LANDSLIDES AND BOULDER FALLS FROM NATURAL TERRAIN : INTERIM RISK GUIDELINES

GEO REPORT No. 75

ERM-Hong Kong, Ltd

GEOTECHNICAL ENGINEERING OFFICE

CIVIL ENGINEERING DEPARTMENT

THE GOVERNMENT OF THE HONG KONG SPECIAL ADMINISTRATIVE REGION

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PREFACE

In keeping with our policy of releasing information which may be of general interest to the geotechnical profession and the public, we make available selected internal reports in a series of publications termed the GEO Report series. A charge is made to cover the cost of printing.

The Geotechnical Engineering Office also publishes guidance documents as GEO Publications. These publications and the GEO Reports may be obtained from the Government's Information Services Department. Information on how to purchase these documents is given on the last page of this report.

R.K.S. Chan
Principal Government Geotechnical Engineer
October 1998

FOREWORD

In 1993, the Geotechnical Engineering Office (GEO) embarked on a programme of research and development studies on landslide risk management under the R & D theme on Quantitative Risk Assessment, which encompasses evaluation of risk of landslides and boulder falls from natural terrain.

As part of the formulation of natural terrain landslide risk management strategy, it is necessary to establish appropriate tolerable risk criteria for risk assessment purposes. This study was carried out by Dr A.B. Reeves of ERM-Hong Kong, Ltd as consultants under the Consultancy Agreement No. GEO 4/97. Mr K.K.S. Ho and Dr D.O.K. Lo of the Special Projects Division coordinated the work.

In this report, two options are recommended for consideration as the interim risk guidelines. These have been developed based on a detailed review of current international practices and benchmarking against the risk acceptance criteria for Potentially Hazardous Installations (PHI) given in the Hong Kong Planning Standards and Guidelines dated 1993. A presentation of the initial findings was given by the consultants to CED colleagues and geotechnical consultants on 13 October 1997 and also to the Slope Safety Technical Review Board in the November 1997 meeting. Comments received have been taken into account in finalising the Report. The draft report of the study was also reviewed by Dr J. Wrigley of the Environmental Protection Department, whose assistance is gratefully acknowledged.

It is intended that the practicality of the recommended interim risk guidelines will be verified in site-specific quantitative risk assessment (QRA) studies of natural terrain landslide hazards. Suitable refinement will be made where necessary and the geotechnical profession will be widely consulted before the risk guidelines are finalised. In the meantime, the interim guidelines can be used as a basis for the evaluation of QRA results. This staged approach in taking forward the use of QRA techniques in the formulation of an assessment framework for natural terrain landslide hazards has been endorsed by the Secretary for Works.

P.L.R. Pang
Chief Geotechnical Engineer/Special Projects

EXECUTIVE SUMMARY

The Geotechnical Engineering Office (GEO) had commissioned ERM to develop risk guidelines for landslides and boulder falls from natural terrain in Hong Kong. Given the demand for additional housing accommodation in the coming years, there may be increasing pressure to develop areas close to steep natural terrain. The objective of this study is therefore to develop a risk guidelines which can then be adopted to examine if developments close to or within the natural terrain can be permitted.

The approach for developing risk guidelines for landslides and boulder falls follow the steps described below:

Review

A review of the approaches adopted overseas in the development of risk criteria was carried out. This review included mainly criteria for major hazard installations handling dangerous chemicals in countries such as UK, the Netherlands, Australia, France and Switzerland. Criteria adopted by rail operators in UK and criteria adopted for civil engineering projects such as large dams (by BC Hydro and ANCOLD) were also examined.

A review of the risk guidelines adopted in Hong Kong for Potentially Hazardous Installations (PHI) handling dangerous chemicals was carried out. In addition criteria adopted for dangerous goods transportation and those adopted by local rail operators were also covered.

A review of the recent QRA studies on landslides and boulder falls in Hong Kong was carried out to examine the risk levels estimated by these studies and the approaches adopted for comparing the results with say existing PHI criteria.

A review of natural hazards worldwide was carried out to examine the frequency of such events and the fatalities caused to compare with man-made events. The natural hazards covered include earthquakes, tsunamis, windstorms, floods, volcanic eruptions etc.

Conclusions from the Review

The conclusions from the above review can be summarised as follows:

- all of the countries reviewed have specified acceptability criteria for major hazard installations. Such criteria are either risk based or consequence based although both the approaches acknowledge the requirement of a minimum separation distance between a major hazard facility and the surrounding population;

- there are no established criteria backed by a Government for landsliding although various criteria have been evolved and adopted for example in projects such as dams;

- the public may tolerate a relatively high risk from natural landslide hazards. However, the distinction between man-made and natural hazards is not a rigorous one. For landslides from natural terrain affecting a new development, the public may perceive a strong element of human involvement since the development was allowed to be permitted by Government in the first place. Therefore, while the hazard may be regarded as an outcome of a natural phenomenon, the risks imposed on the population are outcome of decisions made by men.

It was therefore concluded to develop criteria similar to the existing PHI criteria for Hong Kong which relate to man-made hazards.

Proposed Criteria for Individual Risk (IR)

As regards risk guidelines for Individual Risk, the study recommends adoption of the existing criteria for PHIs.

The maximum allowable Individual Risk level to a member of the public in a new development from any natural terrain landslides and boulder falls should not exceed 10^{-5} per year.

For existing developments it is proposed that the maximum individual risk to which any member of the public should be exposed from natural terrain landslides and boulder falls is taken to be 10^{-4} per year.

It is also recommended that the maximum IR criteria of 10^{-5} per year for new developments, and 10^{-4} for existing developments should also be applied to the most vulnerable population. The risk calculations should therefore take account of the higher vulnerability of such persons, and the criteria is therefore more stringent (if such vulnerable persons are present) than the current PHI risk guidelines.

Proposed Criteria for Societal Risk

The study considered various options to evolve criteria for societal risk and has recommended that the preferred option is to use the existing PHI societal risk criteria as a direct basis for the development of criteria for landslides and boulder falls from natural terrain. However, some changes have been proposed:

There should be no "acceptable" line on the F-N curve, and the principle of ALARP (As Low As Reasonably Practicable) should be applied for all risks which fall below the "unacceptable" line. This is consistent with the recent approaches for example in the Netherlands where the lower 'acceptable' line has been eliminated.

The limit of tolerability for the number of fatalities (from a single event) should be extended from the 1000 fatalities used for PHI sites to 5,000 fatalities. A vertical line should be drawn on the F-N graph at 1000 fatalities (up to the -1 slope 'unacceptable' line), and fatalities in the region 1000-5,000 (up to the -1 slope 'unacceptable' line) should be treated as an 'Intense Scrutiny' region.

It is strongly recommended, however, that the societal risk criteria should not be mandatory, and should be used as guidelines only.

The recommended societal risk guideline is shown in *Figure 7.4a*. An alternate option for the societal risk guidelines is shown in *Figures 7.4b* for further discussion. The alternate option is similar to the current guidelines for a PHI, except that the criteria include an 'intense scrutiny' region for fatalities in the 1000-5000 region.

The reason for including an 'intense scrutiny' region in the risk guidelines is to provide an option to regulators to permit certain types of developments. Such developments may not necessarily be unacceptable but would be examined with special scrutiny considering the social needs.

Application of the Criteria

In order to apply the criteria, it is necessary to define the area of natural terrain that must be considered. The study proposes an approach whereby *a 500m length of natural terrain (which presents risk to the community) should be considered as the basis for the QRA*. The study proposes a Consultation Zone which extends about 150m from the toe of the slope but includes the slopes themselves up to the summit. Any development with a significant population increase within the Consultation Zone should require a QRA study.

The study also provides an approach for Cost Benefit Analysis (CBA) which must be carried out to demonstrate ALARP, a requirement under the proposed criteria. A 'value of life' figure of HK$24 million adjusted suitably for inflation may be adopted.

An approach for consideration of aversion factors for multiple deaths is proposed whereby *an aversion factor of greater than one may be considered for 'high risk' situations, ie when the F-N curve is within one order of magnitude to the 'unacceptable' or 'intense scrutiny' region.* It is also suggested to *apply a higher aversion factor of up to 20 for FN curves within the 'intense scrutiny' region.*

The proposed criteria should be regarded as a starting point for extensive consultation on the subject. Further work may be required to assess public perception and expectation, the practicality of adopting the criteria including cost-benefit implications etc.

Figure 7.4a - Proposed Societal Risk Criteria for Landslides and Boulder Falls from Natural Terrain (Preferred Option - X)

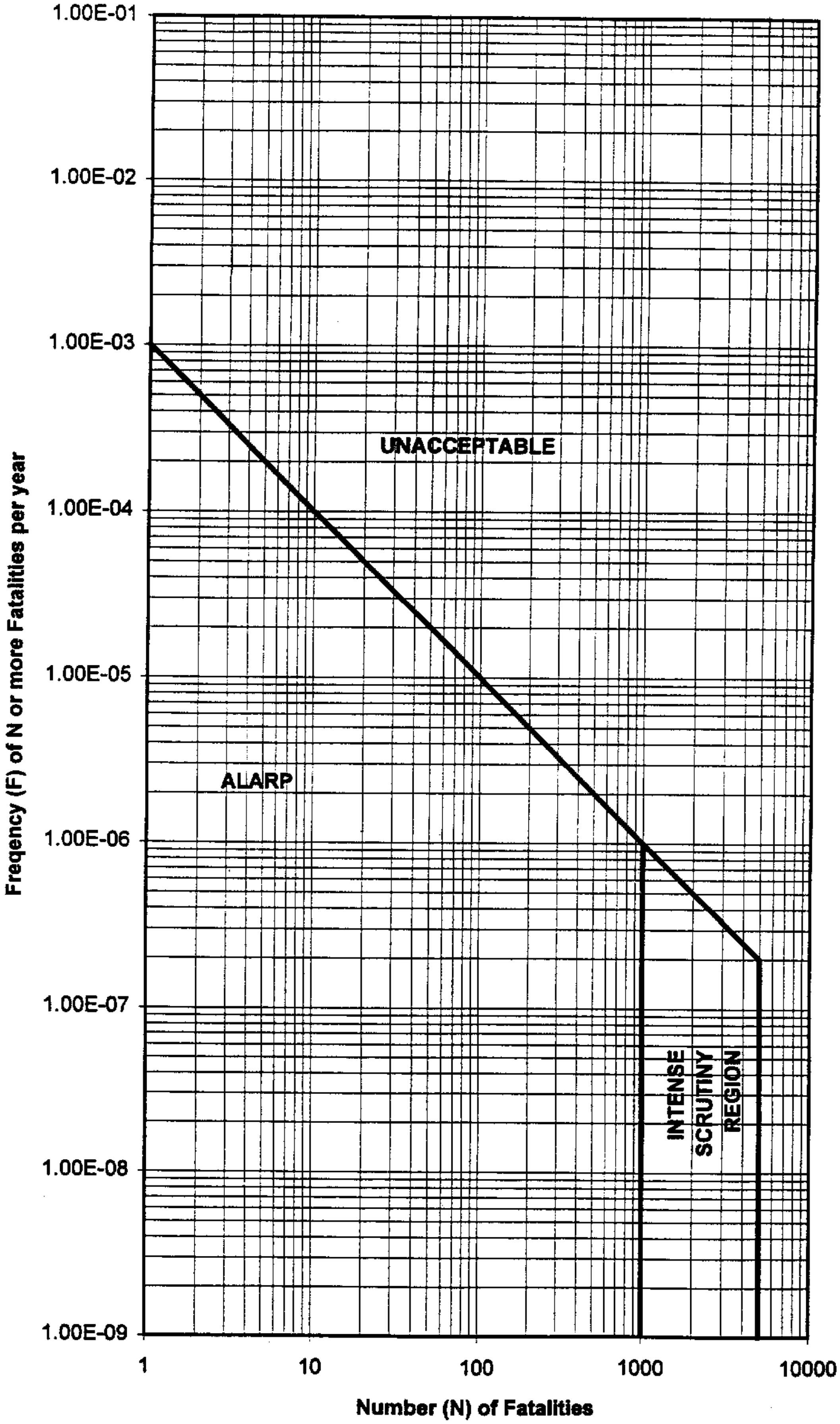
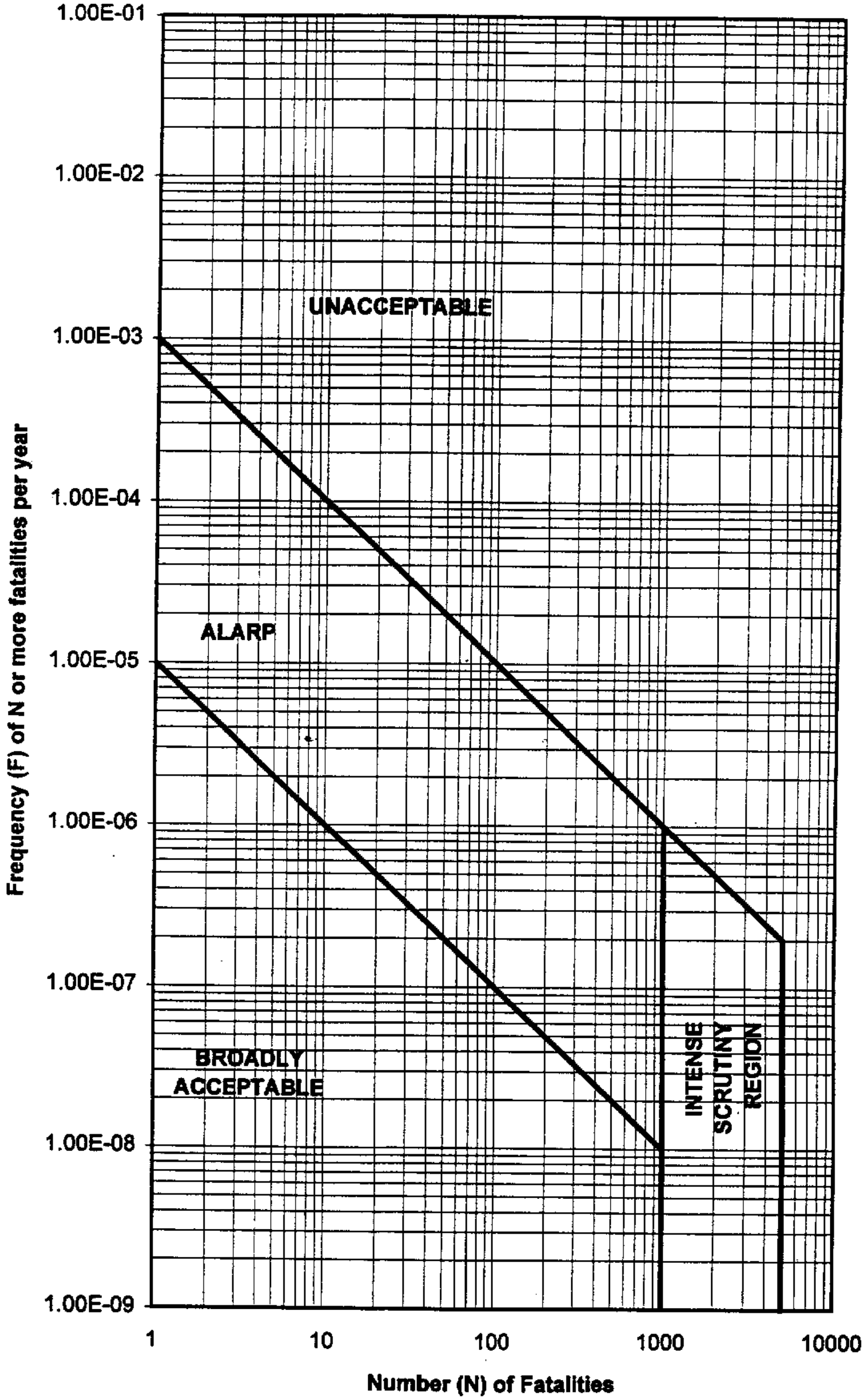


Figure 7.4b - Proposed Societal Risk Criteria for Landslides and Boulder Falls from Natural Terrain (Option Y)



CONTENTS

1 *INTRODUCTION*

Hong Kong is a relatively small territory of about 1000 sq km with some of the most densely populated urban areas worldwide. Much of the territory also consists of steep natural terrain and there is a history of landslides occurring, many of which have resulted in fatalities and injuries. Such incidents have mainly resulted due to failure of old man-made slopes and retaining walls - Wong & Ho [*Ref. 28*] provide an overview of such risks.

There has also been a large number of landslides from natural terrain in the territory, with evidence of over 26,000 landslides of which about 8,800 have occurred during the last 50 years [*Ref. 49*]. There are no reported fatalities or injuries from any of these natural terrain incidents - mainly due to the majority of these incidents occurring in undeveloped areas. As urbanisation continues in the territory there is increasing pressure to develop the areas comprising steep natural terrain.

As discussed by Roberds & Ho [*Ref. 16*] landslips on natural terrain (which would most probably be initiated by intense rainfall) can develop into large, rapid, mobile failures which pose a significant hazard with the potential to demolish multi-storey buildings and cause significant casualties and damage.

One concern therefore is that future development within steep natural terrain areas will place persons at risk (in and around the new developments) from landslides. Over recent years, since the formation of the Geotechnical Engineering Office (GEO) and the implementation of the Landslip Preventive Measures, and other components of the Slope Safety System, there has been a dramatic reduction in the number of fatalities per year resulting from landslides in the territory. Should the rate of urbanisation within steep natural terrain areas escalate, then landslide incident rates (affecting the public) and the corresponding fatality rate could increase.

Another concern is that the potential for large-scale landslides from natural terrain may exist for some of the existing areas of intense urban development within the lower parts of the hill slopes in Hong Kong.

