River channel management in flood risk reduction

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Abstract

Managing increasing flood risks is one of the most pressing problems for Asian Region. Rapid urbanization on one hand contribute to increasing flood hazards from improved drainage and increase flood runoff while on the other hand, associated population and wealth concentration continuously increase the exposed population and wealth at risk. Integrated flood management with a holistic approach for basin wide water management is essential for developing sustainable flood reduction strategies. This paper discuss the role of river channel management in a basin wide context with the objective of lowering the loss-frequency curve that take into consideration both high and low frequency floods and examines the potential role for financial instruments in flood risk management.

Key words: Flood Risk Reduction, Risk Assessment, Loss Functions, Extreme Events

1. Introduction

In preparing for the global disaster platform, UN has produced a document titled *Disaster Risk Reduction, Global Review, 2007* analyzing the global trends of disasters and main issues needed to be addressed in reducing disaster risks. The analysis is mainly based on the data available in EM-DAT Emergency Events Database (OFDA/CRED , 1988). Recent disaster trends from 1980 to 2005 reveal that while mortality associated with geologic hazards has increased since 1990's mainly due to 2003 Bam earthquake, 2004 Indian Ocean earthquake and 2005 Kashmir earthquake, mortality associated with climate data has remained unchanged while that associated with droughts have dramatically reduced. This trend in stabilizing mortality is significant when the same data sets show that number of disasters has almost doubled between 1995 and 2005. This may be due to an increased effectiveness of warning and preparedness as well as a rapid increase of reports of small scale climatic hazards that does not cause deaths. The same analysis also shows that if mega disasters with over 10,000 deaths are excluded mortality associated with climatic disasters is increasing at a rate faster than global population increase.

In the case of economic risks, there is a clear upward trend of economic losses according to data compiled by Munich Re. (Munich Re. , 2007). From the data of great natural disasters from 1950-2006, climatic events (windstorms, floods and extreme temperatures) comprise 71% of all large scale economic disasters and accounts for 69% of total economic losses while causing 49% of mortalities. Thus, the economic impacts of climatic events has a much higher share among all disasters compared to mortality. In this distribution, floods comprise 25% of all events, accounting for 24% of total economic losses, while causing 7% of fatalities (Munich Re. , 2007).

Disasters result from a combination of natural hazards events and the degree of exposure and vulnerability of the society. The trend in increasing economic risk of extreme events in recent times can be attributed to the increased concentration of population and assets in vulnerable areas. According to Munich-Re there had been 20 egreat natural catastrophesf between 1950 and 1959 that has caused US$ 38 billion economic losses where as the number of such disasters has increased to 82 between 1990 and 1999 causing US$ 535 billion damage. It is clear that damage from *catastrophic events*, rare events that go beyond the coping capacity of infrastructure inflict heavy losses, and these losses are increasing.

The recently released Intergovernmental Panel on Climate Change (IPCC) report 4 has explicitly warned against increase of flood disasters as a consequence of climate change. The working group II that focuses on Climate Change Impacts, Adaptation and Vulnerability, has identified following risks. In Asia, glacier melt in the Himalayas is projected to increase flooding, and rock avalanches from destabilized slopes. Coastal areas, especially heavily populated mega-delta regions in South, East and Southeast Asia, will be at greatest risk due to increased flooding from the sea and, in some mega-deltas, flooding from the rivers. Europe will experience increased risk of inland flash floods, and more frequent coastal flooding and increased erosion (due to storminess and sea-level rise). In Australia and New Zealand, on going coastal development and population growth in areas such as Cairns and Southeast Queensland (Australia) and Northland to Bay of Plenty (New Zealand), are projected to exacerbate risks from sea-level rise and increases in the severity and frequency of storms and coastal flooding by 2050.

