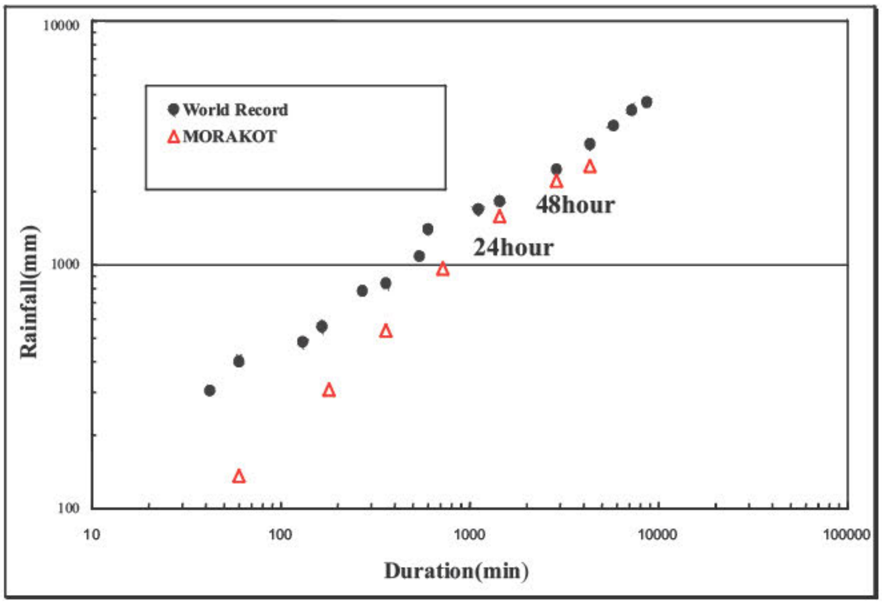

Figure 7 Typhoon Morakot's and the World's Maximum Accumulative Duration Rainfall in Comparison

Figure 8 Distribution of Flooded Area

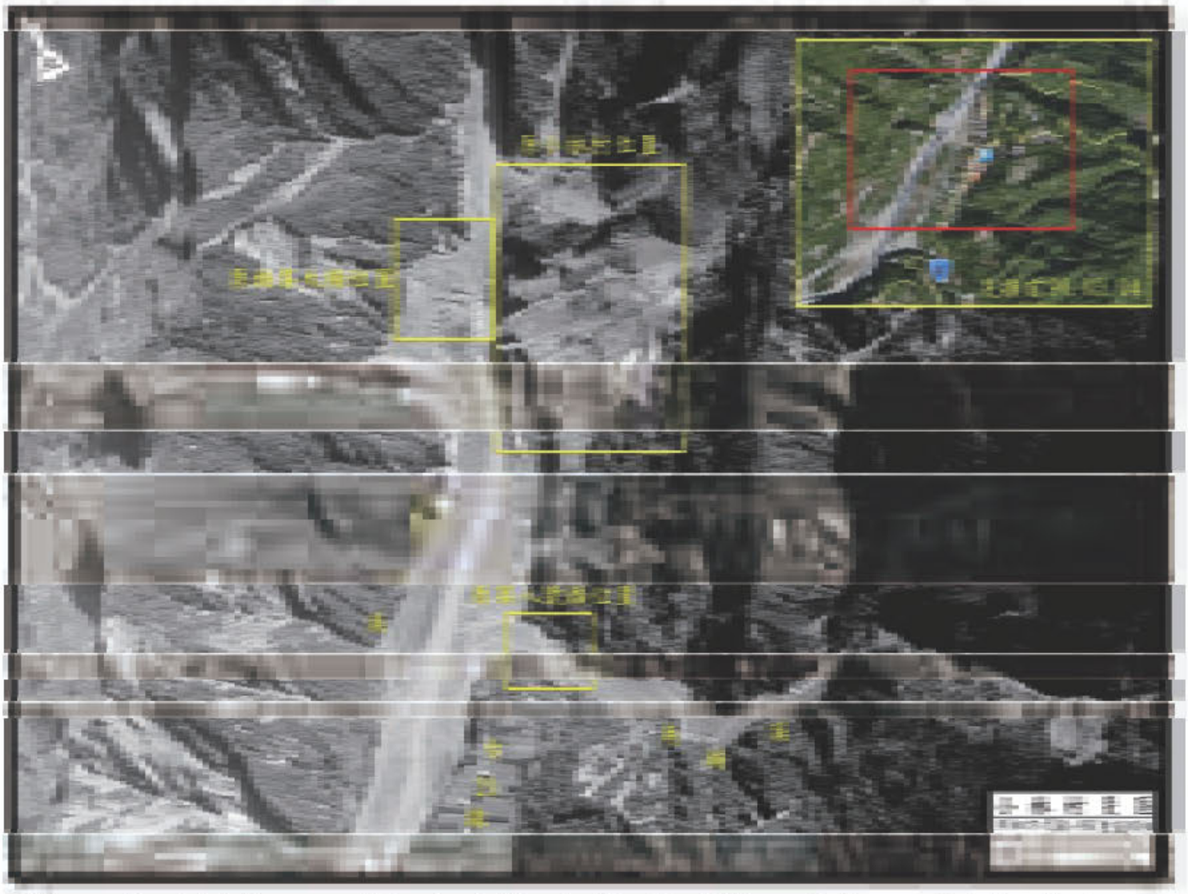

Figure 9 Arial Images of the landslide in Xiaolin Village: Before and After Typhoon Morakot (left and upper right, respectively)

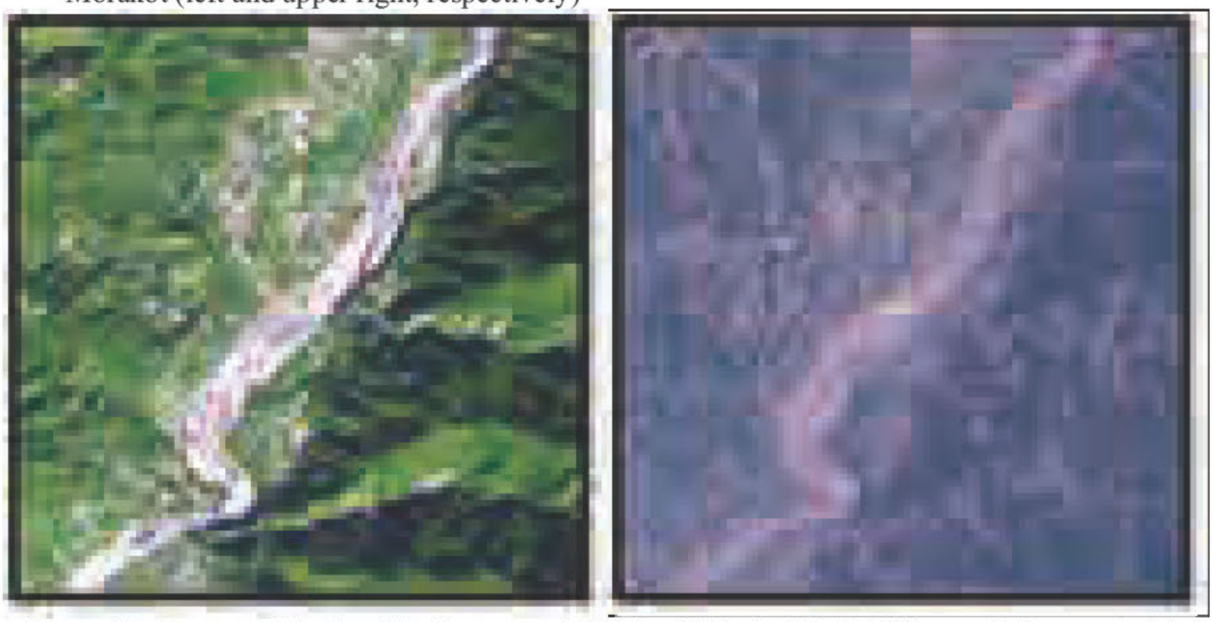

Figure 10 Formosat-2's Satellite Images of the landslide in Xinfa Village: Before and After Typhoon Morakot (left and upper right, respectively)

3.3 Road Block and Bridge Collapse

According to the Directorate General of Highways, road blocks, rock slides, landslides and bridge damage caused by Typhoon Morakot were distributed on Provincial Highway No. 3, 16, 18, 20, 21, 27, 24, 8, and 9 (Figure 11). Many of the highways in the mountains are still under recovery. Bridges suffered various types of damage: deck slabs and bridge piers were washed out, deck slabs deformed or displaced, decks tilted, and some bridges even buried by mudslides. Figure 12 shows the distribution of damaged bridges in Taiwan.

Figure 11 Distribution of Damaged Roads (the small icons indicate the location, the dark yellow color denotes the impacted townships)

Figure 12 Distribution of Damaged Bridges (the small icons indicate the location)

3.4 Damage to Schools and Public Infrastructure

According to the Ministry of Education, 231 primary schools, 48 junior high schools, 30 senior high schools, and 6 colleges were damaged by floods, landslides, mudflows or suffered from damage to structural stability. (Figure 13)

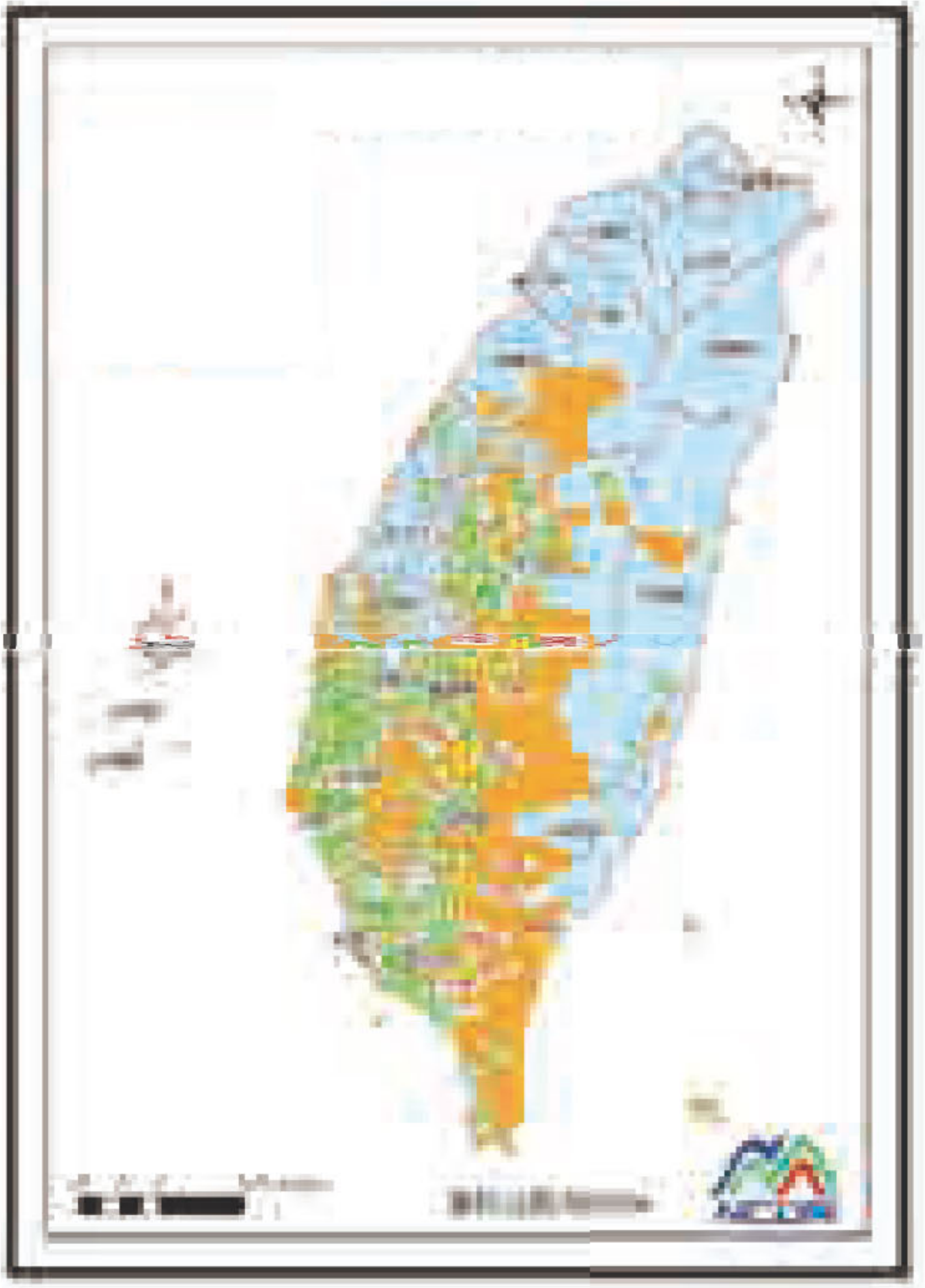

Figure 13 Distribution of Damaged Schools (the small yellow icons indicate damaged schools, the small green icons indicate not-heavily-damaged schools, and the dark yellow color denotes the impacted townships)

3.5 Financial Loss in Agriculture

The Council of Agriculture report shows Morakot caused a total of 19.4 billion dollars of financial loss in agriculture, forestry, fishery, and husbandry, as of September 8. (Figure 14)

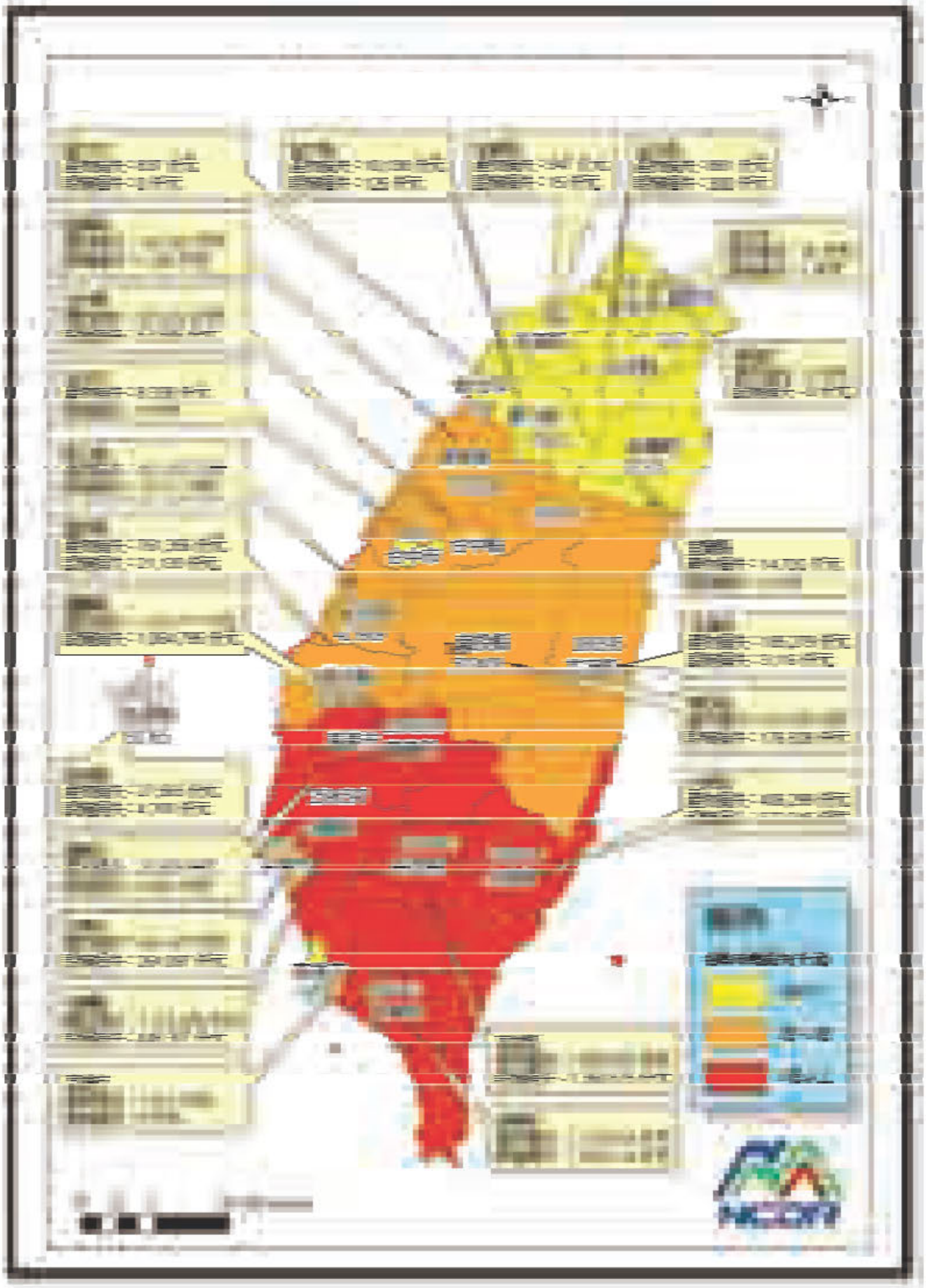

Figure 14 Distribution of Financial Loss in Agriculture

3.5 Damage to Utility Infrastructure

According to the Ministry of Economy and National Communication Commission, 769,159 households lost water supply, 1,595,419 households lost power supply, 118,335 households lost telecommunication services, 626 households lost gas supply, and 7 people were injured or lost their lives during Typhoon Morakot.

As of September 9, the Central Emergency Operation Center reported 619 deaths and 76 injuries during Morakot, the gravest and most catastrophic typhoon in the history of Taiwan.

4. EMERGENCY OPERATION PROCESS OF DISASTER REDUCTION

Both central and local governments were mobilized to prepare for the strike of Morakot since its genesis. The following outlines the government's emergency operation process and the focus of disaster reduction.

4.1 Close Observation of Morakot's Track

Typhoon Morakot formed on August 4 and was immediately under the close observation of CWB and the National Science and Technology Center for Disaster Reduction (NCDR). Both CWB and NCDR forecast Morakot's track and concluded a very high probability of its strike on Taiwan. Based on weather forecasts from other countries, both agencies continued plotting and modifying Morakot's track as it approached, landed, and left the island.

4.2 Activation of Central and Local Emergency Response Operation Center

At 20:00 of August 5, CWB issued typhoon warnings for the ocean area. Both central government and local governments in the warning zone set up Class-2 disaster emergency operation centers to consolidate resources for disaster prevention and relief. As Morakot's radius approached Taiwan, CWB issued warnings for the ocean and land areas at 08:00 of August 6, and the Class-2 operation centers were upgraded to Class-1 to facilitate early warnings, evacuation, emergency relief, and damage report.

4.3 Analysis of Early Warning Information

The Central Emergency Operation Center (CEOC), after its activation, analyzed early warning information and issued flood and debris flow forecasts every three hours. To predict Morakot's track, CEOC first analyzed Taiwan's rainfall potential, and combined the results with data such as accumulated rainfall in each river basin, real-time river water levels, in- and out-flow discharge of reservoirs, and tidal conditions in order to determine flood-prone and landslide-prone areas. During Typhoon Morakot, CEOC conducted 11 analyses and reported the results to its commander to consolidate disaster relief resources, reinforce emergency operation efforts, and devise evacuation policy.

4.4 Deployment of Disaster Relief Resources

Before Morakot hit Taiwan, government agencies had deployed disaster relief resources based on early-warning information. For example, the Water Resources Agency allocated mobile pumps to flood-prone areas, and the Department of Civil Affairs and Social Affairs set up shelters and ensured a sufficient supply of necessities.

