PART II

DISASTER PREVENTION

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CHAPTER 3

THE ROLE OF DISASTER PREVENTION IN NATIONAL PLANNING

In recent decades people throughout the world have become increasingly alarmed by natural disasters which have tended to become more and more destructive as they affect ever larger concentrations of population. Mankind has not so far been able to control the forces of nature. He cannot prevent the formation of a tropical cyclone, nor can he prevent an earthquake or the eruption of a volcano. However, he is able to contain rivers, to stem tides and to build structures that will give very considerable, if not total, resistance to the forces of nature. Since natural phenomena will continue to occur, the problems they present must be faced, giving due priority to policies for disaster planning and prevention and using all the resources and skills that can be derived from every field of knowledge.

It should be realized from the outset that it would be grossly inadequate merely to plan and implement relief actions to be applied after disasters have occurred. The actual and potential consequences of disasters are so serious that much greater emphasis should be given, nationally and internationally, to planning and prevention.

Priority should be placed on planning and prevention because of the dual phenomena of rapid urbanization and the high rates of population growth, particularly in the developing countries which have experienced frequent recurrence of large-scale natural disasters. According to United Nations estimates, more than 50 per cent of the world's population will be living in urban areas by the year 2000. Whereas most countries in the developing world double their national populations every 25 to 30 years, the same countries double their urban populations every 12 to 15 years. In the case of the urban poor living in slums and squatter settlements, there is often a doubling of population every seven years or less. The sheer magnitude of the human problem in disaster-prone areas, especially the rapid expansion and concentrations of population in slums and squatter settlements, indicates that relief measures and post-disaster action alone are not sufficient.

Objective of disaster prevention

The objective of disaster prevention is to promote the prevention, control and prediction of natural disasters. Three important findings of the UN system have indicated that: (*a*) disasters constitute a major development problem for most disaster-prone countries; (*b*) most disasters can be prevented; and (*c*) the most basic preventive measures are also the least expensive.

As already explained, natural phenomena such as tropical cyclones which can cause disasters will continue to occur. The more that is known about these natural phenomena, the more practicable it becomes to avoid disasters. Whilst it is not possible to forecast a long period ahead precisely when and where a dangerous natural phenomenon will take place, it is nevertheless feasible to make an assessment of the vulnerability of different countries or regions. For example, climatological records give the frequency of occurrence of tropical cyclones month by month in the different areas affected by them. These records can be further analysed to show how often an individual country will experience a tropical cyclone, how often the winds will exceed a given strength, how often the rainfall will exceed specified amounts and how often severe storm surges may occur. Furthermore, within a country it is possible to indicate the most vulnerable areas, bearing in mind that the major proportion of human losses and property damage in a tropical cyclone is caused by flooding, produced by intense rainfall, and by storm surge, generated by violent winds.

The type of hazard analysis just described is but one step, a highly important one, in meeting the objectives of disaster prevention. With this knowledge, it can be claimed that disasters can be averted if human activities take place in areas having the most favourable conditions, that is, in those sites least exposed to disaster. This is self-evident but

is worthy of fresh emphasis in the form that there is always a choice between a dangerous site and a less dangerous one. This approach is clearly appropriate for new development but can also be applied, in the sense of relocation, to existing settlements of high vulnerability.

Role and purpose of planning

Well-organized planning making full use of all available and relevant data confers the advantage of highlighting the good and bad choices in any disaster problem. A key factor is to include in any development project a "vulnerability analysis" for an evaluation of the risks for the region concerned. The cost of such a study would be negligible in comparison with the total cost of the project being considered. The benefits to be gained are of inestimable value not only from the point of view of human lives saved and damage avoided but also in terms of the costs of relief and reconstruction which would be mitigated or avoided altogether.

The prevention and mitigation of disasters comprises action designed to prevent natural phenomena from resulting in disasters or at least to limit their catastrophic consequences. In other words, whilst the purpose of disaster preparedness is to deal with disaster situations which cannot be avoided, the objective of disaster prevention and mitigation is to avoid such situations as far as possible. Prevention refers to long-term measures which will be effective over many years, preparedness is the readiness to take action during the approach of a tropical cyclone, while it is affecting a country and after it has passed.