The current characteristics of flood risk increase, coupled with intensification of flood risks associated with climate change require increased efforts to reduce flood damage with a new vision. The current flood risk reduction emphasis on saving lives has produced positive results as indicated by the trends discussed above. However, this approach should be complemented by protecting livelihoods and economic assets. The concentration of economic assets in areas exposed to climate hazards would continue to grow and will not be protected by improved early warning, preparedness and response although they are effective against reducing mortality. This protection should be provided by safe buildings, developing basic flood protection infrastructure, risk sensitive planning and ensuring adequate investment. Use of financial instruments in reducing basin wide flood risk reduction, need to be incorporated to make flood reduction strategies sustainable. This require not only the improvement of river channels, but also use of river channels as an integral component of comprehensive flood risk reduction strategies.

2. Strategy for flood risk reduction

The figure 1 shows a typical flood loss curve for different flood frequencies in a basin. The upper curve shows the state of current flood losses and the lower curve represent the flood loss characteristics targeted by implementing different flood reduction strategies. To categorize various flood control measures, it is useful to divide the frequency domain in to 3 zones as (1) rare, (2) less-frequent and (3) frequent as shown in the figure.

In order to ensure uninterrupted agriculture and industrial development, it is necessary to provide a minimum degree of protection against frequent floods. This is to be achieved by infrastructure solutions that could push the line AB towards less-frequent direction. The second zone of less-frequent flood management would require both soft and hard solutions. The range of this zone may depend on the flood risk reduction policies to be adopted for the region. The measures may involve a combination of soft and hard measures that include early warning, preparedness and insurance. The first zone corresponding to extreme events would require measures mainly to ensure reduction of mortality and rapid recovery in the aftermath of a disaster including preparing recovery plans in advance and setting up financial mechanisms to support recovery and reconstruction.

Another perspective of these domains would be to consider the different flood mechanisms involved in the three domains. While this would depend on the catchment physical characteristics and a host of other factors, there could be some common features associated with large urban cities that are most vulnerable to floods. In such a mega city context, dominant flood type in the 3rd zone could be urban flooding due to lack of adequate drainage. In many parts of Asia flood drainage could not keep pace with rapid urbanization and many mega cities can only manage 1:3 or 1:5 year flood which correspond to about 50 mm/hour in Japan or China. The flooding of a river to an urban area due to accumulation of basin wide flood waters that exceed river capacity would have a much more devastating impact. In

