ASSESSMENT OF VULNERABILITY TO FLOOD IMPACTS AND DAMAGES

Disaster Management Programme, UNCHS (Habitat), 2001

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Guidance for Readers and Users

The current document has been prepared for the purpose of: (i) introducing the concept of vulnerability to flood impacts and damages (for the sake of practicality, here in after it is referred to as flood vulnerability); and (h) providing guidelines on how to make assessment of vulnerability to flood impacts and damages. The first part adopts, among many, definition and scope of flood vulnerability, which involves a wide range of interactions between floods and the environment and human settlements. The readers may want to change the scope of vulnerability depending on the purpose of vulnerability setting and assessment for a specific river basin and depending on local situation. The latter part includes generic guidelines on how vulnerability assessment can be carried out. The users should adapt the guidelines to prepare more specific guidelines for vulnerability assessment to be applied to specific river basins or areas. A list of vulnerability index or indicators was included to give an idea of such indexing system. Particularly, vulnerability index or indicators should be devised based on specific environmental, human settlements and socio-economic conditions of a river basin or area and depending on availability of data and information.

The current document is prepared by Takehiro Nakamura (UNEP) and Chris Hutton (UNCHS) based on a report by the Flood Hazard Research Centre commissioned by UNCHS. Xia Kunbao (UNEP) and Jorge Gavidia (UNCHS) provided comments and advice. UNEP and UNCHS accumulated experiences in flood mitigation and management through their assistance to the Yangtze River Flood project in China and regional co-operation for flood mitigation and management for South Asia. The review of the draft was also carried out by UNEP/UNCHS staff members engaged in Sustainable Cities Programme, Urban Indicators, Global Environment Outlook, and Forest Indicators.

I. Introduction

The recent flood events, which might have been associated with El Nino and La Nina events, have shown the devastating effects that floods have on the development of affected countries. Losses suffered by Asia, Europe and Africa are staggering and seriously affect economic and social circumstances and development. For instance, it is estimated that the 1998 floods in Bangladesh caused losses of over US$55 million in shelter sector alone. The direct economic loss incurred by the 1998 floods in China is estimated to amount to US$30 billion. Rehabilitation costs are unaffordable and the countries and communities have suffered a drastic fail in their living conditions and expectations for future development.

The intensity of natural hazards such as floods is exacerbated by unsustainable environmental and resource use practices, including deforestation, inappropriate land uses and poor management of water resources. Understanding of and responding to floods requires a comprehensive view of intervening environmental, social and economic factors. This calls for joint approaches by all relevant national agencies, as well as for the development of integrated support strategies by international agencies with expertise on the subject, such as UNEP and UNCHS (Habitat).

There is a close relationship in the way inhabitants, authorities and developers plan and build their communities in terms of form and function, and the ability of these communities to reduce their vulnerability to extreme natural events. The nature of this relationship demands that more attention be given to aspects of community development and environmental and resource management, such as where and how they are planned, how do they relate to each other, and the way they are inserted in the national and local planning. This also includes community development patterns, configuration of infrastructure and services, and the involvement of the various actors on environmental management and regional development in the decision making process.

In many cases, the underlying causes of the intensity of floods and the vulnerability of settlements and the environment are common to countries facing similar environmental conditions and development patterns. The experience available on the subject in such countries as China and India can be extremely useful to neighbouring countries facing similar problems. There are opportunities and benefits to be obtained by the establishment of horizontal technical co-operation and exchange mechanisms in flood mitigation and management.

Following the recent floods in China, Bangladesh, Vietnam and India a number of concrete steps have been take by UNEP and UNCHS (Habitat) to collaborate in the preparation of needs assessments and assistance proposals on the subject. The experience gained by both agencies in the assessment of similar events in the past reconfirms the long-standing belief that it is difficult to disassociate the natural and the built environment in formulating sustainable solutions for environmental management and human settlements development. Lessons learned from previous floods indicate that there are only a limited number of actions that can be taken to prevent floods from occurring. Conversely, there is a wealth of methods to prevent the flood from becoming a disaster.

In this document, IJNEP and UNCHS(Habitat) are introducing the concept of ‘vulnerability’ to flood impacts and damages. Human and financial resources are always limited and scarce and to be used efficiently and cost-effectively. The allocated funds and human resources for flood mitigation purposes need to be targeted where interventions can achieve the most significant effects in flood mitigation and preparedness. In this way, decision-makers and investors can choose for their intervention and investment the areas where vulnerability is estimated to be highest.

In the vulnerability of floods, two important principles are considered: (i) catchment perspective; and (ii) an integrated, or holistic approach to management of catchments. Integration should cover both the different aspects of water management and also the relations between land and water use. Flood management fits into this broader perspective; flood management should neither dominate land and water management nor should flood management be seen as solely about the use of flood plains.

To make such integrated management possible, some generalised tools are necessary in order to make comparisons across the entire catchment and also between catchments. The guidelines given here should be treated as such a comparative tool, as being a way of identifying the relative vulnerability of different areas rather than providing an absolute assessment of vulnerability. For easy comparison purposes, vulnerability index is introduced, comprising of a set of indicators representing various aspects relevant to magnitude and range of impacts and damages of floods to communities and environment.

These guidelines should not be applied mechanically; if they are inconsistent with local knowledge then they should be revised in the light of that knowledge. Again, it is possible to screen in or to screen out cases; to exclude areas assessed to be of low vulnerability from further assessment, or to identify for further action only those areas assessed as being highly vulnerable.

II Environmental and Human Settlements Vulnerability to Flood Impacts

II-A. Definition and Scope of Vulnerability

The vulnerability is the concept that has been argued in the arena of natural disaster mitigation, food aid and other emergency issues. In these areas, vulnerability lias been defined from risk management perspective. The United Nations Department of Humanitarian Affairs (UINDHA, 1993) defined the relevant terms as follows:

> Hazard: A threatening event, or the probability of occurrence of a potentially damaging phenomenon within a given time period and area
> Vulnerability: Degree of loss resulting from a potentially damaging phenomenon.
> Risk: Expected losses (of lives, persons injured, property damaged, and economic activity disrupted) due to a particular hazard for a given area and reference period.
> Disaster: A serious disruption of the functioning of society, causing widespread human materials or environmental losses which exceed the ability of affected society to cope using only its own resources.

Vulnerability lias been defined in different ways by different experts based upon what is the desired result. It lias been variously treated as a passive characteristic of the system under threat; as an innate adaptive characteristic of the system, similar to the concept of ‘resilience’ applied to ecosystems (Ludwig, Walker and Hollings 1997); or in terms of the active, adaptive response of which the system is capable. How ‘vulnerability’ is defined is important because the definition of vulnerability specifies the approach that then logically follows to reduce vulnerability.