Countries in which considerable efforts have been made over the years to achieve a high degree of disaster prevention are able to demonstrate the substantial benefits that are constantly being attained. Countries which have not yet been able to devote much effort to disaster prevention should not be deterred by the accumulated burden of their experience with successive disasters. In disaster prevention a late start can be a matter for regret but not for despair. Governments must bear the basic responsibility for making sound decisions and for subsequent action with respect to disasters, especially for initiating appropriate measures and promoting a national awareness of, and an active interest in, disaster prevention.

Scope and complexity of disaster prevention

Disaster prevention measures are complex because of their wide scope and their technical content. They relate not merely to disasters themselves but also reflect the interaction between development and the environment on the one hand and between social and economic aims on the other. Except where social considerations are of overriding priority, decisions on disaster prevention should be based on cost-benefit and associated criteria. For example, a proposal to locate industry in a disaster-prone area should be examined in relation to the probability of damage (vulnerability) and to such economic factors as access to water, energy, transport, labour, raw materials, etc. The environmental impact of disaster prevention measures should also be considered. For example, flood-control measures and proper flood-plain management may yield valuable benefits by reducing risks of silting, soil erosion and landslide. These illustrations are superficially fairly straightforward and self-evident. However, the complexities and variety of technical aspects are seen when consideration has to be given to social, economic and even psychological factors at national, regional and local levels.

The first requirement of successful disaster prevention is a clear and forceful policy. Policies for disaster prevention should be closely allied to economic, social and environmental policies so that the cost-benefit elements of disaster prevention may be clearly incorporated into the national planning process.

Another major requirement is that policies for disaster prevention should receive the support of appropriate legislation. Basically legislation should be passed to enable governments (both national and local) to enforce essential measures within the limits of the capabilities of the government and the public concerned. In the various aspects of disaster prevention it is essential to distinguish between policies, legislation and technical measures. Firm and active

policies give strength to legislation which in turn assures the implementation of essential measures. In a general sense policies, legislation and prevention measures should be consistent with what can reasonably be done. Disaster prevention requires considerable capital and human resources. In the developing countries where such resources are still scarce, great weight should be given to those policies and measures which will steer development away from high-risk areas and diminish the vulnerability of new investments.

A third requirement for effective disaster prevention is that politicians and decision-makers in those developing countries which are vulnerable promote disaster awareness at all levels of government. Education and training are essential requirements for effective long-term benefits of disaster prevention.

Further on in these *Guidelines*, mention is made of the desirability of establishing a national disaster-preparedness organization. Such an organization, essentially concerned with contingency planning for disaster-emergency situations, may assist the national, regional and local planning authorities in identifying some of the priorities for action in long-term disaster prevention and mitigation. However, it should be made clear that governments would be well advised to avoid burdening disaster-preparedness organizations with responsibilities for prevention. Where prevention and preparedness overlap, consultation should naturally be encouraged between those organizations responsible for preparedness and national planning officials.

The conclusion to be drawn from examining the effect disaster prevention has on national development planning is that no single method or plan for prevention can be prescribed. Disaster prevention policies should encourage the incorporation of disaster prevention as one of the variables in the normal process of social, economic and physical planning. The harmonizing of disaster prevention policies and measures between different sectors of national development should be achieved in much the same way that national planning authorities harmonize economic and social goals across different sectoral boundaries. What is certain is that disaster prevention is not merely the preserve of technical sectors such as public works and building. There is a long road to cover between policy and technical implementation.

CHAPTER 4

LEGISLATION FOR DISASTER PREVENTION

Need for legislation

In every country the long-term plans and day-to-day activities of government are guided by some recognized existing legislation, decree, constitution or other measures giving authority and responsibility to departments of government or to designated boards or establishment or to individuals.

Since no country is immune to disaster which may disrupt or immobilize the normal functions of government, it is essential for each country to have legislation which firmly establishes responsibility for all necessary action, whether of a long-term or short-term nature, which are related to disaster. It is, of course, recognized that legislative provision against disaster already exists in countries concerned. Indeed, over the years as disasters and their wide-ranging effects have been experienced by a country, laws have been enacted in order to anticipate and cope with problems recognized at the time and assessed as recurring ones. In this way a body of legislation could have been built up, in some cases of general scope, in others for specific contingencies. To name but a few examples, there could be separate legislation covering land conservation, river management, coastal installations, the relief of disaster victims and the provision of finance for reconstruction.