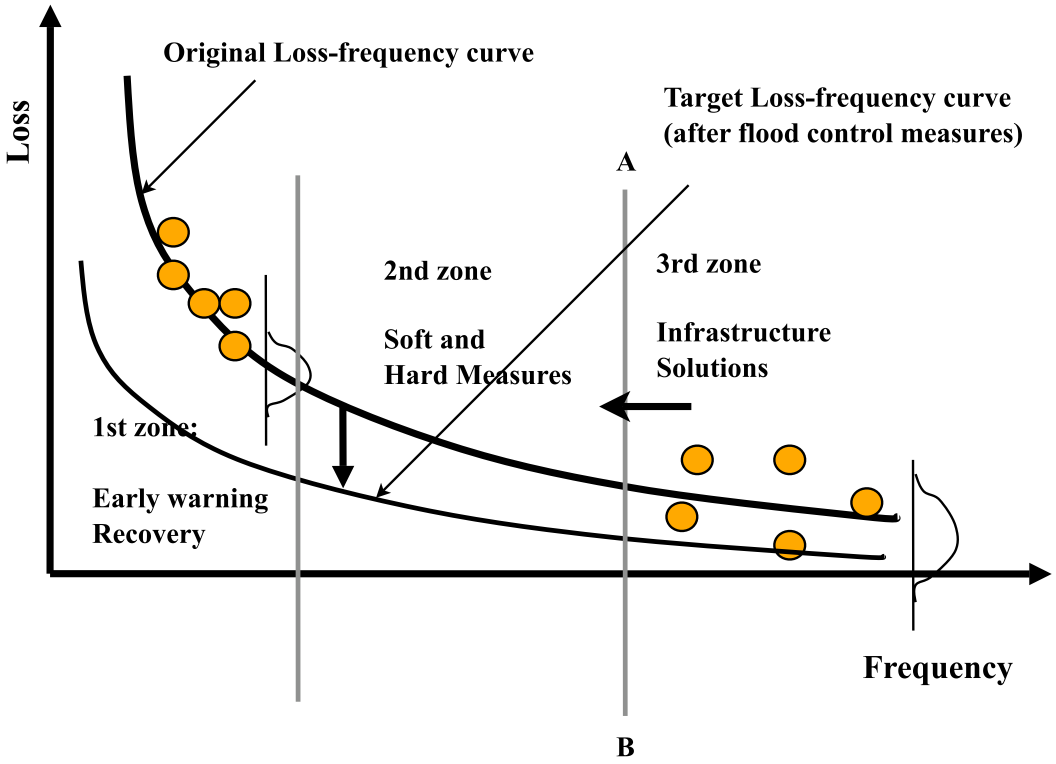

Figure 1: Loss-Frequency Curve

many cases the major river flood control works are set to 1:100 years to 1:200 years, while some cities may have 1:500 year or more flood protection from neighboring rivers (for example flood control works of Red River against a flood in Hanoi, Viet Nam). Even though flood control targets are set up at a high level, many Asian cities have not completed the river improvement works required to achieve those targets. Another important point to bear when setting up these standards of complete protection is that they invariably increase the risks from an eventual event that exceed the design standards. From this perspective, some argue that having floods from rivers of the order of 1:60 years would provide a mechanism to ”live with flood risk” and transfer knowledge across generations on preparedness and prudent land use. The floods in zone 1 will be catastrophic and most likely their impacts cannot be anticipated from past experiences alone due to rapid growth in population and urbanization process. Therefore, it become necessary to carry out prior risk assessment to develop extreme flood scenario and prepare for the *unforeseen* to reduce impacts from floods in zone 1.

Yet another perspective in discussing these 3 zones would be to consider the region of influence and resources required to reduce flood risks. Most likely, the flood risk reduction in zone 3 need to be carried out by the government and possibly managed with the local resources. Floods in zone 2 require basin wide strategies and involvement of private sector. Most likely, zone 1 flood management would require resources available beyond the basin, and even beyond the country. Global financial measures need to be promoted to support recovery from catastrophic floods. At the same time it is necessary develop scenario’s and establish evacuation strategies as well as develops mechanisms to reduce the damages from an extreme flood.

3. Flood Loss estimation

There are basically two methods in carrying out flood damage estimations. One is to carry out a thorough questionnaire survey of affected population and properties to estimate the incurred loss. The other is to use what are known as stage-damage functions which describe the damage extent to different types of property for a given inundation depth and inundation duration. Using such stage-damage functions economic damage to different property categories are estimated and the summation provides the total flood damage. Stage-damage functions are derived either from past flood data analysis, or through analytical descriptions of flood damage to various properties considering the possible damage ratio to a given flood depth and duration. A number of studies are reported in literature that describes stage-damage functions derived from post flood damage analysis (Parker et. al., 1987; Smith, 1994; NTIS, 1996; etc.). In Japan and United Kingdom, the procedures are standardized to estimate flood damage for any part of the country using normalized stage-damage functions.