4.5 Closure of Dangerous Bridges

The Directorate General of Highways Departments utilized early-warning information to closely monitor the change of water levels in nearby rivers. Bridges were closed immediately when the water level rose up to less than 1 meter below the bridge deck. Such a measure prevented casualties caused by bridge collapse, but some people were still killed when passing bridges that had not been closed but their piers had already been ruptured.

4.6 Emergency Evacuation Protocols by Local Governments

CEOC requires local governments to enforce emergency evacuation protocols in flood-prone and landslide-prone areas to prevent casualties. Those living in areas with high debris flow potential are required of early evacuation. During Typhoon Morakot, although CEOC determined that Jiaxian, Taoyuan, and Liugui Villages in Kaohsiung County were the most typhoon-prone areas, the local governments failed to evacuate these villages in time and catastrophic casualties occurred.

4.7 Disaster Reporting System

When a typhoon strikes, disasters initially occur in the forms of floods and agricultural damage. With increasing rainfall, landslides, debris flows and bridge collapses join in the scene. However, these disasters often fail to be reported immediately upon their occurrence, and such failure results in CEOC's inability to stay informed of each and every disaster and initiate immediate rescue efforts. Thus, a comprehensive and effective disaster reporting system must be established in the future.

4.8 Emergency Rescue and Relief

Disaster reports showed that many areas were in urgent need of emergency rescue and relief to contain the expanding damage. For instance, breached dikes needed repairing lest the damage caused by floods should expand.

4.9 Victim Relocation

For victims who were left homeless or whose community was under the threat of disasters, the government should provide immediate assistance in their relocation.

4.10 Prevention of Repeated Disasters

Typhoon Morakot breached dikes, displaced slopes, congested riverbeds and rainwater drainage systems, and left many regions vulnerable to the strike of another typhoon. Therefore, CEOC has drafted preventive measures, such as a standard operation procedure for evacuation in disaster areas.

5. DISASTER RECOVERY MEASURES

In order to accelerate the pace of recovery and help typhoon victims return to their normal life after the ravage of Typhoon Morakot, the government has implemented many disaster relief measures as follows:

5.1 Subsidies for Agriculture

In areas suffering severe agricultural losses, Article 14 of the Implementation Rules of Agricultural Natural Disaster Relief was immediately applied for victimized farmers to receive immediate financial assistance to return to their normal life.

5.2 Environment Restoration

Disaster areas were buried deeply under sludge and mudslides, so the government mobilized the army and volunteers to assist environment restoration.

5.3 River Dredging

Debris flows brought from upper stream led to heavy silting on the riverbeds, sapping the protective capacity of the rivers against floods and jamming drainage systems along the rivers. These rivers need dredging to restore their flood-preventing capacity.

5.4 Epidemic prevention

Forward command posts for epidemic prevention were established for antisepticising the disaster areas.

5.5 Institutional Arrangements

The Morakot Post-Disaster Reconstruction Council (MPDRC) was established by the Executive Yuan to lead the resettlement of victims and community restoration.

5.6 Post-Typhoon Morakot Reconstruction Special Act

The Post-Typhoon Morakot Reconstruction Special Act, drafted by the Executive Yuan, passed the third review of the Legislative Yuan and was later announced by the President on August 28. The restoration funds, subject to a 120 billion-dollar limit, can be raised through government debts, impervious to the annual credit limit set forth in the Public Debt Act. A reconstruction plan was mandated by this special act to reconstruct communities, infrastructure, industries, normal way of life and local culture. The reconstruction should also be in compliance with the enforcing rules of public land conservation and restoration.

5.7 Demarcation of Disaster-stricken Areas

The Post-Typhoon Morakot Reconstruction Special Act stipulates that all articles apply only to disaster-stricken areas, which makes demarcation an important issue. In view of the lack of precedents, the chairperson of the National Disaster Prevention and Protection Commission appointed MPDRC as the authority responsible for the demarcation and requested the National Science and Technology Center for Disaster Reduction to offer technical assistance. The demarcation of disaster-stricken areas involves the definition of disaster areas, the principles of demarcation, the collection and analysis of data on disaster areas and the publication of the operational procedure. The demarcation result is illustrated in Figure 15.

5.8 Post-disaster Mental Health Promotion Mechanism

The National Health Care Assistance Plan for Victims of Typhoon Morakot was created, which includes 24-hour toll-free telephone counseling services. Besides, mental health specialists from county public health bureaus were sent to interview victims and evaluate their mental health.

5.9 Victims Resettlement Strategy

The principle of “Safety First, On-site Relocation Second” guides the resettlement strategy. The government should facilitate the resettlement of victims to safe areas in the same township and the construction of permanent housing. If on-site resettlement is unavailable, victims would be advised to move to a safe neighboring area in the same county.

5.10 Permanent Housing

National land is provided free of charge for private charity organizations to construct permanent housing. Typhoon victims will have the permanent ownership of the property, but it cannot be for lease or sale.

Figure 15 Demarcation of Disaster-stricken Areas by Typhoon Morakot

5.11 Initiating Disaster Investigation Mechanism

The National Science Council (NSC) commissioned the National Science and Technology Center for Disaster Reduction (NCDR) to investigate damage inflicted by Morakot. NCDR and its partners set up investigation teams consisting of experts and scholars from nearby universities, the private sector and non-disaster areas. The investigation focused on flooded areas, hydraulic infrastructure, slope displacement, damage to bridges, roads, utility infrastructure, schools and public facilities, and buildings.

6. FUTURE CRITICAL PROBLEMS

Typhoon Morakot has laid bare many existing problems in our disaster prevention and response mechanism, including typhoon observation and warning technology, disaster monitoring and collection systems, emergency response and mobilization capabilities and evacuation measures. To improve the problems above, future efforts will be needed in the following aspects.

6.1 Enhancing the Monitoring System for Meteorological Changes, Landslides and River Floods

The rugged landscape of Taiwan creates many blind spots to the radar system. Together with the insufficient number of ground rainfall stations, it is difficult to identify a pattern of rainfall distribution. For instance, the insufficient number of ground rainfall stations in Taitung County contributes to the inability to cross-check the accuracy of the radar's precipitation forecast, making it difficult to estimate the severity of disaster. The serious shortage of flood monitoring stations fails the attempt to keep track of the fluctuations of water levels in the mid- and downstream. Furthermore, the flood monitoring stations of Kao-Ping, Zengwun, and Bajhang Rivers were destroyed in this typhoon, so the repair and reinforcement of the stations are in urgent need.

The problems of the existing monitoring mechanism include:

a. Lack of high-resolution radar hyetometers (for meteorological observation);
b. Insufficient monitoring data on near sea, off-shore islands, and outer regions (for meteorological forecast);
c. A flawed tidal monitoring system and lack of investigation systems for flood-prone areas (for flood control);
d. Inadequate monitoring systems for land and soil changes (for landslide monitoring and drought prevention)

The problems with the existing monitoring mechanism involve not only the lack of advanced technology, but also inadequate integration and management of data. Therefore, it is now a pressing issue for Taiwan to upgrade domestic monitoring systems and create an integrated and regular monitoring framework.

6.2 Developing Warning Technology for Compound Disasters

Under the efforts of NSC, CWB, the Water Resources Agency (WRA) and the Soil and Water Conservation Bureau (SWCB), an effective forecasting and warning system for typhoon tracks, floods, and debris flows is in place. Nevertheless, the technology for compound disaster warning is underdeveloped. For instance, the scene and remote sensing data showed that Xiaolin Village was not buried by mudslides. Instead, it was flooded away by the collapse of a barrier lake formed by land- and rock slides from the 1,600-meter-high Xiandu Mountain, a typical compound disaster. The meteorological data used in the past for forecasting slope displacement, including accumulated rainfall and precipitation forecast, failed to serve as a valid reference for forecasting compound disasters.

6.3 Integrating Disaster Report Systems

When disasters occur, the commanders of emergency operation centers need to take immediate measures in a limited period of time. However, disasters occur fast, unpredictably and without warning. Under time constraint and insufficient information, the management and distribution of rescue resources is often ineffective, especially in local governments. Even though most of the disaster emergency operation centers are equipped with basic hardware and software, the capability of disaster forecasting, decision-making tools for disaster prevention and relief support, and real-time alert systems still leave great room for improvement. In particular, the first step to today's emergency operation lies in disaster warning and forecasting, whose accuracy is still limited due to underdeveloped weather and disaster evolution forecasting technology and inadequate databases. To keep track of real-time disaster information, the existing reporting system needs modifying and a reliable reporting mechanism between local communities and command centers must be established. To facilitate the dissemination of disaster information among all levels of governments, a one-stop, cross-agency contact window should be created to streamline cross-department coordination and automate real-time information distribution.

6.4 Evacuation Operation Procedure

In the present evacuation mechanism, post-flood recovery plans proposed by the WRA for local governments apply in times of flood, while the Debris Flow Disaster Prevention and Response Operation Plan presented by the SWCB applies to mudslide disasters. In both plans, the following stipulations can be found: (1) the demarcation of areas with disaster potential, (2) response and evacuation measures for such areas, and (3) the division of authority and labor for enforcing these measures. However, there are no well-defined regulations for penalty in these plans, so, in times of evacuation, local governments' attempt of forced evacuation have often failed. Thus, a revision of the current evacuation mechanism must be conducted.

6.5 Calamity Response Plans

Calamities represent the magnitude of damage areas, life, death, injury and serious economic loss. In face of calamities, scattering resources lead to slow response. In the case of Typhoon Morakot, most of southern Taiwan was in the disaster-stricken regions. The immense scale of the disaster exposed the inefficiency of the central command system. In times of calamities as such, response measures and allocation of resources would be more complicated than those for single-area disasters. Therefore, it is advisable to invite scholars and experts from authorities concerned to draw up a comprehensive response plan for calamities. A plan as such will determine the effectiveness of emergency response and the possibility of containing ever-changing disasters.

6.6 Comprehensive River Basin Management

The management of river basins aims at minimizing the damage of disasters through the restrictions or policies of land use. However, a river basin, including its origin, upstream, midstream, downstream and estuary of the river, is under the jurisdictions of different levels of government authorities, both local and central. In addition, issues concerning each river section are inter-related. How to effectively integrate government authorities and establish a cross-agency platform remains a challenge. Furthermore, the governance of river basins involves a wide range of legal regulations. An unconventional and integrative legal framework should be established for better management of river basins.

6.7Legislation of National Land Use Planning

With the belief that man can overcome nature, constructions are done to prevent and reduce natural disasters on the one hand, and endless exploitation of natural resources for economic profits continues on the other. However, these constructions cannot withstand the destructive force of Mother Nature, as it is seen in the damage brought by Typhoon Morakot. Besides the casualties and loss of properties, post-disaster resettlement and restoration require more social resources, which definitely exceed economic benefits gained from exploiting marginal land. Respecting and coexisting with the nature and staying away from disaster-prone regions should be the guiding principle for future disaster prevention efforts. Reducing the development of marginal land is no loss at all. Instead, conservation is a more beneficial alternative. Natural resources such as water, soil, minerals and plants support our life and economy. Reducing the development of marginal land and promoting conservation and restoration ensure a green environment for future generations. The enactment of the National Land Use Planning Act (NLUPA) is intended to carry out a sensible development of national land, facilitate sustainable development, and mitigate climate change. The essence of this act is to divide the use of national land into four categories: natural conservation, agricultural development, urban and rural development, and marine resource development. The existing planning framework under the Regional Planning Act will be replaced with a new one guided by NLUPA. On June 30, 2009, the Executive Yuan submitted the draft of NLUPA to the Legislative Yuan for review. The legislation of NLUPA is expected to be expedited in order to facilitate post-Morakot reconstruction.

6.8 Assessing the Impact of Climate Change

According to NSTCDR’s research, rising temperature, increasing frequency of extreme temperatures, extreme rainfall, an increasing number of strong tropical storms, and rising sea levels and sea temperatures are the results of climate change. As the results of multiple simulations suggest, future climate change may include a rise of temperature between 1.8°C and 4.0°C from 2080 to 2099 compared to the period from 1980 to 1999 and a rising frequency of extremely high temperatures, heat waves, and extreme precipitation. It will be drier in the inland regions of all continents during the summer time. In most of the tropical and mid- and high-latitude regions, the amount of precipitation from extreme rainfall will exceed that of average rainfall. Tropical cyclones will also become fiercer with a higher maximum wind speed and more rainfall. Many recent studies indicate, though with lower credibility, that the total number of tropical storms may decrease. The number of weaker storms will decrease while that of stronger ones will be on the increase. The concentration and intensity of rainfall along with the changes of spatial distribution of extreme storms will contribute to the uncertainty and difficulties of disaster prevention and response, as will in turn inflict a great impact on the economic development and all industries in Taiwan. Therefore, efficient integration of climate change information is required to facilitate disaster simulations and studies, so as to formulate sound disaster prevention strategies in advance.

7. CONCLUSION

The World Meteorological Organization pointed out Taiwan as one of the prone areas to natural disasters. Taiwan can never be immune to the strike of typhoons. Hurricane Katrina’s ravage on New Orleans in the US should have been taken as a warning that Taiwan needs a sound mechanism of disaster prevention and response for extreme events, but obviously Taiwan did not learn the lesson. Typhoon Morakot has laid bare many existing problems in our capabilities for disaster prevention and response, leaving great room for improvement in the future. It is hoped that Taiwan has learned lessons from Morakot and will try every means possible to improve its disaster prevention and response capabilities against future disasters.

Chapter 8

Metro Manila Flash Flood of 26 September 2009: Causes, Impacts and Lessons Learned

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EXECUTIVE SUMMARY
On 26 September 2009, the most devastating flash flood occurred in Metro Manila inflicting enormous casualties and widespread damage to infrastructure and properties. Meteorological analyses of the flood event indicate that the ingredient for the unprecedented flooding was extreme rainfall of convective nature occurring over a highly urbanized catchment for an extended period of time. Clearly, the extent of damage evidently depicts the tradeoff between environmental degradation and accelerated development in the flood plains of the Pasig and Marikina river-Laguna Lake basin. This report presents the causes, impacts, and lessons learned from the worst flood in recent times in Metropolitan Manila. The major factor contributing to floods and flash floods is the process of urbanization itself; extending impervious areas lead to higher runoff peaks and volume and also reduce runoff travel time. Other factors which have heightened the degree of flooding are the occurrence of tides, the blockage of drainage systems by urban debris and the encroachment of waterways.

The floods of 26 September 2009 in Metro Manila and nearby areas were basically of the flash flood type. There was concentration of heavy rainfall over Metro Manila resulting in an average areal rainfall of 57 millimeters for a period of 5 hours (from 1000H to 1400H). The maximum 24-hour rainfall of 540 millimeters that occurred from 2000H 25 September to 2000H 26 September in Quezon City has a return period of 500 years. The flash flood of 26 September 2009 resulted in unprecedented flood heights. It also registered the highest water level in Laguna de Bay since 1988.

Flood forecasting in Metro Manila, especially the flash flood type is basically a nowcasting problem; hence, quantitative precipitation forecasts (QPF), especially for short lived convective weather systems, are a need that requires immediate action.

Recommendations on how to address flooding in Metro Manila have been identified by various sectors such as foreign organizations, the national government, academe as well as other private institutions, but the key to better planning and reconstruction efforts is to recognize that flooding in the metropolis is now conditional. It depends on land-use conditions, urbanization, and climate variability and change.

1. INTRODUCTION

The 26 September 2009 flash flood in the Pasig-Marikina River and Laguna Lake is considered the most devastating event in the urban river basin. Not only areas near the rivers were flooded but also about 80% of Metro Manila was inundated. Stages were exceeded at many locations, levees either failed or were overtopped, and hundreds of tons of debris and mud deposits and sediments were all over submerged villages and cities.

So many articles in the web, broadsheets and journals have been written and reported about the 2009 flood and so many fora and meetings have been organized to discuss the event that it would be impossible to cite all of them. Quite a number of reviews consider the event as a manifestation of climate change, but it is important to analyze available data and information in order to fully understand the impact and magnitude of damage caused by the flood. The paper is a retrospective account of what happened and will present underpinnings that aggravated the flood event.

Metro Manila lies in a flat alluvial and deltaic land extending from the mouth of the Pasig-Marikina River. The Pasig-Marikina River and Laguna Lake are located in the central part of Luzon Island (Figure 1). The Pasig-Marikina River basin occupies the major part of Metro Manila, which is the National Capital Region (NCR), and of Rizal and Laguna provinces. The Pasig-Marikina River has a total drainage area of 634 square kilometers, a length of 78 kilometers and a slope of 1/29000 1/1200. On the north western part of the Laguna Lake basin can be found the most densely populated and highly urbanized area known as Metro Manila.

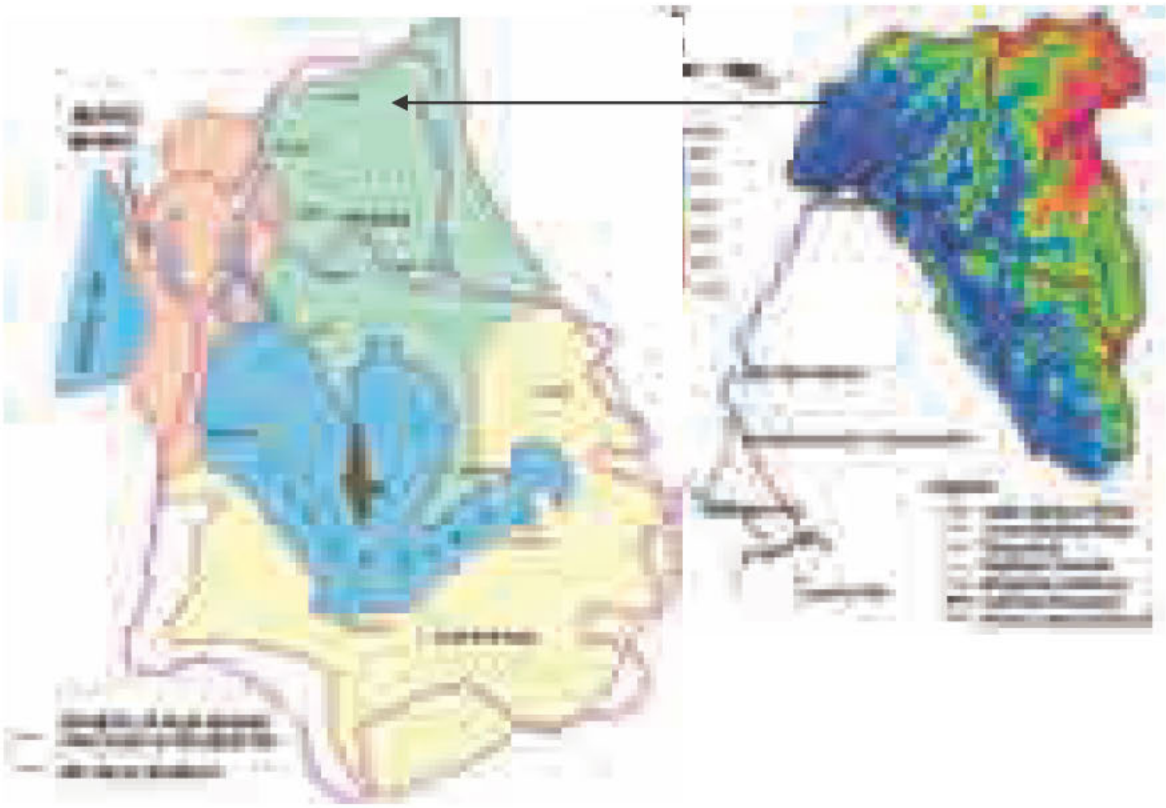

Figure 1 Location of Metro Manila and the Pasig and Marikina River-Laguna Lake basin (left) and the elevation map (right) of Upper Marikina river basin (Badilla, 2008)

The Marikina River originates from the western slope of the Sierra Madre Mountains, which is about 35 kilometers northeast of Manila (Figure 2). At the town of Montalban in Rizal province, the river emerges from the foothills of the mountain range, flowing southward through the Marikina Valley until it becomes the Pasig River. The Pasig River, which flows from east to west through the center of Metro Manila, extends about 17 kilometers from the confluence of the Marikina River and the Napindan channel to the Manila Bay. It has a fairly direct course, except for its double loop meander at the Punta-Santa Ana area. One of its principal tributaries is the San Juan River, which enters the Pasig River at the lower river meander about 6 km upstream before the river drains to the Manila Bay.