The Geotechnical Engineering Office (GEO) has therefore commissioned ERM-Hong Kong, Ltd (ERM) to develop risk guidelines for landslides and boulder falls from natural terrain in Hong Kong. The objective of the study is to derive appropriate risk guidelines for use within risk assessment studies on landslides and boulder falls from natural terrain, where applicable, by extending the existing risk criteria for Potentially Hazardous Installations (PHIs).

The scope of work for the study is as follows:

(a) Review literature relevant to the study including reports on quantitative risk assessment studies on landslides and boulder falls in Hong Kong;

(b) Compile relevant information necessary for the study, including information on and relating to risks and risk guidelines for PHI sites in Hong Kong;

(c) Compile and review the approaches adopted in the development of risk criteria in Hong Kong and abroad;

(d) Develop suitable risk criteria for landslides and boulder falls from natural terrain by evaluating appropriate scaling factors to extend the existing risk criteria for PHI to natural terrain landslides taking into account relevant factors including:

  (i) difference in the scale of the hazards and contrasts in the extent of vulnerable population;

  (ii) difference between site-specific criteria and SAR-wide criteria;

  (iii) difference between tolerable risk levels for man-made features and those arising from natural events.

From a risk management perspective, risk criteria are the means by which the results of a risk analysis can be translated into recommendations on whether the risk should be tolerated, or whether there is justification for taking (further) measures to reduce it. As such, they are intended as anchor points within a structured and repeatable decision making process for prioritising safety investment. It is important therefore that the risk criteria provide a complete framework for decision making.

For example, in the narrowest sense a risk criterion might be simply a level of risk, which if it were exceeded, would indicate that the risk cannot be tolerated. However, if it were found that the risk is not intolerable, a decision needs to be made on how much effort should be expended in reducing it further, if any. In Hong Kong and the UK there are precedents for performing some form of cost-benefit analysis, essentially to determine if the cost is not grossly disproportionate to the benefit, and thus to generate a recommendation on whether a particular risk reducing measure is worth implementing.

This in turn raises questions about the cost-benefit method. For example, what aspects should be included on the benefit side? Should commercial and safety aspects be integrated into a single measure of benefit, and in any case, how are improvements in safety to be valued in financial terms? Consideration of these issues is beyond the scope of the present work, which focuses on the development of risk guidelines for landslides and boulder falls from natural terrain.

Section 2 of this report provides definitions for risk criteria, ie for Individual Risk and Societal Risk. *Section* 3 gives an overview of approaches adopted worldwide in the development of risk acceptability criteria, whilst *Section 4* presents examples of risk guidelines which have been developed in Hong Kong. *Section 5* gives a review of literature relating to QRA studies on landslides and boulder falls in Hong Kong. *Section 6* summarises the review (in Annex A) of natural hazards worldwide. *Section 7* presents the development of risk guidelines for landslides and boulder falls from natural terrain, whilst *Section 8* provides an approach for Cost-Benefit Analysis.

2 DEFINITIONS FOR RISK CRITERIA

It is common in risk assessment to differentiate between "individual risk" and "societal risk". These are described further below:

2.1 INDIVIDUAL RISK

Individual risk is, as the name suggests, the risk to specific individuals (for example, various categories of workers, the general public, road users, etc.). Individual risk is in fact a frequency with which individuals within the specified category are expected to suffer the harm (eg, to be fatally injured, or receive major injuries).

Definitions of individual risk commonly used in connection with the risk associated with Potentially Hazardous Installations (PHIs) are as follows:

- Individual Risk (IR) is the frequency of harm per year to a theoretical individual who is exposed to a hazard or hazards from a facility for 100% of the time.
- Personal Individual Risk (PIR) is the frequency of harm per year to an actual individual who is exposed to a hazard or hazards from a facility, with account taken of temporal factors which expose the individual to the hazard(s), and with account also taken of the probability of escape or protection from the hazards.
- For PHIs, individual risk (IR & PIR) is normally shown on a map around the hazardous installation (hazard source) as a series of frequency contours (say, 10^{-4}, $10^{-5,}$ 10^{-6} per annum, etc.) which represent the locations around the facility at which an individual would be subjected to that frequency of harm per year due to exposure to hazards induced by the facility.

2.2 SOCIETAL RISK

Societal risk is a measure of the overall risk associated with a situation or system. It accounts for the likely impact of all accidental events, not just on a particular type of individual, as in the case of individual risk, but on all individuals who may be exposed to the risk, and it reflects the number of people exposed.

The simplest measure of societal risk is the Rate of Death (RoD) or Potential Loss of Life (PLL) which is the predicted number of fatalities per year. Societal risk levels need to be determined because decisions based on Cost-Benefit Analysis (CBA) usually take account of the risk to society due to an activity. CBA could also be based on individual risk, although it is more usual to base the CBA on societal risk, with PLL being the most useful risk parameter for this purpose. In some cases the societal risk may be significant even though the risk to any one person may be insignificant.

To calculate societal risk, estimates have to be made, for each identified accidental event and its possible outcomes, of the frequency of the event per year, f, and the associated number of fatalities, N. The resulting data takes the form of a set of f-N pairs. They can be plotted on a graph, in which case they will appear as series of unconnected points.

However, it is more usual to consider the cumulative frequency, *F*, of all event outcomes that lead to *N* or more fatalities. These data are usually plotted on a graph as a continuous curve against logarithmic axes for both *F* and *N*. This allows for ready comparison against criteria (eg, for example, for intolerable and broadly acceptable levels of risk), which themselves can be represented as *F-N* curves. This representation of societal risk highlights the potential for accidents involving large numbers of fatalities.

Typically criteria distinguish three levels (areas) of risk: an upper level above which risk is unacceptable (intolerable); below this a region in which risk is tolerable providing it has been reduced to a level which is As Low As Reasonably Practicable (ALARP - see subsequent discussion in *Section B2.1* in *Annex B*); and finally a lower level below which risk is (broadly) acceptable, so long as precautions are maintained, because it is very small. However, other levels, such as that corresponding to risk which require "Close Scrutiny", may also be defined.

Critical considerations when defining criteria using an F-N curve include:

- the intercept on the y-axis of the "Unacceptable/ALARP" boundary line;

- the slope (and shape) of the "Unacceptable/ALARP" boundary line;

- whether to include an "ALARP /Acceptable" boundary line, and if so;

    - the intercept on the y-axis of the "ALARP /Acceptable" boundary line;
    - the slope (and shape) of the "ALARP /Acceptable" boundary line;
    - the width of the ALARP region (ie the difference in risk between the "Unacceptable/ALARP" level and the "ALARP /Acceptable" level.

It follows that there is variation between the criteria adopted for different hazards, and also certain criteria have additional features. For example, the criteria applied in the regulation of Potentially Hazardous Installations (PHIs) in Hong Kong incorporate a consequence (rather than risk) criterion, where a vertical "Unacceptable/ALARP" line appears at the 1000 fatalities level to reflect the fact that no credible event which could result in more than 1000 fatalities is considered acceptable.

This report reviews many examples of F-N curves which have been developed worldwide, for major hazard facilities, natural hazards, landslide events and other civil engineering areas such as for dams.

3 APPROACHES ADOPTED IN THE DEVELOPMENT OF RISK ACCEPTABILITY CRITERIA OVERSEAS

3.1 RISK ACCEPTABILITY CRITERIA FOR MAJOR HAZARDS

3.1.1 *Summary of Approaches Overseas on Major Hazards*

Annex B presents the review of approaches overseas for acceptability criteria for land use planning for major hazard installations. The following countries have been reviewed in detail:

- United Kingdom;
- The Netherlands;
- France;
- Switzerland;
- Australia (NSW).

The following table summarises the approaches adopted.

Table 3.1a *Summary of Approaches Overseas*

Country	QRA	Hazard Analysis	Acceptability Criteria for Land Use Planning		
			Criteria Adopted	Risk Based	Conseq-Based
UK	Yes	Yes	Yes	Yes	Yes
Netherlands	Yes	Yes	Yes	Yes	No
France	No	Yes	Yes	No	Yes
Switzerland	Yes	Yes	Yes	Yes	Yes
Australia (NSW)	Yes	Yes	Yes	Yes	Yes

All of the countries reviewed have implemented laws and procedures to ensure that major hazard installations are identified and classified as such. Most of the countries in Europe carry out some form of hazard analysis for major hazard installations, Germany being the one exception since they adopt a standards-based "state of the art technology" approach. The countries which have formally implemented QRA as part of the land use planning process are UK, The Netherlands, Hong Kong and Australia (NSW).

All of the countries in the above table have specified acceptability criteria for major hazard installations. In line with their QRA approach, the UK, The Netherlands, and Australia (NSW) have all specified risk acceptability criteria for land use planning. The UK and Australia (NSW), however, have also specified consequence-based acceptability criteria. France have specified consequence acceptability criteria only.

In summary, risk management in most of the countries discussed above is achieved through either a risk-based or consequence based approach, or a combination of each approach. The general aim (although not always stated) appears to be to ensure that an adequate separation distance is established between a major hazard facility and the surrounding population such that the population are not exposed to unacceptably high risk levels.

The consequence based approach acknowledges that there is a minimum protection that should be afforded to the general public from hazardous installations regardless of the likelihood of accidents. Given this minimum permissible protection further exposure is controlled through acceptability criteria.

3.1.2 *Risk Acceptability Criteria*

Table 3.1b summarises the individual risk acceptability criteria which have been specified for land use planning purposes within the countries reviewed.

The principle of ALARP (As Low As Reasonably Practicable), or its equivalent, is adopted in the UK and the Netherlands. The ALARP principle is shown on *Figure B-2.1a* in *Annex B*. In weighing the costs of extra safety measures the principle of ALARP applies in such a way that the higher or more unacceptable a risk is, the more proportionately an employer is expected to spend to reduce it. Where the risks are less significant, the less, proportionately, it is worth spending to reduce them, and at the lower end of the zone it may not be worth spending anything at all. Below this region the levels of risk can be considered as so insignificant that little attention needs to be paid to them.

Societal risk criteria for land use planning purposes have been developed by The Netherlands, as shown in *Annex B* as *Figure B-3.1b.*

Approaches overseas for the control of developments around major hazard installations have increasingly led to the use of a risk-based approach within an overall risk management framework. It has been recognised in countries such as the UK, The Netherlands, and Australia (NSW), that a consequence-based approach did not provide a sufficiently robust and consistent basis for control of major hazard plant, whilst also presenting severe problems with land-use planning in land-scarce countries.

It is stressed here, however, that some countries, whilst implementing a risk-based approach, have not completely discarded the use of consequence-based assessment. The current approaches adopted in the UK and Australia (NSW) tend to be a combination of both methods.

Table 3.1b *Summary of Individual Risk Acceptability Criteria*

Country	Acceptability Criteria (per year)					IR or PIR calc*	ALARP applied	Notes
	Site boundary	Industry/ Commerce	Community /leisure	Residential	Sensitive			
UK	-	- -	- 10^{-6} lower	10^{-5} upper 10^{-6} lower	10^{-5} upper $3x10^{-7}$ lower	PIR	Yes	Dangerous dose criteria. 'upper' indicates max permissible limit. 'lower' indicates "broadly acceptable".
		- -	- *$3x10^{-7}$*	*$3x10^{-6}$* *$3x10^{-7}$*	*$3x10^{-6}$* *10^{-7}*			*Calculated (equivalent) fatality criteria [9]*
Netherlands	-	-	-	10^{-6} (new) 10^{-5} (exist)	- -	IR	Yes	Criteria represent 'maximum permissible risk'
Australia (NSW)	$5x10^{-5}$	$5x10^{-5}$	$5x10^{-6}$	10^{-6}	$5x10^{-7}$	IR	No	

* IR - the calculation of individual risk assumes that a person is at a specific location for 100% of the time, all year round, with no mitigating effects allowed for such as escape out of cloud, or being indoors.

PIR - the calculation of individual risk takes account of occupancy factors, and mitigating effects such as escape out of cloud, or being indoors.

For land use planning purposes in the UK, HSE define three zones around a major hazard facility. The limit of each zone is determined by consideration of individual risk levels or consequence criteria. The individual risk criteria used are as follows:

Table 3.1c ***Individual Risk Zones For Land-Use Planning***

	Individual Risk (per year) of HSE Dangerous Dose
Inner Zone	$10^{-5} \leq IR$
Middle Zone	$10^{-6} \leq IR < 10^{-5}$
Outer Zone	$3 \times 10^{-7} \leq IR < 10^{-6}$

The criteria are based on concept of a 'dangerous dose' and not fatality, ie, a dangerous dose is a level of harm at which is probably equivalent to a likelihood of fatality of between 1% to 3% for an average cross-section of community [*Ref. 21*].

A Consultation Distance (CD) is defined for all major hazard installations, within which HSE must be consulted by local planning authorities (LPA) for advice on planned developments. The CD is usually defined by the limit of the "outer zone".

HSE adopt the following decision matrix for land-use planning decisions, with the zones defined by use of either the risk-based criteria or consequence-based criteria.

Table 3.1d ***HSE's General Approach to Land-Use Planning Decisions***

	Inner Zone	**Middle Zone**	**Outer Zone**
A (housing)	Not Acceptable	Maybe/Not	Acceptable
B (commerce/ industry)[a]	Acceptable	Acceptable	Acceptable
C (community/ leisure)[b]	Maybe/Not	Maybe/Not	Acceptable
D (sensitive)	Not Acceptable	Maybe/Not	Maybe/Not

(a) includes small housing developments ≥10 houses
(b) includes small housing developments <10 houses

It should be noted the above table is very much a simplified summary of HSE's overall approach to land-use planning decisions. In reality, many additional factors need to be taken into account as part of the complex landuse planning decision-making process.

3.1.3 Consequence Criteria

Of the countries reviewed, consequence criteria are used by the UK, Australia (NSW) and France for land use planning purposes. Of these, Australia (NSW) uses a frequency against specific criteria, so, strictly speaking, they are still risk-based criteria. The criteria adopted are summarised in *Table B-9.1b* in *Annex B*.

It can be seen that both the UK and France use consequence criteria in order to define 'zones' around a major hazard installation. The UK define three zones, whilst two zones are usually defined in France.

For thermal consequence criteria, the UK define their inner zone by the fireball radius (giving up to 100% fatalities), the middle zone by 1000 thermal dose units (threshold of lethality, possibly 1%) and the outer zone by 500 Thermal Dose Units (TDU) (blistering of the skin, may be serious for elderly people).

3.2 *RAIL TRANSPORTATION RISK CRITERIA*

Railway risk criteria are discussed here because although the risks from travelling by rail are very different in nature to the risks from natural hazards, there have been approaches to deriving criteria for railways which are considered to have applicability in a wider context such as to landslides and boulder falls.

There are a limited number of precedents for the setting of risk criteria in the railway industry, essentially because risk assessment has only been used to any significant degree in the past few years. Those which do exist relate primarily to rail operations in the UK, partly influenced by the 1994 Railways (Safety Case) Regulations, and to railway systems in Hong Kong where the regulatory regime closely follows that adopted in the UK.

A brief review of relevant aspects of the 1994 UK Railway Safety Case Regulations is presented in *Annex* C, and a summary of the approaches adopted by various railway operators is given.

There are essentially two approaches adopted by railway operators to defining risk criteria.

- Simple adoption of the criteria defined by HSE in relation to nuclear or chemical *process plant,* and taking these to apply to passengers on the railway, ie assume that the upper and lower boundaries of the ALARP region for individual risk are defined as 10^{-4} and 10^{-6} per year respectively;

- By reference to the level of risk currently tolerated for existing systems providing a comparable type of *service* to passengers.

Risk acceptability criteria have been developed and adopted by Eurotunnel, Railtrack, London & Continental (formerly Union Railways) and London Underground Limited (LUL) regarding the Jubilee Line Extension Project. In Hong Kong both the MTR Corporation and Kowloon-Canton Railway Corporation have developed risk acceptability criteria for new railways.

The applicability of the second approach above to boulder falls and landslides, whereby criteria for new developments could be derived based upon the maximum levels of risk currently tolerated from such hazards, is further discussed in *Section 7.4*.

3.3 Landslide Risk Management & Risk Acceptability Criteria and Other Relevant Civil Engineering Acceptability Criteria

3.3.1 *Landslide Risk Management*

Fell & Hartford *[Ref. 29]* provide a detailed overview of the application of risk assessment for landslide risk management, with a number of case studies discussed. They review landslide risk management approaches at a number of locations worldwide and present examples risk acceptability criteria which have been developed. They also note, however, that *"while several authors, including Fell (1994), Hungr, Sobkowicz and Morgan (1993) and Morgan et al (1992) [Ref. 73, 74, 75] have discussed acceptable risk criteria for landsliding, there are no established criteria backed by a government or a national technical society".*

The case studies discussed are:

- "Big Slide", John Hart Lake, Vancouver Island, British Columbia, Canada;
- Rockfall at the Argillite Cut on BC Highway 99;
- Debris flow risk zoning at Montrose, Victoria.

"Big Slide"

"Big Slide" is a large slope on BC Hydro's Campbell River Development, which is a cascade system of three dams and reservoirs in a Provincial Park. Aerial photographs indicate that there is a relatively high probability of small, relatively slow slides, but also that large landslides have occurred in the past, before the reservoir was filled, with debris volumes up to and over 7 million m^3 estimated. A large scale failure of "Big Slide" could cause a wave large enough to overtop the dam, resulting in a disaster with large loss of life and major environmental damage. Failure of the slope could arise due to liquefaction induced by seismic activity and BC Hydro has developed processes to evaluate the probability of such failures.

Rockfall at the Argillite Cut on BC Highway 99

Fell & Hartford review the work of Bunce, Cruden and Morgenstern (1997) and Bunce (1994) [*Ref. 76, 77*] which assessed the risks from rockfall at a cutting on BC Highway 99 between Vancouver and Squamish. The cutting was constructed in 1955 and has a history of rockfall from the slopes affecting the highway, with a fatal incident recorded in 1982 when a rock fell on a vehicle killing a woman and disabling her father. Models were developed by Bunce et al, to predict the probability of rocks hitting stationary and moving vehicles.