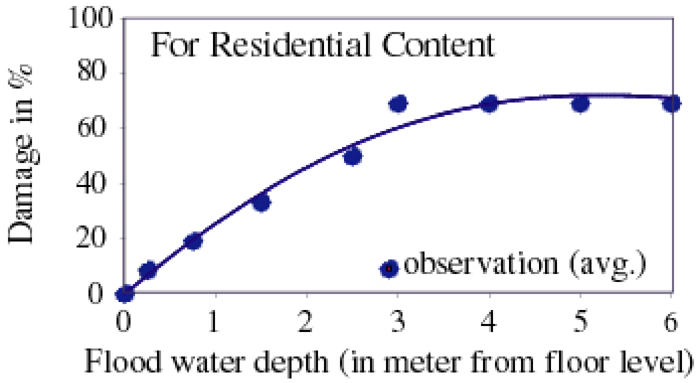

Figure 2: Depth-damage function for residential content

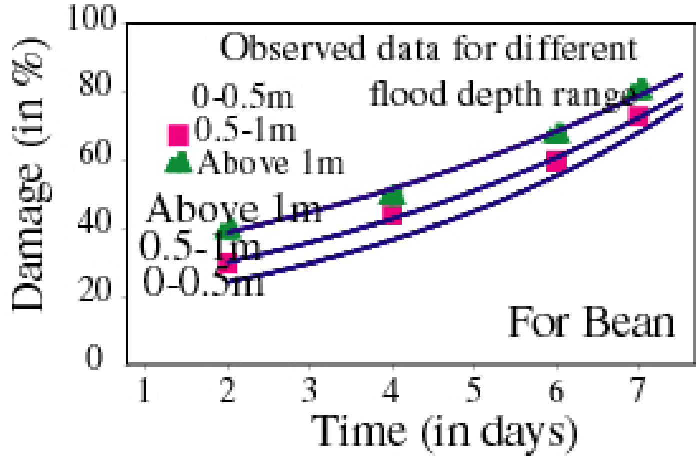

Figure 3: Depth-damage function for Beans

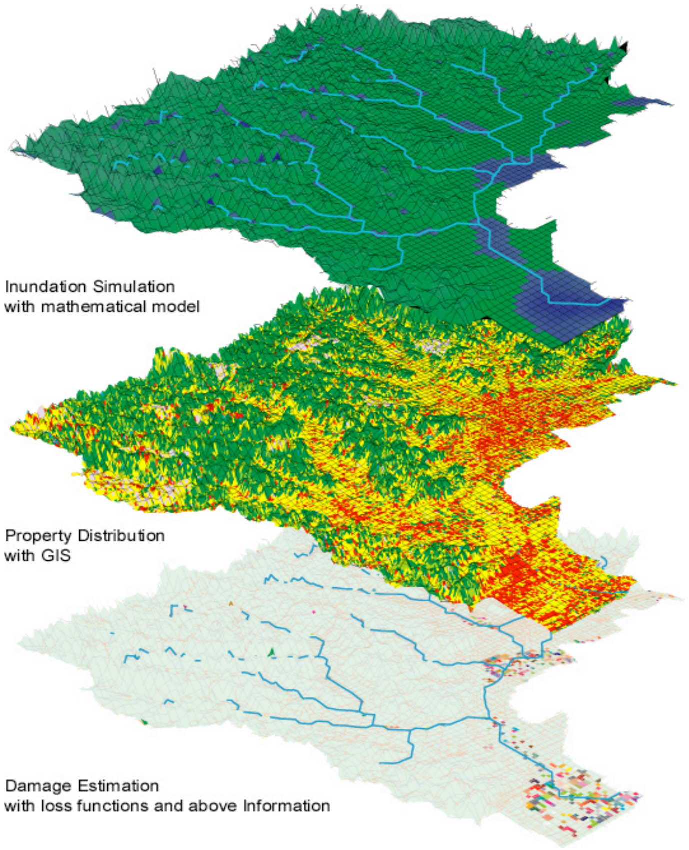

Figure 4: Procedure for flood loss estimation

The main purpose of these procedures is appraisal of flood control projects through standardized economic loss assessment. However, as these methods provide a means to estimate the *potential flood loss* for different scenarios, the approach can be used to estimate the effectiveness of a particular flood control project in terms of benefit compared with no-flood control mechanism scenario.

The methodology of flood loss estimation is outlined through the figures 2, 3 and 4. The figures 2 and 3 show samples of depth damage functions for Japan established through field sampling of flood events carried out continuously since 1950's.

In order to estimate the potential flood loss, first the flood inundation map is prepared as shown in the top layer of fig 4, either from numerical simulation corresponding to a future scenario or from past inundation data, in a GIS environment with high spatial resolution. Next an asset map categorized according to available depth-damage functions is prepared and the properties distributed at same grid resolution as in the inundation map. Using the depth-damage functions and these two layers, the distribution of flood loss can be estimated as shown in the last layer of the map in figure 4.