2. THE GREAT FLOOD OF 26 SEPTEMBER 2009

The flood event of 26 September 2009 is a classic example of urban floods for having all the ingredients of a disaster, and it exposed the vulnerabilities of the mega city to an extreme climate event. The work of Bankoff (2003) described in depth that Metro Manila's vulnerability to flooding has evolved over time as a result of the degree of interplay between climate, topography, resource use, and culture.

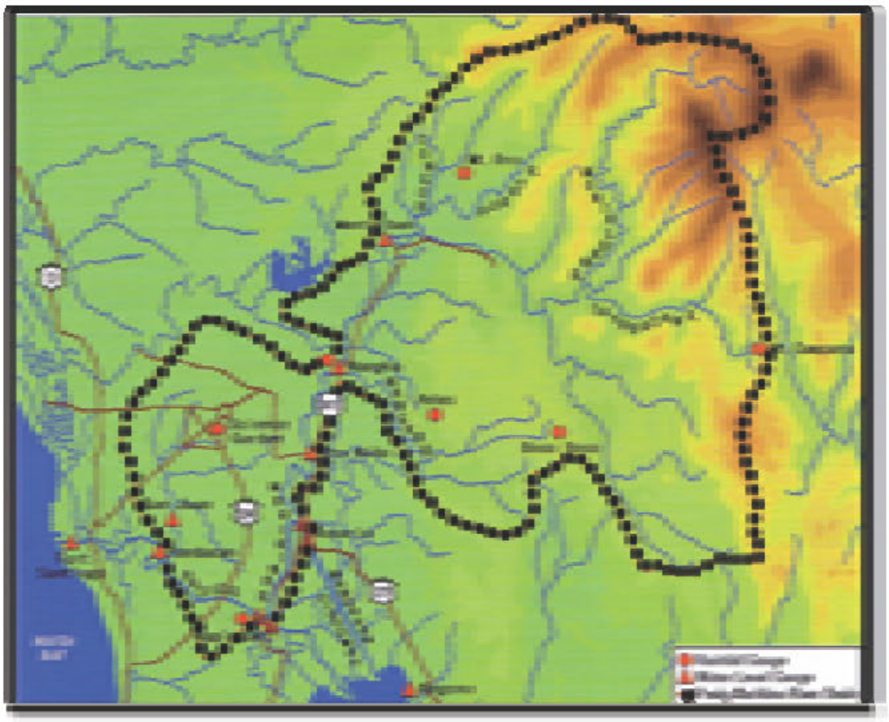

Figure 2 River System in the Pasig-Marikina River basin

2.1 Meteorological aspects

Metro Manila belongs to the Type-I climate (according to Corona's classification) characterized by the dominant rainy season from May to September and the dry season for the rest of the year. About 80% of the total annual rainfall occurs during the wet season. Rainfall is due to passing tropical cyclones, the monsoons, local thunderstorms and the inter-tropical convergence zone (ITCZ).

2.1.1 Synoptic situation of 26 September 2009

Tropical Storm Ondoy (Ketsana) started as a depression in west-central Philippine Sea in the morning of 25 September 2009 when it was tracked at 500 miles (~800 km) east southeast of the Central Luzon coast (Figure 3). The system was intensified into a weak tropical storm by the evening of the 25th as it moved westward towards Luzon. Ketsana maintained its strength as it crossed Central Luzon in the afternoon of the 26th . The main deluge in the Metro Manila area, located on the western side of Luzon, began around 0800H local time (00 UTC 26 September) even though the center of Ketsana at this time had yet to make landfall on the eastern side of the island.

The torrential rain over Metro Manila was the result of the interaction between Ketsana's low-level circulation and the seasonal southwest monsoon. The southwest monsoon comes about from the summertime heating of the Asian landmass. As warm air rises over the continent, it induces low pressure at the surface, which draws air in from surrounding regions. The southwest monsoon typically runs from June to September in the Philippines and draws warm, humid air up from the southwest across the South China Sea and into the islands, where it interacts with the topography. Storm Ketsana's counterclockwise circulation enhanced the effect in the south of the storm, which caused the torrential rains in Metro Manila and adjacent areas.

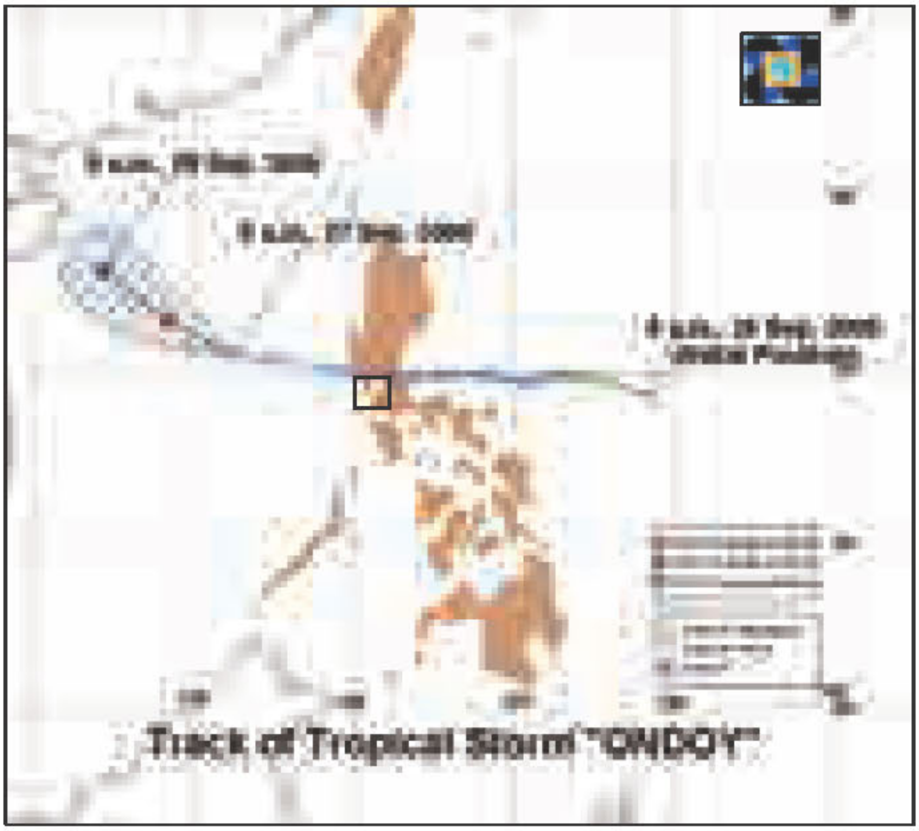

Figure 3 Track of Tropical Storm Ondoy (Ketsana)

2.1.2 Rainfall Observation

The Tropical Rainfall Monitoring Mission Multi-satellite Precipitation Analysis (TMPA) of the NASA Goddard Space Flight Center showed that the highest rainfall totals around the Philippines occurred south of the storm's track (indicated by the thin black line in Figure 4) in an east-west band over central Luzon. The rainfall amounts in this region are in the order of 375 mm (~15 inches, shown in dark yellow) to over 475 mm (~19 inches, shown in orange). The highest recorded amount from the TMPA around Manila was 585.5 mm (almost 24 inches) as shown in Figure 4.

Compared with ground observations at the PAGASA Science Garden station, the estimated 24-hour rainfall from the TRMM was higher by 45 millimeters.. The observed rainfall intensities of 1-hr, 3-hr, 6-hr and 24-hr from 25-26 September 2009 exceeded all records since 1951. The observed 24-hour rainfall from Ketsana is equivalent to more than a month's rainfall since the average rainfall for September is only 392 millimeters. The four (4) rainfall stations within the Effective Flood Control Operation System (EFCOS) of the Pasig-Marikina-Laguna Lake complex (Figure 5) also recorded extreme rainfall intensities at various time scales as shown in Table 1.

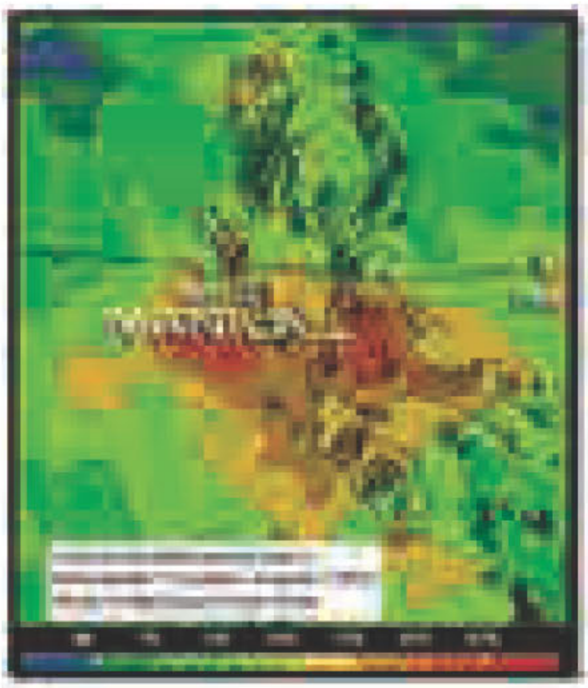

Figure 4 Rainfall analysis from the Tropical Rainfall Monitoring Mission (TRMM)

Table 1 Rainfall intensities in the Pasig-Marikina river basin due to the passage of Tropical Storm Ondoy (Ketsana) * *EFCOS data;* ** *PAGASA data*

Station	Max 1-hour rainfall (mm)	Max 3-hour rainfall (mm)	Max 6-hour rainfall (mm)	Max 24-hour rainfall (mm)
Boso-boso*	**58**, 9/26 10am	**162**, 9/26	**286**, 9/26	**388**
Aries*	**77**, 9/26 11am	**180**, 9/26	**293**, 9/26	**391**
Mt. Oro*	**91**, 9/26 11am	**202**, 9/29	**322**, 9/26	**366**
Nangka*	**73**, 9/26 10am	**179**, 9/26	**286**, 9/26	**358**
Science Garden** (Quezon City)	**92**, 9/26 11am – 12nn Ret Pd – more than 10 years	**229**, 9/26 11am – 1pm RP – more than 50 year	**382**, 9/26 9am - 3pm RP – about 350 years	**540** 8pm, 9/25 – 8pm, 9/26, RP – more than 500 years

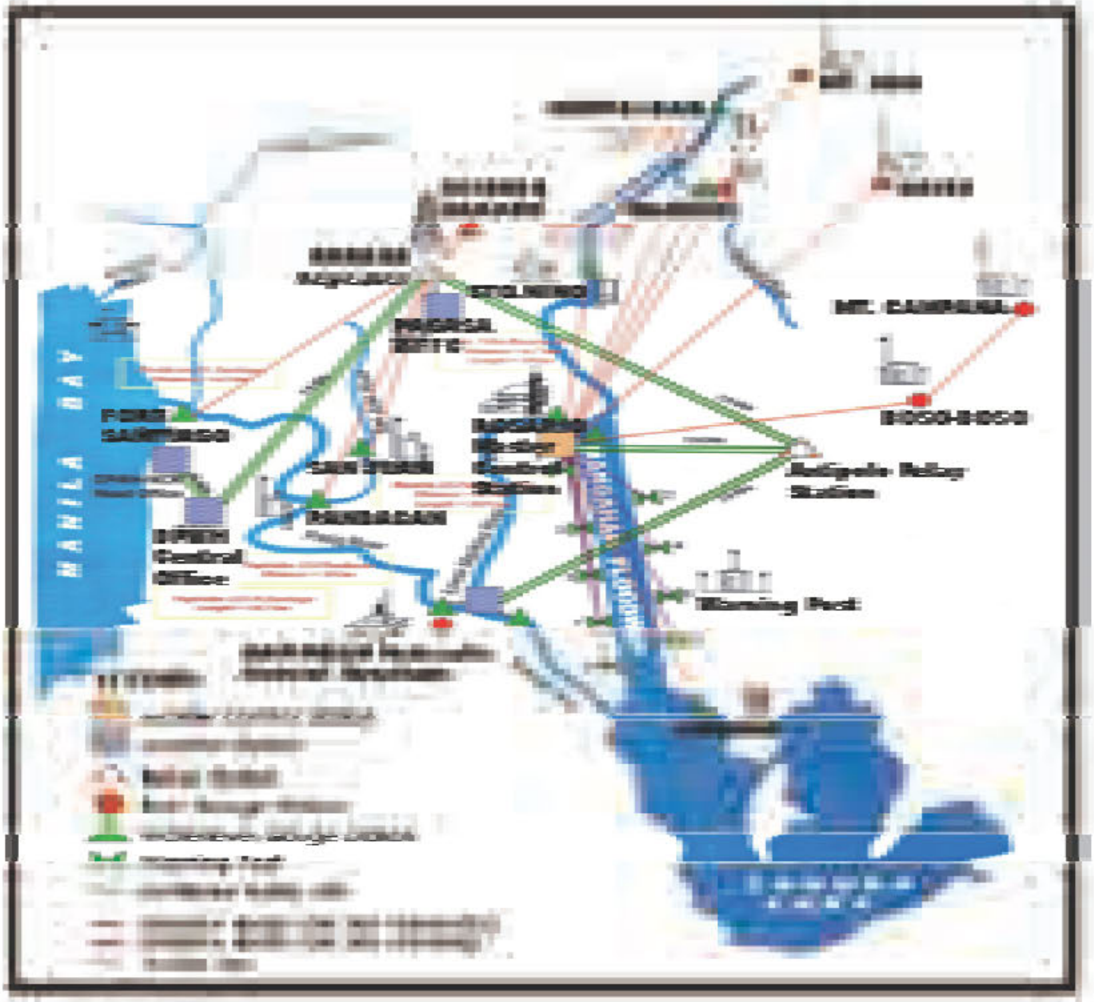

Figure 5 schematic diagrams of EFCOS

The predictability of the rainfall event that triggered the devastating flood in Metro Manila was investigated based on available rainfall observation in order to assess the return period of the rainfall event. Numerical weather prediction (NWP) models that were referred to in deriving the rainfall forecasts on 26 September 2009 include the Global Spectral Model (GSM), ETA, GFS, and MM5. During the passage of Tropical Storm Ketsana, the rainfall forecasts from all these models were underestimated compared with the observed rainfall.

Another source of rainfall forecasts is the eTRaP, a simple ensemble of 6-hour forecasts from the single-orbit TRaPs of several microwave sensors from satellites initialized at several observation times. The eTRaP consists of deterministic and probabilistic rain forecasts for each of four 6-hr time periods (e.g., 00-06h, 06-12h, 12-18h, 18-24h) as well as the 24 hour cumulative time period. However, there is a delay in the transmission of data; for instance, a 00Z eTRaP would not be available until around 0315Z. The eTRaP of 00Z (0800H) 26 September showed that the forecast rainfall from 8AM to 2PM over Metro Manila is within the range of 100mm to 254 millimeters (Figure 6). All the other eTRaPs of 25 September forecasted the maximum rainfall north of Metro Manila.

At the present state of technology, flood forecasting is still limited due to the lack of reliable quantitative real-time forecasting of rainfall. The analyses of quantitative precipitation forecasts (QPF) provided by the NWP models indicate the need for considerable fine tuning of the initial boundary conditions before they can be used as operational tools for real-time forecasting. In addition, the space-time resolution of the NWP models is still not sufficient for real-time flood forecasting systems to apply to small basins.

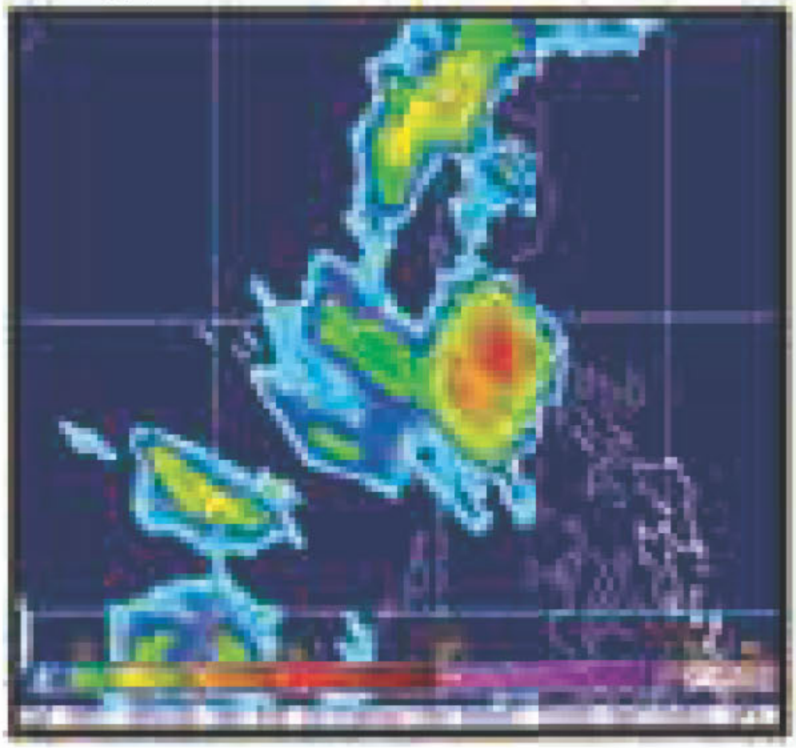

Figure 6 eTRAP of 00Z, 26 Sep 2009

2.2 Hydro-meteorological analysis

Hydro-meteorological data from the Effective Flood Control Operation System (EFCOS) and PAGASA (Figure 6) were analyzed to determine the response of the Pasig-Marikina River to the rainfall intensities from 25-26 September 2009 (Figure 7).

Antecedent rainfall between 1900H to 2400H of 25 September was more than enough to saturate the basin, and the excess rainfall caused a slow rise in the water level of the Marikina River and its tributary, the Nangka River.

The observed data indicated that the water level of the upper Marikina River at the Montalban gauging station peaked at the elevation of 32.70 meters above mean sea level (MASL) at 1400H. From the occurrence of the maximum basin rainfall of 84 millimeters at 1100H, the elevation rose by 5.13 meters within a period of three (3) hours.

About nine (9) kilometers downstream of Montalban is the Nangka gauging station, located about one (1) kilometer before the confluence point of the Marikina and Nangka Rivers. The peak elevation of 26.25 MASL at the Nangka station occurred at 1500H 26 September, about 6 hours after the commencement of heavy rainfall. There was an increase in the Water level of 5.56 meters within a period of 5 hours, after which the station was totally submerged.