However, as some countries have found, it is a wise course to conduct a critical examination of disaster legislation from time to time. Such a review can be expected to reveal any weaknesses that might exist. Among the questions to be considered are, apart from the adequacy of the legislation, whether responsibilities are clearly defined, whether participating organizations are properly co-ordinated, whether provision is made for overall direction and for forward planning, whether it would be appropriate to integrate all relevant items of legislation into a comprehensive system covering all aspects of disaster prevention, mitigation and preparedness.

In any system of disaster legislation it is, of course, necessary to distinguish between that body of technical legislation empowering various national, regional and local agencies to impose controls for disaster prevention purposes and the legislation which is enacted to facilitate rescue and relief operations during emergencies caused by natural disasters. Thus there are two basic types of legislation relating to natural disasters: legislation for long-term construction and reconstruction and for prevention purposes; and legislation for preparedness, emergency and short-term recovery purposes. The former, which is the concern of the present chapter, establishes the legal framework and directives for orderly and safe development or redevelopment in a fairly lengthy time scale; the latter, which forms the subject of Chapter 10, facilitates immediate access to rescue and relief.

As suggested in the previous chapter, whereas detailed legislation covering disaster preparedness, rescue and relief may be incorporated into one body of legislation, comprehensive legislation for disaster prevention is bound to be more general in the attempt to bind a variety of sectors of the national planning system to include disaster prevention criteria in the development planning process. Legislation for disaster prevention, which is aimed at enforcing specific policies or measures, should be incorporated within the general body of technical legislation covering, for example, urban development, regional development, environmental management, resources management and exploitation, public works, communications, housing, and so on.

Vulnerability analysis

A country's past experience of disasters will go far in determining the legislation required for disaster prevention. A description and analysis of the natural hazards and consequent risks involved should therefore be undertaken as a preliminary step in reviewing current legislation and assessing what new measures are required. Moreover, legislation for disaster prevention should stipulate that analyses of all risks should be undertaken before new development is approved in disaster-prone areas, and that micro-zoning risk maps for all hazards should be included in the preparation of land-use maps and land-use controls.

Scope of legislation

Probably the most important aspects to be covered in legislation for disaster prevention are concerned with physical planning, urban planning and building. The following are some examples of the types of measure that might be covered by legislation:

(*a*) The preparation of risk micro-zoning maps for all hazards;

(*b*) Land-use and zoning laws to restrict or prevent industrial and/or residential development in areas where the risk is high, e.g. flood plains and low-lying coastal areas subject to storm surges;

(*c*) Building codes setting out minimum safety standards in areas vulnerable to tropical cyclones;

(*d*) Soil and plant conservation measures to guard against erosion;

(*e*) Engineering measures relating to the management and control of rivers, canals and other areas vulnerable to flooding or storm surge;

(*f*) Public health measures concerned with sanitation (air, water and waste disposal) and related matters.

Furthermore, in the context of regional development, legislation may be needed to establish resettlement criteria in areas of high vulnerability. In economic development, disaster prevention legislation may be used to enforce the establishment of cost/benefit criteria with regard to disaster risk and vulnerability.

Since legislation exists to protect the natural environment, disaster prevention legislation should be made to harmonize with environmental criteria. This is particularly true with reference to river basin and flood-plain management. In this area the interaction between the environment and disaster prevention is evident and its consequences far-reaching.

Social legislation and disaster prevention legislation may interact vigorously. For example, the location of given populations and the way they build are important factors in their social and, of course, economic development. Disaster-prevention legislation should not negate the goals of social development by forcing systematic relocation or resettlement or by enforcing building codes that are technically so complicated for the population concerned or too costly. The harmonizing between social and economic goals and between short-term and long-term goals is no simple task, especially in the social field where the public tends to look to immediate or short-term benefits even when the risk is known to be high. Significant legislative modifications to the social pattern in order to satisfy disaster-prevention purposes should be accompanied by legislation to stimulate corresponding economic and infrastructural changes so that the fabric of society is not damaged. This is an extremely costly procedure and thus legislation which is likely to have a social impact should be formulated with great caution and flexibility.

The above examples are not exhaustive, but are designed to point out some of the intricacies of disaster-prevention legislation. They are also designed to point out that disaster-prevention legislation is but one variable in the body of legislation covering development in general.