4. Case study of effect of river improvement works

The above methodology was applied in a case study to assess the effectiveness of different river improvement works in reducing flood losses. The study area is a moderate size basin, named Ichinomiya river basin, with an area of 220 km^2, located in the Chiba prefecture, Japan between latitude 3518 N to 3530 N and longitude 14010 E to 14025 E as shown in figure 5. The mean annual rainfall is approximately 1,700 mm and total population within the basin is about 144,000 mainly concentrated in the urban areas in lower flat part of the basin. The basin has suffered a large scale flood in 1996 and a detailed field survey has been carried out to assess the total flood damage. The main categories of depth-damange functions used in Japan are shown in table 1. In this study the following procedures were carried out.

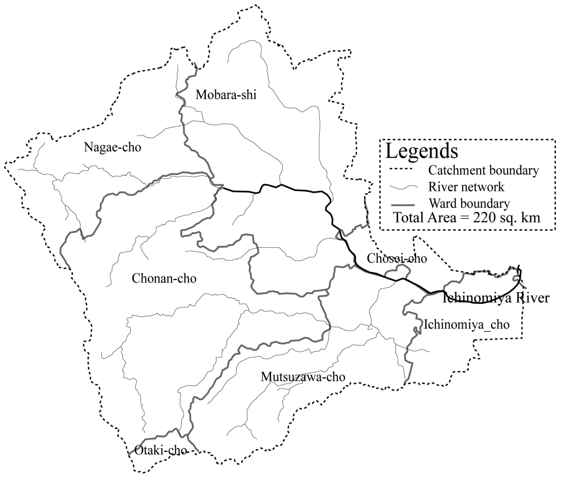

Figure 5: Study Area with administrative boundary and river network

1. Established a detailed GIS using remote sensing and administrative data at 50m grid scale.
2. Estimated the flood loss using actual flood heights observed in the ground and compared with the flood damage assessment carried out using the GIS.
3. Carried out numerical simulation to establish inundation map to estimate potential flood loss and assessed the accuracy of predictions compared to the field survey as well as estimations done with actual flood height observations.
4. Carried out numerical simulation considering river bed smoothening, increasing embankment, widening river stretches and incorporating detention storages along the river reaches to assess effectiveness of flood control in terms of economic loss reduction.
5. Carried out flood simulation corresponding to 1:50 year return period and 1:100 year return period with and without river improvement works to identify degree of flood loss reduction and major beneficiaries from flood loss reduction measures.

Details of these studies are given in (Herath et. al. , 1999) and (Dutta et. al. , 2006). The main results of the studies were:

Table 1: Damage categories and details considered in loss estimation

Damage Category	Details	Considered	Normalizing parameters	Influencing flood parameters
Urban Residential	Structure	Wooden	Floor area, region	Flood depth
		Non-wooden		
	Contents	All types	Household unit	
Urban Industry	Structure	Ten types of industry classes	Number of employees, region	Flood depth
	Content	Ten types of industry classes		
Crop Damage	Nine types of major crop classes		Crop area, production per crop, unit price per crop	Flood depth, duration, season

1. The flood loss estimation from the established GIS using the measured water heights match very well with the flood loss estimated from field survey. This means that asset distribution is adequately represented in the GIS.
2. Compared to flood loss from the field survey, estimates from actual water heights as well as those from the simulated water levels tend to under estimate losses. This error could be due to the use of grid averaged the elevation for deriving damage coefficients. The comparison of different estimates are shown in figure 6.
3. Figures 7 shows two emergency river improvement measures adopted in the basin soon after the floods. One aims to smoothen the river bed, where as the other increase embankment heights. The effect of these measures on flood losses is shown in figure 8
4. The methodology adopted can provide information on flood loss distribution, enabling to understand investment that can produce the maximum benefits. The figure 9 shows the spatial distribution of flood damages to residential content, while the figure 10 shows the spatial flood damage distribution for non-residential building property.
5. The estimation procedure also can be used to identify the major beneficiaries and extent of benefits from flood control works. The figure 11 shows the damage-frequency relations for 1/50 and 1/100 return period floods. The figure also shows the loss reduction for different assets. According to the figure, non residential structure contents and residential structures are the biggest beneficiaries from the flood control works.