The runoff from Montalban generally travels a distance of nine (9) kilometers before it merges with the discharge from the Nangka River. From the confluence point of the Marikina and Nangka Rivers, the river traverses about 5.30 kilometers to reach the Sto. Niño gauging station located in Marikina City with an estimated travel time of 50 minutes. In this way, after 50 minutes, the Sto. Niño station is expected to peak at 1700H, or two (2) hours after the occurrence of the peak water level in Nangka; however the river height leveled off at 22.16 MASL from 1600H to 2200H until the station stopped recording any observation. The leveling of the river height indicated the overflowing of the river leading to the breaching of dikes that may have caused the widespread flooding of Marikina City.

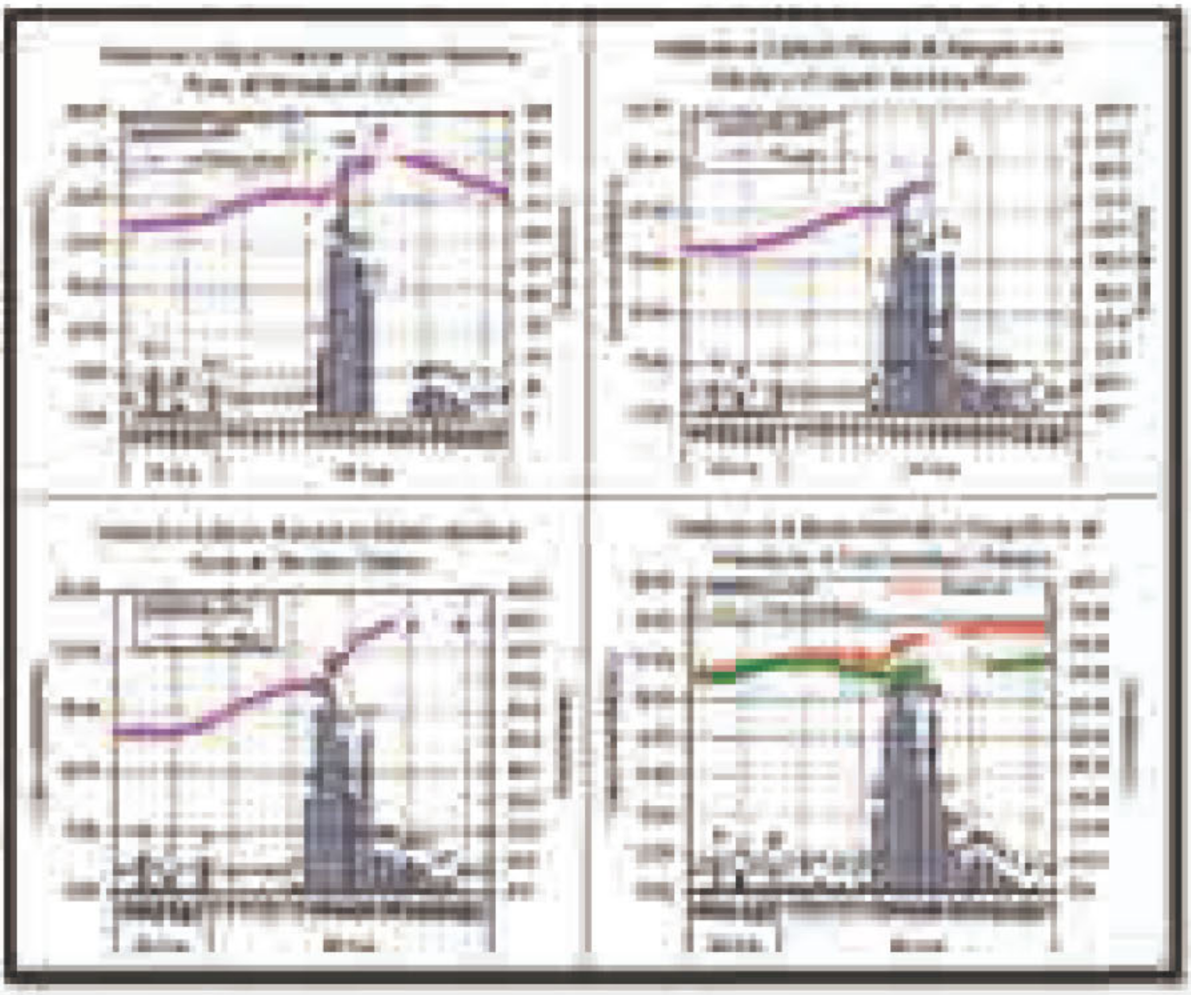

Figure 7 Graphs of basin rainfall and water level in the Pasig-Marikina River basin during the passage of Tropical Storm Ondoy (Ketsana)

Table 2 Flood Propagation (Travel time)

River	Section	Travel Time (min)	Distance (km)	Propagation velocity (m/s)
Upper Marikina	Montalban - Nangka	80 (1hr & 20min)	9.0	1.9
	Nangka – Sto. Niño	50	5.3	1.8
	Sto. Nino - Rosario	30	6.7	3.7
San Juan	Tatalon – Junction	30	7.1	3.9

About 6.7 kilometers from the Sto. Niño gauging station is Rosario, Pasig, where the gates of the Manggahan weir are opened to divert the runoff from the Marikina River to Laguna Lake.

The peak elevation at the junction side of Rosario recorded at 17.92 MASL at 1800H of 26 September. Since water-level data is complete at the Rosario junction side (JS), the propagation of flow from Rosario to Montalban was reconstructed to check the time of the observed peak heights based on the distance between gauging stations and the propagation time of the flood (Table 2). It was found out that with the peak elevation of 17.92 MASL at Rosario JS observed at 1800H 26 September, the distance of 6.7 kilometers and the flood propagation time of 30 minutes, the corresponding peak elevation in Sto. Niño occurred at 1700H 26 September. Consequently, the peak flow in the Montalban gauging station occurred at 1500H. This proves that the actual peak elevations at Montalban, Nangka and Sto. Niño are correct.

Table 3 Record of maximum flood elevations of Laguna Lake

Date	Laguna Lake Elevation (m)	Remarks
September 1919	14.62	**WITHOUT** Manggahan Floodway and Napindan Hydraulic Control Structure
October 1952	13.08	
October 1960	13.17	
August 1972	**14.03**	
October 1978	13.58	
October 1986	13.54	
November 1988	13.60	**WITH** Manggahan Floodway and Napindan Hydraulic Control Structure
November 1995	13.47	
June 1999	12.69	
November 2000	13.53	
September 2009	**13.84**	

Source: Gatan, 2009: Learning from the Ondoy Flood –A Dialogue with Experts, ADB Seminar – 14 October 2009

Due to the antecedent rainfall in 25 September, the elevation of the lake started to rise at 0100H 26 September and peaked at 13.84 MASL at 2200H 27 September based on the data of the Angono station. Historical data in Table 3 shows that the maximum elevation recorded on 27 September 2009 was the highest level of Laguna Lake since 1988, when the Manggahan and Napindan hydraulic structures were put in place. The high elevation of the lake persisted until October 2009 and prolonged the inundation of areas surrounding the lake.

Table 4 Maximum observed elevation of the Pasig-Marikina River and Laguna Lake

River	Section	Observed Max. Elev. (MASL)	Time & Date of Occurrence	Remarks
Upper Marikina	Montalban	32.70	1400H / 26 Sep	
	Nangka	26.25	1500H / 26 Sep	Station was totally submerged
	Sto. Nino	22.16	1700H / 26 Sep	
Lower Marikina	Rosario	17.92	1800H / 26 Sep	
Pasig river	Pandacan	13.64	2000H / 26 Sep	
	Fort Santiago	12.02	0200H / 27 Sep	
Laguna Lake	Angono	13.84	2200H / 27 Sep	

In the lower portion of the basin, continuous light to moderate rainfalls were observed starting from 1900H 25 September until the morning of 26 September (Science Garden, Quezon City). However at 0900H of 26 September, a very intense rainfall occurred and persisted until

1500H (approximately 6 hours). There was already widespread flooding within the Pasig River basin, which started before noon and lasted until the evening of 26 September; however, the maximum elevation of 13.64 MASL at the Pandacan station was recorded at 2000H September 26.

The most downstream station of the Pasig River at Fort Santiago, Manila, is affected by tidal fluctuation being nearest to the Manila Bay. However, it registered a maximum elevation of 12.02 MASL at 0200H 27 September.

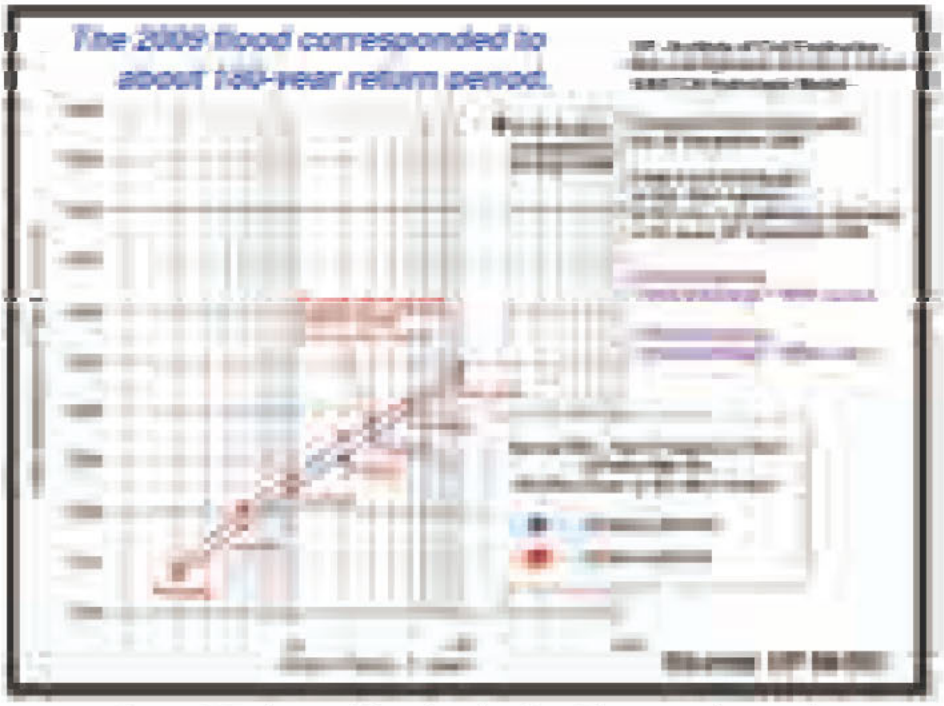

Figure 8 Estimated flood at the Sto. Niño gauging station

In a forum entitled "Preliminary Engineering Analysis of the Marikina River Basin Flood of September 26, 2009" conducted on 2 October 2009, the University of the Philippines Institute of Civil Engineering National Hydraulic Research Center (UP-ICE-NHRC) presented some key findings and lessons learned on the Metro Manila flood. Using the published discharge rating curves of the Marikina River (JICA-DPWH Study, March 2002), the peak flood at the Sto. Niño gauging station was estimated to be 5,770 cubic meters per second (Figure 8). The estimated flood which corresponds to the 180-year return period matched with the observed markers of the maximum flood water levels on 26 September 2009 relative to the low banks.

3. CAUSES OF FLOODING AND DAMAGE ASSESSMENT

Due to its physical profile, flooding in Metro Manila is a natural phenomenon. The archive of the Manila Observatory chronicles major flooding from 1691 to 1911 (Bankoff, 2004) and most of the flooding were associated with tropical cyclones. However, in recent years, flooding situations vary with rainfall intensity. A heavy downpour alone or monsoon rains may result in flooding. For instance, a 50 millimeters rainfall in one hour can inundate roads while a 100 millimeters of rainfall in 3 to 4 hours results in traffic congestion.

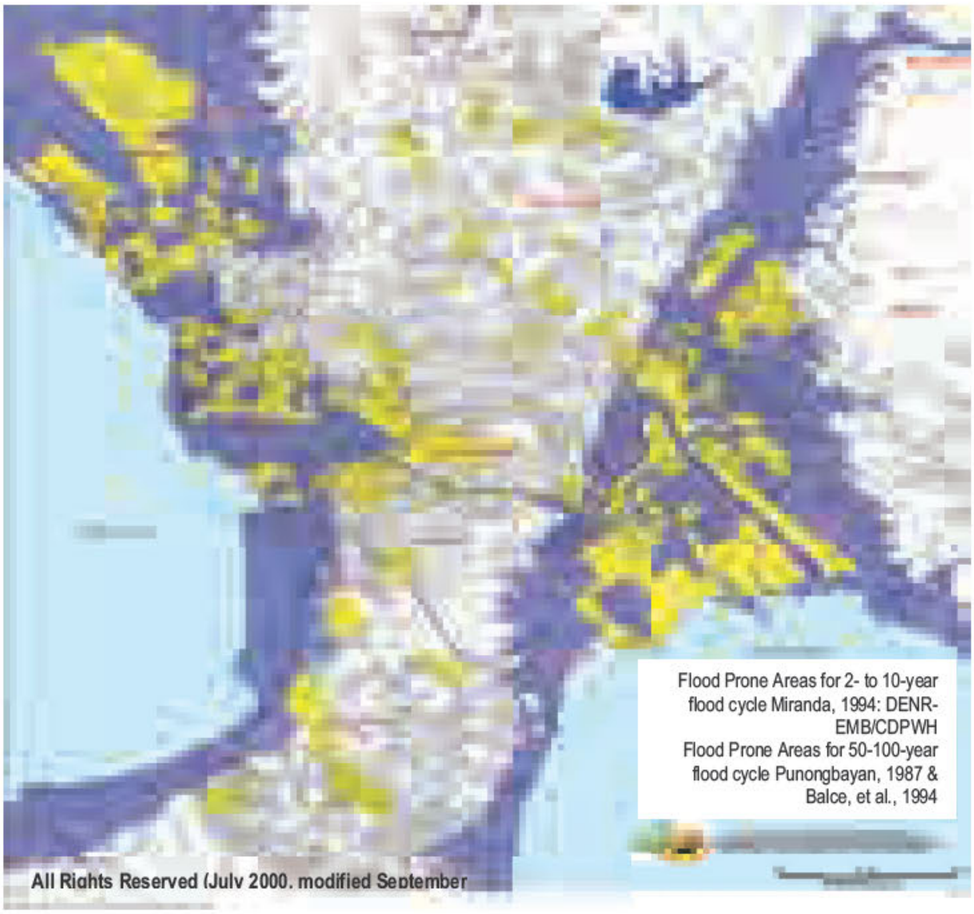

Figure 9 Modified flood prone areas of Metro Manila

According to a survey conducted by the Department of Public Works and Highways (DPWH), the 1943 flood was the biggest with an inundation area of 109.50 square kilometers. In September 1986, the passage of Typhoon Miding inundated about 103.6 sq. km, or more than 16% of Metro Manila. The floods in 1966, 1967, 1970, 1972, 1977, 1978, 1986 and 1988 have also resulted in serious damages in the Metropolitan area. From the 1990s to the present, flooding became more frequent and widespread such as those that occurred in 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2003 and 2004. The recent flood of 26 September 2009 enveloped about 80% of the Metropolitan area for which the modified flood hazard map of Metro Manila (Figure 9) was produced.

3.1 Unusually extreme rainfall event

The 24-hour rainfall of 540 millimeters that occurred in the basin between 2000H 25 September and 2000H 26 September 2009 was too much for Metro Manila's greatly reduced absorptive capacity. The weather conditions of the time provided a very moist atmosphere that triggered the prolonged duration of heavy rainfall. The 24-hour rainfall event is equivalent to an event with a return period of approximately 500 years based on the rainfall intensity-duration-frequency (RIDF) analysis of PAGASA. In terms of estimating the quantity of such an extreme rainfall event in an urban catchment, the PAGASA has yet to install Doppler radars which have realized in the middle of 2010.

3.2 Rainfall and flood monitoring, forecasting and warning system

The PAGASA is responsible for issuing warnings occasioned by typhoons, floods and other weather systems. Severe warnings on tropical cyclones are based on wind strengths and not on rainfall intensities. Flood forecasting is basically a rainfall forecasting problem and the quantitative estimates of rainfall intensities can be derived from Doppler radars which are not yet available at the moment.

For Metro Manila, the EFCOS project was established as a flood forecasting and flood control facility in 1993 and expanded in 2001. The EFCOS is equipped with a real-time rainfall monitoring system in the upper Marikina River as well as water level stations along the upper and lower Marikina River and warning stations along the Manggahan Floodway. As such, the EFCOS is designed to forecast the flooding of the Marikina River for the effective flood control operation of the Rosario weir and the Napindan Hydraulic Flood Control Structure in Pasig River.

The master control station is at the Rosario station in Pasig with monitoring stations at the Napindan Hydraulic Control Structure, DPWH Central Office, NCR DPWH Office and the PAGASA Weather and Flood Forecasting Center (WFFC). As a monitoring agency, the PAGASA utilizes EFCOS data as basis in the issuance of Metro Manila Flood Situationer. However, in September 2006, the radio equipment at the Antipolo Relay station was destroyed due to the passage of Typhoon Milenyo (locally called Xangsane) and since then the PAGASA WFFC was not able to monitor the data from EFCOS.

3.3 Carrying capacities of rivers

Based on the study of JICA in March 2000, the bankful flow capacities of the rivers in the Pasig-Marikina river basin are as follows: lower Marikina (500 m^3/s), floodway to Sto. Niño (1000 m^3/s), Sto. Niño to Montalban (1500 m^3/s), the river mouth to confluence with San Juan (700 m^3/s), the confluence with San Juan to the Napindan junction (500 m^3/s), Laguna Lake to Pasig River (50 m^3/s), San Juan River (50 m^3/s), Tullahan River (100 m^3/s) and Cainta, Antipolo, Angono and Taytay (22 m^3/s only).

Bongco (2009) estimated that the flow rates of the Pasig-Marikina rivers including the Manggahan Floodway and the Napindan Channel during the passage of Typhoon Ketsana far exceeded their design values as shown in Figure 10. For instance, the bankful flow capacity of the Marikina River at Sto. Niño is just 1000 m^3/s, but the estimated flood on 26 September was 4150 m^3/s and about 3000 m^3/s was diverted to Laguna Lake via the Manggahan Floodway.

In addition, the old drainage system constructed in 1975 is already 70% silted and clogged due to indiscriminate garbage disposal. The design of the drainage system was based on a 10-year return period flood event. Due to the effect of urban development which is being undertaken at a very fast and alarming rate, the runoff coefficient significantly increased from the originally designed 50% to 95% (Gatan, 2009).

Further, existing waterways traversing subdivisions are filled up and replaced with very inadequate reinforced pipes and culverts with a return period which is less than the 10-year return period adopted by the DPWH.