Legislation for land-use control, zoning and building codes

Special mention should be made of land-use control and zoning and of building codes, for these are subjects of immense importance in disaster prevention and are dealt with separately in Chapters 6 and 7 respectively. Due weight must be given to these subjects in legislation for disaster prevention and, because of their importance, some discussion of them in this chapter is justified.

It is noteworthy that in some areas which are affected by tropical cyclones, the process of urban and industrial development has often tended to create new or enhanced hazards for the inhabitants and their property and for commercial installations as well as for public utilities. Although the existence of potential danger may be recognized, various factors such as the lack of a vulnerability analysis may lead to a failure on the part of responsible authorities to appreciate that when the potential danger becomes an actual one, the results may be measured in lives lost and in enormous damage. Often, particularly in coastal or riverine areas, the natural attractions of a locality for industry, housing or recreation are allowed to override safety considerations As a result, development continues with apparently little objective examination of the uses for which the land is best suited and, as a further consequence, structures are not adapted to the extreme conditions that are likely to arise whenever a tropical cyclone is experienced.

These points are illustrated, and indeed emphasized, by remarks made about the building boom in hurricane-prone coastal areas of the United States of America. As recently as 1974, an official made the comment: "Unless something is done to curb overbuilding in such areas, nature is likely to impose its own solution." It is to avoid radical and devastating solutions of this kind that the regulation of land use and zoning and the application of building codes based on an evaluation of the risks of the area are necessary. As examples, areas of extreme risk could be left undeveloped; areas of medium hazard could be inhabited at a low density; emergency services should be based in safe areas.

A little consideration will show the need for a nationally recognized set of disaster prevention or mitigation criteria derived partly from climatological, geographical and geological characteristics and partly from the records of past disasters. Such criteria would be applicable to both governmental and private construction. By means of this national approach to the subject, it is possible to avoid a number of problems that could lead to inefficiency and confusion. Responsibility would be clear-cut with no uncertainty as to the role of government or municipal authority and on all technical matters the best available professional advice would be brought to bear. National agencies that have large construction programmes and have the expertise to contribute to the development of building standards should be invited to participate in the formulation of the required criteria for disaster prevention and mitigation. The designation of a lead agency would have the valuable effect of imparting direction and consistency to the effort.

When nationally recognized criteria come into existence with all appropriate authority there will remain a need for effective leadership to ensure that at local level hazard-reducing regulations are introduced to cover land use and construction. A national focal point could be established to provide this leadership and to undertake the following activities:

(*a*) Co-ordinate land use and construction research in the private and public sectors;

(*b*) Evaluate new land use and construction technology and foster the use of new products and practices by industry and by government units at all levels;

(*c*) Keep under review national land-use planning and construction standards and their regional application, taking into account variations between one region and another in the degree of vulnerability to natural disasters;

(*d*) Act as a clearing house for information on land use and construction.

One way to establish this focal point would be to charge an existing department of government with the functions listed above. The department so charged should possess a broad technical expertise in both land use and construction and should have contacts with national and local jurisdictions and also with private organizations active in land use and construction.

Disaster-prevention legislation in practice

In the past decade or so some countries have reviewed, updated and codified their legislation on disaster prevention and it may be helpful to give a brief description of the body of legislation that might be the outcome of such an exercise. It should be emphasized that such legislation, if it is to meet all requirements in a comprehensive manner, will be complex and voluminous. The formulation of the legislation is no simple task but it is essential and well worth while.

So that orders of magnitude may be appreciated it might be mentioned that in one country with considerable experience of tropical cyclones, disaster-prevention legislation amounts in all to more than a hundred articles divided into ten or more chapters. For purposes of illustration it is suggested that separate chapters might deal with subjects as follows:

(*a*) The first chapter would state the objectives and purposes of the legislation and would show the relationship between the disaster-prevention legislation and other laws of the country. This chapter would also contain definitions of terms and would set out clearly the responsibilities of central government, regional and local authorities, public corporations, other bodies and of individuals;

(*b*) The second chapter might deal with the machinery of disaster prevention, e.g. the establishment, functions and terms of reference of a Disaster Prevention and Preparedness Board; making provision for corresponding bodies at regional and local level; laying down the arrangements for direction, control and co-ordination;