5. Catastrophic flood loss reduction

With the increase of population and wealth flood control activities continuously strived to increase the design targets and construct flood control systems that could withstand higher and higher flood magnitudes. As a result, flood frequencies reduced, attracting more people and investment in flood planes. Now, in many places it had become extremely difficult to increase design standards anymore whereas an event beyond the design levels would bring huge losses. The threat of increases in rainfall intensities and magnitudes that could be brought about by climatic change amplify the problems. Various approaches such as the super-embankment construction

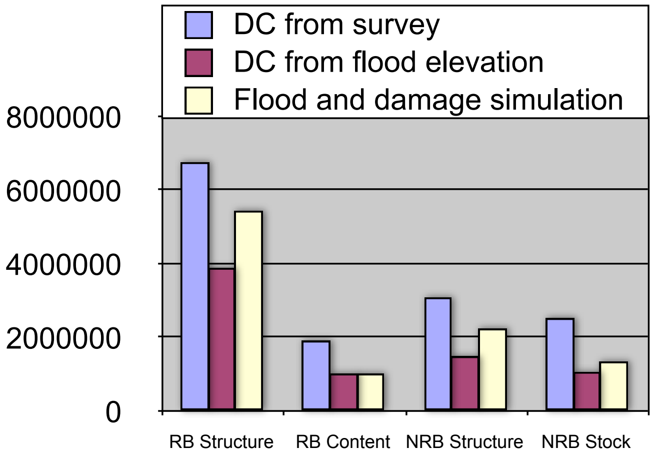

Figure 6: Comparison of different estimates of damage coefficient

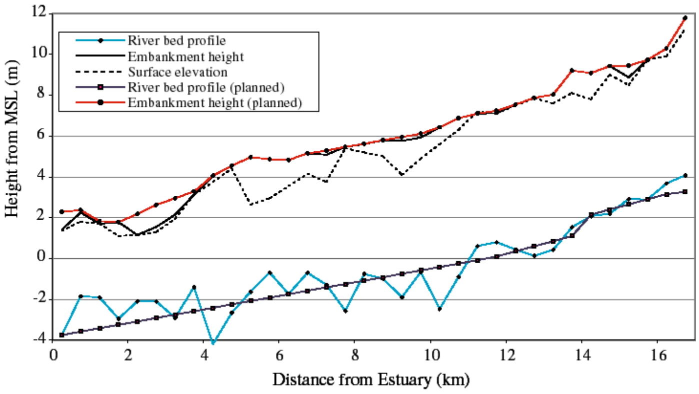

Figure 7: Proposed improvement of river bed profile and embankment height increase

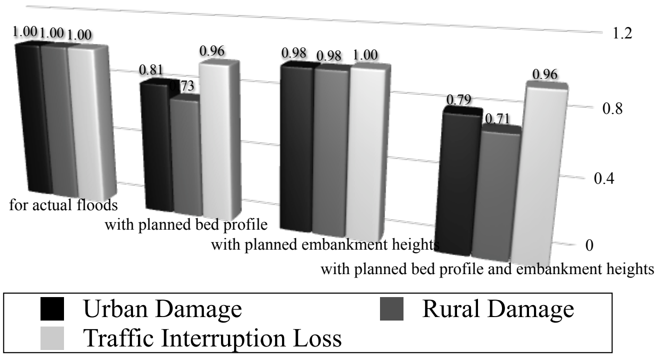

Figure 8: Comparisons of loss reduction due to river bed and embankment improvements