In this document, interpretation of vulnerability, which stresses interaction between the hazard (flood) and the recipient subject (the environment and human settlements), is adopted, leading logically towards projects which seek either to reduce the challenge presented by the hazard and/or to enhance the resources available to people to cope with the hazard when it occurs. This definition of vulnerability is akin to Lazarus's (1966) definition of stress, as that which results when coping resources are inadequate to meet the challenge posed by the flood. Vulnerability is viewed as a product of the interaction of the flood event and some of the characteristics of the affected land uses and population. It directs attention to the two questions:

- What characteristics of a particular flood result in a severe challenge?
- What is the adaptive capacity of the affected system, be this a household, the environment or an economy?

For example Penning-Rowsell (Green et al 1994) proposed that the following equation be used to define vulnerability to flooding of households

Household vulnerabiliilty = Social/economic variables, Property and infrastructure variables, Flood characteristics, Warning variables, Response variables

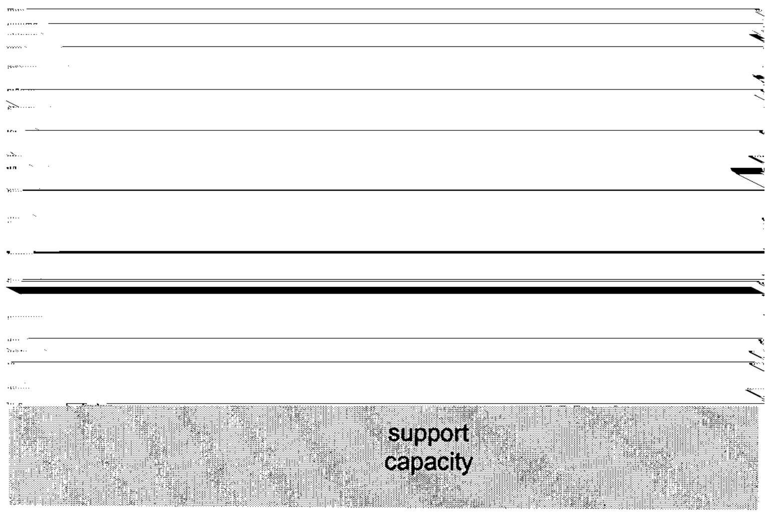
$$= f\left[\frac{A}{H, S, I, C, F}\right], \left[\frac{S_c, S_b, I_t}{S_t, R_o}\right], \left[\frac{D_e, D_t, S_d, S_t, W, V, P_j, R}{\quad}\right], \left[\frac{\quad}{W_o, W_t, W_a}\right], \left[\frac{T_r, R_a, R_q}{\quad}\right]$$

where:

A = Age profile of household
H = Health status and/or mobility of household
S = Savings of household
I = Household income
C = Cohesiveness of community
F = Flood knowledge
S_c = Susceptibility of building contents to damage
S_b = Susceptibility of building fabric
I_t = Time taken to restore infrastructure
S_t = Number of storeys
R_o = Robustness of building fabric
D_e = Depth of flooding
D_t = Duration of flooding
S_d = Sediment concentration
S_t = Sediment size
W = Wave/wind action (e.g. coastal or Not)
V = Velocity
P_1 = Pollution load of flood waters
R = Rate of water rise during flooding onset
W_o = Whether a flood warning was received
W_t = Warning time provided
W_a = Advice content of warning
T = Time taken for assistance to arrive after or during event
R_a = Amount of response available
R_q = Response quality

In this model, buildings and infrastructure can be seen as mediating variables that either amplify or reduce the challenge posed to the population **(Figure** 1). Buildings, in any case, naturally mediate the challenge to households by flooding because they can be a place of refuge in a flood or can be destroyed in a flood.

Figure 1 Vulnerability model for households (Source: Green 2000)



The important issue here is that the vulnerability is to potential consequences or impacts of floods, and not to floods themselves. This means that people and ecological systems are vulnerable to loss of life, housing and assets, and destruction of ecological habitats. Further, the vulnerability is dependant on (i) the rate of change in discharge or flow in rivers, or in water levels; (ii) existence of natural and artificial river structure that may give change in the flow and water level conditions; and (iii) forms of interventions to address potential flood impacts. Therefore, different type of floods, flow regimes and interventions strategies will create different vulnerability in the river basins. The characteristics of the flood that are significant to the vulnerability of the impacted system vary between systems **(Table** 1). The primary characteristics of different types of flood also vary **(Figure** 2).

Primary flood characteristics creating challenge

Flood characteristic	**Vulnerability**			
	Agriculture	**Buildings**	**Regional/National Economy**	**Risk to life**
Timing of flood	•			
Depth of flooding		•		•
Duration of flooding	•		•	
Flow velocity		•		•
Extent of flooding			•	
Debris load	•	•		

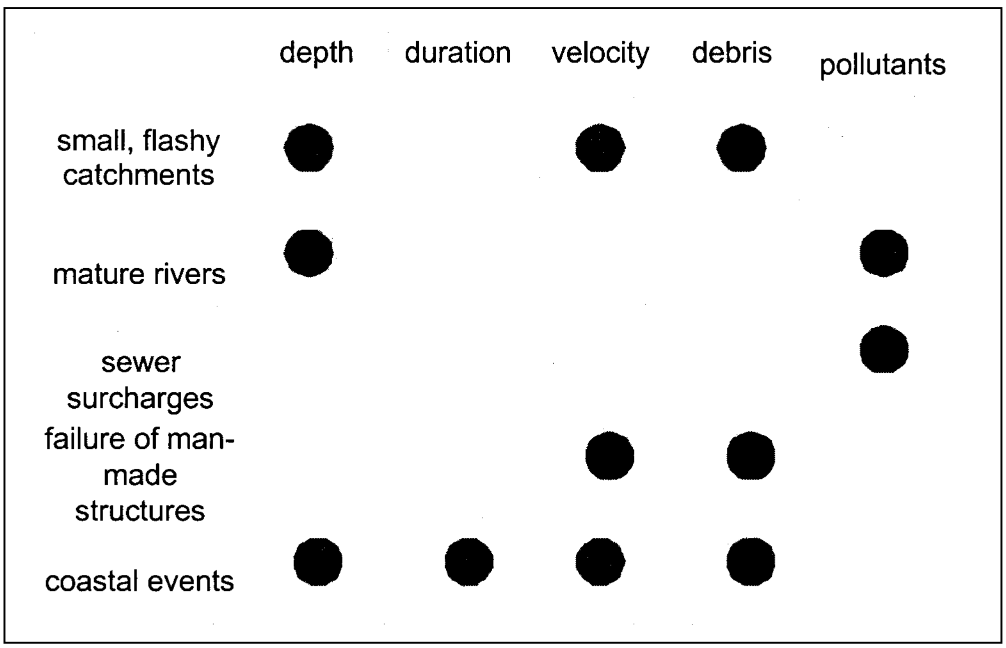


Figure 2 Flood characteristics and the type of flood

II-B. Vulnerability and Flood Preparedness Policy

The questions of what is vulnerability and why does it matter are inherently interlinked: we are only interested in vulnerability to the extent to which a decision is affected by it. The definition of vulnerability therefore depends what is the decision that must be made. Some of the possible decisions that may then be influenced by assessments of one or another form of vulnerability are:

- Where to locate a new development or infrastructure so as to minimise its vulnerability to flooding;
- How to maximise ecosystem management efforts for flood control

purposes;

- How to intervene most effectively to decrease the vulnerability of an existing settlement or Province;
- In assessing the likely impact of some change (e.g. climatic change) on vulnerability to flooding;
- Identifying which groups in the population are most vulnerable to flooding so as to target disaster aid;
- Identifying those types of development that most vulnerable to flooding in order to avoid locating them on a floodplain;
- Identify needs for a change in structural designs; and
- Setting priorities over time or between areas for actions to reduce vulnerability.