(*c*) The third chapter might be concerned with administrative matters and subsidiary plans related to disaster prevention, e.g. flood control and fire precautions;

(*d*) A chapter on logistic aspects such as the deployment of facilities and the stockpiling of materials in designated locations;

(*e*) A chapter on social and welfare matters where the efficiency of local or municipal authorities is of paramount importance. This chapter would deal with the emergency organization, warning systems, evacuation of towns and villages and so on;

(*f*) A chapter on financial and budgetary arrangements;

(*g*) Other chapters dealing with the control and other arrangements in an emergency situation, with the maintenance of public order, etc.

CHAPTER 5

RISK EVALUATION

Risk evaluation or, in other words, an assessment of a country's vulnerability to disaster, should be regarded as an essential element in the planning and implementation of measures which are designed to prevent or mitigate the disasters which tropical cyclones may cause. Naturally, if a country lies in the path of tropical cyclones, action of various kinds must be taken in order to save lives and reduce damage even if detailed risk-evaluation studies have not been carried out. Such action is well worth while, certainly better than no action at all, and if it is based on a reliable stock-taking of past experience, it would probably be endorsed to a high degree by the results of any subsequent studies of disaster potential. However, whilst action should be taken which, on qualitative considerations, is thought to be necessary, this should be followed as soon as possible by a risk-evaluation study which offers the best means of ensuring that protective measures are comprehensive, i.e. that no important requirements are overlooked, and economical, i.e. that excessive, even unnecessary, expenditure is not incurred.

The description and assessment of hazards should be regarded as an essential element of disaster prevention and mitigation. If sufficient data of acceptable quality are available, it may be feasible to estimate risks in quantitative terms for small areas, i.e. at local level. This procedure is called risk-micro-zoning and maps showing the spatial distribution of risks are especially important in regard to river flooding and storm surges. Such maps can play an essential role in economic and physical planning and in the equitable financing of insurance schemes.

A number of countries with well-developed organizations for coping with the multitude of threats presented by tropical cyclones regard risk evaluation as a subject for intensive and constant study. In countries such as Australia, Japan and the U.S.A. such studies play a part in the review and further development of the national facilities for disaster prevention and preparedness and for early warning. In Hong Kong a series of vulnerability studies is proving of great value.

The importance of risk evaluation has also been recognized by the World Meteorological Organization and the United Nations Environment Programme, which have jointly prepared a report to assist national meteorological and hydrological authorities to contribute to any fundamental investigations carried out in their country in order to assess the hazards which the country faces from tropical cyclones. An overall assessment will include not only meteorological and hydrological aspects but also social, economic, geographical and other factors. When all necessary studies have been completed, the findings should be examined carefully by appropriate government departments and the resulting decisions should then be made public and fully explained.

The national problem

Considering the national viewpoint on disaster prevention and preparedness, if a country is vulnerable to natural disasters, such as tropical cyclones, the best way over a long term of saving lives and of reducing damage is first to investigate the country's potential for disaster and then to take suitable action on the results that are produced by the investigation. If a type of disaster is ignored, it will go on taking its toll and, whether it occurs frequently or seldom, lives will be lost unnecessarily and a great deal of avoidable damage will occur. A tropical cyclone, often described as the most powerful storm on Earth, need not become a disaster unless man heedlessly exposes himself and his property to its destructive forces.

A tropical cyclone, as a single event, is a test of the effectiveness of a country's organization for disaster prevention and preparedness By the time a tropical cyclone has formed over the ocean and been detected, there will not usually be much time to do more than implement the emergency measures that already exist. The Meteorological Service will make every effort to plot and predict the movement of the cyclone and, as it approaches the country, issue warnings to responsible officials and to the general public, but the protection of the country and its people from the effects of violent winds, of river flooding and of storm surge will largely be dependent on measures that have been taken over several or more years in the recent past and on the efficiency and zealousness with which they are applied in time of emergency.

By evaluating the risk to which a country is liable in the case of tropical cyclones, or its potential for disaster, it becomes practicable to plan and implement the means of protection in an economical manner. For example, without such evaluation it is possible that buildings would be constructed with so little strength that they would be demolished by the winds associated with a tropical cyclone of no more than moderate intensity. At the other extreme buildings might be made strong enough to withstand winds which are unlikely to occur during the normal life of the building. Considerations of location are of equal importance. The vulnerability analyses will reveal that some zones are less vulnerable than others and will therefore provide valuable guidance in the planning of residential, business or industrial areas where the density of occupancy is likely to be high.