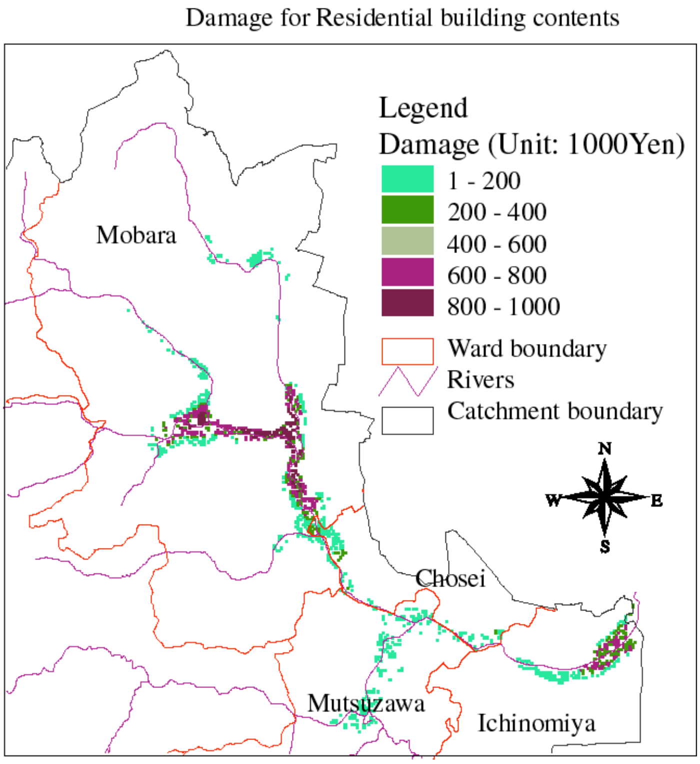

Figure 9: Distribution of flood damage to residential content

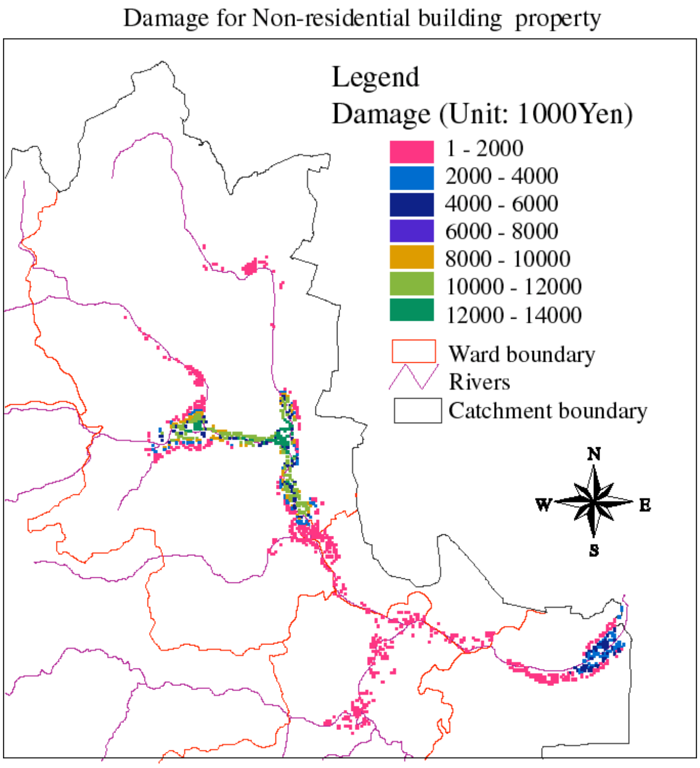

Figure 10: Distribution of flood damage to non-residential building property

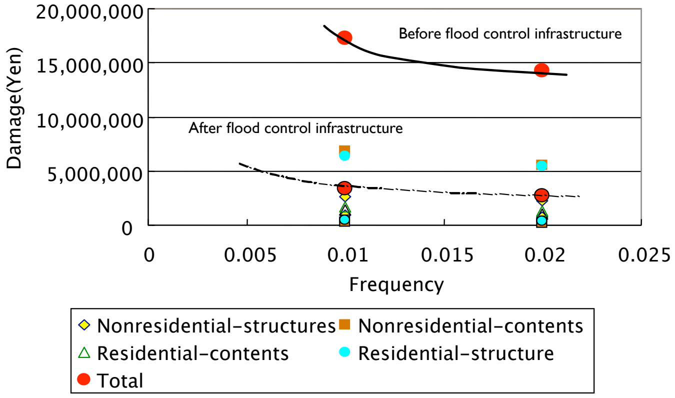

Figure 11: Damage-frequency curve for with and without flood control works (for 1:50 and 1:100 rainfalls)

in Japan and underground multi-purpose tunnel-river systems in Japan and other countries are being undertaken to address this issue.

In 2003, the United Nations University with a number of partner organizations conducted a workshop to discuss the issue of catastrophic flood risks in Asia. Representatives of 15 Asia-Pacific countries participated in the meeting and made a resolution calling for regional cooperation in developing common methodologies and assessment indices for flood risk assessment. The adopted resolution recommended a joint action program focusing on,

1. Estimation of extreme rainfall
2. Inundation modeling
3. Risk assessment and developing response planning
4. Community participation and
5. Institutional capacity building for effective risk assessment and its use in practice.

The program would enable the creation of what if scenarios to support decision makers to realistically assess what is at risk in the event of an unprecedented flood in a major city in their country. In following up, two pilot studies have been conducted, one in Hanoi, Viet Nam and another in Bangkok, Thailand to assess the extreme flood risks from a major flood. This is now followed by a five country study, and a community discussing extreme flood risks is being developed. One of the important discussions underway is how flood risk in a basin can be managed by transferring downstream risk to upstream. In many catchments downstream is highly urbanized with high economic loss potential and if adequate estimates of loss reductions can be made, the risk can be transferred to control inundation and compensation/recovery schemes upstream. For