In this way, definition of vulnerability and actual assessment of vulnerability will lead to establishment or modification of flood preparedness policies on a variety of scales. The assessment will and must indicate where the intervention should take place in what form.

III. Assessment of Vulnerability to Flood Impacts

A vulnerability assessment is a profile with a specific focus on the relationship between a natural hazard and recipient subject. The vulnerability assessment identifies the strengths and weaknesses of the recipient subject in relation to the identified hazard, based upon readily attainable information. At the same time, it identifies the stakeholders relevant to the recipient subject and the decision making process of the stakeholders. This is done in an effort to allow stakeholders to more effectively mobilise and allocate the finite resources available in an effort to strengthen the ability of the subject to prevent and mitigate the effects of the hazard so as to further development.

A vulnerability assessment is carried out so as to allow stakeholders to better make decisions on how to protect the recipient subject from a certain hazard. The goal of the stakeholders is always to ensure the greatest protection of the subject from the hazard, be it a house, factory or bridge, or specific ecosystems, in order to limit any loss. This is important because any loss among the stakeholders lias the potential to either temporary or permanently retard the development of the stakeholders and the larger community, and the management and utilisation of the environment and natural resources. Therefore vulnerability is related to the following three types of potential intervention as the results of identification and assessment of vulnerability:

- Reducing the challenge;
- Mediating the challenge; or
- Enhancing coping capacity.

Different levels of decision-making require assessments of vulnerability across different geographical scales. In addition, administrative boundaries rarely coincide with the boundaries of catchments or sub-catchments. However, the larger the geographical scale on which the vulnerability assessment is based, the greater the detail that is lost is. The risk to life tends to be less homogeneous over space than other forms of vulnerability. In particular, the most severe flash floods, in which there can be a significant number of deaths, are those floods that occur in small, hilly catchments of less than 100 square kilometres. In making generalised assessments across larger geographical areas, it is desirable to note such areas as amongst the ‘maybe’ category where a more detailed assessment is desirable.

As indicated in the preceding Chapter, it is understood that vulnerability is not a readily measured or monitored parameter, rather than a combination of various parameters that are related to socio-economic, political and environmental settings of specific locality. Further, it is again to be noted that the concept of vulnerability is for relative comparison for the decision-makers to decide on how and where their interventions should take place. Therefore, the threshold or critical level of vulnerability should be agreed upon by decision-makers, particularly through economic and political processes.

The aim of vulnerability assessment is to provide decision-makers with information as to where and when interventions should be made in what form. Such assessment should also provide indication as to what development restriction exists in specific location within a basin. In other words, vulnerability assessment should be designed so as to produce such information for specific target areas. In this way, presentation of vulnerability constitutes part of the early warning system to flood damages.

Vulnerability can be assessed at various levels: individual, household unit, village, ecosystem, sub-basin, basin and national. For different levels, different sets of information will be required.

In this document, it is recommended that the following procedure be taken at any level of assessment:

1. Decision on a target geographical area or assessment unit, taking into consideration scale effects;
2. Scoping concerning for whom the assessment results can be used and for what decisions;
3. Preparation of a causal chain schematic illustration; and
4. Preparation of profile (assessment statement) for:

- The activity sectors for development (the population);
- The supporting environmental resources and (mediating factors); and
- The hazard (flooding).

For practical purposes, this document including guidelines on vulnerability assessment is for vulnerability assessment for a river basin (or sub-basin), based on the smaller assessment or information collection unit (scale of county or prefecture), so that relative vulnerability of the small assessment units can be obtained for the purpose of basin-wide vulnerability comparison. Further, it is assumed that the vulnerability assessment results can be used for decision making for environmental and human settlement management at a river basin scale. Although the guidelines contained in this document are meant for a river basin scale, the approach presented here can also be applied to vulnerability assessment on other scales, but required information and indicators may largely be modified depending on the scale and mode of assessment.

III-A. Target Audience and Target Use of the Vulnerability Assessment

Ultimately the whole purpose of the vulnerability assessment exists as an inexpensive process to allow stakeholders to have clear and concise information to make decisions
that will most effectively reduce their vulnerability to floods and consequently further to their development. Partially in order to do this, there must be a clear understanding of who the stakeholders are and the process by which decisions are made. In this regard, three specific areas need to be looked at and broken down into various components.

1. Key stakeholders
   (a) Public sector
   - Local government
   - Regional government
   - National government
   - Public sector organisations

   (b) Community sector
   - Non-governmental organisations
   - Community based organisations
   - Private voluntary organisations

   (c) Private sector
   - Chambers of commerce etc
   - Informal sector organisations

   (d) Others
   - Relevant actors, interest groups

2. Urban and environment management structures and functioning
   (a) Information, knowledge and technical expertise
   - Organisations responsible for collection, distribution, analysis, management and use of information and specialised knowledge
   - Accessibility of information
   - Main areas of technical expertise available
   - How information and technical knowledge is applied

   - (b) Decision making, policy formulation and policy co-ordination **e** Across development sectors
   - Across levels of government
   - Between public, private and popular sectors
   - Across geography
   - Over time
   - What are the decision-making roles of different

organisations within the public sector

(c) Policy implementation

- Main organisations responsible for implementation of public policies
- How policies are implemented using different instruments of implementation
    - Public awareness and education
    - Economic incentive mechanisms
    - Regulatory mechanisms
    - Strategic capital investment
    - Annual budgeting
    - Physical planning

- How is implementation inspected and monitored
- Enforcement mechanisms
- Gaps between plans and actual implementation

3. Strengthening urban and environmental management

III-B. Analysis of the Causal Chain of the Pressure-State-Effect-Response System

The floods occur due to strong and/or long rainfall, bank structural problems or their combination. However, other environmental factors are also contributing to increased frequency and/or enhanced magnitude of floods. These environmental causes are considered to be rooted in the human activities and socio-economic development in the catchment. For instance, agricultural activities the upstream areas in the catchment might have increased soil erosion from slopes, which resulted in increased siltation and sedimentation in the river beds. The changed river hydrology and morphology by this might have led to a shorter return period of a flood of a certain magnitude or to a change in the shape of a hydrograph of a certain flood magnitude.

In this way, environmental and human settlement conditions and patterns contribute to the flood events; and at the same time, these are the recipient subject of flood impacts and damages. Although the environment and human settlements and floods are interacting, in many cases, the environmental and human settlements contributing factors do not necessarily exist at the same place as environmental and human settlement system or entity that receives flood impacts and damages.