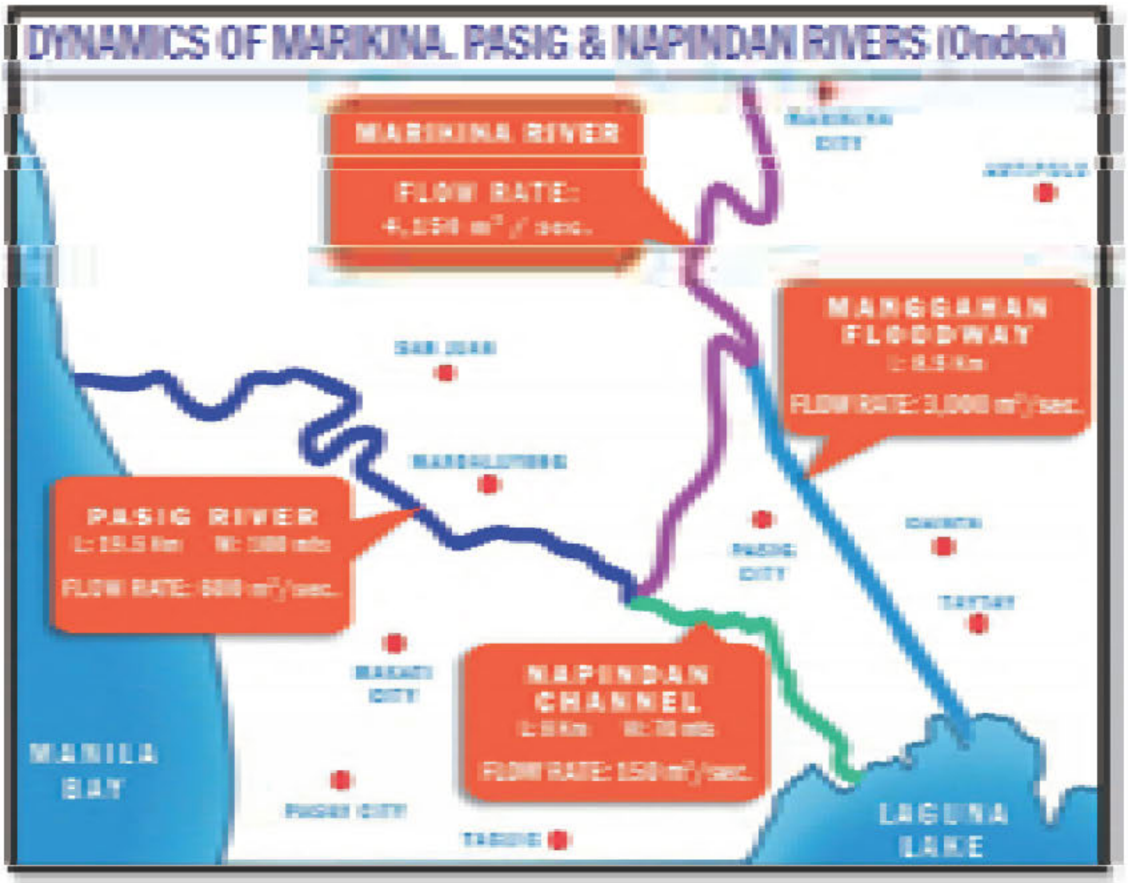

Figure 10 Observed flow rates of the main rivers and channels that traversed Metro Manila during the passage of Ketsana (*Source: Bongco, 2009*)

Under the Master Plan for Flood Control Structures for Metro Manila, flood control structures along rivers were designed to withstand a 100-year return period flood and 10-year flood for drainage structures. Obviously, the estimated flood of 26 September surpassed the design return period of the flood control structures in place.

3.4 Population and growth rate

During the post war period from 1948 to 1980, the total population of the NCR has increased by almost 3.8 times resulting in a total population of 5,926,000 in 1980. A remarkable increase of nearly 2,000,000 was recorded from 1970 to 1980. In terms of growth rate, a noticeable declining trend was recorded from 25.3% in 1970 to 1975 to 19.2% from 1975 to 1980. Population density in the region also rose accordingly from 517 people per square kilometer in 1903 to 3,872 in 1960 and 16,495 by 2000 (Bankoff, 2008).

With a growth rate of 2.11%, the population of NCR increased to 11,553,427 from 2000 to 2007 (Figure 11) and elevated the Metropolis to the rank of a mega city. It is worth mentioning that from a population density of 517 in 1903, the figure increased to 3,872 (749%) in 1960 and soared to 16,495 (3190%) in 2000. But the figure does not show a high contrast in distribution of persons among cities and municipalities which are staggering in the slum and congested areas. For instance, the population density of Navotas, a coastal municipality near Manila City, is 88,617 as of 2000 while Pateros has 5,520person per square kilometer.

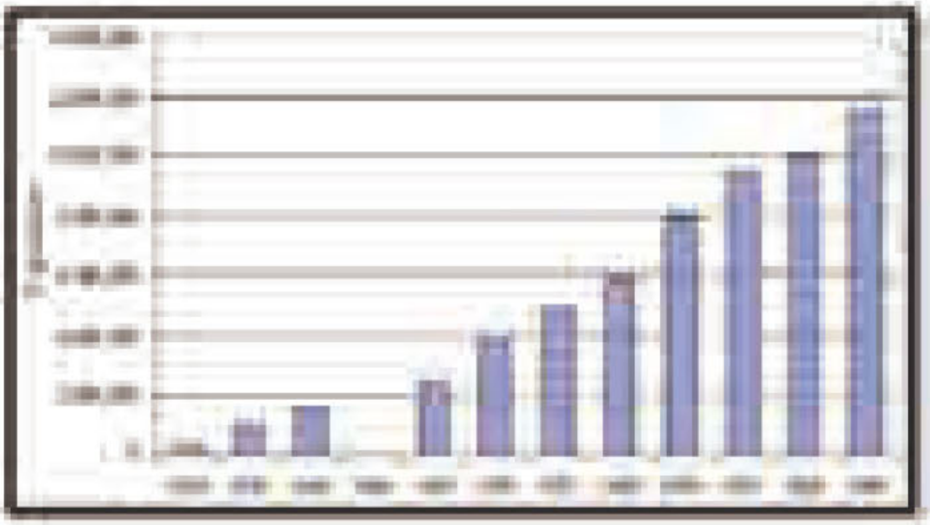

Figure 11 Population data of the National Capital Region (Metro Manila)

3.5 Land Use and Urbanization

The high population density of Metro Manila has resulted in intensified intervention to its environments. Natural landscapes have been transformed as a result of various effects on the structure, function, and dynamics of ecological systems at a wide range of scales. The impacts of recent hydrometeorological disasters have brought into focus the vulnerability of the metropolis' ecological environment and biological diversity.

In the Philippines, the Local Government Act of 1991 prescribes that a normal city with a population of 200,000 and revenue of over 50,000,000 Philippine pesos in the past year can transform into a highly urbanized city. At present, Metro Manila is composed of 16 cities and 1 municipality (Figure 12).

The 2008 report of the Asia Pacific Network (APN) for Global Change quantified the land-use urbanization level based on the analysis of scale effects in landscape pattern of three (3) developing countries in Asia, namely Shanghai (China), Manila (the Philippines) and Hanoi (Vietnam). The study which utilized remote sensing technology revealed that among the three (3) urban areas investigated, Metro Manila was found in the highest stage of urbanization, and with the earliest suburb urbanization (Figure 13). Shanghai depicted a high degree of urbanization and obvious suburb urbanization. In contrast, Hanoi demonstrated a lower level of urbanization and unobvious suburb urbanization.

Plantilla (2009) presented vividly in the video recorded on 1 May 2009 the rampant quarrying and deforestation of the Sierra Madre Mountains, the upstream portion of the Pasig-Marikina River basin as shown in Figure 14. According to the official statement of the Haribon Foundation on the devastation caused by Tropical Storm Ketsana, human factors compounded the magnitude of the disaster. The report cited that the "annual rate of deforestation in Sierra Madre caused by large-scale industrial logging is alarming and is pegged at 22,546 hectares (UNDP GEF SGP 2006)". In addition, based on the data from the UNDP GEF SGP, mining claims in Sierra Madre cover an area of 811,541 hectares.

Figure 12 &13 Political subdivisions of Metro Manila (left) and urbanization level and images in Metro Manila, Philippines (right)

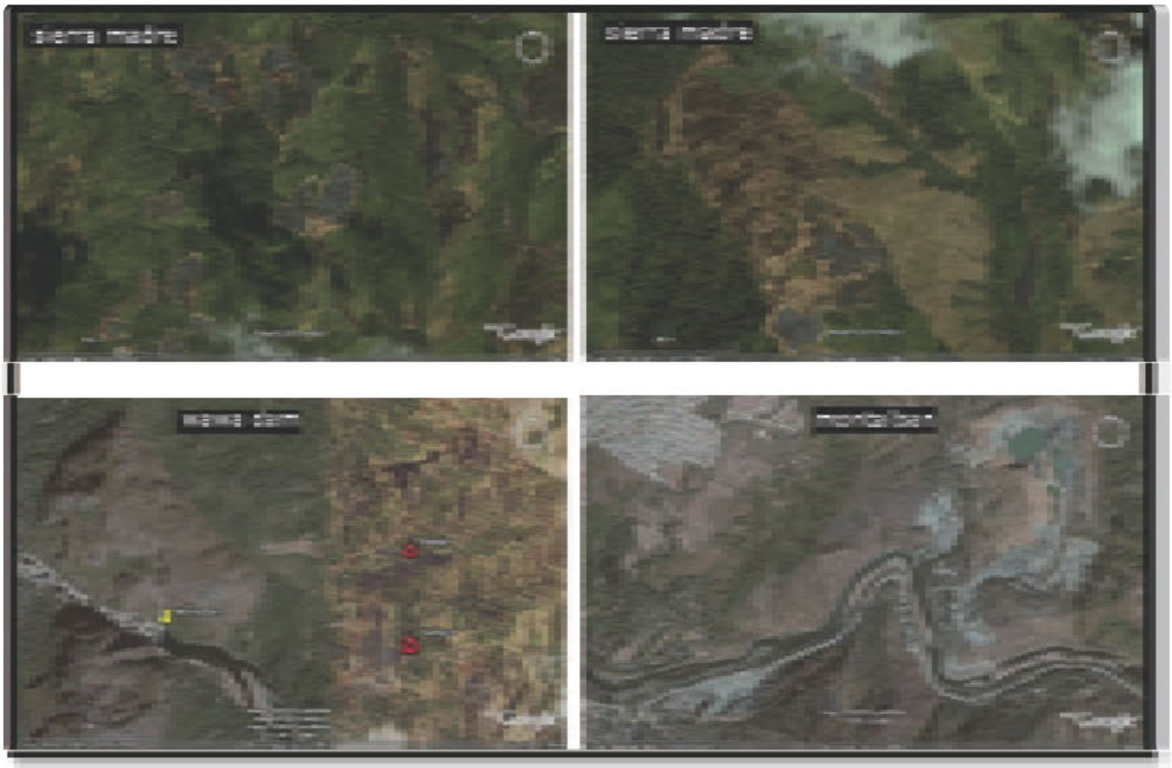

Figure 14 The treeless Sierra Madre Mountains (above); the "kaingin" spots (in red circles at the lower left photo) and the quarry site in Montalban, Rizal (lower right photo)
Source: Plantilla, 2009

3.6 Disaster mitigation and preparedness

Disaster management for Metro Manila is participated in by quite a number of agencies such as the MMDA, national government agencies, non-government organizations and private institutions. Activities on disaster management are coordinated by the National Disaster Coordinating Council (NDCC) through its implementing arm, the Office of Civil Defense (OCD) and also the city and municipal Disaster Coordinating Councils (DCC) at the local level. The NDCC, Regional DCC, and the City/Municipal Disaster Coordinating Council (CDCC/MDCC) were created through Presidential Decree (PD) 1566 to strengthen the Philippines' disaster control capability and to establish a national program for community disaster preparedness in June 1978.

There are several good programs on disaster mitigation, preparedness and response, one of which is the deployment of Mobile Flood Teams, which will be out on the streets as soon as a built up of floodwaters is observed. Other structural measures for flood mitigation include: dredging of rivers, creeks, esteros and open channels which are usually undertaken every 2 years depending on the degree of siltation; while the desilting of drainage laterals is a year round activity.

To help alleviate the plight of informal settlers or the poorest in Metro Manila, the government through Republic Act 7279 has prioritized the relocation of some 66,334 families residing in danger areas, specifically those exposed to serious health hazards and life threatening situations. The implementation of this Act has provided local government units with the assistance of different national government agencies. However, as indicated in recent disasters, informal settlers were everywhere in highly vulnerable areas despite of warning signs as shown in Figure 15. The worse is that flood prone areas were developed as residential and business areas without the proper engineering measures (Figures 16 and 17).

3.7 Flood damage and impacts

The total damage brought about by the flood and flash flood due to the passage of Tropical Storm Ketsana was staggering: Affected population 4.9 million; casualties 464; affected provinces 26; damage to infrastructure and agriculture PhP11.1 billion (USD234 million).

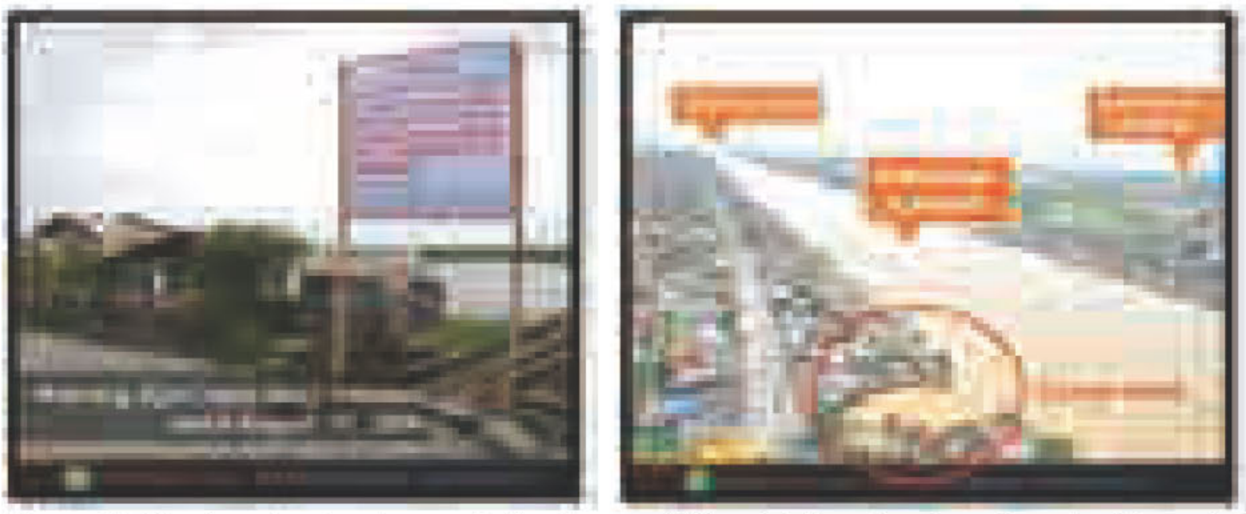

Figure 15 Warning sign that the area is flood prone (left) and informal settlers along the Manggahan Floodway (*Source: Bongco, 2009*)

Figure 16 Bay Breeze subdivision (*Source: Bongco, 2009*)

Figure 17 Provident Village in Marikina City (*Source: Tabios, UP-ICE-NHRC, 2009)*

4. LESSONS FROM THE GREAT FLOOD

The damage wrought by the onslaught of Tropical Storm Ketsana was unprecedented but expected considering the extensive development that have encroached the flood plains of the Pasig-Marikina-Laguna Lake complex. Upmanu Lall of Columbia University (2008) has averred that the assumption of stationarity no longer holds since flood risk is now dependent on watershed or land-use conditions, climate variability and change, and the changing distribution of population and assets. The impacts of the recent disaster in Metro Manila is a proof to the statement and therefore be a good basis to review and modify the flood management policy practices in the reconstruction efforts of the Philippines as enumerated in the subsequent discussion.

4.1 Flood preparedness and emergency response policy

On 29 September 2009, Administrative Order 270 was issued to direct "the various heads of the departments, bureaus and agencies under the executive branch, including government-owned and -controlled corporations as well as local government units (LGUs) to mobilize their respective officials and employees in the relief and rehabilitation of calamity-stricken areas affected by Tropical Storm Ondoy (Ketsana).

4.2 Flood damage assessment methodology and relevant policy

On 12 October 2009, Executive Order (EO) 832 created the National Public-Private Reconstruction Commission to undertake a study of the causes, costs and actions to be taken in the wake of typhoons Ondoy (Ketsana), Pepeng (Parma), and Frank (Fengshen) and to seek fresh aid to fund reconstruction.

EO 832 was enhanced by EO 838, issued on 22 October 2009, which created the special National Public Reconstruction Commission to undertake a study of the causes, costs and actions to be taken in the wake of these tropical cyclones to seek fresh aids to fund reconstruction and to enter into a partnership with the private sector for the foregoing purposes.

4.3 Urban flood management policy

President Gloria Macapagal-Arroyo ordered her Cabinet to look into the 1977 World Bank-funded study entitled the Metro Manila Transport, Land Use and Development Planning Project (Mmetroplan) submitted to then Ministry of Public Works and Highways (now DPWH) in July 1977 but was never implemented.

The Mmetroplan cited the Marikina Valley as among the areas deemed unsuitable for development and that development should be restricted by the application of controls in three major areas: the Marikina Valley, the western shores of Laguna Lake, and the Manila Bay coastal area to the north of Manila. Likewise, no structure should have been allowed within nine meters from the riverbank. The study identified that "The unsuitable areas for development, where pressures are nevertheless considerable, are primarily the flat coastal areas to the north where extensive areas are liable to flooding and where increased pressures for reclamation are likely to further exacerbate this problem."

4.4 Climate change issues and relevant policies

Considered as one of the most comprehensive and most integrated legislation so far in the region, the President has signed into law Republic Act (RA) 9729, or the Philippine Climate Change Act of 2009, on 23 October 2009. The Act hopes to mainstream climate change into formulation of government policy, establish a framework strategy and program on climate change, and serve for other purposes.

4.5 Public awareness and education policy
The Department of Education (DepEd) has implemented a program for the inclusion of hydro-meteorological hazards and climate change topics in the school curricula.

4.6 Land use policy
An Executive Order has been signed to mandate local government officials to relocate people living along creeks and riversides. The government has fast tracked the completion of housing projects to relocate informal settlers living in flood prone areas. At least 1,400 housing units in state-run relocation sites are readily available for families in Metro Manila displaced by Storm Ketsana.

The government's response to lessen the incidence of poverty and hardship during calamities is summarized as follows:

- The renewed offensive against illegal loggers;
- The continuation of the government's reforestation program;
- Preventing residents from re-populating calamity-stricken areas by providing relocation sites; and
- Cleaning up the waterways.

4.7 Early warning system policy and improving e ffectiveness in dissemination of forecast information
In recent years, weather is becoming more difficult to predict due to climate change. Heavy storm rainfall appears to become more frequent. The so-called "urban heat island" effect has strengthened thunderstorm activity because urban surfaces attain higher temperatures than surrounding areas and create a local air circulation that triggers a rainfall event.

A project for an early flood warning system (EWS) entitled "Establishment of Early Warning and Response System for Disaster Mitigation in Metro Manila" will be put up by the PAGASA to complement the existing Effective Flood Control Operation System (EFCOS) for the Pasig-Marikina-Laguna Lake Complex under the MMDA in coordination with the LGUs. Real-time meteorological and hydrological data and information will be monitored by local government units (LGUs) in Metro Manila and nearby areas to improve and strengthen their disaster preparedness plans.

To address the issue on nowcasting, or quantitative precipitation forecasting, two Doppler radars will be established in CY2010 covering the Pasig-Marikina-Laguna Lake complex.

5. CONCLUSION

The major factor contributing to floods and flash floods is the process of urbanization itself; extending impervious areas lead to higher runoff peaks and volume and also reduce runoff travel time. Other factors which have heightened the degree of flooding are the occurrence of tides, the blockage of drainage systems by urban debris and the encroachment of waterways.