example, in Vietnam, spillway type openings in Red River embankments are proposed to protect Hanoi city in the event of a catastrophic flood event. These measures coupled with adequate financial support based on loss reduction methods can provide risk transfer methods that could be practical methods to redistribute wealth for upstream rehabilitation and development.

References

Dutta, D., Herath S., Musiake K.: *An Application of a Flood Risk Analysis System for Impact Analysis of a Flood Control Plan in a River Basin* Hydrological Processes, 20(6) (2006), pp. 1365?1384

Herath, S., Dutta, D., Musiake, K.: *Flood Damage Estimation of an Urban Catchment using Remote Sensing and GIS* Proc. International Conference of Urban Storm Drainage, Australia, 1999.

IPCC: *Summary for Policy Makers, Working Group II* IPCC, UNFCC, 2007.

Ministry of Construction (MOC), River Planning Section, River Department: *Outline of River Improvement Economic Research Investigation* National Government of Japan, (in Japanese), 1996.

Munchener Ruckversicherungs-Gesselschaft Geo Risks Research: *Great weather disasters 1950?2006, Economic and insured losses* Munich Re, 2007.

National Technical Information Service (NTIS): *Analysis of Non-residential Content Value and Depth-Damage Data for Flood Damage Reduction Studies* U.S. Department of Commerce, USA, 1996.

Parker, D. J., Green C. H. and Thompson P. M.: *Urban Flood Protection Benefits - A Project Appraisal Guide* Gower Technical Press, UK, 1987.

Smith, D. I.: *Flood Damage Estimation - A Review of Urban Stage-Damage Curves and Loss Functions* Water SA, vol. 20, pp. 231-238, 1994

University of New South Wales (UNSW): *Economic Evaluation Methodology of Flood Damage in Australia*, UNSW, Australia, 1981.

USAID Office for Foreign Disaster Assistance / Centre for Research on the Epidemiology of Disasters: *International Disaster Database at Centre for Research on the Epidemiology of Disasters* Catholic University of Louvain, Brussels, Belgium (http://www.em-dat.net).