In order to describe such interaction between the environmental and human settlement system and the floods, and to provide assessment for decision making on an equitable basis between flood contributors and impact recipients, it is suggested to make a qualitative schematic illustration of causal chain relationship. Figure 3 indicates a simplified illustration of causal chain of pressure-root causes-causes-floods-primary and secondary impacts-macro impacts, based on the case of the Yangtze River basin (Nakamura, 2000). By analysing the basin system (ecology, hydrology and socio-economics), such causal chains can be derived. This also allows development of numerical models by defining the relationship among the listed factors. These models can also be used for scenario studies for defining future changes in vulnerability.

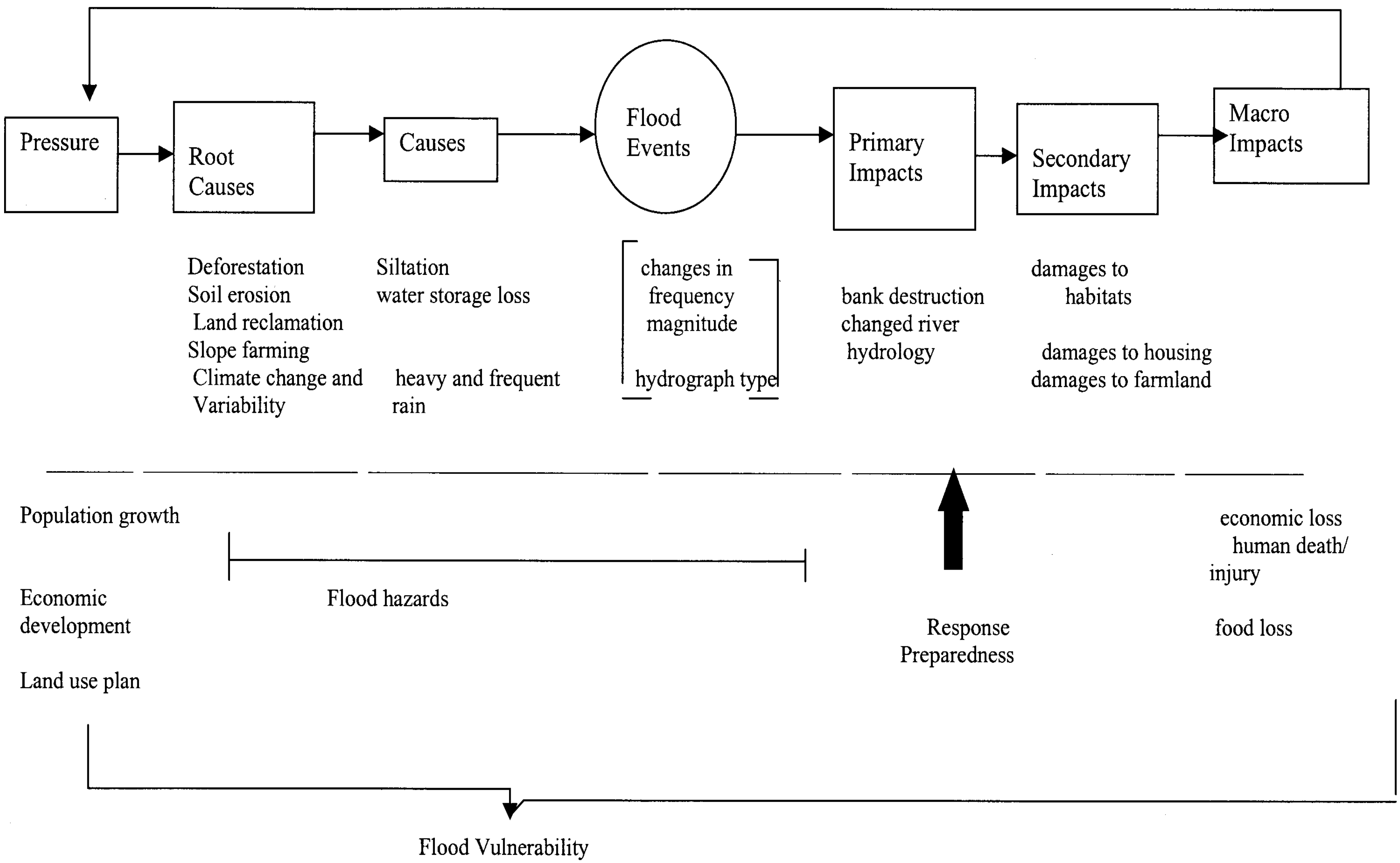


Figure 3 Schematic illustration of causal chain for floods in the Yangtze River basin (Nakamura, 2000)

III-C. Development of vulnerability assessment statement (profile)

Based on the schematic illustration of causal-chain of the flood events and impacts, a statement (qualitative assessment) of basic environmental and human settlement conditions of the assessment units will be prepared. Such a profile will be composed of four sections:

1. Basic situation of activity sectors;
2. Supporting environmental resources;
3. Characteristic of floods; and
4. Mitigating factors.

Activity Sectors to be Addressed to Protect the Population

The activity sector is the focal point of the vulnerability assessment. It is through the activities that are the basis of the stakeholders' importance to protect. There is an interaction between the activities, the environmental resources and the flooding. Each activity sector is a group of organisations and people who are engaged in the same general economic activity. Each category is important to the general development at the local/regional/national level. The activity sectors are an interlinked set of activities and establishments that is the basis of supporting a population and furthering development. It is therefore important to ensure that all activity sectors are protected from the effects of flooding. Below listed are a number of areas, which are ought to be addressed. However, it should be noted that it would be up to those who will actually have to carry out the vulnerability assessment to decide which sectors are relevant to the assessment.

- Housing
- Manufacturing
- Construction
- Energy
- Agriculture and Forestry
- Fisheries
- Environmental protection (protected areas, etc.)
- Transportation and Telecommunication
- Tourism
- Education
- Health
- Water Resources (water supply, drainage, liquid waste), and River Basin Authorities
- Solid Waste Management
- Informal Sector
- Pollution

Focus for Activity Sector
Each activity sector that is considered relevant to the vulnerability assessment should highlight the following information so as to give a fuller understanding of the recipient subject that is being assessed.

- Characteristics of the activity sector
  - General type of activities
  - Numbers employed
  - Recent trends
  - Important linkages to other activity sectors
  - Any other relevant information

- Sector' s use of environmental resources (land, water, etc.)
  - Specific resources used by the sector (water, land, minerals etc)
  - What scale of use of resources
  - Approximate quantitative terms
  - Special needs for quality of resources
  - Recent trends in consumption
  - Main sources of supply
  - Specific shortages of resources
  - Competition for resources with other sectors
  - Trends on availability of resources
  - Initiatives to overcome resources
- Sector' s impact on the environmental resources
  - What are the main polluting effects or environmental degradation effects
  - Activity sectors depletion for environmental resources
  - How else does the activity affect indirectly or directly the quantitative and qualitative environment
  - Changes in the pattern of the impact of the sector on resources
  - Initiatives undertaken to relieve detrimental effects for the resource depletion
- How sector is affected by flooding
  - Describe how flooding specifically affects the activity sector either directly or indirectly and either positively or negatively
  - How frequently do these impacts occur and with what severity
  - What is the damage/benefit sustained
  - What is the cost/benefit imposed
- Contribution of the sector to flooding
  - In what way does the sector contribute to the damage
  - What is the relationship between the activity sector and flooding
  - How lias the situation changed in recent years

It should be noted that the above stated questions and headings need to be modified to the specific situation that the tool intends to address. In many cases the questions may not be fully relevant or answerable for a whole host of reasons. The information needs to be kept as minimal and precise as possible in order to ensure that the information for the analysis can be quickly collected and analysed to make the assessment in a timely manner.