Debris Flow Risk Zoning at Montrose, Victoria

Fell & Hartford review the work of Moon et al (1992) which described a debris flow risk zoning at Montrose, Victoria, which is an outer suburb of Melbourne, Australia. A large landslide event occurred in 1891, with about 30,000 m^3 of debris travelling down the mountain slope and depositing over a distance of up to 2 km from the source landslip. A house was destroyed but no fatalities resulted. A similar incident today could result in large loss of life. The study included an investigation into evidence of previous landslides, with 58 landslides being mapped on the steep slopes in the study area. A risk assessment was carried out for the area, and 30,000 m^3 was considered as a reasonable upper limit of the size of the landslide considered possible in the future.

The individual risk results showed that:

- 39 properties where individuals were exposed to an upper bound estimate of individual risk of fatality of 10^{-3} per annum;

- 20 properties where individuals were exposed to an upper bound estimate of individual risk of fatality of 10^{-4} per annum;

- 92 properties where individuals were exposed to an upper bound estimate of individual risk of fatality of 10^{-6} per annum.

They also estimated that the potential loss of life in a single rainstorm event which might initiate several debris flows as follows:

- 1 in 100 rainstorm events 68 persons
- 1 in 1000 rainstorm events 83 persons

The risks to which the public are exposed in this area are clearly high and exceed the "normal" acceptable limit of individual risk of 10^{-5} to 10^{-6} per year for public surrounding a hazardous facility. Despite an extensive education programme by the local government, which advised all exposed persons of the risks, it appears that no one has moved from their houses. These same residents indicated on a survey by Finlay (1996) that they considered 10^{-5} to 10^{-6} per year to be the acceptable individual risk limit for loss of life. Importantly, Fell & Hartford observe that *they are tolerating much higher risks than they would prefer to accept.* This could indicate that the public (at Montrose) will tolerate a higher level of risk from landslides on natural terrain than is usually accepted elsewhere for man-made events, although it is not clear whether the public did genuinely appreciate the relative levels of risk.

Having said that, the public referred to were the residents of existing dwellings, presumably built before the potential high risk levels were understood, and the future attitude of the public to new developments in the area is not clear. It is feasible that, given the local government now have a clearer picture of the risks from landslides in the area, the public would be less tolerant of the risks for new developments.

Fell & Hartford considered that one way of establishing acceptable risk criteria for landslides is to consider what has been adopted in related areas, and their reference to acceptable risk criteria for dams is summarised briefly below.

3.3.2 Risk Criteria for Dams

Dams probably represents the most well developed area in civil engineering where risk management is practised and risk acceptability criteria are being developed and applied. The most active areas for development appear to be Canada, Australia, USA, The Netherlands, Norway, and South Africa. Fell & Hartford reviewed the risk acceptability criteria developed by:

- BC Hydro, Canada;
- Australian National Committee on Large Dams (ANCOLD);
- US Bureau of Reclamation.

These acceptability criteria are briefly reviewed below.

BC Hydro, Canada

BC Hydro own and operate 61 dams in British Columbia. Their dams were built between 1908 and 1985 and range from head ponds through to very large reservoirs.

Individual Risk: Fell & Hartford report that BC Hydro's individual risk criteria include an upper limit of 10^{-4} per annum on total risk to an identified individual from dam failure, with further reduction to be sought in terms of the ALARP principle. This total risk is the sum of the risks due to all causes (flood, earthquake), reservoir rim instability, internal erosion, and operational vulnerability).

Societal Risk: for societal risk the F-N curve presented here as *Figure 3.3a* is adopted. It can be seen that only an upper limit line for "intolerable" risk is defined, with risks above this line considered "intolerable", whilst risk levels falling below the line would be looked on as "tolerable" providing that the ALARP principle is demonstrated. There is no lower limit line for "acceptability". It is also interesting to note that the F-N curve does not actually refer to the "Frequency of N or more" casualties, but rather just the "Annual Probability (actually "frequency") of Dam Incidents ...". Also, the criteria address "Economic Losses", with a $10 million(US) loss appearing to be considered as equivalent (in terms of tolerability) to 1 fatality.

Australian National Committee on Large Dams (ANCOLD)

Fell & Hartford report that ANCOLD has prepared a detailed document entitled "Guidelines on Risk Assessment" for use in the assessment of risk for existing and new dams. The guidelines proposed the following risk criteria:

Individual Risk: for new dams, and upgrading of existing dams, a maximum individual risk of 10^{-5} per annum for any member of the public. The average risk of death to particular members of the public from dam failure should not exceed 10^{-6} per exposed person per annum.

Societal Risk: the criteria are being revised to those presented on *Figure 3.3b*. These are less conservative than the previous societal risk criteria established by ANCOLD which adopted a higher aversion factor for high fatalities, with the slope being greater than -1 at the high fatality end and increasingly so, ie the F-N acceptability lines, drawn on the log-log scale, were curved). The revised F-N acceptability criteria now exhibit a constant slope of -1, although it can be seen that the "unacceptable" limit is truncated horizontally at 10^{-6} per annum. This is in recognition of ANCOLD's view that it is unrealistic to design a dam with a failure probability lower than 10^{-6} per annum. This is an unusual feature for F-N acceptability criteria, and tends to imply that it is no more unacceptable to kill 10,000 or more persons than 100 or more persons. One problem with this approach is that it could lead to significant increased residential development within the exposed area from an existing dam, and result in high societal risk levels. It is understood that ANCOLD are, however, currently revising this criteria to remove this horizontal line.

Figure 3.3a - BC Hydros Societal Risk Criteria for Dam Failures

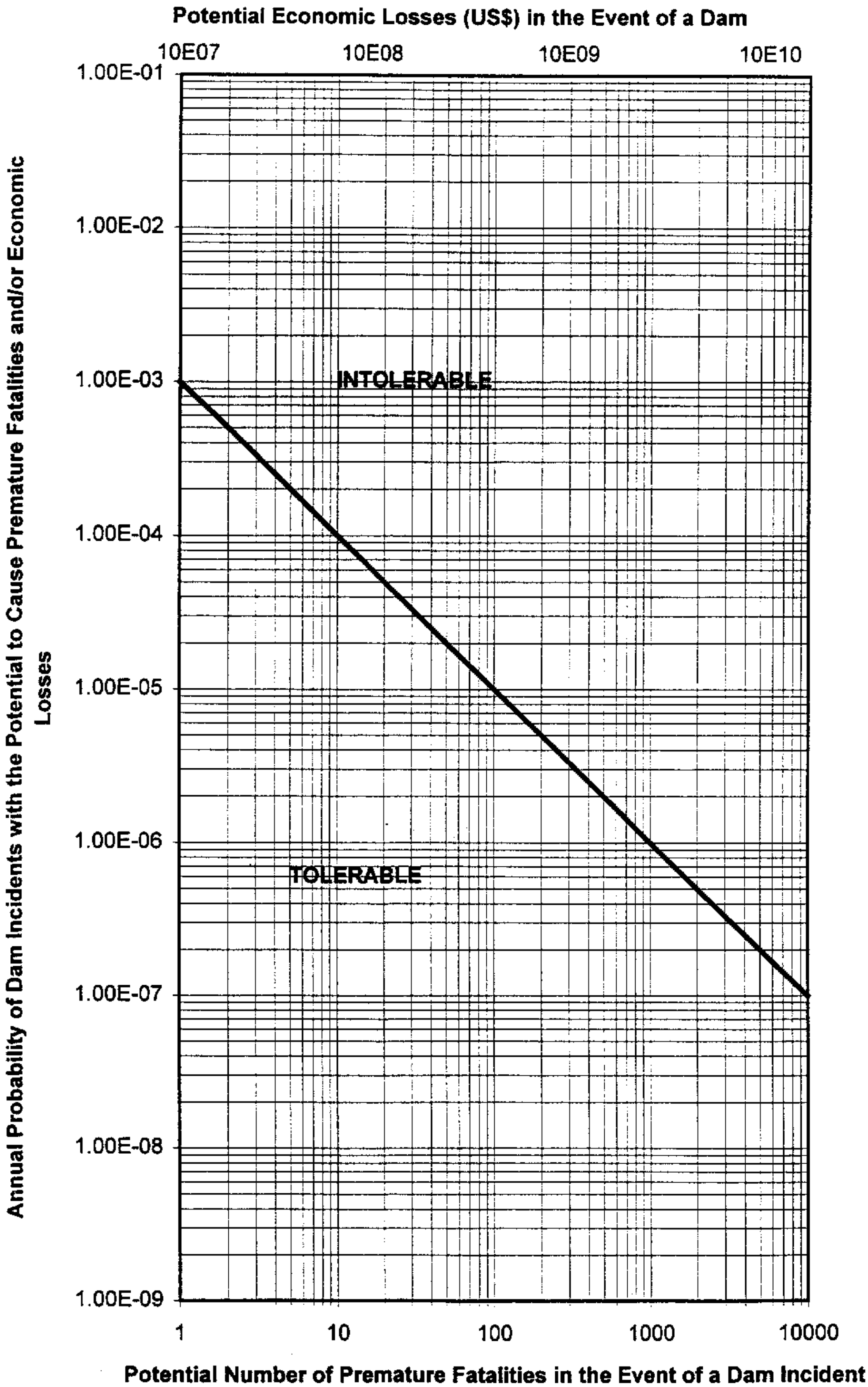
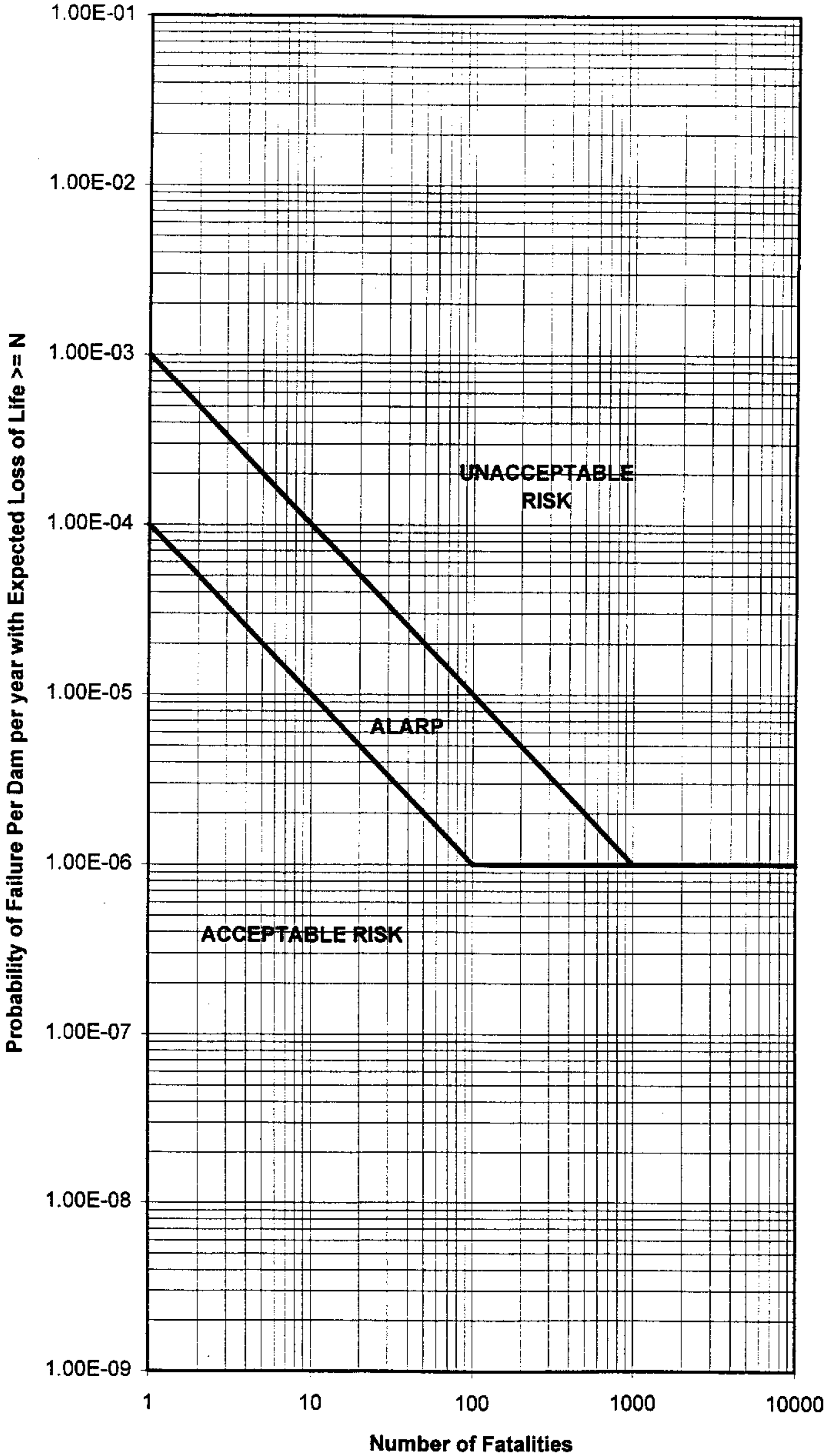


Figure 3.3b - ANCOLD Amended Interim Societal Risk Criteria



US Bureau of Reclamation

Fell & Hartford report that the USBR are developing risk assessment techniques for their dams, with acceptable societal risk criteria proposed as shown in *Figure 3.3c*. Whilst the upper limit line coincides with the BC Hydro and modified ANCOLD criteria, the USBR criteria are applied for each loading case (static, seismic, flood, other) whereas the BC Hydro and ANCOLD criteria apply to total risk. The USBR criteria are therefore less conservative.

3.3.3 *Acceptable Risk Criteria for Landslides*

Fell & Hartford's review did not identify any risk acceptability criteria for landslides established to date by a government authority, National or International Technical Society. The work of Morgan (1991) [*Ref. 78*] summarised the occurrence of fatalities in Japan, the European Alps and Canada, and the European experience was considered to be a reasonable model of the likely background for Canada. *Figure 3.3d* shows the F-N curves which were developed. Morgan suggested the acceptability criteria for individual facilities presenting hazards of large landslides (estimated as applying to about 50 facilities) should be 2 to 3 orders of magnitude lower than the country wide model.

The work of Cave (1992) [*Ref. 79*] described the acceptance criteria for use in land use planning against natural landsliding and flooding for the Regional District of Fraser-Cheam in British Columbia. The limits of acceptability implied within these criteria are summarised here in *Table 3.3a* below.

Table 3.3a ***Fraser-Cheam, British Columbia, Land Use Planning Acceptability Criteria - Limits of Unacceptability***

Hazard Type	**Annual Return Frequency for Type of Development (Limit of Unacceptability)**		
	New Building	**New Subdivision (20 to 100 persons)**	**Re-zoning (for new community)**
Rockfall: small scale detachment	2×10^{-3}	10^{-3}	10^{-4}
Debris flood	None	5×10^{-3}	2×10^{-3}
Major catastrophic landslide	10^{-3}	10^{-4}	No approval given, even for $<10^{-4}$
Inundation by Fraser River	None	2.5×10^{-2}	2×10^{-3}

The 'Unacceptability' figures included above refer to 'not approvable', eg a new subdivision would not be approved if the threat of a major catastrophic landslide was greater than 10^{-4} per annum. Other criteria were also given by Cave for acceptability with conditions for mitigation of the hazard. For large landslide events the above "annual return frequencies" could be considered as equivalent to the Unacceptability criteria for maximum individual risk to the most exposed persons (since the probability of harm given an event could be close to unity), but not so for "rockfall: small scale detachment" since the probability of harm for rockfall would expected to be less than unity for any single incident. It should be noted that the criteria imply that the development of a new community within a previously undeveloped area, which is under threat of a major catastrophic landslide, would not be approvable. This appears to be the major restriction on land use and it could be argued that it is unreasonable not to give some indication of an unacceptability limit for land re-zoning whilst still appreciating the major difficulties in estimating annual return frequency. However, the approach could be considered as akin to the definition of 'buffer zones' around major hazard sites to restrict certain types of development. Such buffer zones are set up by countries such as the UK, France and Australia (NSW). The buffer zone is usually defined by the limit of serious consequences from a defined catastrophic event (see *Annex B*).

The societal risk criteria developed by Sobkowicz (1996) [*Ref. 80*] for landslide risks are shown in *Figure 3.3e*, this criteria were based on earlier criteria developed by Hungr, Sobkowicz and Morgan (1993) [*Ref. 74*], and Sobkowicz (1996), who proposed group risk criteria for a development site in British Columbia which was under threat of landslides. They developed their criteria from data on natural disasters in the European Alps. In Fells & Hartford's review they note importantly that *"the premise of the derivation is that communities remained in exposed locations for long periods of time and thus tolerated the frequency of disasters given in the record"*.

The lower line in the figure refers to the tolerated risk from a single event, whilst the upper curve refers to the frequency of N or more deaths, and hence is more comparable to other F-N curves. This curve has a very flat slope, ie less than -1, which tends to imply little aversion to larger loss of life by the communities involved.

Fell (1994) considered acceptable risk from landsliding and concluded that:

- the public may tolerate relatively high risks from natural landslide hazards;
- the public was willing to "tolerate" much higher risk levels than they "accepted";
- for man-made slopes, a risk of 10^{-5} to 10^{-6} per annum may be what the public expects.

Fell & Hartford [*Ref. 29*] concluded in their paper that the individual risk criteria given in *Table 3.3b* seemed appropriate for landsliding involving engineered slopes. They propose that the limit of tolerability for persons most at risk from existing slopes is 10^{-4} per annum. For landslides from natural slopes they consider that the situation is less clear, but that it seems likely that the public will tolerate risks as high as 10^{-3} per annum.