The evaluation of risk or the investigation of disaster potential can generally be done in a fairly straightforward way, using long-term meteorological and hydrological records of the country, supplemented if necessary by data available from neighbouring countries. Analyses of all these data may be expected to highlight the different measures that can be taken in order to counteract the possible consequences of every tropical cyclone that may reach the country in the future. It would then be necessary to make decisions based on social, economic, regional and other considerations on how to plan and organize the protective measures over a wide range of requirements. It may be decided, for example, that some facilities should be protected against the worst tropical cyclone likely to occur every 100 years; other facilities may only be made strong enough to withstand the tropical cyclone with a return period of ten years. In general, the longer the period of protection, the greater will be the expense.

As a first step the climatological records should be analysed in order to discover how often tropical cyclones of various intensities strike different areas or regions of the country. All possible sources should be considered in order to have available the most complete data possible, e.g. by recourse to World and Regional Meteorological Centres in WMO's World Weather Watch. Old records in libraries and newspaper offices will often furnish valuable information especially about the worst storm experiences since these are likely to have been more fully documented by journalists and historians.

Figure 5 is based on a study of hurricane frequencies along the south-eastern coastline of the United States of America. The coastline was divided into segments, numbered 1 to 58 in the figure, each segment being about 80 km in length. In analysing the data for the 85-year period, 1886-1970, it was assumed that if a tropical cyclone of hurricane intensity crossed the coastline in one of the 80 km segments, the adjacent segment to the right was also affected. For example, a tropical cyclone which crossed the coastline in segment 2 was counted for that segment and also for segment 3. Below each segment in the figure is given the probability, expressed as a percentage, that a hurricane (winds exceeding 33 metres per second) or a great hurricane (winds exceeding 56 metres per second) will occur in any one year in a segment of the coastline.

In addition to tropical cyclone frequencies, information should be obtained about tropical cyclone tracks for the past 50-100 years over the ocean adjoining the country. All the data so far referred to can be used to estimate the probability of storms of various intensities striking the country and the probabilities can readily be transformed into mean return periods of storms of specified intensities for different sections of the country.