Supporting Environmental Resources (Determining Factors)

These determining factors encompass a wide variety of natural resources. They are relevant to the vulnerability assessment for two basic reasons. Firstly, it is these environmental resources that mediate the effect of the hazard of flooding and secondly they are resources to be used by the activity sectors to further the development.

The environmental factors are to be addressed in relation to their relationship with the activity sector and the natural hazard. Specifically how they affect the activity sectors' ability to cope with the hazard as these factors decide on how the hazard will naturally materialise. Therefore each of the different categories of environmental resources must address the following questions.

- Characteristics of the environmental resource
- The use made by the resource of all activity sectors
- The impact of the resource on all activity sectors
- Competition for the use of the resource
- Management arrangements

Below listed are a number of areas, which are ought to be addressed. However, it should be noted that it would be up to those who will actually have to carry out the vulnerability assessment to decide which sectors are relevant to the assessment.

- Relief
- Soil Type
- Soil Cover
- Vegetation
- Hydrology
    - Soil Moisture
    - Level of Groundwater table
    - Surface Filtration Rate
    - Impervious Cover
    - Channel Flow
    - Velocity
    - Type of Banks
- Precipitation
- Annual Variations
- Water Distribution
- Intensity
    - Depth of Water
    - Extent of Inundation
    - Velocity

    - Duration
    - Erosion and Sedimentation
- Runoff
- Topography
- Air
- Agriculture
- Mining
- Forests
- Wildlife
- Heritage

It is important to understand the relationship between the various sectors for when the activity sectors and environmental resources are addressed in relation to the hazard.

Characteristic of floods

Flooding is a hazard to the activity sectors of the population (including environmental and ecosystem protection) as well as to the population itself and is a retardant to development. As such the hazard must be analysed in detail to fully understand how it impacts the environment and the population.

- Flooding (River flooding) specifically:
    - Flood Rate
    - Sediment Flow and Distribution
    - Volume
    - Duration
    - Area Affected

The specific hazard that is being addressed by the vulnerability assessment is that of flooding but the activities explained below are relevant to most other natural hazards that could be assessed.

- Characteristics of flooding
- Impact of flooding on activity sectors
- Influences of the activity sector on flooding
- Conflicts among activity sectors related to flooding
- Managerial arrangements to deal with flooding

Considering the fact that the hazard of flooding affects a wide area and that the situation and efforts of one area directly and indirectly affect other areas it is important to fully comprehend the relationship between activity sectors, environmentally resources and their impact on each other in various geographical areas, including impacts on lifeline services/infrastructure.

Mediating Factors

The mediating factors are the systems that cause the initial force of the flood to be lessened. These mediating act in two ways. Firstly through retarding the flood and secondly through specific coping mechanisms which mitigate the affect of the floods.

1. Mediating Factors
    - Dams
    - Dykes
    - Spill Ways
    - catchment Areas

2. Coping Mechanisms through specific construction techniques related to:
    - Transportation
    - Infrastructure
    - Energy production and distribution
    - Pollution Control
    - Early Warning.

III C. Vulnerability Index and Indicators

In carrying out the vulnerability assessment, it is ideal that vulnerability is quantified for comparison purposes. Such quantification would facilitate comparison of necessity of intervention among various hot spots, sectors and areas. For this purpose, it is advisable that vulnerability index be developed to be used as policy-support instrument.

An "index" can be defined as a composite of more than one indicator. For example, the Human Development Index aggregates life expectancy at birth, adult literacy rate, school enrolment and GDP per capita. An indicator is a single measure of a characteristic, for example, per capita income. In the process of combining indictors into an index (or composite index), techniques like summing/averaging, weighting, and normalisation may be used. In this process, specific indicators may be given weight in the averaging (Downing et al, 2000).

In assessing and valuating vulnerability, this document suggests a sectoral approach, i.e., Assessment of vulnerability is carried out for each of identified sectors (such as water, ecology, human settlements, infrastructure, etc.), and then these assessments are weighed and integrated into a single assessment.

It is worth discussing whether or not a single index can represent vulnerability of the target area. One may consider dividing the whole vulnerability scope into several components. One possible direction is dividing the vulnerability into: (i) present state of environment and socio-economic situation; (ii) flood hazards and underlying causes; and (iii) response/preparedness capability of the society, and resistance and adaptability of the ecosystem.

Criteria for indicators of vulnerability to flooding

There are a number of criteria with which the indicators should be consistent. They should:

- require only existing and readily available data;
- be easy and cheap to apply;
- be appropriate to the particular rainfall and streamflow conditions in the country or province under consideration;
- discriminate to a reasonable degree between different levels of vulnerability; and
- be valid, the results being reasonable predictors of the results of more detailed studies.

In carrying out the assessment, the following issues should be answered:

- Scale of study (all counties, sample counties or percentage of counties etc)
- Scale of flooding (depth, velocity or occurrence (time) etc)
- Rural vs. urban
- Type of structure
- Type of environment
- Jurisdiction of government
- Etc.

For example the scale of study could be by taking a representative number of counties from each part of a basin that represent the different geographical areas, both rural and urban environments. The various industries and levels of infrastructure would be represented as well. While with each specific type of structure it could be broken down into different categories of house and the effect of different severity of floods upon the structure.

Indicators of vulnerability

The indicators are relative rather than absolute and are anticipated to be more reliable for comparing vulnerability within a particular country than for making comparisons between countries. For example, in the Lisbon flood of 1963, a rainfall 24 hour intensity of 240 mm resulted in some 600 deaths. In tropical countries, 24 hour rainfall intensities of 1,000 mm are not unknown. It is not necessarily true that the risk to life in tropical countries is greater than existed in Lisbon; the unexpectedness of the rainfall intensity may be more important than the absolute level. Because the primary purpose is make comparisons between different parts of a country, where physical parameters are used, those shown should not be taken as more than indicative and other values may be applied. The rationale for using a particular parameter value is more important than the actual value used. One instance where different parameter values would be appropriate is when the indicators categorise either a large part, or a negligible part, of a country as a high or low risk. The relative assessments are useful for decision making: an assessment that the whole country is highly vulnerable to flooding is of little use in assessing priorities within the country.