Table 3.3b *Possible Tolerable Individual Criteria for Landsliding from Engineered Slopes*

Situation	Tolerable Individual Risk of Fatality per Year
Existing slopes	10^{-4} person most at risk
	10^{-6} average of persons at risk
New Slopes	10^{-5} person most at risk
	10^{-6} average of persons at risk

Figure 3.3c - USBR Proposed Risk Evaluation Criteria and Guidelines

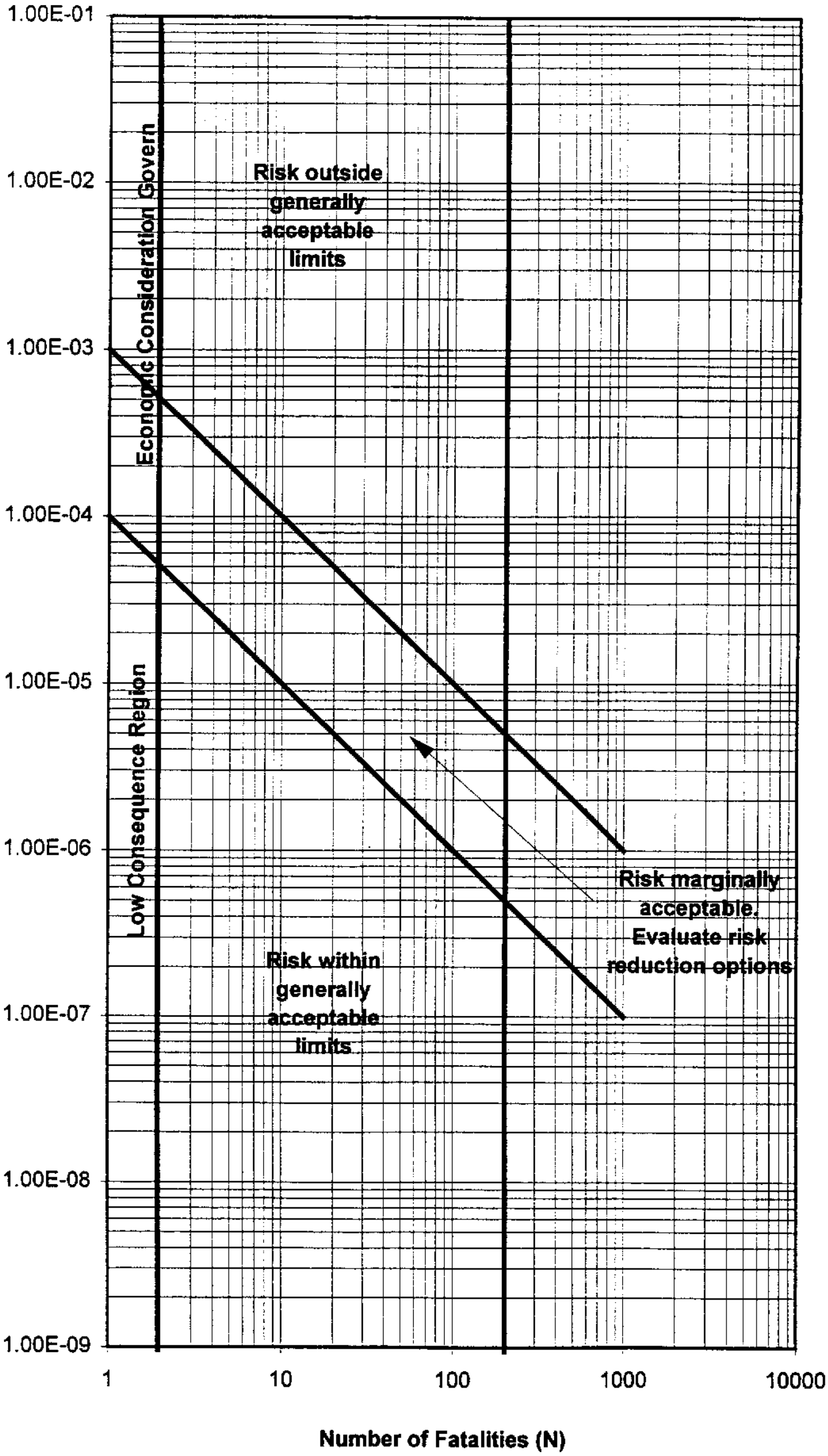


Figure 3.3d - Probability and Frequency of Multiple Deaths for Various Natural and Man-Made Sources Based on Reported Occurences

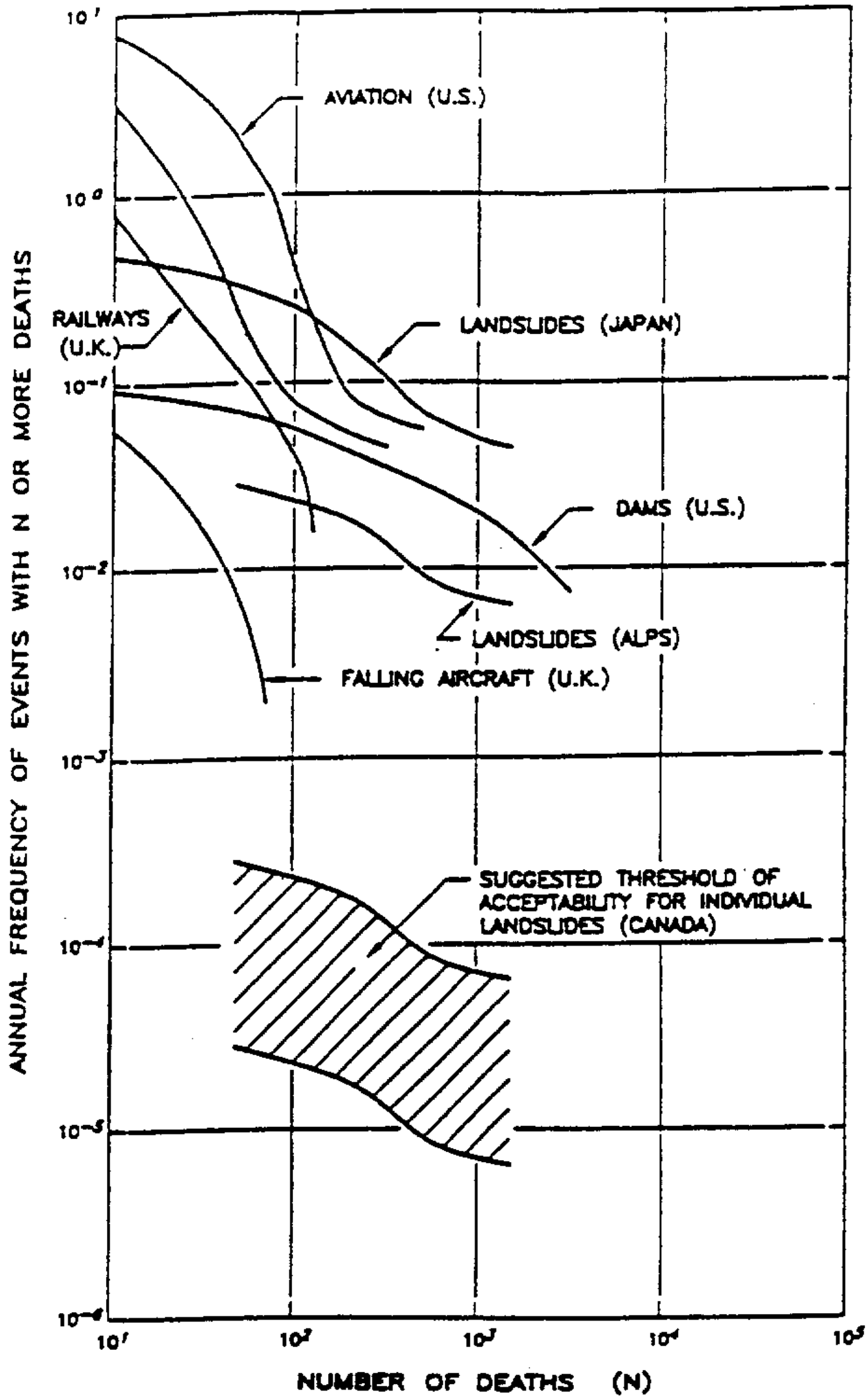
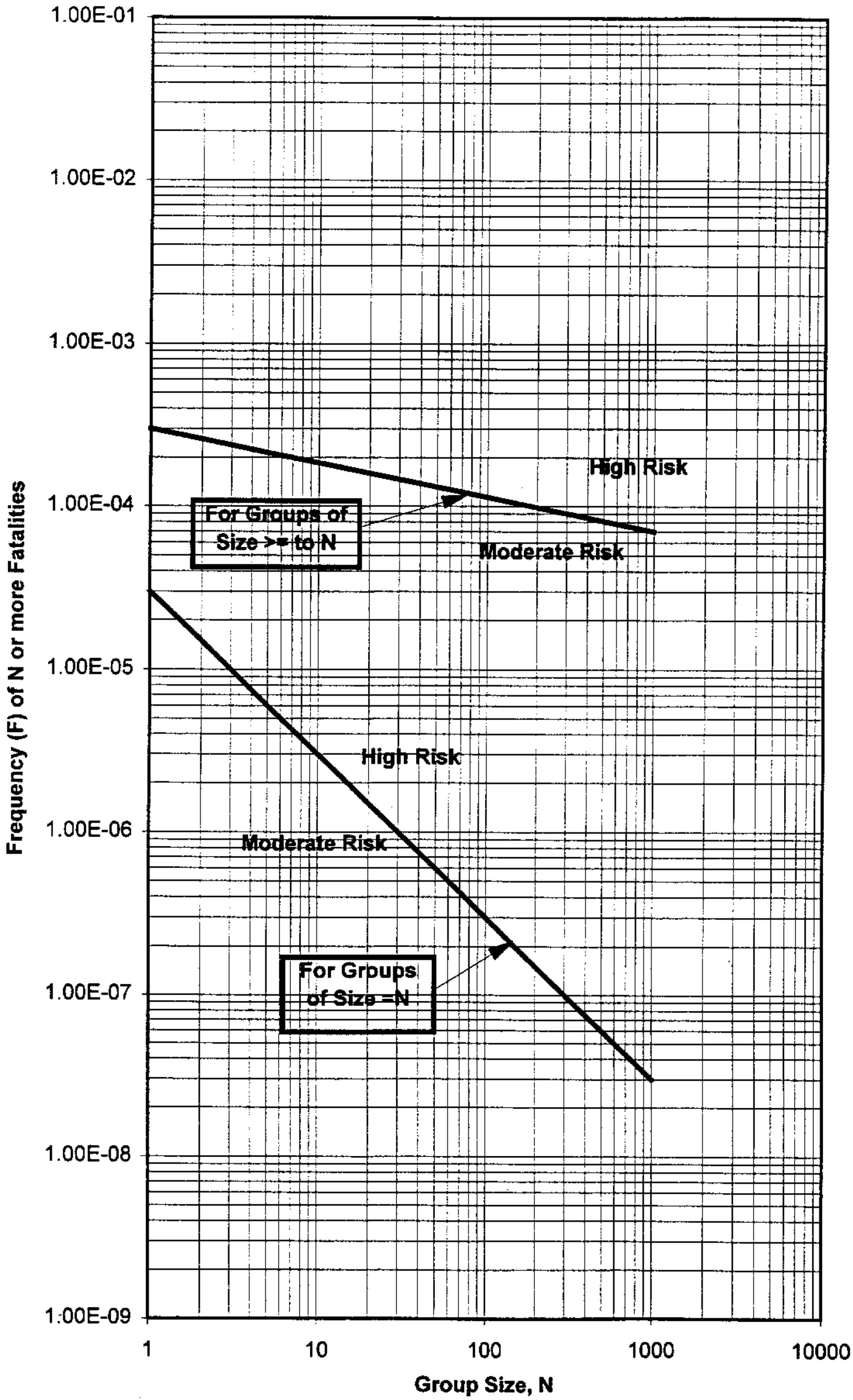


Figure 3.3e - Proposed Group Risk Acceptability Criteria for Landslides for Residential Land Use (Sobkowicz, 1996)



4 *RISK GUIDELINES ESTABLISHED IN HONG KONG*

4.1 *OVERVIEW*

The use of QRA, and the application of risk criteria to assess the acceptability of risks to the public, is well-developed in Hong Kong. For many years QRA and risk guidelines have been applied to PHI sites and more recently for other facilities, to include:

- Potentially Hazardous Installations (PHIs), i.e. installations which store, process or use more than specific (significant) inventories of dangerous substances, i.e. Chlorine, LPG, Hydrocarbons, Explosives, Industrial gases and chemicals, etc;

- Rail industry - KCRC and MTRC have recently developed risk criteria for their respective operations (public transportation);

- Dangerous Goods (DG) Transportation, i.e. DG transport operations associated with the PHI sites.

Risk criteria have also been proposed for a previous QRA study (in order to assess the acceptability of risks from landslides) for GEO, i.e. the Atkins Haswell Study which assessed the landslide risks to Squatter Villages in Lei Yue Mun [*Ref.* 3], wherein the existing PHI risk criteria were used as a basis for the development of specific criteria (different to the PHI criteria) for the squatter areas.

Annex D gives an overview of the risk criteria which have been developed in Hong Kong. A brief summary is given below.

4.2 *PHI RISK GUIDELINES*

The individual risk criterion specifies that the risk of fatality to an off-site individual should not exceed 10^{-5} per year. There is no distinction between different types of individuals, i.e. whether a member of the general public in residential accommodation, or a worker in an adjacent industrial site. The 10^{-5} criterion therefore applies to any off-site individual and, in effect, the criterion specifies that the 10^{-5} per year individual risk "contour" should not extend off-site. No ALARP region has been specified for individual risk, and risks are regarded as intolerable above and tolerable below this figure.

The societal risk criteria established by the Hong Kong Government are shown in *Figure D-2.2a* in *Annex D* in the form of an F-N curve (Frequency vs Number of fatalities). An F-N curve provides a measure of the likelihood of multiple fatalities by plotting the (cumulative) frequency of accidents which affect various numbers of people. There are three (3) regions indicated on the figure, i.e.

- Unacceptable region;
- ALARP region;
- Acceptable region.

The guidelines were originally intended for application to new PHIs or expansion of existing PHIs. They have, however, been applied to all PHIs in Hong Kong, i.e. those in existence preceding the introduction of the risk guidelines, and to all other new PHIs and expansion to PHIs. The guidelines are not rigid criteria. They are intended for use as guidance in the complex decision-making process involving planning for and around PHI sites, although it is probably fair to say that in reality the criteria have been applied fairly rigidly.

Annex D also provides an overview of how the risk guidelines are applied and interpreted in Hong Kong.

4.3 *DG TRANSPORTATION*

A number of QRA studies [*Ref. 1,5,6,7,8,9*] have recently been carried out on DG transportation in Hong Kong. These studies included consideration of non-fuel gas dangerous goods (i.e. Chlorine, Explosives, Hydrocarbons, Industrial Gases and Chemicals) and also fuel gas transportation (i.e. LPG and Naphtha).

The studies included the development of (draft) interim risk criteria to be used as guidelines for DG transportation in Hong Kong. The (draft) interim criteria were developed such that they were, as far as possible, consistent with the existing PHI risk guidelines in Hong Kong, and risk guidelines overseas.

The Technica Study [*Ref. 1*] included a review of risk criteria worldwide and concluded that no reasons had been identified for having different individual risk criteria for DG transport risks and DG site (storage, production and usage) risks. It was therefore concluded that the individual risk acceptability criteria for risks imposed on members of the public by hazardous activities should be independent of the activity to which they apply. Henceforth it was concluded that the same individual risk criterion of 10^{-5} per year should be used for fixed PHI installations and transport. Different options for application of this criterion were proposed.

Technica [*Ref. 1*] also developed (draft) societal risk criteria for DG transportation to and from PHIs, i.e. separate criteria for the following materials: Chlorine, Explosive, Hydrocarbons, Industrial gases and Chemicals, LPG, Naphtha. The proposed interim guidelines were based on the PHI guidelines using frequency scaling factors to determine the configuration of the three regions [on the F-N curve] specifying acceptability limits. These frequency scale factors equate to the number of PHI sites in the transport network. This approach is consistent with the approaches adopted for the development of DG transportation risk acceptability criteria in the Netherlands, UK and Australia. *Annex D* presents more discussion on the DG transportation (draft) criteria.

4.4 *MTRC AND KCRC RISK CRITERIA*

As described earlier, there are essentially two approaches adopted by railway operators to defining risk criteria.

(i) Simple adoption of the criteria defined by HSE in the UK in relation to nuclear or chemical *process plant*, and taking these to apply to passengers on the railway (factored down where applicable for application to new railways).

(ii) By reference to the level of risk currently tolerated for existing systems providing a comparable type of *service* to passengers

The Kowloon and Canton Railway Corporation (KCRC) has adopted the first of these approaches in defining risk criteria for its new West Rail project [Asia Rail 97]. The precise values for the new railway are understood to be taken as an order of magnitude reduction in the criteria for KCRC's existing operating systems. These in turn are essentially based on the precedents established by HSE (10^{-4} and 10^{-6} as the boundaries of the ALARP region). The criteria are defined for passengers, staff and the general public living in the vicinity of the railway as follows:

Passenger fatality risk upper limit	1×10^{-5} per year
Passenger fatality risk lower limit	1×10^{-7} per year
Staff fatality risk upper limit	1×10^{-4} per year
Staff fatality risk lower limit	1×10^{-7} per year
Public fatality risk upper limit	1×10^{-5} per year
Public fatality risk lower limit	1×10^{-7} per year

By contrast, the MTR Corporation has derived criteria for the upper level of tolerability for a planned new extension based on the levels of risk currently tolerated on the railways (the MTR network) by the travelling public in Hong Kong. This is a far more robust and defensible approach. MTR's criteria comprise an overhead risk associated with entry and exit to the systems and boarding and alighting of trains (set equal to the maximum regularly tolerated for a journey involving the maximum number of interchanges), and a component which varies with distance travelled (benefit). In this way criteria can be defined for any journey on the new railway. The precise values are not yet in the public domain.