The floods of 26 September 2009 in Metro Manila and nearby areas were basically of the flash flood type. There was concentration of heavy rainfall over Metro Manila resulting in an average areal rainfall of 57 millimeters for a period of 5 hours (from 1000H to 1400H). The maximum 24-hour rainfall of 540 millimeters that occurred from 2000H 25 September to 2000H 26 September in Quezon City has a return period of 500 years. The flash flood of 26 September

2009 resulted in unprecedented flood heights. It also registered the highest water level in Laguna de Bay since 1988.

Flood forecasting in Metro Manila, especially the flash flood type is basically a nowcasting problem; hence, quantitative precipitation forecasts (QPF), especially for short lived convective weather systems, are a need that requires immediate action.

Recommendations on how to address flooding in Metro Manila have been identified by various sectors such as foreign organizations, the national government, academe as well as other private institutions, but the key to better planning and reconstruction efforts is to recognize that flooding in the metropolis is now conditional. It depends on land-use conditions, urbanization, and climate variability and change.

Acknowledgment:
The authors wish to extend their appreciation to the Post Flood Survey Team of the PAGASA headed by Mr. Heraclio M. Borja, Jr, and the care takers of the EFCOS gauging stations, who provided the data and narrative account of what happened during the fateful day of 26 September 2009.

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Chapter 9

Recent Trend of Flood Disasters and Countermeasures in China

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EXECUTIVE SUMMARY

Due to its special geographic climate conditions, China is vulnerable to severe water-related disasters with high frequency of flood, drought, typhoon and landslide. Since 1990, the average economic loss resulting from floods has amounted to about 1.5% of GDP and drought economic loss has been over 1% of GDP of the same period.

China witnessed severe floods and mudslide both in South and North China in 2010. The Gansu mudslide that occurred on 8 August 2010 was the most deadly individual disaster among the 2010 China floods. The Gansu mudslides killed more than 1471 people and 294 remain missing. In total, flooding and landslides have left 3185 people dead and more than 1060 missing in China in 2010. The Yangtze River at the Three Gorges Dam experienced its highest river discharge in 130 years, and the highest since the dam was built. The Three Gorges Dam has withstood its biggest flood control test in 2010 as the key aims behind its construction. It has managed to contain the raging flood waters as the Yangtze River rose to levels not seen in over a decade. The inflow volume was 20,000 cubic meters greater than during the catastrophic Yangtze floods of 1998 when 4150 people died and 18 million were evacuated. It released 40,000 m^3/s of flood water, while 30,000 m^3/s of the river flow was held back in behind the dam, after water levels in the Reservoir had risen four meters overnight.

Investment in development of several water resources management projects such as multi-purpose dams and flood management projects for the decades enabled China to successfully combat a few historical basin-wide floods, and greatly minimized losses caused by large-scale water-related disasters. Since 1949, the direct economic benefit obtained from flood control reaches about 3.7 trillion Yuan, with 160 million ha of farmland protected from flooding and a yearly average reduction of inundated farmland of 2.71 million ha. Along with improvement of the flood control system, the death toll caused by flood disasters has been reduced dramatically year by year in large-scale floods. However, as Gansu mudslide showed, there are lots to do for flood mangamnet in local-scale and mountaonise basins.

1. INTRODUCTION

Due to its special geographic, climatic and socio-economic conditions, flooding has been a natural hazard greatly threatening the survival and development of the Chinese nation since ancient times [1]. Although historical records show that flooding events in large rivers with a death toll of more than 100,000 occurred frequently, the average annual death toll in recent floods indicates a decreasing trend from 8,571 (1950s) to 1,454 (2000s) as flood control systems has been improved since 1950 (Table 1). However, in 2010 China suffered serious flood damage again; both property losses and casualties exceeded those of the 1998 flooding event (Figure 1 and Figure 2).

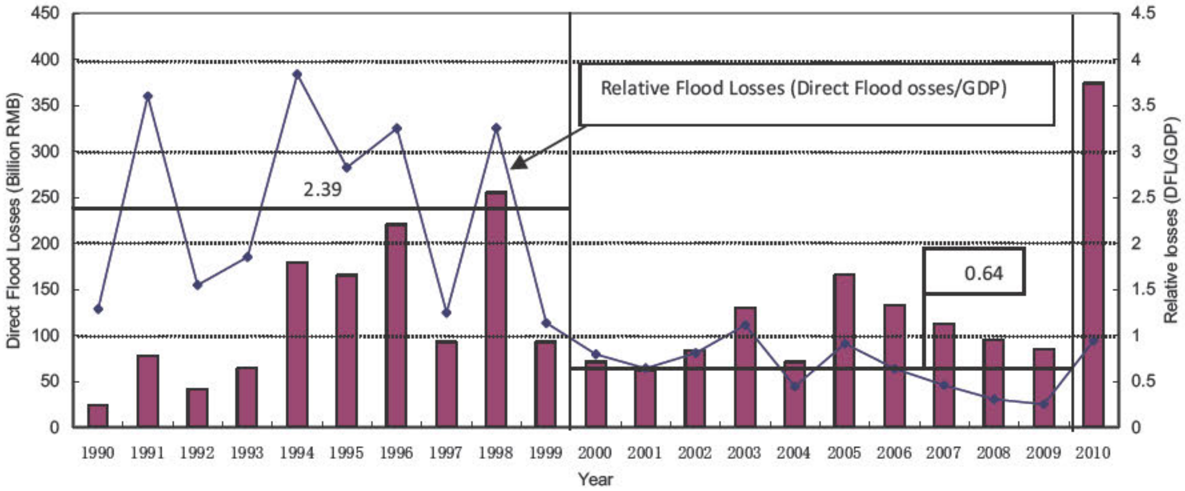

Figure 1 Flood direct economic losses in China (1990-2010)
Data Source: Bulletin of Flood and Drought Disasters in China (2010)

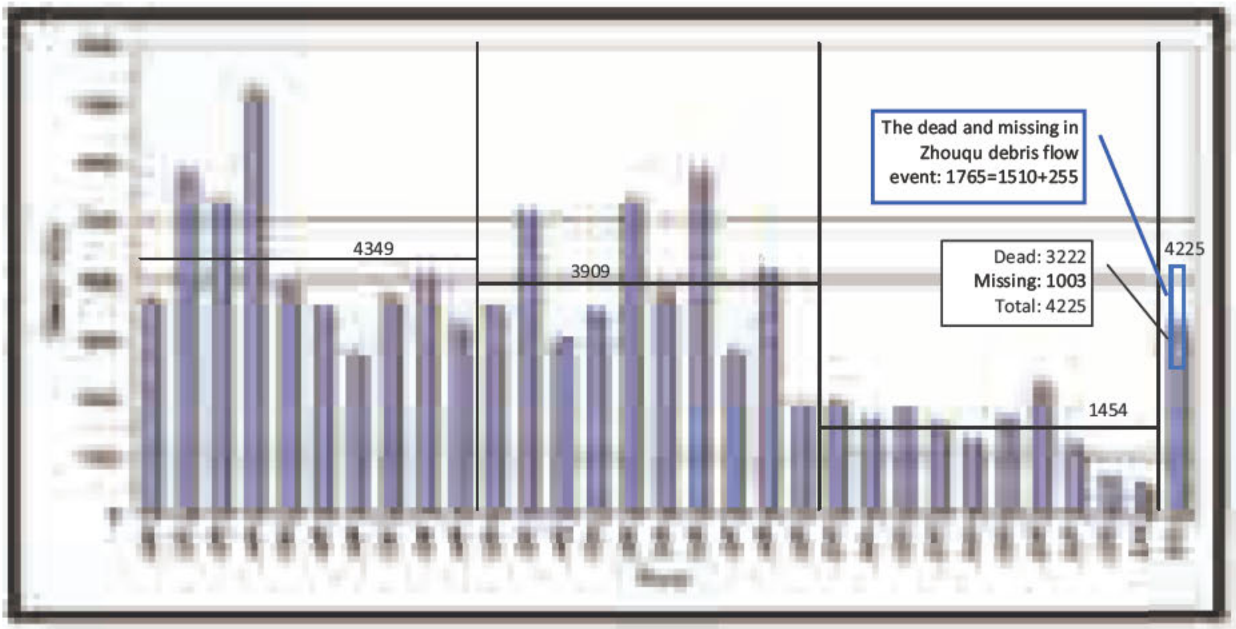

Figure 2 Death toll caused by flood related hazards in China (1980-2010)
Data Source: Bulletin of Flood and Drought Disasters in China (2010)

It is worth pointing out that 1998 saw severe floods that lasted for the whole summer in several major river basins from south to north in China, while in 2010, the operation and adjustment of some key flood control projects virtually prevented large-scale floods from occurring in the mainstreams of large rivers. For instance, in the mid July 2010, the maximum peak discharge of a large flood occurred in the upper Changjiang River reached 70,000 m^3/s, exceeding that of the 1998 event. However, controlled by the Three Gorges Dam, about 7 billion m3 floodwaters were stored in the reservoir, and the peak discharge reduced to 40,000 m^3/s, which eliminated the flood risk in the downstream areas.

Table 1 Average annual flood death toll in China (1950s – 2000s)

Decades	1950-1959	1960-1969	1970-1979	1980-1989	1990-1999	2000-2009
Average annual flood death toll	8571	4091	5181	4349	3909	1454

In fact, after the 1998 flood, China commenced to explore flood prevention and mitigation issues from a wider field range of perspective, covering society, economy, environment, ecosystem, population, resources and public security, etc. As a result, a new approach to water governance took shape featuring a harmonious coexistence between man and nature for sustainable development[2]. The input to the construction of flood control systems for the mainstreams of large rivers increased exponentially. For example, 178.6 billion Yuan RMB was invested by the Central Government during 1998-2002, which is 2.36 times more than the accumulative investment in the period of 1949-1997; the average investment per year reached 35.7 billion Yuan RMB, which is 4.2 times more than that during 1991-1997.

In the beginning of 2003, the State Flood Control and Drought Relief Headquarters and the Ministry of Water Resources declared that flood and drought disaster mitigation in China should shift "from flood control to flood management" and "from simplex drought fighting to comprehensive drought management". In view of actual problems and pressing needs, three major tasks of risk management, floodwater utilization and regularizing flood control activities were emphasized in China [3].

In the beginning of 2006, the State Council developed emergency response plans, including "State Flood Fighting Emergency Response Plan". In this plan, emergency response activities have been divided into four levels. A series of measures have also been taken to enhance emergency response systems and capacity building to mitigate flood and drought damage.

In order to ensure the water security, sustain rapid development and promote harmoniousness, water issues related to people's livelihood have been taken as the top priority since 2007[4]. The key tasks include improving flood and drought management, speeding up reinforcement of dams with hidden trouble, ensuring the safety of drinking water in rural areas, and strengthening construction of key water conservancy works and capital construction on farmland.

All of these efforts have made remarkable achievements. In Figures 1 and 2, the average relative loss (Direct Flood Losses/GDP) reduced from 2.39 (1990-1999) to 0.64 (2000-2009), and the average annual death toll reduced from 4,349 (1980-1989) and 3,909 (1990-1999) to 1,454 (2000-2009).

However, in 2010 the flood-related economic losses and the number of death toll rose again in China, which shows the changes of flood risk in the country due to rapid development and urbanization along with global climate change. This report will briefly analyze the causes of such phenomena and introduce countermeasures that will be taken in 2011-2020 to cope with the challenges.

2. ANALYSIS OF FLOOD DAMAGE IN 2010

Figure 3 shows the annual average precipitation in China from 2000 to 2010, which finds that the highest one (682mm) appeared in 2010, exceeding 53mm above the average level of 609mm. In particular, torrential rains frequently hit China from May to October in 2010.

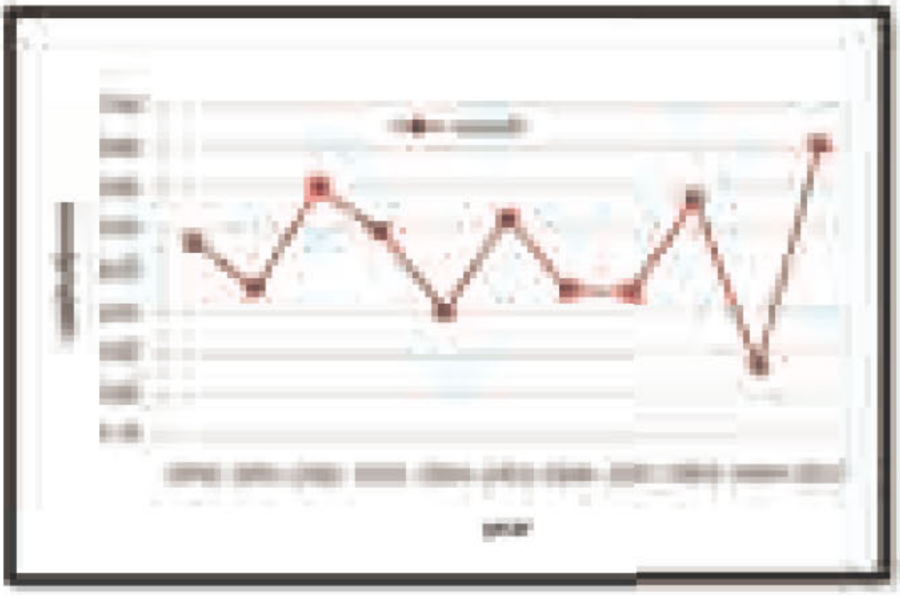

Figure 3 Annual average precipitation in China from 2000 to 2010
Data Source: China Water Resources Bulletin (2000 - 2010), MWR.

For instance, the daily rainfalls in three counties in Fujian Province exceeded the maximum records in June and the highest rainfall reached 413mm/day. From September 30 to October 10, Hainan Province suffered heavy rains with a cumulative watershed average precipitation of 648mm, which is the maximum in the same period after the province started observing data in 1961. The highest daily rainfall was recorded as 964mm at the Boao, Qionghai station. Heavy rains caused severe floods mainly in medium and small rivers, cities, and mountain areas. Flash floods and associated landslides and debris flows occurred more frequently than previously recorded.

The analysis of statistical data shows that in the total direct economic losses caused by floods in 2010, only 35.3% came from the damage of agriculture, forestry, animal husbandry and fishery, much less than the rate in the traditional agricultural society in the past. The remaining nearly 2/3 of the total losses was composed of the damage of industry, traffic and transportation, and infrastructures. Especially, 258 cities at or above the county level were inundated in 2010, and most of them suffered pluvial floods due to local heavy rains. Among them, industrial and mining enterprises whose production interrupted in flood disasters amounted to 35,260. Railway and road transportation were disrupted 83 and 58,606 times, respectively. Power failures occurred 23,063 times and communication lines were cut off up to 16,098 km. 3,751 dams were harmed (57 with storage capacity larger than 10 million m3, and the other 3,694 were smaller ones) and 11 small-sized dams were broken. 21,154 sluices and floodgates were damaged to different degrees. Levees were damaged in 81,824 reaches with a total length of 19,146 km.

Apart from the natural effects of heavy and frequent rainstorms, social and economic factors have to be taken in to consideration. In the past three decades, China's social patterns have undergone tremendous changes. The urban population in 1980 was less than 20% while it rose to 49.68% by 2010. That means that nearly 400 million people moved from rural to urban areas. In China, a large number of water infrastructures in the countryside were built in the 1950s-1970s, which had been maintained by farmers themselves. However, in recent years, necessary maintenance for water infrastructures cannot be guaranteed since most of the young people moved from rural areas to urban areas, leaving the small water conservancy facilities are easy to be damaged from flooding. In the meantime, city managers have to face enormous pressure in solving the issues of housing, traffic jam, power supply, water supply and gas supply, communications and sewage treatment, while the construction of underground drainage systems are often ignored. Even in some large cities, separate sewerage systems have not been constructed. That is why urban pluvial floods become more and more serious.

Most of the casualties in 2010, 2,824 dead and 1,003 missing, were caused by 371 events of flash floods, debris flows and landslides in mountain areas. The most serious disaster occurred in the central town of Zhouqu County, Gansu Province, in August 7, 2010, which left 1,510 people dead and 255 people missing. The ratio of the death toll in mountain disasters to the total death toll of flood-related disasters in 2010 reached 87.65% (compare the dead only) or 90.76% (include the missing). In fact, those rates were higher than 70% during the years after 2003. Further analysis shows that, in the last 50 years of the 20th Century, the death toll exceeded 5,000 in 13 years, exceeded 10,000 in 4 years, in which the large numbers of death toll were caused by flooding in the middle and lower reaches of large rivers in China. The rate of death toll in mountain areas rose to a high level (figure 4) mainly because of the decrease of death toll in plain areas. Due to the intensified human activities in mountain areas, such as mining, road building, hydropower exploitation and, traveling development, etc., it becomes more difficult to reduce the casualties in mountain areas.

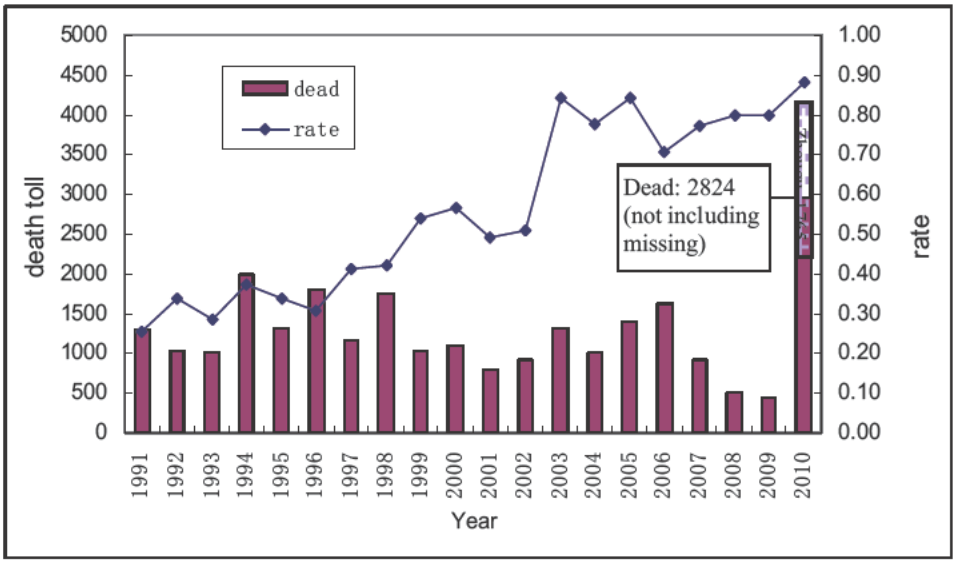

Figure 4 Death toll caused by flash flood, landslide and debris flow in China (1991-2010)
Data Source: Bulletin of Flood and Drought Disasters in China (2010)

3. COUNTERMEASURES

A serious flood damage in 2010 has caught the attention from the Chinese Government. In the beginning of 2011, the No 1 Document issued by the Central Government aimed to accelerate the reform and development of water governance. The input for water security and sustainable utilization will be multiplied by the governments at all levels, i.e. to invest 400 billion Yuan RMB on average per year in the 12th and 13th five-year plans (2011-2020).