A series of different indicators is proposed; in consequence, different parts of a country are likely to be shown as being vulnerable in different ways. This should be expected; for example, flash floods in hilly or mountainous parts of a country are one of the contexts where large numbers of details still occur from floods. However, because those valleys are narrow or steep and the catchments are small, flash floods are rarely associated with large economic losses. It also follows that the indicators are not intended to be additive but rather overlaid on each other so as to identify the particular forms of vulnerability in different geographical areas. In the simpler scales it would be possible to choose scores so that the overall number uniquely identified the conditions that generated it.

Again, because they reflect different forms of vulnerability, the indicators are appropriately applied at different geographical scales. In this document, the following indicators are recommended to be considered, but not necessarily meaning additional or other indicators should not be adopted. Among the proposed indicators, appropriate indicators should be adopted. The guidelines for application of the proposed indicators below are for the scale of 100 km^2 or a small county level administrative units. Where data are not readily available, surrogate variables may be used. It is noted that proposed indicators for only selected Activity Sectors are listed here, and depending on the objectives and scope of vulnerability assessment, indicators for other Activity Sectors should be devised. Annex 1 discusses the rationales for showing some of the indicators for selected Activity Sector.

Land Use

Indicator	Rationale
Land surface area (km^2)	The land surface lias various functions for controlling water retention and run-off, and lias potential for human productive activities.
Population	Population is indicative for the size of productive activities and life.

Agriculture

Indicator	Rationale
When flooding occurs (1= immediately prior or during harvesting period; 0 otherwise) Duration (0 = less than 5 days; 1 = 15 days; 2 = 6 weeks or more during growing seasons) Crop type (0-2, depending on crop type significance in the basin)	Flooding in any fallow periods will have little impact on crops; flooding extending over the harvest period will destroy crops Loss to standing crop is dependent on duration of flood; extended flooding may preventing planting of the next crop. Some crops are more important than the others in a specific river basin.
Arable land area/land surface (%) Depth (<2 metres = 0; > 2 metres = 1)	The arable land surface is indicative of the size of agriculture. Loss of draft animals will impoverish

—loss of draft animals and livestock	the population and make agricultural production very difficult

Risk to life

Flashy catchments	
Steepness of sloop	**> 0.3 (1) < 0.3 (0)**
Ratio of discharge of 200 year return period flood to annual average flood*[1]	**> 20 (1) K 20 (0)**
Slope stability under 200 year return period rainfall intensity	**Low (1)** **High (0)**

Behind natural or artificial defences	
Behind a natural or artificial defence line (including in natural depression)	Yes (1) No (0)
Depth of flooding	**> 2metres(1)** **< 2 metres (0)**
Velocity of flood flow	**> 2 metres/sec (1)** **< 2 metres/sec (0)**
Potential warning lead time	**<** 12**hours(î)** **> 12 hours (0)**

***** use 200 year 24 hour intensity rainfall for small area in absence
[1]return period and ratio should be adapted to national or regional conditions

Economy

Score	Indicator	Rationale
%	Economic value of flood losses* as equivalent to a % of the Gross National Product OR as a % of Government income	Represents the difficulty of funding replacements to buildings, services and goods lost in the flood
%	Percentage of capital value of the basin's buildings, infrastructure and plant (if statistics available)	Represents likely impact on long term economic growth
%	Critical industrial sites at risk (% production in specific categories e.g. power)	Represents the extent to which flooding will disrupt production elsewhere in the basin (use highest % of industrial sectors identified)
%	% basin's stable food production that might be lost in a flood	Represents the difficulty of replacing food supplies from reserves or imports

	(measured as proportion of average daily intake)	
%	Population at risk as a proportion of the basin's population	Represents the difficulty of sheltering displaced population

Exclude reductions in indirect and direct taxes as in economic terms these are transfer payments; economic value of flood losses should be measured using the standard methods for assessing flood losses.

Populations

Score	**Indicator**	**Rationale**
0— no 1 - yes	Newly Urbanised areas populated by migrants from rural areas	Low in social capital (Krishna and Shrader 1999), lacking in family and kinship links
0— below national average 1 — above national average	Landless workers in rural areas	Loss of income from harvesting, lack of assets against which to borrow
0— below national average1 — above national average	Elderly/disabled	Physical difficulties in coping with the flood
0— below national average 1 — above national average	Poor	Lack of capital and ability to borrow
0— below national average 1 — above national average	Ethnic minorities	Whilst these are not invariably discriminated against in a country, they frequently are in most countries
0 — below national Average1 — above national Average	Female headed households (both permanent and temporary i.e. partner is a migrant worker)	Likely already to experiencing over work; gender biases likely to restrict access to resources (e.g. in extreme cases, requiring male relative to accompany her in public)

Housing

The housing in the basin is categorised into the following groups:

Category A	A1	Mud Walls (ah roofs)
	A2(a)	Unburnt brick or adobe wall with sloping roof
	A2(b)	Unburnt brick or adobe wall with flat roof
	A3(a)	Stone wall with pitched/sloping roof
	A3(b)	Stone wall with flat roof
Category B	(a)	Burnt brick wall with sloping roof
	(b)	Burnt brick wall with flat roof
Category C	C 1(a)	Concrete wall with sloping roof
	C 1(b)	Concrete wall with flat roof
	C2	Wooden walls (all roofs)
	C3	Ekra walls (all roofs)
Category X	Xl	Corrugated iron, zinc or other metal sheet walling (all roofs)
	X2	Bamboo, thatch, grass leaves,

(Building Materials and Technology Promotion Council 1997)

Risk level could be broken down into various degrees of damage. For example:

Rating	Very High Damage Risk	Total collapse of buildings
4	Higo Damage Risk	Gaps in walls; parts of buildings may collapse; separate parts of buildings lose their cohesion and inner walls collapse
3	Moderate Damage Risk	Large and deep cracks in walls, fail of chimneys on roofs
2	Low Damage Risk	Small cracks in walls; fail of fairly large pieces of plaster, pantiles slip off; cracks in chimneys, part may fall down
1	Very Low Damage Risk	Fine cracks in plaster; fall of small pieces of plaster

(Building Materials and Technology Promotion Council 1997)

As a result based upon some basic criteria and historical records, for example, it would be estimated that a rural village made up of burnt brick walls with sloping roofs faces a high risk of damage from a fifty-year flood.
Category A2(a) / Fifty Year flood = High Damage Risk

Environment (Ecosystem)

	Indicator	Rationale
Rate	Ecosystems linked to river (0) Ecosystems dependent upon artificially created water regime (1)	Flooding is only a severe threat to ecosystems that have developed because of an artificial water regime.
Number	Number of Internationally important protected areas; Nationally important protected areas; and Locally important protected areas.	As determined by the national government.
Number	Number of endangered/rare/indigenous species (according to IUCN and national Red Books)	As determined by the national government
%	Natural and regrowth vegetation coverage	The vegetation cover is relevant to coping capability of the catchment.
%	% of degraded land	Flooding might cause soil erosion in the catchment
Degree	Degree of slope (average)	The soil erosion is relevant to the slope degree
Ton/hectre	Use of chemical fertilisers (N,P and K) per unit area	This represents possibility of nutrient run-off, which potentially cause pollution.
Ton/hectre	Soil erosion rate	This represents possibility of soil loss by floods.
Rate	Recovery time > 25 years (4) Recovery time < 25 years (1)	Some ecosystems can be re created relatively quickly and with a fair certainty of success. Others have developed over hundreds of years.