5 *REVIEW OF LITERATURE RELATING TO QRA STUDIES ON LANDSLIDES AND BOULDER FALLS IN HONG KONG*

5.1 *OVERVIEW*

To date there has been a number of studies carried out for GEO on the application of QRA for the assessment of risks associated with landslides and boulder falls in Hong Kong. These have included studies on the risks associated with:

- landslides from man-made slopes and retaining walls;
- boulder falls;
- landslides on natural terrain;
- landslides affecting squatter areas.

Most of the above studies are briefly reviewed below, with the intention of providing an overview of landslide risks in Hong Kong. A review of the Atkins-Haswell study on landslides affecting squatter areas is given in *Section 8.3.*

5.2 *LANDSLIDES FROM MAN-MADE SLOPES AND RETAINING WALLS*

Technica's study *[Ref. 12]* included a review of historical landslide frequency in Hong Kong and overseas (Japan and world-wide). The F-N curves developed from this review are included here as *Figure 5.2a.*

The Hong Kong landslide data have been analysed separately for 1948 to 1977 and for post-1978, since the Geotechnical Engineering Office, GEO, (formerly known as the Geotechnical Control Office, GCO) was set up in 1977, with implementation of a wide-ranging Slope Safety System. The effects of this system as indicated by the reduction in the fatality rate for landslides since 1978, can be seen quite clearly on *Figure 5.2a.* On this figure, the incidents resulting in fatalities in Hong Kong involved landslides from man-made slopes, whilst the incident types in Japan and worldwide are not known, but it is thought that they probably include landslides from both man-made and natural slopes. The high fatality incidents on the figure are probably natural slope disasters.

The historical landslide data for 1917 to 1995, excluding boulder falls from natural terrain, consisted of 117 man-made slope incidents resulting in 73 fatalities in the worst-case (from the collapse of a low-rise building in Po Hing Fong in 1917). From 1948 the data were reasonably comprehensive, but less reliable prior to this, although the major incidents have probably all been recorded.

It can be seen that no single event with over 5 fatalities has occurred since 1978, although the potential for large fatality events must still exist.

The world-wide data, including Japan, indicates that the potential may exist for very large scale incidents. The data extends to 5000 fatalities, although it is understood that both man-made and natural terrain events are included.

The Technica study also included an assessment of the risks associated with specific slopes, with slope-specific models developed, i.e. for slope incidents at:

- Cheung Shan (1993) - soil cut slope;
- Sau Mau Ping (1976) - fill slope;
- Kwun Lung Lau (1994) - masonry retaining wall.

In order to provide a comparison against the Hong Kong Government PHI criteria the PHI criteria have been included on *Figure 5.2b*. It can be seen that none of the three specific slopes considered would have been considered "acceptable" under the PHI guidelines. In fact, both the Kwun Lung Lau (retaining wall/slope) and the Sau Man Ping slope would be considered as "unacceptable", since the F-N curve lays partly within the "unacceptable" region.

It is important to note, however, that the assessments made for Sau Mau Ping, Cheung Shan and Kwun Lung Lau were only pilot studies to explore the different approaches of assessing the probability and consequence of failure given the respective adverse settings and the probability of having such a setting had not been considered. It could be reasonably argued therefore that it is not appropriate to compare the F-N curves with the PHI criteria.

Discussion on the applicability of the PHI criteria to landslides is given later in this report.

5.3 *BOULDER FALLS*

ERM [(*Ref. 10]* carried out a study for GEO on the application of QRA for boulder fall hazards. The study included an assessment of the historical frequency of boulder falls incidents and also the prediction of boulder fall frequency for 4 identified areas (which are at risk from "boulder fields").

Figure 5.3a presents the F-N curves developed in the study for historical boulder fall incidents and for the three areas assessed during the study.

The PHI criteria have also been included on *Figure 5.3a,* although it must be emphasized that the criteria are less applicable (than for *Fig. 5.2b*) since the three "boulder areas" analysed were very large areas and far exceeded the normal boundaries of a PHI site, and even more so exceeded the "boundaries" of the community at risk from the man-made slopes considered by Technica in their man-made slopes assessment [*Ref. 12].*

The study included an analysis of 261 rockfall and boulder fall incident reports from 1978 to mid-1995. Of the 261 incidents, only 149 were shown to be actual boulder falls from natural or man-made slopes. Of these 149 boulder fall incidents, 74 initiated from natural terrain. These incidents were used as a basis for the frequency analysis for the QRA. During the period 1978-95, only one such incident resulted in fatalities. Further review, however, did identify 3 boulder fall incidents from natural terrain since 1926 which have caused fatalities, ie

Figure 5.2a - Historical Landslide Risk

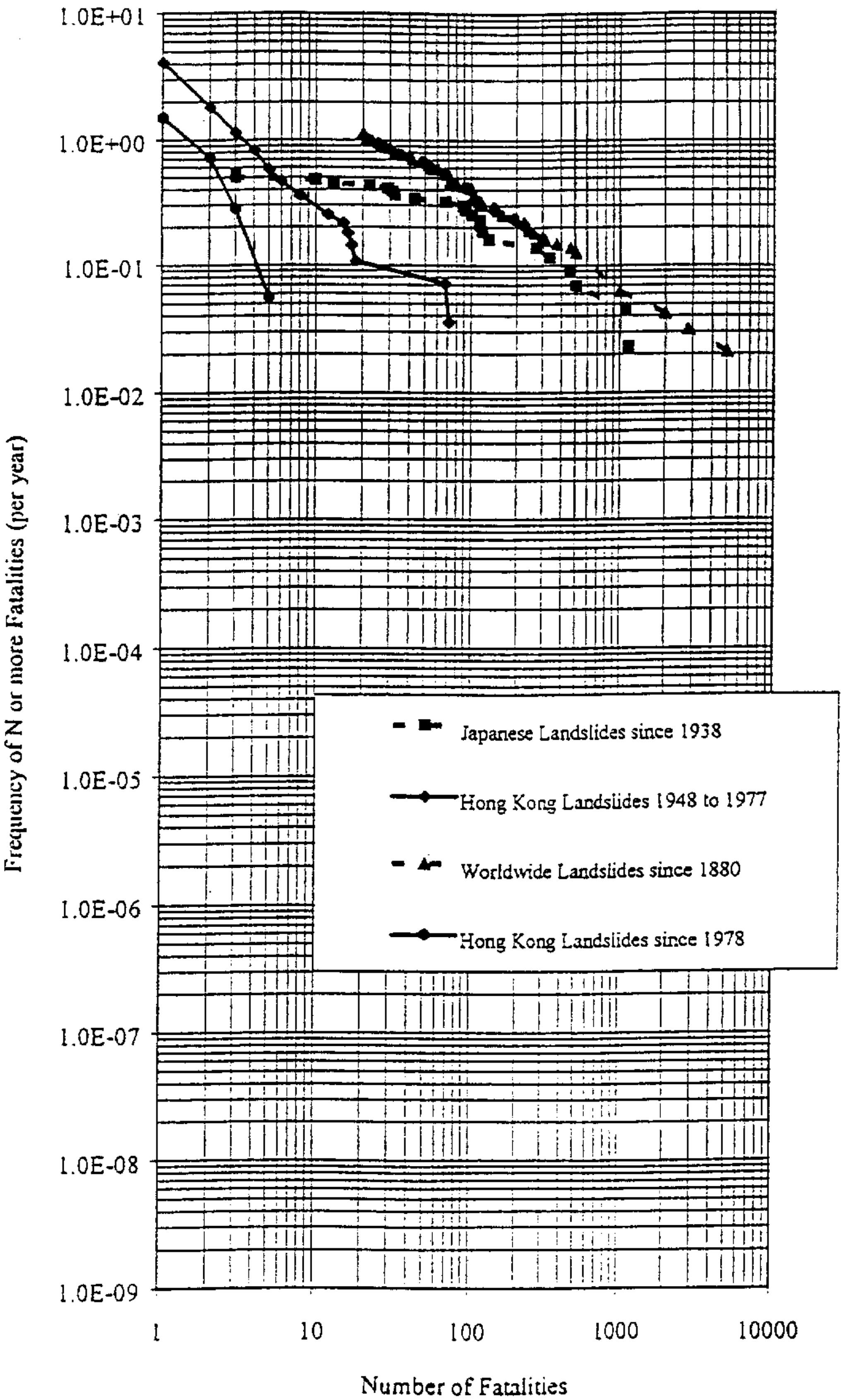


Figure 5.2b - Comparison of Landslide Risks from Man-Made Slope against PHI Criteria

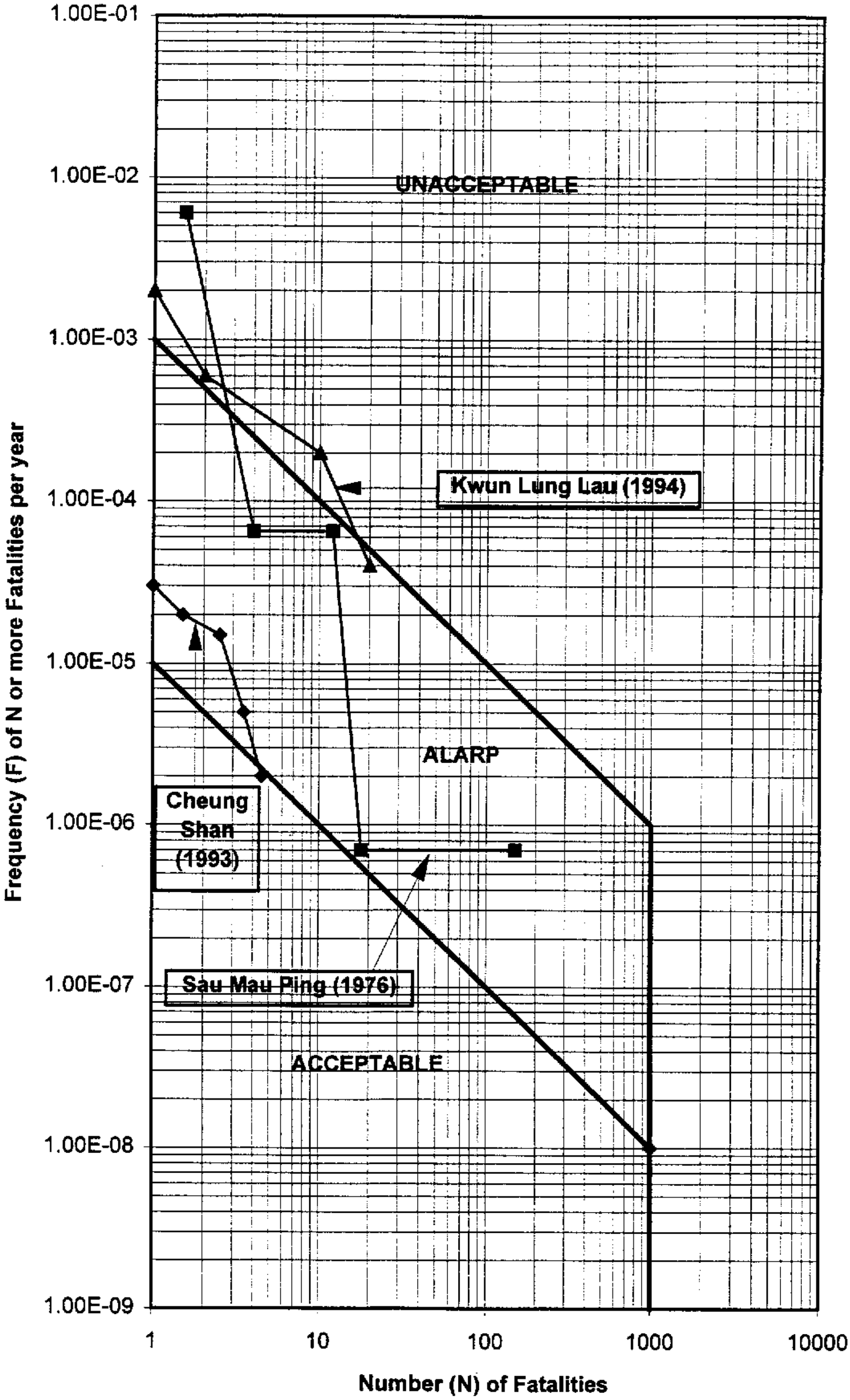
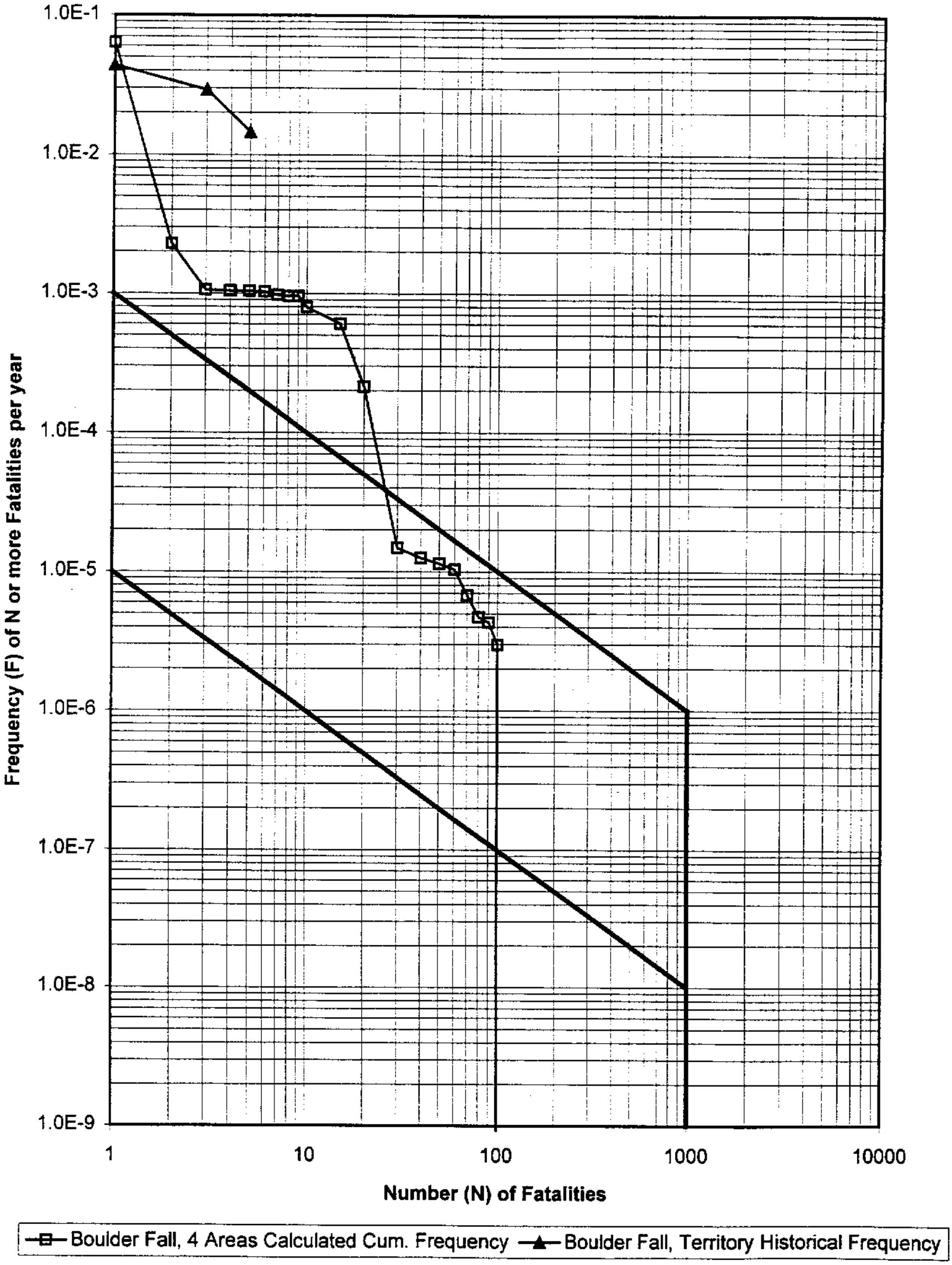


Figure 5.3a : Results of ERM's Boulder Fall Study (Phase II) in Hong Kong



- Elliot Pumping Station, Pok Fu Lam, 1926 - resulted in 5 fatalities (thought to be a 700 tonne boulder);
- Shau Kei Wan squatter areas, 1976 - resulted in 3 fatalities;
- Kings Road, 1981 - resulted in a single fatality.

Only 1 fatal boulder/rockfall incident occurred during the period 1978-95.

5.4 *LANDSLIDES ON NATURAL TERRAIN*

Golder Associates *[Ref. 14]* have carried out a study for GEO which involved the development of a QRA methodology for landslides on natural terrain in Hong Kong. The study analysed failure modes for landslides and developed models for the assessment of the consequences of landslides on natural terrain. A variety of mitigation strategies were identified.

There has also been a large number of landslides from natural terrain in the territory, with evidence of over 26,000 landslides of which about 8,800 have occurred during the last 50 years *[Ref. 49]*. However, there are no recorded fatalities from such landslides. The absence of any recorded fatalities is because the majority of these landslides have occurred in areas with no development. The concern for the future would be, of course, that as urbanisation increases in these areas (eg such as increasing development on Lantau Island) then the public will become more exposed to the risks from landslides and boulder falls from natural terrain.