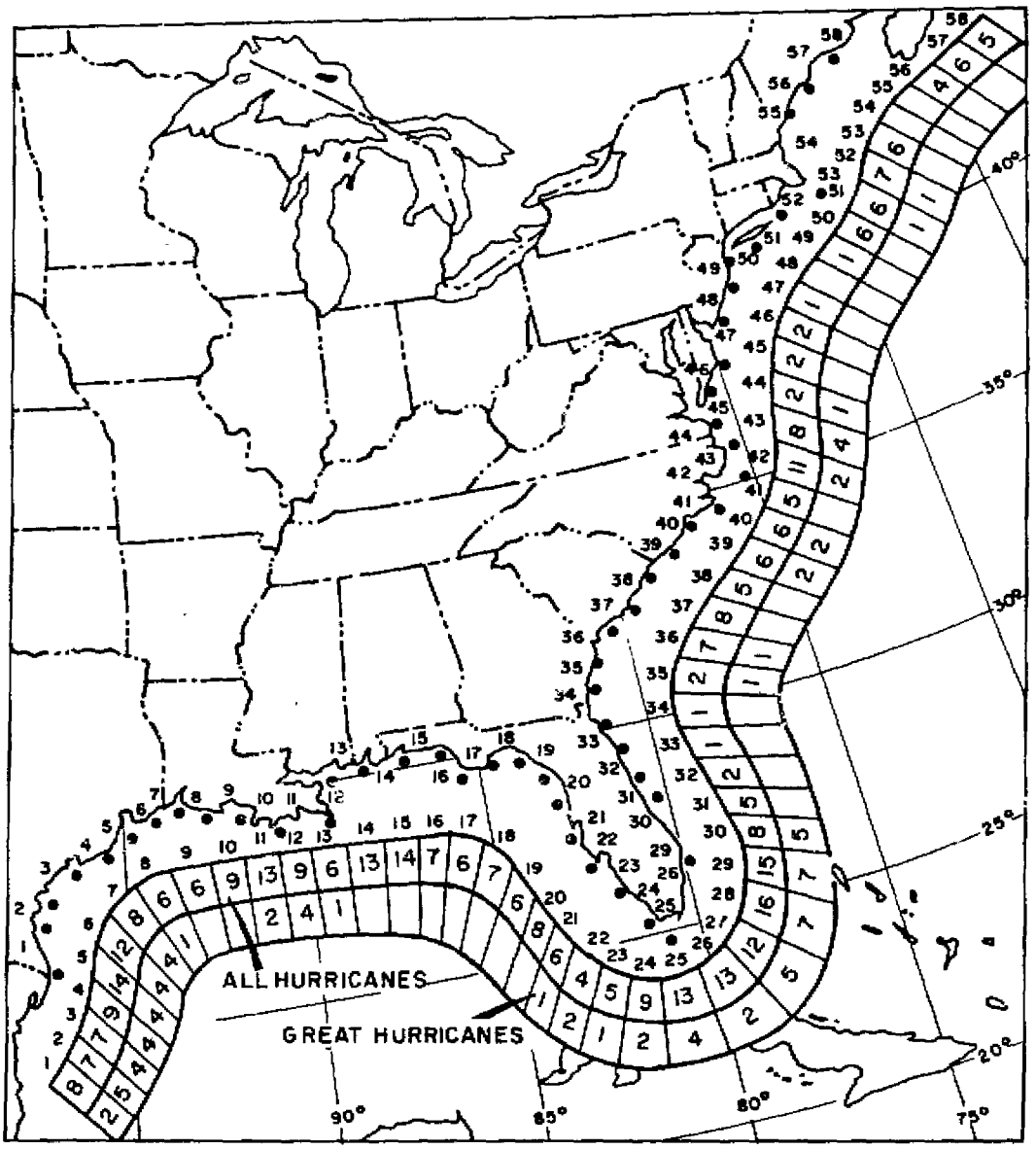

Figure 5 – Probability (percentage) that a hurricane (winds exceeding 33 m s^{-1}) or great hurricane (winds in excess of 56 m s^{-1}) will occur in any one year in a segment of the coastline *(After Simpson and Lawrence, 1971)*

Evaluation of different hazards

When a tropical cyclone approaches a country the threats are threefold – winds, river floods and storm surges. Although strong or violent winds are a fundamental characteristic of tropical cyclones, it is often the rain-induced river floods and the storm surge which cause the heaviest loss of life and do the greatest damage. In any planning for disaster prevention and mitigation, the hazards likely to arise from winds, river floods and storm surges should be analysed separately and also collectively. It is most important to carry out composite vulnerability analyses, taking all risks into account so that measures for disaster prevention may be comprehensive and effective. In coastal areas in particular, it is necessary to make a combined analysis of storm-surge and river-flood frequency.

Winds

A tropical cyclone of the intensity of a typhoon or a hurricane has, by definition, wind speeds of at least 115 km h^{-1} (32 m s^{-1}) but maximum speeds in the most severe storms may reach about 300 km h^{-1} (85 m s^{-1}). The force due to the winds varies with the square of the speed and so a wind of 200 km h^{-1} exerts a force four times as strong as that exerted by a wind of 100 km h^{-1}. Winds in tropical cyclones are usually very gusty and may persist for a period up to about three days if the storm is very slow-moving.

Evaluation of the hazards due to the wind is primarily a matter for the structural engineer when the Meteorological Service has prepared charts or wind roses showing the frequencies of various wind velocities at selected points on the coast and inland. The engineer establishes design criteria for different sizes of building erected at various elevations above sea-level. When these design criteria become available, it is worth while to carry out any strengthening of existing buildings that may be needed to satisfy the criteria

River floods from tropical cyclone rains

The amount of rainfall experienced at a place during the approach and passage of a tropical cyclone is generally between about 75 mm and 300 mm and may be spread over a period which is as short as three hours or as long as three days. It is not possible to relate satisfactorily the quantity of rainfall to the intensity of the tropical cyclone. Some weak storms have, in fact, given very heavy rainfall and occasionally a violent storm has crossed a country quickly without causing abnormal rainfall.