III D. Data Needed and Use of Remote Sensing Techniques

The vulnerability assessment will require a wide range of data/information. In principle, no primary data/information will be produced out of the vulnerability assessment. The assessment will rather based on the readily available information and data. When data/information collection is designed and selection of indictors are made, it is proposed that the following two data collection schemes are designed:

1. Data already produced by an administrative unit (country, prefecture, province, river basin, etc.); and
2. Data already available for a rather wide area (country, region, big river basin, etc.).

Concerning the second data collection scheme, it is recommended that remote sensing techniques be applied as much as possible, since such techniques made available data and information that could not otherwise be available. In doing this, it is recommended that a scale of mapping and frequency are decided and incorporated into the vulnerability assessment schemes. The vulnerability should change from time to time depending on the environmental and socio-economic conditions, the vulnerability assessment be repeated at a certain time interval. When such repeated assessment is designed, it is crucial that data collection schemes are already incorporated into the assessment process, so that data acquisition efforts can be saved.

It is recommended that, prior to the vulnerability assessment, data collection plan and scope of data should be determined in consultation with relevant stakeholders and data holders.

III E. Presentation of Vulnerability Index/Indicators

Each indicator should be shown on a map using the GIS. Further, it is recommended that each category of vulnerability indicators will be composed into an index (land use, economy, risk to life, building, etc.) to be also shown on a GIS presentation. Finally, an overall vulnerability index (a composite of all the indicators, most probably weighted based on the significance of each indicator) will be presented, if such index is deemed meaningful.

III G. Capacity Building Activities

The results of the vulnerability assessment should be used for future decision making for establishing or modification of flood preparedness plan, involving a wide range of stakeholders. This means that a wide range of stakeholders should be aware of the objectives and potential use of results of the vulnerability assessment and should be involved in data collection activities. Therefore, in carrying out the vulnerability assessment, the following type of capacity building activities are proposed to be carried out:

1. Sensitisation of the concept of vulnerability and its assessment among a wide range of stakeholders through workshops and community meetings, etc.
2. Training courses on data quality control for input to vulnerability assessment, particularly administrative units that would be engaged in data collection;
3. Training courses on use of remote sensing for data acquisition; and
4. Training courses on use of GIS for data presentation.

It is therefore ideal that capacity building activities will be carried out parallel to the actual assessment.

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Annex. I

Discussion on vulnerability in selected Activity Sectors.

In this Annex, some discussion on the perceived vulnerability based on the interactions with other factors for floods is given for, as examples, agriculture, risk to life, economic section and environmental sectors. This discussion does not cover all the interactions a specific Activity Sector lias. Further, the Annex is indicative examples of several selected Activity Sectors.

Agriculture

For crops, the duration of the flood lias some effect but the timing is more important. In areas where two or three crops are harvested each year, a flood that extents over the harvesting season for one crop and the planting period for the next can result in both crops being lost. Whilst flooding may result in fertile silt being deposited, or nitrogen fixing algae brought by the flood water may also increase subsequent crop production, floods may also deposit sand and reduce soil productivity. Now there is a risk that the flood will be contaminated with either a herbicide or toxins that make crops unfit for human consumption. This may occur if, for example, a factory upstream, in which such materials are produced or are stored as part of the production process, is flooded.

In the case of rice growing, vulnerability to flooding can be reduced by growing deep water varieties of rice but at the cost of a reduction in yield.

The risk to life

Buildings are a potential place of refuge in a flood and are frequently used as such by the people in a flood risk area. The partial or complete failure of the buildings in which they are sheltering to provide a safe refuge is consequently a significant factor in the number of deaths resulting from flooding. The probability that a building will partially or completely collapse in a flood is therefore an important factor. Unfortunately, there is very limited data on the conditions that will induce the collapse of a building in a flood and that work is restricted very largely to the lightweight timber construction typical of domestic buildings in North America. There is limited data for masonry structures and none for concrete framed domestic buildings. In each case, it is the combination of depth of flooding with the velocity of flooding that is important. The available data implies that it is the velocity of the flood flow that is the critical factor and agree in defining a velocity of 2 metres a second as the critical velocity. Velocities in flash floods have been known to reach 15 metres a second.

Because they present less of an obstacle to the flood flows, it may be that the concrete framed structures are less likely collapse in a flood than load-bearing masonry buildings. That the more modem structures are often designed against earthquakes also probably decreases their vulnerability to flood flows.

Observing buildings on the Yangtze floodplain that were flooded following the failure of secondary dikes suggest that the criteria given in the figures are conservative. Traditional structures of dried
mud/sun dried brick are probably best assumed to be destroyed in a flood but the same may not be true of bamboo or timber framed dwellings: in Bangladesh, a traditional place of refuge in a flood is under the roof space of the dwelling.

Unfortunately, a combination of depth and velocity is not the only mechanism that causes the structural failure of buildings. The debris carried by a flood in the form of trees and boulders can cause battering damage; one flood in Nepal deposited what is reported to be a 5000 tonne boulder. Buildings close to a watercourse frequently experience undermining as the flood erodes the channel and undercuts the buildings' foundations.

In addition to offering a possible place of refuge in a flood, damage to buildings is also one of the primary components of flood losses. Depth alone is sufficient to cause damage to most structural types. Since most activities take place in buildings, the repair or reconstruction of buildings is a critical factor in the time taken after a flood for normal activities to resume.

Bridges quite frequently fail in a flood either because scour undermines the bridge supports or abutments, or because the openings are blocked by flood borne debris, the bridge then failing catastrophically under the build up of water. The flood wave, together with the debris carried with it, then poses a threat to the lives of those people downstream.

The failure of buildings as a place of refuge is not the only way in which a flood can pose a risk to the lives of those living or working on a floodplain. A number of studies have been undertaken to assess the limiting conditions under which it is safe to walk or drive through a flood (Abt et al 1989; Emergency Management Australia 1999; New South Wales 1986). A number of statistical analyses have also been undertaken of past floods in order to try to calculate the probability of death in a flood (DeKay and McClelland 1993; Kraak 1994). The difficulty in such analyses is in determining the appropriate divisor: the population in which the deaths occurred. It may be that whilst the number of people who were affected by the flood was several hundred thousand, most of the deaths occurred in one or two specific areas in which only a few hundred people were located. In those specific areas, the probability of death may have been very high indeed.

The economy

An economy can be described (Green 1995) in terms of network: a series of nodes linked together. The nodes then represent different forms of productive and service capacity and the links include transport, utility and telecommunications infrastructure. In the event of a flood, some of these nodes are directly flooded and some of the links are cut. As a result of these cut links and flooded nodes, some of the remaining unflooded nodes are prevented from functioning normally and some of the links may become overloaded.