Roberds & Ho [*Ref. 16*] have provided a summary of the Golder Associates study for GEO as part of the development of a risk management methodology for natural terrain in Hong Kong. The work consisted of the following:

- identification of the range of hazards and the corresponding consequences for landslides from natural terrain, with the "mechanisms" for such failures examined;

- development of a framework methodology to evaluate such risks;

- development of various modules (forming part of the methodology) in detail, including algorithms and potential risk mitigation strategies.

The study identified the following mechanisms which determine the occurrence and consequences of landslides on natural terrain:

- Potential "detachment" mechanisms and their "triggers" (eg intense rainfall is the main trigger event); and

- Potential "downslope movement" mechanisms.

The potential *detachment* mechanisms include: mass detachment, collapse, rockfall or boulder fall, and erosion. One of these mechanisms will tend to dominate, and result in a landslide of a specific type, amount of debris, and mobility.

Mass detachment refers to slippage of a significant mass of slope materials which occurs when the shear stress along a potential and kinematically feasible failure plane exceeds the shear resistance on that plane. Collapse refers to the collapse of the internal structure of a soil if it is loose, especially if it was initially cemented and subsequently leached, due to strains (such as from dynamic loading) or increased pore pressure (such as due to rainfall and infiltration). Such collapse can occur throughout a soil mass, or can be confined to a limited zone.

The potential *downslope movement* mechanisms include: mass sliding, viscous flow, liquid flow, and bouncing/rolling. Combinations of these mechanisms can occur during a landslide incident.

The various detachment and downslope movement mechanisms are related to the types of materials involved, ie boulder, colluvium, in situ soil and weathered rock, and jointed rock. Roberds & Ho [*Ref. 16*] have provided the following table which summarises these mechanisms.

Table 5.4a ***Mechanisms for Natural Terrain Landslides***

Dominant Initial Detachment Mechanism	Downslope Movement Mechanism			
	Mass Sliding	Viscous Flow	Liquid Flow	Bouncing /Rolling
Mass Detachment	CSR	CS	CS	BR
Collapse	CS	CS	CS	
Rock/Boulder Fall				BR
Erosion		CS	BCS	

{B = Boulder} overlying {C = Colluvium} overlying {S = in situ soil or weathered rock} overlying {R = jointed rock}

The mechanisms for landslides and boulder falls from natural terrain are complex and the study included uncertainty analysis to determine the extent of uncertainty in the data and models for risk assessment.

The mitigation methods considered for reduction of natural terrain landslide risks included:

- Reducing the probability, magnitude and/or mobility of slope detachment, eg by surface or sub-surface drainage and, for exposed rock slopes, by scaling or selective rock bolts/wire mesh/shotcrete;

- Reducing the probability of sufficient post-detachment downslope movement, eg by redirecting surface flow away from potential debris channels or by installation of energy dissipation barriers;

- Modify the characteristics of debris runout, eg containment or energy dissipation by provision of substantial barriers or basins;

- Reducing the vulnerability of population and property in the sensitive area, eg through land use planning restrictions or structural strengthening/protection of critical structures.

Roberds & Ho concluded that further work was required on: (1) better understanding of detachment and movement mechanisms; (2) development of a database of all natural terrain; (3) models development; (4) procedures for application of the QRA methodology.

6 NATURAL HAZARDS - GEOPHYSICAL & HYDROMETEOROLOGICAL

6.1 NATURAL HAZARDS

According to United Nations (world-wide) estimates, the last decade of this century was expected to experience tens of thousands of damaging landslides, earthquakes, and tornadoes; 100,000 floods; and several hundred to several thousand tropical cyclones and hurricanes, tsunamis, droughts, and volcanic eruptions [*Ref.* 37]. Large natural disasters have killed an estimated 3 million people in the past two decades [*Ref.* 33], with on average about 14,000 deaths per year due to earthquake disasters alone [*Ref.* 34]. It can be expected that many hundreds of thousands more will perish worldwide within the next decade. *Annex A* reviews incident data on natural disasters worldwide and the societal risks arising from such events.

The following type of natural disasters are reviewed:

- Earthquakes;
- Tsunamis;
- Windstorms (typhoons, hurricanes, cyclones, tornadoes);
- Floods;
- Volcanic Eruptions;
- Mass Movements.

Descriptions of each of these natural hazards are given in *Annex A*.

6.2 SOCIETAL RISKS FROM NATURAL HAZARDS

6.2.1 *Historical Data*

Table 6.2a below provides a summary of worldwide Geophysical and Hydrometeorological disasters worldwide. Geophysical includes earthquakes, landslides, volcanic eruptions, tsunamis etc while hydrometeorological includes hurricanes, cyclones, typhoons, storms and floods.

Table 6.2a ***Worldwide Disaster Statistics, Geophysical & Hydrometeorological (1964-89) [Ref. 44]***

Classification	Number of Disasters	Killed	Affected
GEO-P	315	497, 000	42, 023, 615
HYDRO	1,109	536,820	845,462,237

Analysis of the above table indicates that, on average, 12 geophysical type disasters occur worldwide each year, with an average number of fatalities of about 1500. Hydrometeorological disasters occur with more frequency worldwide, although they tend to result in less fatalities on average, they occur at a frequency of over 40 disasters each year, producing on average less than 500 fatalities.

Figure A-3.1a (in *Annex A*) shows data from the Swedish Red Cross *[Ref. 48]*, this presents the annual average number of disasters worldwide by disaster type. It can be seen that floods and storms occur most frequently (15-25 per year), followed by earthquake (about 15 per year). Landslides (ie, major landslide disasters) occur at a similar frequency to "accidents" (major chemical/petrochemical accidents etc) at about 4 each year. Volcanic eruption disasters tend to occur at about 3 to 4 events each year.

Within the Asia Pacific region the OFDA (Office of US Foreign Disaster Assistance) data *[Ref. 44]* gives the following equivalent table to that above.

Table 6.2b ***Asia Pacific Disaster Statistics, Geophysical & Hydrometeorological (1964-89)***

Classification	Number of Disasters	Killed	Affected
GEO-P	184	353,665	25,123,377
HYDRO	657	500,154	786,443,023

Analysis of the above table for the Asia Pacific region disasters indicates that, on average, 7 geophysical type disasters occur each year, with an average number of fatalities of almost 2000. Hydrometeorological disasters occur with more frequency, although they tend to result in less fatalities on average, they occur at a frequency of over 25 disasters each year, producing on average about 750 fatalities.

It can be seen from the above tables that the Asia Pacific region has had a large proportion of the worldwide experience for these types of disasters, ie Geophysical (58%) & Hydrometeorological (59%). It follows therefore that the public living in the region (who have either personal experience or have access to modern communications such as TV, radio, newspapers etc) should have knowledge of many such disasters from within their own and/or other countries.

The data for each of these disaster types have been summarised in *Tables A-3.1c & 3.1d* in *Annex A*. It can be seen that (for the period analysed) Hong Kong (SAR) is well down the list for 'disaster-prone' countries within the region. The countries most prone to geophysical disasters are mainland China, the Philippines and Pakistan, although it is known from incident records over a greater time period that Japan is particularly prone to earthquake disasters (10% of the world's earthquakes occur in and around Japan). The countries most prone to hydrometeorological disasters are Bangladesh, India, the Philippines, Vietnam and mainland China. It is known that mainland China has experienced flooding incidents which have resulted in very high fatalities but these are not included within the time period for the OFDA data.

6.2.2 *Societal Risk F-N Curves*

Parfitt *[Ref. 45]* has produced a series of F-N curves from the OFDA data, plus other data sources. Incident data on major accidents in the chemical and petrochemical industries was obtained from the MHIDAS database, a database collated by AEA Technology.

The following F-N curves from the Parfitt report are reproduced at the end of *Annex A*:

Figure A-3.2a:	Frequency of accidents for selected categories causing fatalities worldwide
Figure A-3.2b:	Frequency of accidents by origin in the chemical and petrochemical industries causing fatalities (worldwide, 1966-89): analysis by industry type
Figure A-3.2c:	Frequency of accidents in the chemical and petrochemical industries (UK and worldwide, 1966-89)
Figure A-3.2d:	Frequency of occurrence of selected natural hazards causing fatalities (worldwide, 1964-90)
Figure A-3.2e:	Frequency of earthquakes causing harm (worldwide, 1964-90)
Figure A-3.2f:	Frequency of floods causing harm (worldwide, 1964-90)
Figure A-3.2g:	Frequency of cyclones, hurricanes, and typhoons causing harm (worldwide, 1964-90)
Figure A3.2h:	Frequency of volcanic eruptions causing harm (worldwide, 1964-90)
Figure A-3.2i:	Frequency of landslides causing fatalities (worldwide, 1964-90)

It is also important to note that the data is only for a limited time period of about 25 years, and as such, may not include some low frequency/ catastrophic consequence events for certain hazard types.

Annex A gives an interpretation of the F-N curves, which is summarised in *Table 6.2a* below.

The overall conclusion from this data set is that natural disasters (worldwide) occur at a similar frequency to man-made disasters but the potential for catastrophic consequences is much greater for natural disasters, ie there is a the potential for the number of fatalities, injuries, people affected (and associated financial losses) being much greater for natural hazards.

Table 6.2c *Summary of Societal Risks from Natural Disasters and Man-Made Disasters - Worldwide*

Disaster Type	Freq of Events with 10 or more fatalities (per year)	Annual Event Maximum Fatalities/Injured/Affected (N or More)			Worst Event (in 25 years) (Number, N)			Notes
		Fatal	Injured	Affect	Fatal	Injured	Affect	
Earthquake	7	1000	3000	0.1M	0.8M	>1M	>1M	The worst known earthquake in this time period was at Tongshan, China with 250,000 fatalities, although some reports state up to 650,000 killed.
Flood	13	700	1000	1M	30,000	0.1M	30M	Outside of this time period over 100,000 were killed in Bangladesh flood of 1991.
Cyclone/ Hurricane/ Typhoon	10	800	800	0.1M	0.3M	0.6M	5M	The Bangladesh cyclone of 1970 resulted in 500,000 fatalities.
Volcanic Eruption	0.1	-	-	10,000	1000	-	0.3M	Columbia (1985) should have been included with 22,000 fatalities.
Landslide	3	100	-	-	600	-	-	Mount Huascaran, Peru (1974) killed tens of thousands.
Chemical	7	50	300	10,000	3000	0.2M	0.25M	Worst event presumed to be Bhopal (1984) with over 2500 fatalities.
Aircraft	23	200	-	-	600	-	-	

6.3 *RISK PERCEPTION & TOLERANCE OF NATURAL HAZARDS*

Important factors which influence the public's perception and tolerance of risks from natural hazards are considered here to include:

- the perceived involvement of man in a "natural" disaster, either as a causation factor or due to failure to prevent or mitigate the consequences of a natural hazard;
- the knowledge of the potential for natural disaster(s) - the public may be exhibiting an element of "voluntariness" by remaining in (or moving to) a disaster-prone location, but not so if they have no knowledge of the potential;
- the degree of choice which the public (practically) has on whether to move from a disaster-prone location.

6.3.1 *The 'Hand of Man' in Natural Disasters*

Susman [*Ref 46*] has commented that the distinction between man-made and natural hazards is not a rigorous one, as the hand of socioeconomic factors in so-called "natural" disasters is often all too evident.

For example, Bangladesh has suffered many natural disasters, particularly so with famine and flooding. It has been recognised, however, that disasters such as the flood which killed over 100,000 living in the poor coastal regions in 1991 are as much acts of humanity as acts of God *[Ref. 33]*.

Pearce *[Ref. 33]* recounts the views of Terry Cannon of the Institute of Social Studies in The Hague, who argued that: *the description "natural disaster" to describe a major flood or earthquake is about as useful, and as misleading, as a doctor filling out a death certificate with the words "natural causes". Such death certificates tell us nothing about whether that person's diet left them vulnerable to disease, or whether doctors failed to diagnose a curable disease. The missing link is vulnerability .... but it is not getting across to policy makers in the UN ... vulnerability is all but ignored in the declarations made to accompany the UN's current International Decade for Disasters Reduction. The emphasis on natural forces behind disasters fails to distinguish the human causation of disasters; and encourages an approach which seeks technical solutions [which are] a way to avoid more fundamental political underpinning against disasters.*

Pearce comments that: *it is easier to agree on an aid package to build embankments that may (or may not) hold back the flood waters, than to solve the question of why it is that so many millions of (poor) Bangladeshis are forced to live out on the islands of that country's great coastal delta, on the permanent brink of disaster.*

Pearce also notes that: *the poor of Rio de Janeiro have clearly been forced onto the landslide-prone hills, where 300 died in torrential rainstorms in 1988.*

Further indications of the hand of man in "natural disasters", recounted by Pearce, include earthquakes which have resulted in large loss of life due to poor building construction, such as the Armenian earthquake of December 1988 in which up to 100,000 people died.

Conversely, although "earthquake-proof" buildings have been constructed in earthquake-prone Tokyo, it is also argued by Hadfield (Pearce in *[Ref.* 33] refers to Hadfield's book "Sixty Seconds that will change the world") that the buildings may still not survive a major earthquake, and that the death toll from the next great quake to hit Tokyo could be far in excess of the 140,000 who died in the Great Kanto Quake of 1923. Interestingly, Hadfield commented that there is no great stampede to depart. Should another great earthquake strike Tokyo and result in high fatalities, with many "earthquake-proof" buildings collapsing (and thereby contributing to the high death toll) then it can be expected that the public would attach some element of blame to the relevant authorities and organisations involved.

The hand of man is a significant factor in many flooding disasters due to: farming, deforestation, urbanisation, river diversions, etc. In addition to the human contribution to the causes of floods, disaster conditions are created by building in vulnerable areas, poor watershed management and failure to control flooding.

6.3.2 Risk Prevention & Mitigation

Another element of human involvement in natural disasters is risk prevention and mitigation. Housner [*Ref.* 35] argues that the catastrophic impact of many natural hazards, certainly in terms of loss of life, can be avoided or minimised through application of science and technology. Without such intervention then natural disasters will continue to increase as the pressures of population and commerce encourage the use of more hazard-prone areas.

As the public become more knowledgeable of the type of risk prevention and mitigation measures that could have been employed to avert disaster, then they will most probably apportion some blame to the relevant authorities should disaster strike. The trend therefore may be that the public will increasingly see elements of human involvement in disasters that they would have previously considered as purely natural disasters.

Housner lists a number of means for risk prevention and mitigation of natural hazards, under the classes physical adjustments and social adjustments, ie

Physical adjustments include:

- planning and building to withstand a hazard;
- identifying and avoiding the sites where a hazard is likely to occur;
- predicting the occurrence of a hazard; and preventing or altering a hazard's characteristics.

Social adjustments for avoiding a hazard's impacts consist of:

- restricting the use of land and establishing minimum standards for avoiding hazardous sites and conditions;
- instituting public awareness campaigns in areas prone to hazards;

- initiating emergency preparedness programs to protect life and property once a warning is issued or an event occurs;

- spreading the economic loss among a larger population through insurance, taxation, and monetary grants; and,

- reconstructing a community so that it is less vulnerable to the next hazard.

Majumdar et al [*Ref. 34*] lists five broad options for coping with recurrent natural hazards:

- ***Preparation*** - use of basic knowledge about the natural hazard to plan for it and to mitigate its physical effects through building and land-use regulations;

- ***Prediction and Warning*** - use of basic knowledge about the natural hazard to predict the occurrence and/or consequences of future events and to warn the populace at risk;

- ***Intervention*** - use of basic knowledge to evacuate and/or intervene while a natural hazard is in progress in order to suppress its physical effects and to lessen societal impacts;

- ***Recovery*** - use of basic knowledge gained from past experience to restore the essential community services to normal rapidly and economically and to correct deficiencies in building and land-use regulations and siting, design and construction practices;

- ***Emergency Assistance*** - use of basic knowledge to provide effective search and rescue assistance immediately after a natural hazard strikes a community.

Failure of a government (in a disaster-prone area) to effectively implement the above type of risk prevention and mitigation measures against potential natural disasters could be viewed by the public as the government failing to carry out the duties which the public expects of them. Indeed, in a progressive society the public would expect the government to implement many of the above types of measures to protect them from (say) earthquake risks. This is certainly the case in California and Japan, wherein the respective governments have implemented a number of the above measures, particularly so with earthquake-resistant buildings, early warning systems, and emergency response programs. Failure of these measures to adequately protect the public from future earthquake events will probably result in the public apportioning an element of blame to the government for the consequences of the disaster.

6.3.3 Knowledge of Natural Hazards Risks

An important factor in assessing the public's tolerability to risks from natural disasters is whether they have sufficient knowledge of the risk in order to make a valued judgement on whether to remain exposed to the hazard (or hazards).

The public will need to rely on data from government and local experts on the potential for catastrophic events which have not occurred within their own experience. However, there remains much disagreement and often ignorance amongst experts on the potential for catastrophic disasters.

For example, Tiedemann [*Ref. 41*] argues that: *Quite a number of seismologists seem to think that the earthquake magnitude possible in a region will not exceed the largest magnitude actually observed in the past. This notion is wrong.*

Tiedemann goes on to cite several examples where past seismicity has proven to be an unreliable yardstick, including Guatemala (1976) and Tangshan, China (1976). The perception that a future event won't be worse than one that has previously occurred (in a particular location) probably applies to the public also, although the public would most probably not have knowledge of past events which occurred before their time. The public's risk perception of a major disaster would therefore be based on:

- their previous experience within that location;
- their knowledge of disasters at other locations which they perceive could happen where they live.