The National Master Plan for the Integrated Management of Medium and Small Rivers, the Reinforcement for Unsafe Reservoirs, and Prevention and Comprehensive Treatment of Flash Flood and Mountain Disasters have been discussed and approved by the State Council in early April 2011. The master plan covers main reaches of more than 5,000 medium- and small-sized rivers with an area of over 200 km^2; 300 unsafe large- and medium-sized reservoirs and more than 20,000 small-sized reservoirs; more than 2,000 unsafe large- and medium-sized sluices; key polder areas around the Dongting and Poyang lakes and flood detention areas; and the area of 4.87 million km^2, involving 2,058 counties (cities and districts), for flash flood and geological disaster prevention and comprehensive improvement of the eco-environment[5].

In order to reduce casualties in mountain areas, the Ministry of Water Resources and relevant ministries have formulated and officially released the Programme for the Prevention of Flash flood and Related Landslide and Debris Flow in 2007. Moreover, 200 million Yuan RMB was invested in the development of non-structural measures for early warning of flash floods in 103 pilot counties in 2009. The early warning systems were proven effective in 2010 and the number of pilot counties increased to 500. In 2011, another 600 counties have joined the project, and the number is expected to increase up to 1,836 in 3 years. The non-structural measures in this project mainly include the following aspects:

To carry out a broad field survey about flash flood disasters and then to determine dangerous zones in prevention areas. (2) To ascertain rainfall thresholds to implement flood warning systems, which is a difficult issue in the development of non-structural measures. (3) To implement monitoring and warning systems as the most important task in the project. The information from monitoring equipment, such as automatic rainfall stations and automatic water-level stations, is transferred to the warning platform. If a rainfall or water-level exceed the warning threshold, then the platform will give a signal to run the warning equipment, such as high tone loudspeakers in the dangerous zones. (4) To establish flash flood prevention plans, which direct people to evacuate safely and rapidly. (5) To construct systems for residents' self-monitoring and self-warning. Some simple rainfall alarms, gongs, drums and whistles, etc. are provided to local residents. When simple rainfall alarms send escape signals, a local person in charge will use gongs, drums and whistles to inform neighboring residents to evacuate to safe areas. (6) To share information and practice evacuation to be prepared for flash floods.

The key tasks emphasized during the flood season of 2011[6] are as follows: (1) to strengthen key flood fighting motor teams and to establish 19 specialized forces for flood fighting and emergency response; (2) to improve flood control and emergency plans for major rivers and enhance their operability; (3) to ensure the safety of various types of dams and reservoirs; (4) to enhance capacity building against flash floods, landslides and debris flows in mountain areas; (5) to strengthen typhoon defense systems; (6) to improve the cross-department mechanism in emergency response, and (7) to further implement the chief executive accountability for flood prevention at all levels.

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Appendix I (Chapter 9)

An Overview to Flood Management in China

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1. GEOGRAPHICAL FEATURES

1.1 Topography

The terrain of China is higher in the west and lower in the east in altitude. The highest area is the Qinghai-Tibet Plateau with the elevation higher than 4,000 m while coastal plains lie below 50 m. The mountainous area accounts for 33% of the total Chinese territory, plateaus, hilly areas and inter-mountain basins account for 26%, 10% and 19%, respectively, and plains occupy only 12% of the territory.

1.2 Climate

The vast area of the East China and the most part of the South China are dominated by the Eastern Asia monsoon, which in summer are affected by the oceanic air current while in winter by the continental air current. These phenomena result in dry winter and wet summer over the mainland of China. The annual precipitation from southeastern to northwestern parts of the country is extremely uneven in its distribution. In southeastern coastal areas and some regions of the Southwest China, the mean annual precipitation is higher than 2,000 mm. In the south of the middle and lower reaches of the Yangtze River, it is over 1,000 mm. In the region of the Qinling and Huaihe River Basin, it is 800 to 900 mm. In North China Plain and Northeast China, it ranges from 400 to 800 mm. For the vast area of the Northwest and Inner Mongolia, the annual precipitation drops to less than 400 mm.

1.3 Rivers

China has about 50,000 rivers, each with a basin area of larger than 100 km2, among which more than 1,500 rivers cover larger than 1,000 km^2. Most rivers are located in the eastern and southern parts of China. The total basin area of the rivers flowing into the sea accounts for 2/3 of China's total territory, and the remaining 1/3 belongs to the inland river basins.

The majority of rivers in China are fed by rain; a few rivers in the West China are fed by snowmelt and glaciers in spring and rainfall in summer and autumn. In addition, there are some rivers partly fed by glaciers. Table 1 shows the major rivers of China so far as the size is concerned. Taking into account flood issues and social and economic importance, the following seven river basins are considered as the major ones: namely, Yangtze, Yellow, Soughua, Liaohe, Haihe, Huaihe, and Pearl River Basins.

2. FLOODS AND FLOOD DISASTERS

2.1 Flood characteristics

The East China is the region where flood disasters are primarily caused by rainstorms in combination with coastal storm surges, and the western region is subject to mixed-type floods from snow and glacier melting as well as local storms.

The eastern part of China is under the influence of the continental monsoon climate, and the rainfall is high in intensity and concentrated in time. The flood season in the eastern region is from June through September in its north and from May through August in its south with 60% to 80% of the annual rainfall. During the flood season, the maximum rainfall in one month makes up 25% to 50% of the total annual rainfall in some cases. The maximum one-hour rainfall is 401 mm (Shangdi in Inner Mongolia), the maximum six-hour rainfall is 830 mm (Linzhuang in Henan Province) and the maximum 24-hour rainfall is 1,672 mm (Hsinliao, Taiwan). The maximum records of point rainfall of different durations are close to or higher than the corresponding maximum records of the world. Such high-intensity and large-scale rainstorms cause extremely large flood peaks and result in serious flooding. The magnitude of maximum floods varies tremendously from place to place, based on the recorded and historical flood data of 6,000 river reaches of the country.

Table 1 Major River Basins in China

River	Length (km)	Basin Area (km^2)	River Mouth
Yangtze	6,300	1,808,500	East China Sea
Yellow	5,464	752,443	Bohai Gulf
Heilong	3,420	903,418	Tartarian Strait
Songhua	2,308	557,180	Heilong River
Pearl	12,214	453,690	South China Sea
Yarlund Zangbo	2,057	240,480	Bengal Bay
Tarim	2,046	194,210	Taitema Lake
Lancang	1,826	167,486	South China Sea
Nujiang	1,659	137,818	Andaman Sea
Liaohe	1,390	288,960	Bohai Gulf
Haihe	1,090	263,631	Bohai Gulf
Huaihe	1,000	269,283	Yangtze River
Luanhe	877	44,900	Bohai Gulf
Ertix	633	57,290	Kara Sea (via Russia)
Ili	601	61,640	Balchas Lake
Yuanjiang	565	39,768	Beibu Gulf (via Vietnam)
Minjiang	541	60,992	East China Sea
Qiantang	428	42,156	East China Sea

2.2 Flood Disasters

After 1949 large floods occurred in large rivers such as the Yangtze, Yellow, Huaihe, and Haihe Rivers. Yet losses were far less serious because of completed flood control projects and great efforts made in flood fighting.

- From June to August 1954, large floods occurred over the Yangtze River Basin. The water level in the main stream of the Yangtze reached the highest record. The Jingjiang Flood Diversion Works and Dongting Lake were implemented to divert and store flood water. The city of Wuhan was protected and the flooded farmland totaled 3.1 million ha.
- A large flood also hit the Huaihe River in 1954, and the flood stage at Bengbu (Anhui Province) was 2 m higher than that in 1931. However, many cities and towns and

important infrastructures were saved because of the effective function of the completed flood control works.

- An extraordinary flood hit the Yellow River in July 1958. The peak discharge at Huayuankou was 22,300 m^3/s, exceeding the maximum record discharge of 20,300 m^3/s in 1933. The flood water level rose up to the levee top in several places. But after ten days of valiant struggle, the flood was conquered, and vast areas on both sides of the river were out of danger.
- In 1963 an exceptionally large flood occurred in the Haihe River. The rainstorm with high intensity and a long duration covered the southern part of the basin. The seven-day rainfall from August 2 to 8 at the storm center was 2050 mm. However the city of Tianjin and the Tianjin-Pukou Railway were saved.
- In August 1975 an extraordinary storm occurred over the upstream of the Huaihe River Basin. The three-day rainfall (from 5 to 7 August) above the 600 mm and 400 mm rainfall isolines covered 8200 km^2 and 16,890 km^2, respectively. The extreme flood overflowed Banqiao and Shimantan earth dams in Henan Province and led to dam failure, which left 26,000 people dead and 1 million ha of farmland inundated.
- In the 1990s, floods frequently hit the southern part of China, many of which came close to the highest flood record in the last century. The 1998 floods were the most noticeable. The heavy rainfall in 1998 covered a vast area with a long duration, causing large floods in some major rivers such as Yangtze, Songhua, Pearl and Min Rivers. The Yangtze River experienced the second biggest in the 20th century after 1954; the Songhua River had the most serious flood of the 20th century. In Xijiang of the Pearl River Basin, the flood ranked the second biggest of the century, and the Min River suffered the largest flood.

The flood-affected agricultural land during 1950-1990 reached 780 million ha in average, which accounts for about 7.8% of China’s total farmland. Most of these areas were located in the downstream of the Yellow, Huaihe and Haihe River Basins, where historically suffered severe damage from flood disasters.

3. LEGAL AND INSTITUTIONAL SYSTEM FOR WATER MANAGEMENT AND FLOOD CONTROL

3.1 Legislation

(1) The Water Law

Since 1949, large-scale water resources development has been going on. However, the emphasis was long placed on construction while no particular attention was given to management until 1980.

At that time the major issues in the water sector were as follows:

- Serious shortage of water resources in northern China
- Increasing aggravation of water pollution
- Lack of unified management of rivers and lakes
- Groundwater overdraft in the northern China plain
- Inadequacy of integrated utilization of water resources and conflicts among different water users
- Low rate of water charge
- Sabotage and damage of water facilities as well as frequent, widespread interruption to perform normal services

In January 1988, the Water Law of the People's Republic of China (hereinafter referring to as the Water Law) was adopted and enacted by the Standing Committee of the Sixth National People's Congress, making the beginning of a new stage of water management in China.

Chapter 5 of the Water Law deals specifically with flood fighting, which stipulates that governments at all levels should strengthen their leadership and take effective measures for flood fighting, and that every unit and individual has the obligation to take part in flood fighting. It further stressed that flood fighting should be under the unified direction of the FFDDHS of governments at different levels. Article 40 of chapter 5 prescribed that a flood control scheme including the standard and measures of flood control should be determined on the basis of river basin plans. The flood-fighting scheme of major rivers should be formulated by the State FFDDHS and be submitted to the State Council for approval. During emergent cases, the FFDDHS at different levels as authorized by the Water Law can take measures for diversion and detention of floods based upon an approved scheme, so as to safeguard the whole flood control system.

(2) Law of Flood Control

The Law of Flood Control (hereinafter the Law) was adopted at the Twenty Seventh Session of the Standing Committee of the Eighth National People's Congress in August 1997. That was the first law in natural disaster reduction in China and considered very important following the Water Law and the Law of Soil and Water Conservation.

A number of administrative regulations were issued to regulate the activities of the parties concerned in flood control, including the Rules and Regulation of Flood Fighting, the Regulation of River Course Management and the Guide to the Safety Building of Flood Storage and Retardation Basin, which played an important role in flood control in China. However, with rapid economic development, population growth and urbanization, many problems arose and the country had to face new challenges: namely, a) The importance of flood planning was not well acknowledged and approved flood plans were not strictly implemented; b) There was no mighty means in the management of river channels and flood plains, so land use in these areas in many cases were in disorder; c) Inadequate flood protection standard; d) Ineffective management of flood storage and retardation basins including the control of population growth, the policy of economic development, the implementation of safety building projects, the system of post flood relief and compensation; and e) Lack of funds in flood control. All these problems urgently needed special laws on flood control to ensure a legal basis to implement necessary measures.

3.2 Institutional Arrangement

4.2.1 Ministry of Water Resources (MWR)

The State Council was restructured and streamlined in 1998. The purpose of the restructuring is to streamline the government in order to clarify the responsibilities among different ministries and departments under the State Council. The functions and responsibilities of the MWR were redefined. The administrative role of the MWR in hydropower development was moved to the State Economic and Trade Commission. Groundwater management originally under the Ministry of Geology and Mineral Resources and urban flood control originally under the Ministry of Construction were moved to the MWR. Since then, the MWR has been assigned the responsibility for nationwide management of water saving and also for planning and monitoring of the water environment and recommending protection measures to governments at different levels.

The MWR is placed under the Department of Water Administration of the State and discharges the responsibility of unified management of water resources. In accordance with the reform scheme of the State Council in 1998, the major responsibilities of the MWR include:

- Formulation of policies, development strategies and long-term plans, drafting of relevant laws and regulations, and supervision of their implementation;
- Unified management of water resources including surface water and groundwater; formulation, supervision and implementation of long-term water supply and demand plans and water allocation; assessment and verification of available water resources and flood control measures; implementation of water-draw permit systems and levy of water resources fee, etc;
- Formulation and implementation of water saving policies and plans;
- Water resources protection planning, water quantity and quality monitoring, evaluation and examination of water pollution of water bodies;
- Water administration supervision and enforcement; mediation of water affair disputes;
- Formulation of economic regulatory measures in the water sector like water pricing, taxation, loan, etc.;
- Issuance of technical guidelines, regulations, standards in the water sector, examination of proposal of large and medium projects;
- Development and management of large rivers, large lakes and inter-provincial key projects;
- Water resources development and use in rural areas including hydropower generation and water supply;
- Soil and water conservation;
- Undertaking of routine work for the State FFDDHS.

4.2.2 River Basin Commission

There are seven major River Basin Commissions, which are agencies of the MWR to perform water administration in respective river basins. The major responsibilities of the river basin commissions are: enforcement of the Water Law, the Law of Water and Soil Conservation and other related laws, regulations and rules; mapping out strategic planning and mid- and long-term plans of basins' water resources development; joint development of integrated river plans and relevant specialized plans with related departments and provinces and supervision of their implementation; unified management of water resources of the basins; unified management of rivers, lakes, estuaries, tidal flats and key river reaches as authorized by the central government; coordination of flood fighting and drought defying; mediation of water disputes; comprehensive management of water and soil losses in key areas of the basins; construction and management of trans-provincial water projects.

4.2.3 Local water resources management agency

Local water resources management comprises four levels, i.e. provincial, prefecture, country and village (town). The main functions and responsibilities of local water administrative management within their respective jurisdictions are: (a) to be the departments of local governments at all levels responsible for water administration; (b) to work out local water resources development plans and long-term water supply demand plans; (c) to implement local water resources development projects; (d) to carry out flood fighting and drought defying, water and soil preservation, water resources protection, water project management, etc. within their jurisdictions; (e) to be responsible for urban and rural water supply and economical water use. It is worthy to mention that there are village (town) water conservancy stations almost all over China. They are not only agencies of water administration, but also water organizations at the grass roots level to serve and keep a close tie with farmers.

4. CONCLUSIONS

The 21st Century will be the century of water. China has been frequently hit by large floods and suffered from flood disasters. To solve water issues will rely on the renovation of value concepts, advancements of science and technology, and the adjustment of social, operational mechanism. Flood control and management are of vital importance of China in its social and economic development. Disaster reduction and sustainable development are closely linked in the new century. As a large developing country with a huge population, China need learn from advanced countries, and meanwhile, we should contribute our efforts to the progress of the world.

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Appendix II (Chapter 9)

Flood Disaster Losses in China from 2000 to 2010

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1. FLOOD DAMAGE TREND FROM 2000 TO 2010

In this appendix, information about flood disaster losses was collected from all provinces and cities in China during the past decade (2000-2010) mainly in terms of the following three indicators: disaster area of crops, affected population and direct economic loss.

Since the extreme flood in 1998, the Chinese government has attached great importance to the prevention and treatment of flood disasters and increased investments in infrastructure for water conservancy, which has made great achievements. During the past decade, the annual mean flood-affected population was 128.315 million[1], the annual mean disaster area of crops was 10.579 million hectares, and the annual mean direct economic loss was 98.915 billion yuan in China (excluding Hong Kong, Macao and Taiwan). Annual variation curves of affected population, disaster area of crops and direct economic loss (Figures.1-3) were plotted according to the corresponding annual data. The close correlations among these curves are clearly observed. Since the beginning of the 21st century, 2003 and 2010 have seen devastating floods. In 2003, the affected population was 193.27 million, the disaster area of crops was 12.378 million hectares, and the direct economic loss was 119.04 billion Yuan. While in 2010, those three indicators with the same units were 199.354, 17.5246 and 350.5, respectively. During the decade, the year 2006 had the smallest affected population of 72.608 million, 2008 had the minimum disaster area of crops of 6.4765 million hectares, and 2004 had the least direct economic loss of 49.54 billion Yuan. As far as these three indicators are concerned, the figures fluctuated throughout the period with no obvious trend of increasing or decreasing. In this period, the ratio of the maximum affected population to the minimum affected population is 2.74, and the corresponding ratios for the disaster area of crops and direct economic loss are 2.97 and 7.08, respectively. The variation curves show that the affected population and disaster area of crops present a kind of periodical variation over time. For the limitation of the sample data, this periodical variation may need further studies.