The impact on an economy such as a flood is then a function of the extent of the flood and the local nature of the network that is affected, and also on the duration of the flood. No production will take place in industrial plants in the flooded area during the flood or for some time after and production outside of the flooded area may be affected because of the short supply of goods normally produced in the flooded area. Similarly, the population will require to sheltered and supported for the duration of the flood and during the recovery period afterwards.

Because a primary element of the challenge is the total area flooded, the focus should be on the precipitation event, since a single event such as a typhoon or cyclone, can result in floods occurring across several different catchments and not on the probability of an individual river flooding. Thus, in Bangladesh, all three of the great rivers flood simultaneously. The overall geographical scale of the resulting floods is the most important predictor of national or provincial losses.

The nature of the economy as a network are also determine the extent of its vulnerability; a highly concentrated economy made up of a few large plants and with very limited networks of transport and infrastructure, is more vulnerable than an economy made up of many small plants producing very similar goods. In general, flooding of a node will cause greater disruption than of an individual link. For example, a modern railway system is controlled through a few electronic signal boxes, each of which controls a large area of the network. Damage to one signal box may consequently cause disruption over a large area.

The more developed the economy however the greater tends to be the degree of industrial concentration; thus, if one plant is flooded, it can be difficult to make up that production elsewhere because there are very few other plants that can or do produce the same product. Therefore, the proportion of national production of particular goods undertaken in a flood risk area is an indicator of national vulnerability. Unfortunately, national industrial statistics are not generally sufficiently detailed to identify the degree of concentration for different types of production. For example, the factory that produces 60% of the United Kingdom's bakers' yeast production, essentially for baking of leavened breads, is located on one floodplain in England. However, national industrial statistics are not disaggregated to the level of bakers' yeast. Input-output tables, and more particularly the raw statistics upon which they are based, may contain useful information.

Apart from the obvious installations such as power stations, it may be difficult to identify critical industrial installations but these will include pumping stations for gas and oil pipelines. Metro systems are obviously highly vulnerable. Whilst the advice of other Ministries may be sought, the analyst should think like a saboteur and seeking to identify those points in the economy where most disruption can be caused.

Economic vulnerability is increasing over time as a result of a number of trends. Production is becoming increasing specialised and concentrated; cleanliness is a critical requirement for many forms of production, such as micro-electronics, whereas the older industries were inherently dirty; computer controlled machinery is more readily damaged and more difficult to repair than the older style electromechanical machine tools; and ‘Just In Time’ inventorying makes plants more vulnerable to any disruption in supplies of components or raw materials. Conversely, the spread of mobile phones lias probably reduced the vulnerability of telecommunication networks: the tree like structure of telephone systems made these highly vulnerable to flooding, particularly trunk telephone exchanges.

In general, the vulnerability of an economy is lowered to the extent to which redundancy in both nodes and links is increased, there being multiple paths between any two nodes, and there is diversity: there exist different forms of alternatives to each requirement. For example, the 1929 Mississippi literally cut the USA in two, the main means of transport between east and west coasts being the railway and the main means of communication being the telephone and telegraph. The 1993 flood had less impact because of the expansion of air travel and the existence of microwave and satellite based telecommunication links. One form of redundancy is the existence of excess capacity, for example, in generation capacity, the margin of supply over demand. Redundancy can also be increased by the expansion of national grids to transfer power from one region to another.

In the long term, the significance of the losses may lie in the necessity to divert resources away from long-term investment towards replacing or repairing flood losses. Governments in particular must finance repairs to infrastructure and public services, and usually aid flood victims. This additional expenditure can only be financed by additional borrowing or cuts in other current capital and recurrent spending (new financial instruments such as CAT bonds do not change this significantly). The larger the flood relative to the size of the country, the greater is typically the loss relative to annual national capital investment and hence the possible impacts on long term development. Even relatively small proportional losses will displace a large proportion of normal capital investment and even a fraction of recurrent expenditure.

Population

The capacity of a household and population to cope with a flood is partly dependent upon the availability of resources relative to the challenge presented, with resources being defined in the widest sense and including social capital (Krishna and Shrader 1999) for example. But, coping capacity is not defined by access to resources in the time available: it is also limited and defined by the range of coping options open to that household, company, community or society. Those who worship snakes may not kill one if confronted by it. The selection of the best option to adopt is equally limited by knowledge both of alternative options and their likely success if adopted. It lias been found, for example, that males are more likely to agree than females with a statement that they panicked in a flood, and that agreement with this statement is correlated with agreements with the statements that they were afraid and did not know what to do (Green et al 1991). Uncertainty about the best course of action to adopt is itself apparently a stressor for males.

Experience is a two-edged sword: a flood that is a ‘surprise’ thus presents a particularly difficult challenge, particularly if the flood changes state rapidly. Conversely, one role of flood warnings is to attempt to provide the lessons of experience to those who have not previously experienced a flood.

Table 5 summarises the resources that a household may be able to mobilise in order to cope with a flood.

Table 2 Factors influencing household coping capacity

Social capital	The degree to which a community exists influences the extent to which individual households can access shared resources both physical and psychological.
Savings and/or borrowing capacity	Rapid recovery in terms of replacing destroyed goods and replacing/repairing the home depends upon either access to savings or to borrowing.
Skills and number of people in household	Influences ability to respond both during the flood and in the recovery phase.
Health (World Health Organisation definition)	Those who are in less than full health are less able to cope with the physical and psychological stresses imposed by a flood.
Knowledge and experience	Previous experience of flooding or knowledge as to the appropriate responses to adopt
Social capacity	Political power and capacity to obtain support from government and other sources
Family and kinship links	A source of physical, monetary and psychological support.

Environment

In general, it is more likely to be the case that works to mitigate against flooding will cause environmental harm than natural flooding. Dams and changes to the river channel are both likely to result in environmental benefits and damages, and the creation of artificial wetlands to act as flood storage areas can have environmental benefits.

Floods do cause specific damage as a result of ‘disturbance’ following flood events. For example: by covering grassland in sand; washing fish fry away in floodwaters, or by isolating aquatic communities isolated when a river changes course after a flood. However, floods are part of the natural hydrological cycle and in natural floodplains, the effects of a flood are short term (Haeuber and Michener 1998). Even extreme events (for example, 1 in 100 year events) do not seem to cause more drastic changes than lesser events.

- Flood borne pollutants; and
- Sites created by artificial water regimes.

Floods increasingly carry pollutants either picked up from fields pesticides) or from storage areas and production plants. These damage both to the ecology of the river and also to areas of the floods.
(e.g. nitrates and can cause severe floodplain during

In areas where flood alleviation or irrigation works have existed for some time, local ecosystems will have developed to match the resulting water regime: typically one without floods and with a drained soil. Such sites may be susceptible to damage by flooding.

There is a third possible exception and this is the effect of floods on offshore environmental sites. Floods may damage offshore sites by the deposition of sediment and also flood borne pollutants, but the effects of flood mitigation measures may also increase the deposition of sediment in offshore areas.