Another such example, is the June 12, 1991 volcanic eruption of Mount Pinatubo in The Philippines, which had remained dormant for 600 years. The disaster killed more than 300 people and left 100,000 others without food and shelter [*Ref. 47*]. It is doubtful whether the public who had settled in the area had good knowledge of the disaster potential, indeed the local planning authorities also may not have had sufficient understanding of the risks. However, it is important to note that the death toll would have been far higher but for early warning and mass evacuations in the days prior to the main eruption. Seismic monitoring provided the primary data for one of the most successful forecasts of a large volcanic eruption. Public announcements of an impending strong eruption were made. Over 50,000 people were evacuated from the area. This included 5000 people from within a radius of 10 kilometres of the volcano, an area that was later completely devastated by the main eruption.

As already noted above, the largest and most dangerous volcanic eruptions occur from volcanoes that lie dormant for hundreds of years between periods of activity. Such prolonged inactivity leads to the potential hazard being ignored during the planning and development of the surrounding area. Another prime example is the large population which have settled in the hazard zone of the volcano Vesuvius near Naples, Italy.

One could question whether this represents the public's tolerance of the risk of a potential catastrophic volcanic eruption, or whether their decision to live in the disaster-potential area is borne out of ignorance of the potential risks.

The Public Know But Choose to Live There

There are a number of examples where the public choose to remain in a particular disaster-prone location, despite the known risks from natural hazards. Many experts in the risk assessment field would argue that they are tolerating such (possibly high) risks since they perceive a greater benefit by remaining to live in that location. Such benefits are most probably socio-economic in nature, eg cost (or availability of) of housing, family ties, business interests, etc. Such decisions (to remain) may not even be consciously made.

One such example, is where the public continue to live (or even relocate to live) in areas at high risk from active volcanoes despite knowing about the disaster potential, with large (well-documented) eruptions resulting in fatalities having occurred in the recent past. Such an example can be found at the town of Taal, Philippines. The volcano on Lake Taal has erupted 41 times since 1572, and is considered by volcanologists to be one of the world's 10 deadliest volcanoes [*Ref. 47*]. Taal's last violent eruption was in 1965, followed by lesser almost yearly eruptions until 1977. After some dormant years Taal is again active, with sometimes up to 300 seismic movements daily.

Taal killed at least 1,335 farmers and fishermen in 1911, and over 300 people in the 1965 eruption, yet development in the area has increased and farmers and fishermen increasingly continue to exploit the rich shores and waters of the volcano. It is argued here that this is a case where the public are knowingly living in an area of high disaster potential, indeed, as for many volcanoes worldwide the area has become a tourist attraction and recreation area also.

Another case of the public's tolerance towards high risks from natural hazards can be found in California. As noted above, during this century California has experienced over 30 earthquakes of magnitude 5 to 8.3 [*Ref. 40*], with the most recent large earthquake occurring at Loma Prieta in 1989. It has been estimated that there is a 60% chance of a major quake hitting southern California within the next 30 years. Sherif [*Ref. 40*] has noted that: *People in California are generally so preoccupied with their immediate problems and concerns of daily living that they almost forget about the threat of imminent earthquake disaster.*

Lave & Lave [*Ref. 39*] carried out a study in the flood-prone areas of Point Marion and Etna, US on the public's perception of risks from floods. Floods in the US kill an average of 162 people each year and cause $3.4 billion in property damage. The results of the study included the following:

- Most people (who had already experienced a major flood) appeared not to want to grapple with the possible recurrence of a major flood, saying it couldn't, or wouldn't happen again. Many residents characterised, incorrectly, the flood as "man-made". The better educated tended to be more knowledgeable about flood risks;

- Residents tended to focus not on the most recent flood but on the largest, most destructive flood that they had experienced, even if occurred decades ago;

- People were looking for someone to blame. They asserted that a previous large flood had been "man-made" and that a dam upstream of the town should have protected it. This belief led individuals to assert that such a flood could not happen naturally, They did not understand that the upstream dam was designed to generate electricity and had little capacity to protect them against floods.

  Lave & Lave commented that previous researchers had found a similar tendency for people to attribute flooding incidents to human intervention or lack thereof, although sometimes these beliefs were well-founded;

- Overwhelmingly, people concluded that flood control was a government, not an individual, responsibility.

- People knew very little about how to protect themselves from flooding.

- Very few of the people interviewed had purchased flood insurance, even those who had suffered large losses already from flooding did not seem inclined to purchase flood insurance. They tended to rely on the generous post-flood relief from government. A significant percentage said that they had considered moving.

The Public Don't Always Have A Choice!

It is also important to note, however, that just because people continue to live in a disaster-prone area does not mean that they voluntarily do so, even if they have full knowledge of the disaster potential. Such an example, it could be argued, is the poor communities living in exposed coastal regions and islands in Bangladesh. Despite recent catastrophic disasters they continue to live there, but they probably have no or little choice. Their remaining presence may well be influenced by economic, social and political factors, but ultimately the cold fact may be that they have (practically) got nowhere else to go!

It is doubtful whether they are indeed "tolerating" the risks from such natural disasters.

7 DEVELOPMENT OF RISK GUIDELINES FOR LANDSLIDES & BOULDER FALL FROM NATURAL TERRAIN

7.1 OVERVIEW

The previous sections have reviewed the literature on landslides and boulder falls, the development of risk criteria in Hong Kong for PHI sites and other operations, the approaches adopted for the development of risk criteria worldwide in various industry sectors, and the societal risks from natural hazards. This section now attempts to consolidate the lessons learnt from the previous work in order to develop practicable risk criteria for landslides from natural terrain in Hong Kong.

It is stressed that the scope of this study does not extend to the development of criteria for landslides from man-made slopes. Correspondingly, some of the important considerations discussed here may not be applicable for landslides and boulder falls from man-made slopes.

The main considerations in this study include the following areas:

- criteria need to be developed for individual risk and societal risk;
- the implications on public tolerability of risk for "natural" events compared to "man-made" events;
- whether landslide risks can be compared to PHI risks;
- whether the PHI risk criteria can be applied for landslide risks (for natural terrain) and, if so, whether scaling factors need to be applied;
- how risk criteria for landslides from natural terrain can be applied;
- how Cost-Benefit Analysis (CBA) can be applied;
- the value of life to be used within any CBA;
- whether a Consultation Zone should be specified for steep natural terrain which is susceptible to landslide and how this could be used within the landuse planning process.

It should be noted that the emphasis in this study is on the risk of "fatalities" and not "injuries". Certain countries, such as the UK, have based their risk acceptability criteria on injury, although most countries have used fatality as the basis. Injuries are also taken account of by the rail sector and the nuclear industry, since the ratio of injury to death is quite large. However, for landslide risk assessment it is expected that the ratio of injury to death would not be so great so it is not considered necessary to base the risk criteria on injury (or including injury in the risk assessment).

7.2 *APPROACH TO THE DEVELOPMENT OF RISK GUIDELINES*

As discussed earlier there are a number of different approaches adopted worldwide for the development and application of risk criteria. In the Netherlands there has been an on-going debate and review of their risk criteria with the latest revisions involving the elimination of the "acceptable" line on the F-N curve, such that they now have only 2 areas for the F-N tolerability criteria, i.e.

- "Unacceptable";
- ALARP.

This change in policy has been necessary due to the realisation of the difficulties in applying tolerability criteria on F-N curves (or PLL) as a decision tool for landuse planning.

The UK HSE have generally avoided setting tolerability criteria for societal risk for similar reasons and, like the Netherlands, their landuse planning decisions are mainly based on individual risk.

This study, however, whilst taking account of approaches overseas, also aims to develop tolerability criteria for landslides (from natural terrain) which are reasonably consistent with current approaches to risk guidelines in Hong Kong. The study seeks to assess the development of societal risk criteria based on the current PHI criteria for fixed installations, i.e. criteria with the following characteristics:

- *Individual Risk* - the tolerability criteria for individual risk are based on the specification of a maximum permissible individual risk off-site. The individual risk is calculated for actual exposed individuals (ie Personal Individual Risk, PIR), with protection factors applied for persons indoors, and escape factors applied for persons outdoors. The vulnerability of sensitive populations such as the young, old or infirm can also be taken into account;

- *Societal Risk* - the tolerability criteria for societal risk is based on an F-N curve. Three regions are defined within the tolerability criteria, i.e.

  - Acceptable region;
  - ALARP region;
  - Unacceptable region.

In applying the tolerability criteria it will also be necessary to consider approaches for the following:

- Cost Benefit Analysis - which requires the use of a "cost of life" figure;
- Specification of Consultation Zones for natural terrain.

Note: this study concentrates on the use of an F-N curve for the acceptability criteria for societal risk. The Potential Loss of Life (PLL) is also a measure of societal risk and this is suggested later as the basis for the cost-benefit analysis. PLL is not usually used as a basis for acceptability criteria (the offshore oil & gas area is an exception), where some companies have defined in-house criteria for PLL, since it does not tend to illustrate the complex factors which are at play with societal risk. For example, in the railway industry a typical PLL calculation will be dominated by single fatality incidents. This is not too helpful in determination of the acceptability of the risk levels, since (apart from the fact that the individual risk criteria handle single fatality events) the main reason for determining societal risk is to assess society's exposure to and tolerance of multiple fatality events.

7.3 *ACCEPTABILITY CRITERIA FOR INDIVIDUAL RISK*

7.3.1 *Introduction*

As described earlier, the individual risk criterion for PHIs in Hong Kong is that the maximum Personal Individual Risk of death off-site must not exceed 10^{-5} per year. Individual risk criteria generally should be applied equally to all people not involved directly in the dangerous activity. This means that for an industrial activity it is assumed that the people living close to the PHI receive no more benefit from the activity than the average calculated across the whole society. Workers on the PHI site, who do receive a direct benefit from the PHI, are allowed a higher Personal Individual Risk.

Due to the high incidence of landslides in the territory, and the increasing media attention surrounding each disaster, it is likely that the public have been sensitised to the issue of landslide events and have developed an 'aversion' to such events. Although all of the (recorded) landslide incidents to date in Hong Kong which have resulted in fatalities have been due to man-made slope failures, it is thought that the public may not perceive too much difference between a natural terrain landslide and a man-made slope failure.

It is considered that this aversion may be similar to the type of aversion which the public would be expected to display for incidents involving release of chemicals, although the relative level of aversion would need a detailed public opinion survey to assess. It is proposed therefore that the application of the PHI criteria as a basis for development of risk criteria for landslides is appropriate. However, it is necessary to explore whether there is any difference in the public's tolerability to landslide risks from natural terrain (compared to PHI risks) due to:

- the public accepting some voluntary risk by choosing to live or work in the area exposed to the landslide risk;
- a greater degree of tolerance towards "natural events".

It is also important to assess whether different criteria should be applied for existing developments compared to new developments.

It should also be noted that in selecting appropriate risk acceptability criteria it is important to ensure that they can be practically achieved without imposing undue cost to society. That is, should an acceptability criterion be set that is much too strict then it may simply be not possible ever to meet the criteria since the government or developers may not be able to pay the required cost of risk mitigation measures to bring the risk down to within tolerable levels. However, within this study it will not be possible to ascertain the practicability of the criteria, since this can only be done by carrying out QRAs on natural terrain landslide and boulder fall risks (such a full QRA has not been carried out yet in Hong Kong) and to assess the risk results against the criteria, followed by cost-benefit analysis. Only then can an indication be obtained on whether the results of the QRA/cost-benefit analysis are recommending practicable and affordable measures.

7.3.2 *Benefits to Society*

In the case of steep natural terrain the benefits gained by society due to developments on or near such terrain is a complex issue. Detailed assessment of whether such developments provide an overall net benefit to Hong Kong society is beyond the scope of this study.

Developments within steep natural terrain may not seem to generate the clearly defined and measurable economic benefits generated by a PHI. If people were not allowed to live in such terrain, however, this may create other problems. In a land-scarce and mountainous region like Hong Kong, if housing in steep natural terrain were prohibited it would create extra pressures on already densely populated city regions. Indeed, much of the existing development has in fact been on steep natural terrain.

Increasing the density of housing in established areas to accommodate people relocated from areas deemed to be at risk from natural terrain, or to accommodate people who were initially planned for a new development within a steep natural terrain area, would inevitably be costly and, directly or indirectly, affect all of the society. Extra infrastructure such as roads and trains would need to be provided (these would still need to be provided for new developments in steep natural terrain). The cost of levelling slopes, buying flat farm land or reclaiming more land from the sea would incur significant costs.

A further consequence of restricting development on or near steep natural terrain would be the environmental damage caused by possibly increased reclamation developments from the sea. This, however, would need to be weighed against the environmental damage caused by alternative development of natural terrain areas.

The benefits to society, for new developments within steep natural terrain can therefore be briefly summarised as:

- provision of more (virgin) land for development of housing;
- (associated) lesser cost, and better quality of life, to the community since there will be less need for further development of already well-developed areas;
- provision of more housing, and in environmentally attractive areas;
- possibly less environmental damage compared to reclamation from the sea.

People's tolerability to risk tends to be related to the benefits which they gain by remaining in a certain area. Hence there is a direct relationship here. The clearest example in Hong Kong is why squatters tend to remain in their homes (often in steep terrain which is prone to landslides) despite the known risks from landslides. It could be argued, however, that many squatters do not actually have a choice.

The benefits to society in remaining to live in housing already near or within steep natural terrain can be summarised as:

- economic benefits to owners and residents in not needing to relocate;
- economic benefits to government in not needing to find new virgin land or to further develop existing residential areas;
- proximity to existing place of work;
- social benefits (close to family etc).

And, of course, in the case of squatters they obtain extremely cheap or free housing by choosing to reside in landslide prone squatter areas. There is an element of voluntary risk here, although, as noted above, many squatters may not have a choice.

7.3.3 *Voluntary Risk?*

It is generally held that voluntary exposure to risk is more tolerable than involuntary exposure. For example, the level of individual risk associated with some sports (eg rock climbing) would certainly be considered intolerable if it were associated with the impact of a PHI on a nearby population.

If an exposed individual perceives that he is able to affect his environment to the extent of mitigating risk and recovering from "near misses", they may also be willing to tolerate higher levels of risk. Self-determination is thought partly to account for the very much higher level of risk tolerated for car travel, as compared with rail transport, for example. Whereas car drivers typically think that they can influence the likelihood of their having an accident, people living near a PHI can exert no influence whatever over the likelihood of an accident. PHIs have to be that much safer, to compensate for this factor. The same argument applies to people living close to slopes which present landslide hazards.

The question which arises therefore is whether landslide risks from natural terrain be considered as a "voluntary" risk, since presumably many of the persons living or working at a particular location exposed to such risk would have actually chosen to live at that location, and thereby expose themselves to the risk from the slopes. If a significant element of voluntariness can be identified then there could be a case for applying a "scaling factor" against the 10^{-5} per annum Individual Risk criterion (see *Section 4.2.1*).

Whilst there could be a valid case for applying a higher acceptability criteria for squatters on natural terrain, for new or existing permanent developments at risk from landslides and boulder falls from natural terrain it is considered that the public would not consider the risks affecting them to be "voluntary". Voluntary exposure to risk from natural terrain may be subconscious, as awareness of risk may be either inaccurate or absent. The public would most probably expect that the government would have ensured that such risk levels were very low, or the risks even eliminated, with appropriate engineering measures implemented, otherwise the government would surely not have allowed the development to proceed. Furthermore, particular members of the population such as the young, would have had no part in the decision to live at the location, and these same sensitive population may be amongst those most at risk.

It could be argued therefore that there should not be any "scaling factor" to allow for an element of voluntariness for living near a slope in natural terrain.

One example, however, of people possibly exhibiting an element of voluntary risk would be if they continued to reside in their property, despite having being warned to evacuate (under a landslip warning), or if they were to travel outside unnecessarily and expose themselves to landslide risk (during a Landslip Warning).

7.3.4 *Natural Event?*

The review of natural hazards in *Annex A* tended to show that in certain areas worldwide there are indications that the public will tolerate much higher levels of risk from natural terrain landslides than the 10^{-5} per annum level used for PHIs. For example, in Montrose, Victoria, the villagers in mountainous areas are exposed to individual risk levels of up to 10^{-3} per annum, yet despite extensive education from the local government on the high levels of risk they continue to live there. It is important to note, however, that there may well be other socio-economic factors at play which are influencing their tolerability to the high levels of risk, such as their property prices which may well have been reduced due to the adverse publicity relating to the high risk levels and they may not be able to sell or buy new property, or for new buyers possibly the homes are very cheap to buy.

So it is necessary to consider whether the public in Hong Kong will tolerate a higher level of risk from natural terrain landslides compared to PHIs, and if so, whether a "scaling factor" should be applied to provide a less conservative criteria for natural terrain landslides.

An important factor here is whether the public would perceive human involvement in a landslide disaster from natural terrain. The public would probably be reasonably tolerant of, say, a hiker being killed by a landslide whilst walking in open countryside, and may even consider the incident as an "Act of God". However, should a landslide occur from natural terrain onto a new development with fatalities resulting, then the public would most likely see the incident as having man-made causal factors, since it was man that permitted the development to proceed.

The review of natural hazard disasters in *Annex A* has indicated that the consequences of natural disasters, including landslides from natural terrain, can be much greater than for man-made hazards. The public can therefore be expected to show more tolerance to the high consequence of natural hazards relative to the consequence of a man-made hazard.

For landslides which occur from natural terrain and affect a new development, it is thought that the public would perceive a strong element of human involvement, and that they would be no more tolerant of the risk levels compared to a man-made slope, except for possibly an understanding that the consequences of the hazard could be much larger.

It is concluded that there should be no "scaling factor" applied here [to develop risk guidelines for natural terrain landslides] against the PHI criteria except to account for potential for the scale of a natural event being greater compared to a man-made (eg PHI) hazard.

7.3.5 *Recommended Individual Risk Criteria*

As reviewed earlier, the Individual Risk acceptability criteria currently adopted for PHIs in Hong Kong is 10^{-5} per year. This is actually for Personal Individual Risk (PIR), with no ALARP region being applied (ALARP is applied for the societal risk criteria only), and tends to be calculated for an "average" member of an exposed population.