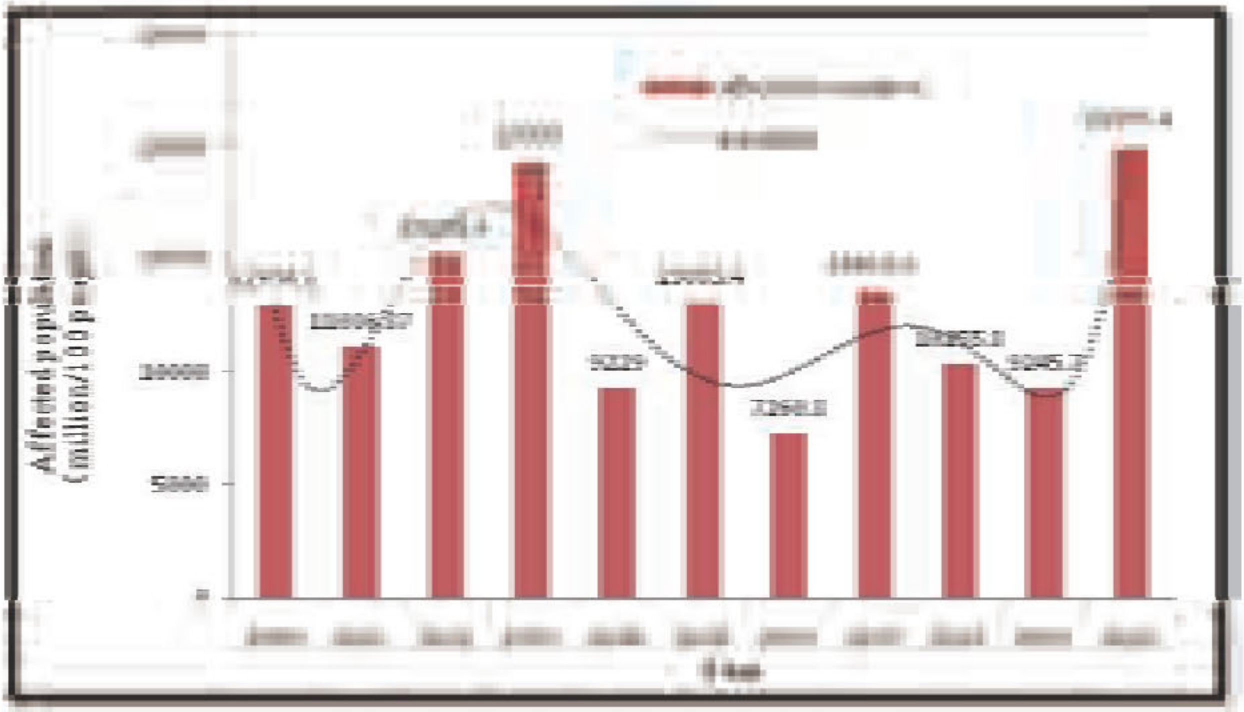

Figure 1 Variation of Affected Population in Flood Disaster from 2000 to 2010

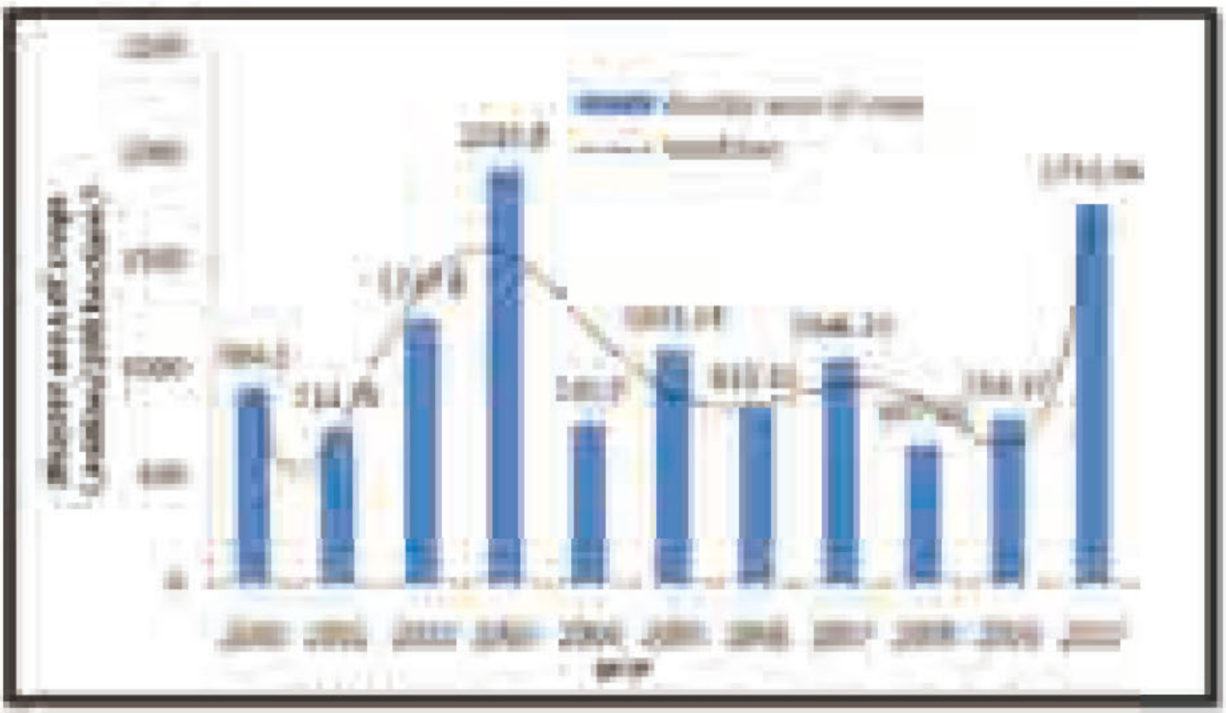

Figure 2 Variation of Disaster Area of Crops from 2000 to 2010

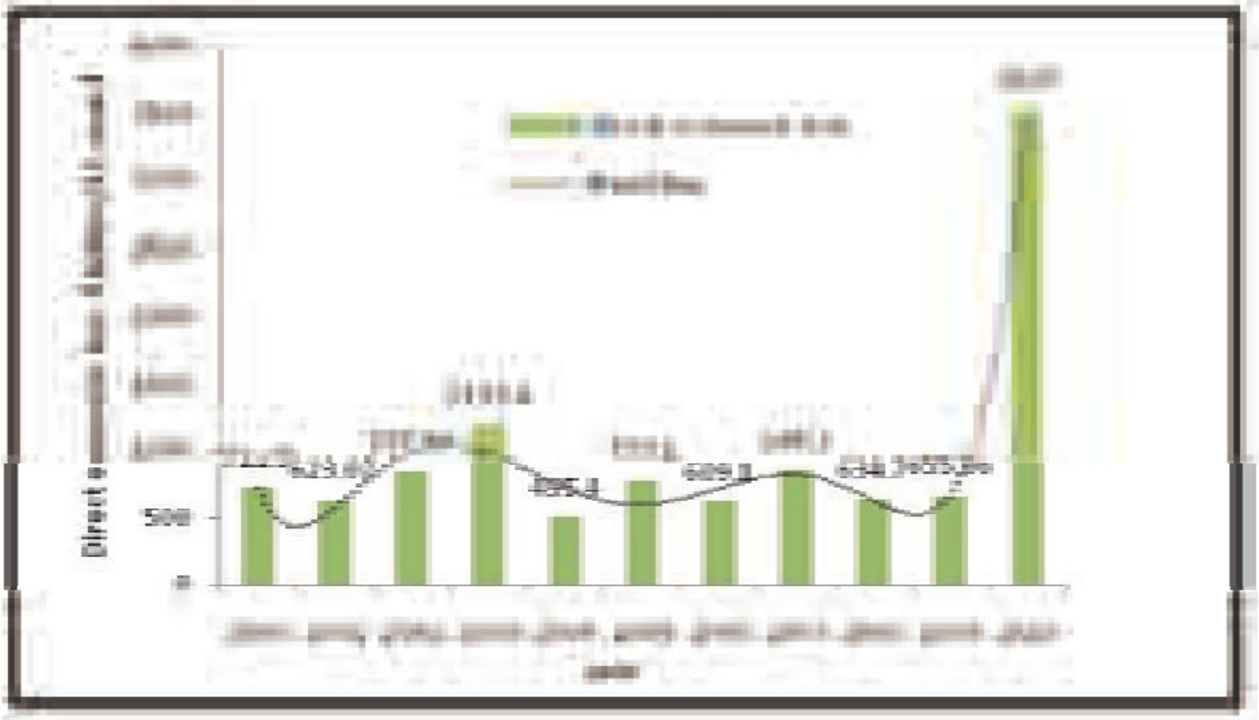

Figure 3 Variation of Direct Economic Loss due to Flood Disaster from 2000 to 2010

2. REGIONAL DISTRIBUTION OF FLOOD DAMAGE FROM 2000 TO 2010

Based on the 2000-2010 statistics of all the provinces and cities in China (excluding Hong Kong, Macao and Taiwan), the top 6 provinces in accumulative direct economic loss are Sichuan, Hunan, Jiangxi, Guangxi, Henan and Hubei. Those provinces account for 43.67% of the total direct economic losses of the whole country. The top 6 provinces in accumulative affected population are Sichuan, Hunan, Hubei, Guangxi, Anhui and Henan. In each province, over 60 million people were affected by floods, and particularly in the first five, over 10,000 million were affected. The top 6 provinces in accumulative disaster area of crops are Hubei, Henan, Hunan, Anhui, Sichuan, and Shandong. Those provinces account for 50.15% of the accumulative disaster area of crops in the whole country. In general, Hunan, Hubei, Sichuan, Anhui, Henan and Guangxi are areas that suffer most serious flood disasters in China (Table 1 and Figure 4 to 6).

Table1 Accumulative Losses in Flood Disaster for Provinces and Cities in China from 2000 to 2010 (excluding Hong Kong, Macao and Taiwan area)

Area	Affected area（100 million hectares）	Affected population（0.01million）	Direct economic loss（0.1 billion Yuan）
Beijing	2.87	9.90	2.17
Tianjin	1.44	6.70	2.36
Hebei	172.76	1491.16	104.63
Shanxi	153.84	1185.80	109.46
Inner Mongolia	249.45	716.68	126.42
Liaoning	183.85	1302.82	268.50

Jilin	146.22	1074.24	577.82
Heilongjiang	656.10	1425.65	198.55
Shanghai	11.65	46.47	10.11
Jiangsu	672.39	5720.90	470.24
Zhejiang	195.67	3602.49	344.94
Anhui	951.58	10264.23	591.90
Fujian	208.82	3769.96	502.01
Jiangxi	634.50	8472.47	819.59
Shandong	682.29	6232.99	441.62
Henan	996.17	9608.75	670.34
Hubei	1141.70	12230.77	627.99
Hunan	984.40	12728.00	907.39
Guangdong	349.40	6020.60	410.96
Guangxi	580.70	10275.52	681.40
Hainan	114.31	1681.59	221.70
Sichuan	849.02	15432.80	1005.56
Chongqing	432.90	8460.15	320.28
Guizhou	288.20	6063.51	192.41
Yunnan	310.00	5756.57	288.98
Tibet	16.76	120.77	19.70
Shaanxi	328.50	4050.63	484.34
Gansu	160.93	1807.65	250.93
Qinghai	19.12	223.93	30.43
Ningxia	34.15	317.56	16.74
Xinjiang	59.09	559.87	90.52

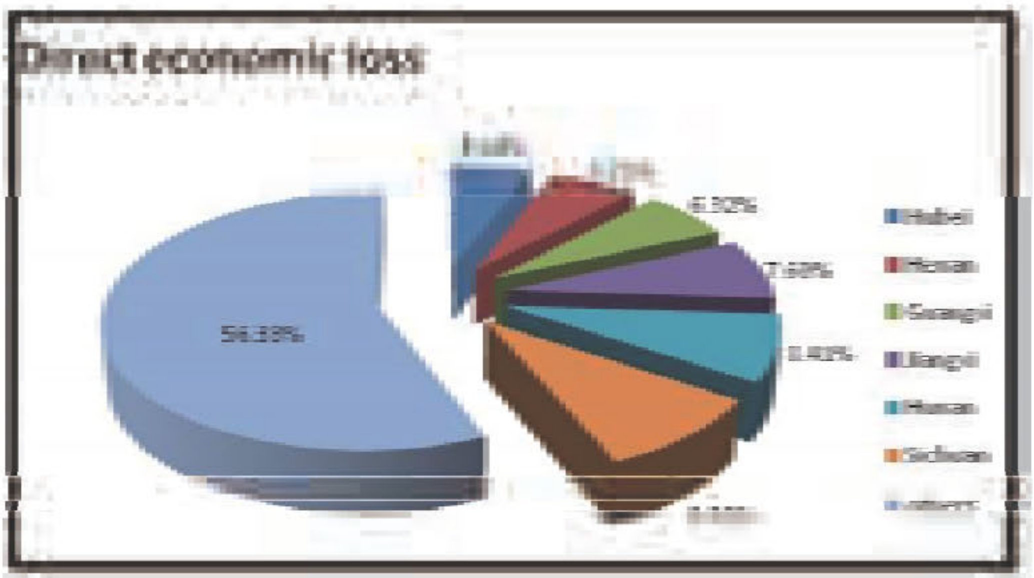

Figure 4 Composition of Accumulative Direct Economic Loss

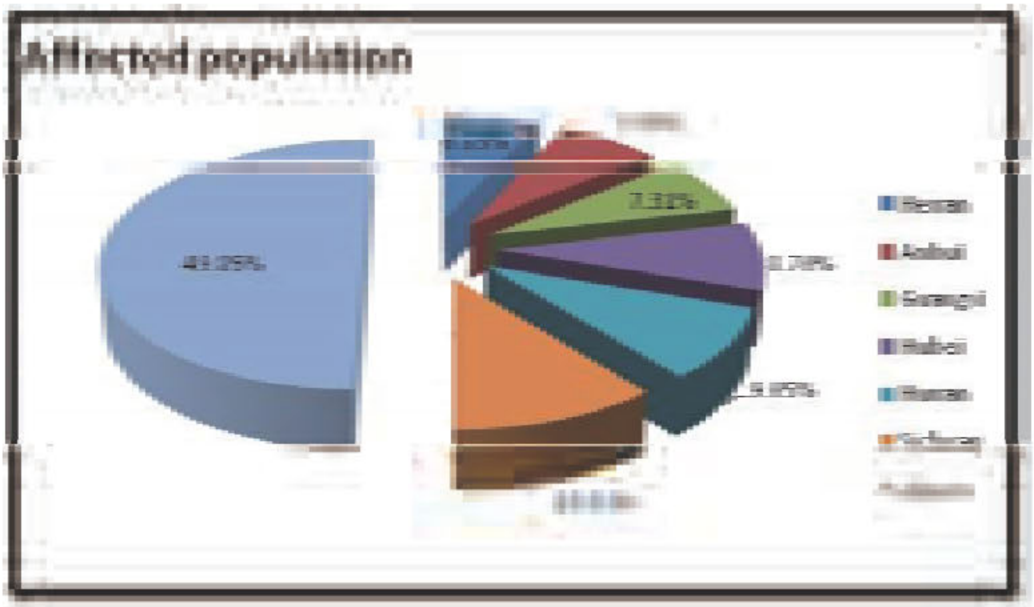

Figure 5 Composition of Accumulative Affected Population

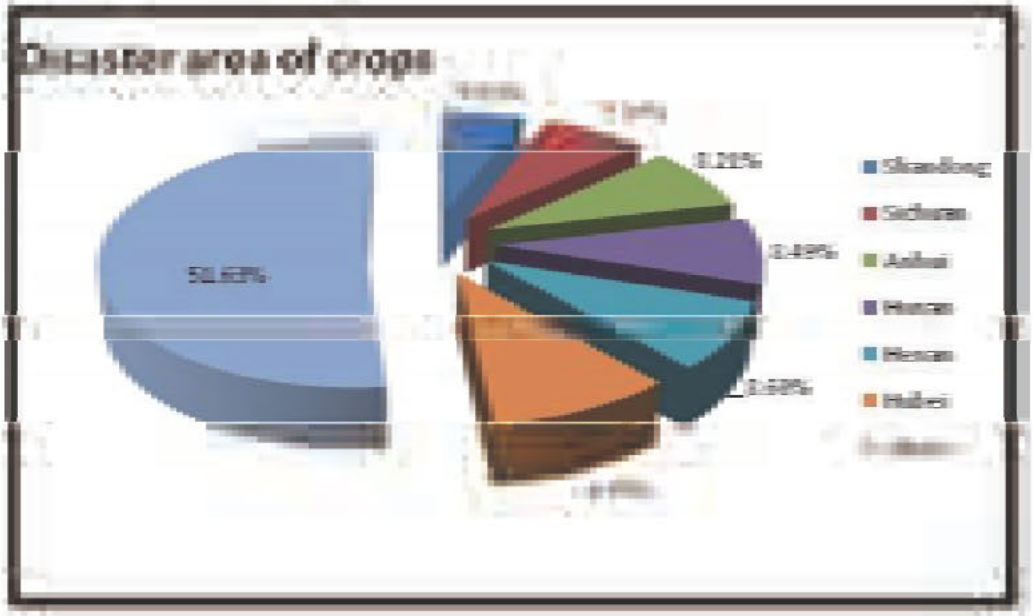

Figure 6 Composition of Accumulative Disaster Area of Crops

Figure 7 shows the regional distribution of direct economic loss. It suggests that North and West China had smaller flood losses. Most of the flood damage is concentrated in South and East China. The southeast and southwest monsoons have a great influence on most areas of China. Every year from April to June, the East Asian monsoon causes torrential rains in the south of Yangtze River. While from July to August, southeast and southwest monsoons are very powerful. Torrential rains move to the west of Sichuan and North China. At the same time, typhoons occur along the southeast coast and become another source of torrential rains.

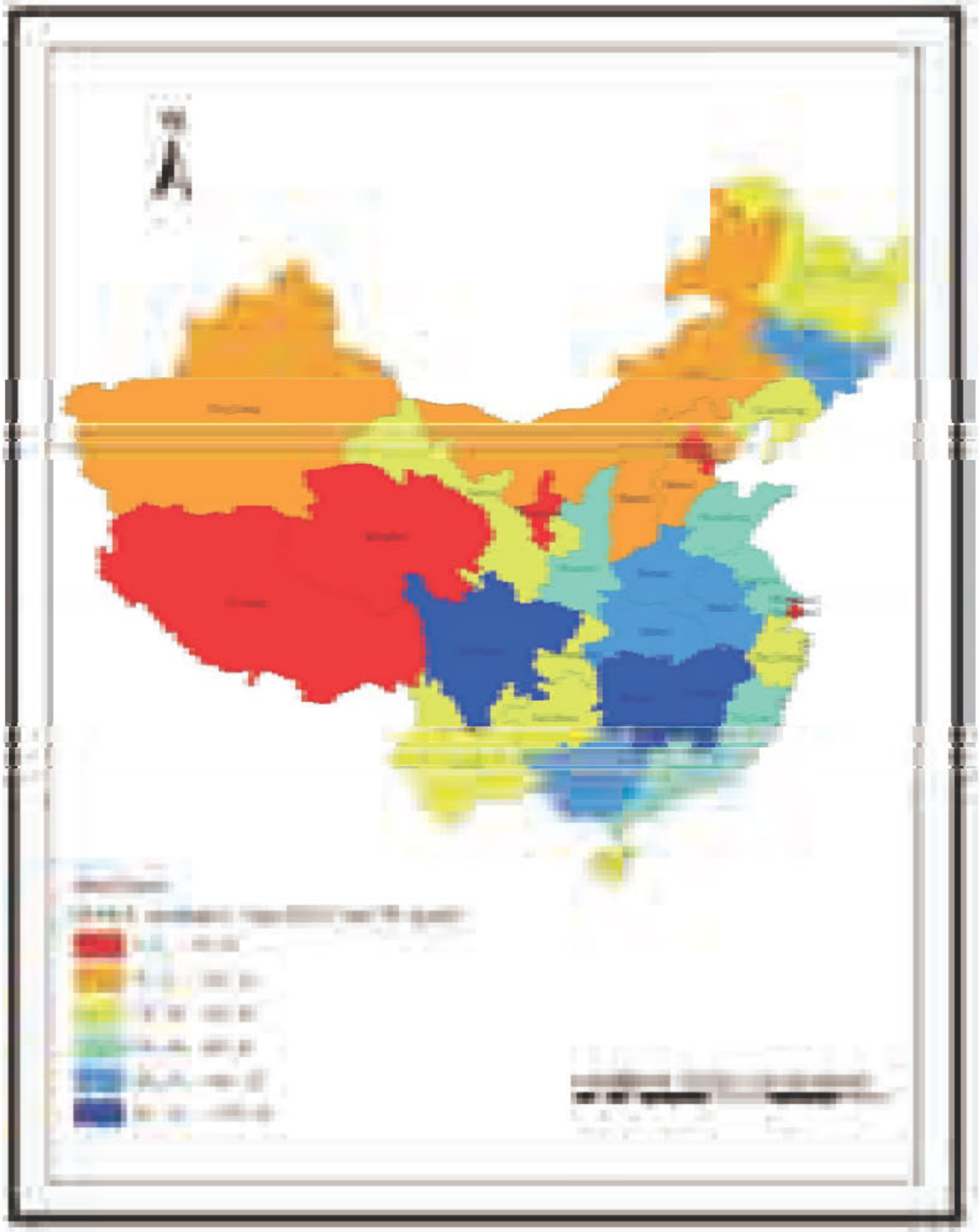

Figure7 Distribution of Accumulative Direct Economic Loss

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