It is best to accept therefore that all tropical cyclones, whatever their intensity, have the potential to produce very heavy rainfall resulting in river floods. The basic statistics giving the frequency of tropical cyclones from the comparatively weak to those of extreme violence therefore provide a useful guide to the incidence of a certain class of meteorological conditions which may produce river floods. This information is extremely valuable because in a tropical cyclone floods are associated with very strong winds and, in coastal areas, storm surges as well. However, rain-induced floods can occur in other conditions besides those of a tropical cyclone, for example, at times of frequent thunderstorms characterized by heavy and prolonged rainfall. The hydrologist is concerned with floods regardless of their origin and, in making an assessment of flood risks, he would not normally discriminate between a flood associated with a tropical cyclone and one which is the by-product of other processes. Nevertheless, in a composite vulnerability analysis when, for example, it might be required to estimate the probability of the simultaneous occurrence of violent winds, river floods and storm surges, the starting point would be the statistics relating to tropical cyclones.

Flooding can cause loss of life and property damage in many ways but the principal mechanisms are inundation, the impact of streams of water moving at high speed and the deposition of silt and debris. This damage can be avoided or its extent considerably reduced by action on the following lines:

(*a*) Construction of works such as levees, drainage systems and dams to divert or to attenuate the floods;

(*b*) Control of development of flood-prone land in order to keep to a low level the number of lives and the amount of property put at risk;

(*c*) Establishment of flood warning systems and emergency procedures.

Steps such as those mentioned above require basic data concerning rainfall and river flow. The construction of drains, culverts and bridges is normally based on design floods which are derived from depth-area-frequency relationships for local rainfall. The construction of these and other protective works is also helped by maps showing which areas are likely to be inundated to a given depth with a specified frequency. These maps are indispensable for the planning and implementation of zoning schemes for flood control and prevention purposes and, in the context of disaster preparedness, for determining areas to be evacuated and the corresponding escape routes.

To summarize, the assessment of risk from river flooding requires the preparation of rainfall depth-area-frequency relationships and of maps showing inundation frequencies for the areas under consideration. With this material, which is readily produced provided the volume of basic data is sufficient, highly reliable risk assessments can be made.

Storm surge

Some of the greatest tragedies associated with tropical cyclones have been from the drowning of people by the sea rising along the coast as the storm moves inland. The storm surge is caused by the high winds and other factors and the height of the storm surge will be related to the intensity of the tropical cyclone.

Important factors contributing to a storm surge are numerous and should be taken into account using all data available in evaluating the risk potential. These factors are:

(*a*) The wind field in the tropical cyclone;

(*b*) The angle and speed at which the tropical cyclone approaches the coast;

(*c*) The topography of the sea bed near the shore;

(*d*) The fall in atmospheric pressure over the sea surface;

(*e*) The funnelling effect in the case of bays along the coast;

(*f*) The lunar tide;

(*g*) Waves.

For risk evaluation frequency charts for intense winds are clearly required and, in addition, surveys of the topography of the continental shelf, bays along the coast and land elevations for a few kilometres inland. It is also necessary to know the normal range of the diurnal tide for each month of the storm season. In general there is a risk of high storm surge when the ocean floor drops slowly with distance from the shore and if the tropical cyclone is intense. The storm surge may be exceptionally high in a semi-enclosed bay. There is also the possibility at mouths of coastal rivers for the streamflow to add to the storm-surge effect.

A study of possible storm-surge hazards must naturally take into account the value of existing and planned buildings and installations. It would probably be impracticable to restrict occupation and industrial development to areas known to be absolutely safe. In any plans for development, therefore, it will be necessary to consider relativities. The most vital services and the most costly equipment should be housed in safe areas and should certainly not be located in places where risks are high, as would be the case on low-lying land near the coast. Activities to be carried on in areas of medium or high vulnerability should be subject to the conditions that human safety is adequately provided for and that buildings and installations are either fully protected or can be regarded as expendable.

In conclusion, it seems important to emphasize that not only separate but also composite vulnerability analyses should be included in the general process of planning development in disaster-prone areas. The costs of carrying out vulnerability analyses would form a negligible fraction of the total costs of pre-investment studies. The benefits to be derived in terms of lives saved and damage avoided by the utilization of the findings of vulnerability analyses would be out of all proportion to the costs of such studies.