This study has found no strong basis for using a scaling factor against this criteria and it is therefore concluded that the same criteria should be used for landslides and boulder falls from natural terrain.

It is therefore proposed that:

The maximum allowable Individual Risk level to a member of the public in a new development from any natural terrain landslides and boulder falls should not exceed 10^{-5} per year.

For existing developments it is proposed that the maximum individual risk to which any member of the public should be exposed from natural terrain landslides and boulder falls is taken to be 10^{-4} per year.

Within the context of this study:

- "existing" refers to an existing development within steep natural terrain;
- "new" refers to a new development within steep natural terrain.

It will be noted that there are differences here compared to PHI sites, with the concept of a "new PHI site" not being applicable for natural terrain (since the natural terrain is already there!). We can compare only to existing and new developments around an existing PHI site.

The above approach for existing and new developments is in line with approaches adopted elsewhere, such as in The Netherlands, where the tolerability level for existing major hazard facilities is a factor of 10 higher than for new facilities, although the criterion adopted there is 10^{-5} per year for existing facilities. Such an approach is in recognition of the need for practicability for risk management of existing facilities, and also that the public may be expected to be more tolerant of failures associated with older facilities than for new facilities. It is thought that the public would be less tolerant of risks for a new development in steep natural terrain, as compared to (say) a 20 year old development. The public tends to expect that advances in technology and knowledge over the years should bring with it reduced risk. There is a number of good references to support this and this is why some countries develop more strict criteria for new facilities.

The IR would normally (in Hong Kong) be calculated as the Personal Individual Risk, and for an "average" person. Current thinking in Hong Kong (for PHI Hazard Assessments), however, is that more account should be taken of vulnerable population. **It is therefore recommended that the maximum IR criteria of 10^{-5} per year for new developments, and 10^{-4} for existing developments should also be applied to the most vulnerable**

population. The risk calculations should therefore take account of the higher vulnerability of such persons, and the criteria are therefore more stringent (if such vulnerable persons are present) than the current PHI risk guidelines.

Another question which needs to be addressed is whether the ALARP principle should be applied for individual risks from landslides on natural terrain. This usually involves specification of a broadly acceptable level below which no further risk mitigation is necessary, with cost benefit analysis only carried out within the ALARP region, eg as applied in the UK (see *Section* 3.1.2). It should be noted, however, that ALARP is currently not applied for IR for PHI sites in Hong Kong, wherein the 10^{-5} criterion is applied as a single acceptability limit with no tolerability region, ie if the IR is below 10^{-5} then it is acceptable, but if it above 10^{-5} then it is unacceptable.

For landslide and boulder fall risks from natural terrain it is considered that there should not be an ALARP region for individual risks, ie as is the case for the PHI risk guidelines. This is recommended since the ALARP demonstration and associated CBA is most effectively carried out based on the societal risk measure, PLL.

The Individual Risk acceptability criteria which are recommended for landslides from natural terrain are summarised in *Table 7.3a* below.

Table 7.3a *Recommended Individual Risk Acceptability Criteria*

Individual Risk Level	New Situations	Existing Situations
Maximum Permissible IR	10^{-5}	10^{-4}
ALARP region	None	None
Acceptable IR level (below which no further risk mitigation is required)	$<10^{-5}$	$<10^{-4}$

7.4 *ACCEPTABILITY CRITERIA FOR SOCIETAL RISK*

7.4.1 *Options Considered*

In setting societal risk F-N acceptability criteria for landslides and boulder falls from natural terrain the following aspects need to be considered:

- should a 3-tier approach be adopted for the criteria, with an "unacceptable", ALARP (ie "tolerability" region), and "unacceptable" region adopted;
- the slope of the F-N "unacceptability" line (and "acceptability" line, if one is adopted). A slope of -1 has been adopted for Hong Kong PHIs;
- should there be a high fatality vertical "high fatality" level and, if so, at what number of fatalities should it be applied. An "unacceptable" high fatality level of 1000 is used for PHI sites in Hong Kong, ie it is unacceptable to kill 1000 people or more in a single incident, unless the associated frequency is less than 10^{-9} per year (which is considered as non-credible).

Each of the above features for an F-N acceptability criterion is considered further below, but first we must consider the feasibility of development of such criteria based on the current Hong Kong PHI criteria, or other approaches. Five possible approaches are considered in *Annex E*, ie

• Option A	Develop risk criteria for landslides from natural terrain based on using the PHI criteria for fixed installations. Determine the number of PHI sites and scale up the criteria to determine the effective overall PHI criteria for the territory. Use this overall criteria as the basis for the development of natural terrain criteria by scaling up or down as necessary to give a SAR-wide natural terrain criteria. Using the 'number of natural slopes' (ie based on consideration of the area of the slopes), scale down the SAR-wide criteria to give societal risk criteria natural terrain, i.e. for a particular "slope" or feature.
• Option B	As for Option A, base the risk criteria on the PHI criteria but also take into account the risk criteria for transportation of DGs in Hong Kong. Scale up to determine SAR-wide societal risk criteria for PHIs/DG transportation. Use these as a basis for the development of the natural terrain criteria as described in Option A.
• Option C	Use the PHI societal risk criteria for a fixed installation as a direct basis for the development of criteria for landslide from a specific "natural slope". Scale the PHI criteria up or down as appropriate.
• Option D	As for Option C but also take into account the DG transportation associated with the PHI.
• Option E	Develop the societal risk criteria from 'first principles' by assessment of the risks from all types of landslides and boulder fall in Hong Kong and determination of the public's tolerability to landslide and boulder fall risks. Assess the relative contribution to societal risk from landslides and boulder falls from natural terrain, and the publics' tolerability (as compared to landslides from man-made slopes), to determine the societal risk criteria for landslides and boulder falls from natural terrain.

Each of the above options are discussed in *Annex E* with Option C being the preferred option identified for further consideration in this study. The need for the application of a scaling factor against the PHI criteria is also discussed.

7.4.2 *Further Discussion*

A large landslide from natural terrain could potentially completely destroy one or more high rise buildings and result in many thousands of fatalities. The mortality percentage in such an incident would be expected to be high - past incidents have indicated that a high proportion of the occupants are killed in a building (total) collapse, possibly 90% or higher. Knock-on incidents, such as fires from rupture of gas mains have the potential to cause further damage in areas not actually affected by the landslide. Therefore, the practicality of setting criteria with a high fatality accident aversion factor, and indeed a 1000 fatalities level, needs to be considered.

Given the propensity for natural disasters to be of a much higher magnitude than man-made incidents, it is thought that the 1000 fatalities "unacceptability" line, as used in the PHI criteria, may need to be modified for the landslide criteria.

In addition, people are expected to be more willing to tolerate a "natural" disaster or "act of God" than they are to tolerate risks from a PHI or any man-made structure. People will live in earthquake-prone or flood-prone areas or even near volcanoes even though there may be warnings or predictions of an imminent natural disaster, and many will often remain when they are recommended to evacuate. Few people would be expected to remain inside their house if there is a toxic gas leak or fire in a nearby PHI and the evacuation order is given. In these cases of an uncontrollable natural disaster, an order of magnitude or more can be expected in the public's tolerability to risk.

However, the public will probably perceive human involvement in a natural terrain landslide disaster involving a new development, since they would expect that such a development would only have been allowed to proceed if it was a safe area, and that adequate protection measures had been taken. Hence, although the actual landslide was still perceived as a natural phenomenon the 'hand of man' in the disaster would be evident. For example, after a number of earthquakes in Los Angeles there was very little public unrest, despite a number of fatalities. Criticisms were mainly aimed at the emergency response which was claimed to be disorganised. After the Kobe earthquake in Japan in 1995 there was public outcry but mainly because structures which the Government had claimed were 'earthquake-proof' had failed. The critical feature, in the mind of the public, is whether the incident "could have been avoided" by better controls or planning.

7.4.3 Recommended Societal Risk Criteria

It is proposed that the existing PHI criteria should be used as a basis for the development of societal risk criteria, with the criteria adapted as suggested in the following options:

OPTION X - PREFERRED OPTION

- **The same line [as for PHI criteria] for "unacceptability" should be used, ie corresponding to a frequency of 10^{-3} per year for incidents involving one or more fatalities, and with a slope of -1. (Current government policy for PHIs is that if the assessed risk for new and existing installations falls within the "Unacceptable" zone, the risk must be reduced to ALARP regardless of cost.)**

  This is, essentially saying, that it is considered that the limit of tolerability for landslides and boulder falls risks from natural terrain is the same as for risks from PHI sites. The use of a possible scaling factor to account for any perceived differences in tolerability has been given careful consideration, with no strong reason identified to modify the PHI criteria. The most relevant factor for use of a scaling factor was the potentially greater tolerability which the public (worldwide) exhibits to natural disasters compared to man-made disasters. Although a large landslide from natural terrain, affecting a new residential development, in itself could not be perceived as 'man-made', there would still be human involvement (in the disaster) by allowing the development to proceed and in possibly failing to implement effective protection and emergency measures. No firm basis has been identified for using a different slope to the -1 used for the PHI societal risk criteria.

- **There should be no "acceptable" line on the F-N curve, and ALARP should be applied for all risks which fall below the "unacceptable" line.**

  This is in line with some of the latest approaches overseas, such as in The Netherlands. Another reason for applying this principle here is that the level of uncertainty for QRA study results on landslides and boulder falls from natural terrain is expected to be greater than for QRA studies on (say) process plant. It is therefore considered to be inadvisable to set a level of acceptability below which no further attempts to seek risk mitigation are attempted - see below for further discussion.

- **The limit of tolerability for the number of fatalities (from a single event) should be extended from the 1000 fatalities used for PHI sites to 5,000 fatalities. A vertical line should be drawn on the F-N graph at 1000 fatalities (up to the -1 slope 'unacceptable' line), and fatalities in the region 1000-5,000 (up to the -1 slope 'unacceptable' line) should be treated as an 'Intense Scrutiny' region.**

  The 1000 fatality level for PHIs was initially proposed to allow for society's aversion to high fatality events, with consideration also given to economics factors. It should also be noted that the public's reaction to a 1000 fatality event in Hong Kong has never been tested, at least in recent times.

  Another means for achieving 'high fatality aversion' would have been to use a slope of greater than -1 for the F-N acceptability criteria, such as -2 which the Dutch government uses. The latter approach was not adopted (for PHI sites) since it was considered that, in the densely populated and land scarce Hong Kong, it would be too restrictive. The use of the 1000 fatality level, however, has proved to be a very severe criteria for PHI sites in Hong Kong.

  The review of natural hazard events worldwide, including landslides from natural terrain, as given in *Table A-3.2g* in *Annex A*, has indicated that there is the potential for much greater consequences from natural hazards, with many thousands of fatalities being possible. It is thought that the potential would exist in some areas of steep natural terrain in Hong Kong for a large landslide to cause complete destruction of high rise buildings, causing more than 1000 fatalities. (A typical high rise building of 40 storeys may house up to 1600 people assuming 6 to 8 residential units per storey and an average of 3 to 5 persons per flat). Although the likelihood of such a catastrophic event would probably be extremely low it may not be possible, within the uncertainties associated with landslide QRA to demonstrate that the frequency is less than about 10^{-6} per year. This would still be some 3 orders of magnitude higher than the current acceptable (considered as "negligible") frequency of 10^{-9} for >1000 fatalities.

Should a 1000 fatality "unacceptable" level be adopted for natural terrain, then it is likely that it would be far too restrictive, with many areas being prohibited from development. Indeed, if the same criteria are adopted for existing developments within natural terrain, then severe problems would be encountered with many existing sites failing to meet the criteria, and with little or no chance of mitigation measures being able to reduce the risks other than to relocate the population and demolish the buildings.

- The above proposed risk criteria are considered to be reasonably consistent with the current PHI criteria, whilst following latest approaches overseas, and also being reasonably consistent with criteria for landslides previously proposed overseas;

- *Figure 7.4a* presents the proposed risk criteria for societal risk for landslides and boulder falls from natural terrain;

- The reason for including an 'intense scrutiny' region in the risk guidelines is to provide an option to regulators to permit certain types of developments. Such developments may not necessarily be unacceptable but would be examined with special scrutiny considering the social needs;

- **It is strongly recommended, however, that the societal risk criteria should not be mandatory, and should be used as guidelines only,** and as just one input into the complex decision-making process, with many other (non-risk) issues considered. The difficulties with interpretation of the F-N curves, together with the uncertainties associated in landslide and boulder fall QRA, would most likely result in significant problems with land-use planning in steep natural terrain areas if the criteria are applied too rigidly.

ALARP

This option proposes that there should be no "acceptable" region and that ALARP should be applied for all societal risks below the "unacceptable" region. This is proposed for the following reasons:

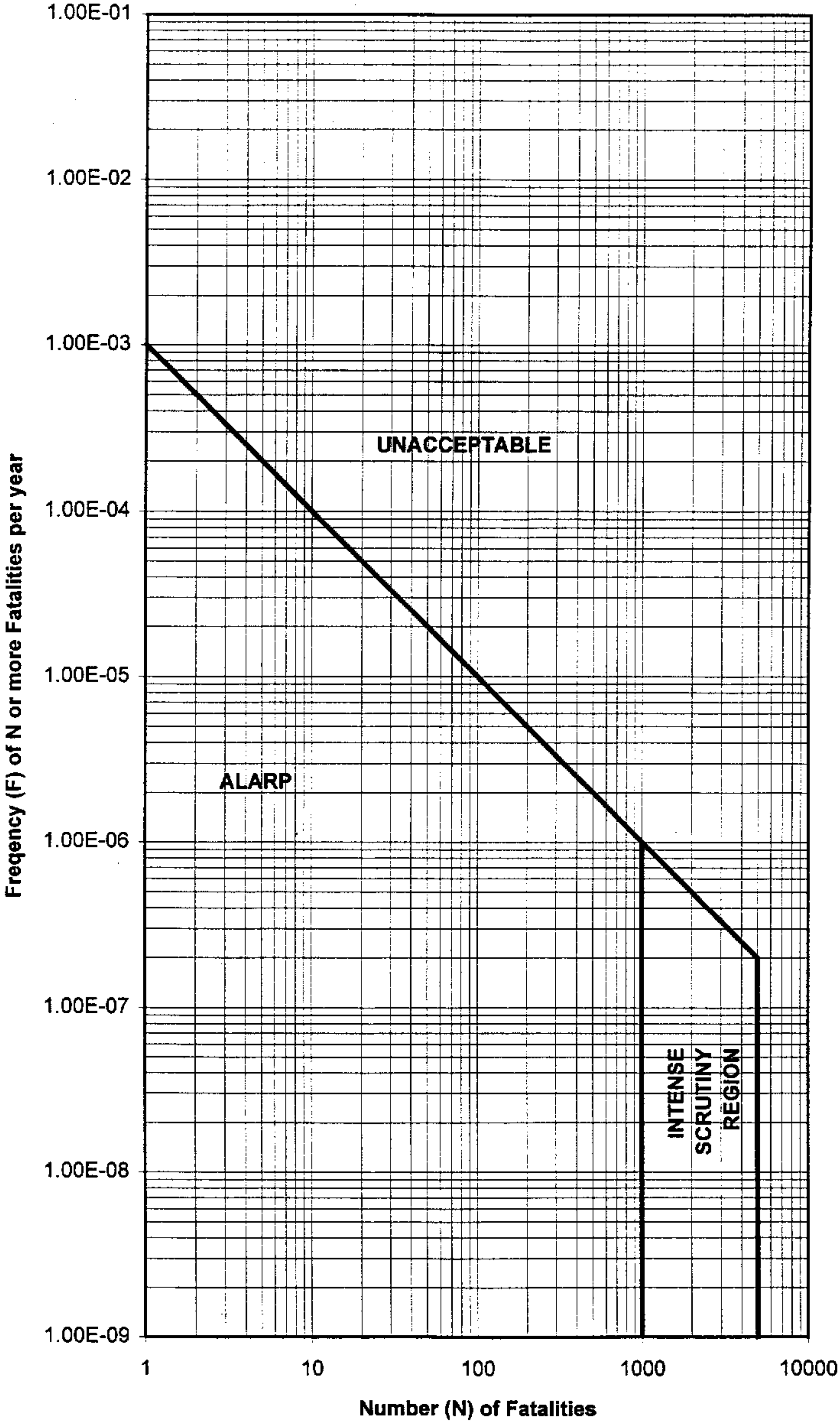
- apply the philosophy that no risk is "accepted" as such by the public, but only "tolerated", and as such efforts should always be made to reduce risks (in a cost-effective manner) even if the (calculated) risks are low;

- provide more flexibility in landuse planning decisions, eg the Government may still wish a developer to seek risk reduction measures even though the calculated risk levels are below an "acceptable" line;

- reduce problems with interpretation of F-N curves;

- avoid problems with uncertainty in risk results, eg a developer would argue that the risk is "acceptable" with the F-N curve just below the "acceptable" line, but the likely level of uncertainty could result in GEO determining a risk level much higher. Difficulties would arise in the landuse planning decision-making process;

Figure 7.4a - Proposed Societal Risk Criteria for Landslides and Boulder Falls from Natural Terrain (Preferred Option - X)



- follow the recent trend in The Netherlands where the "acceptable" line has been removed for the above type of reasons - the line apparently led to many problems with landuse planning over the years.

With ALARP applied for all risks below the "unacceptable" line then practicable risk mitigation options would need to be sought and evaluated in a cost-benefit analysis. This need not be a time-consuming process, however, since standard risk mitigation measures (for landslides and boulder falls), could be agreed with standard unit costs also estimated. The exercise should not create undue problems or burden for Government, indeed for new developments the developer should be undertaking the cost-benefit analysis.

A simple example of how cost-benefit analysis could be applied is presented in the next section.

New vs Existing

It is proposed that the same societal risk criteria should be used for existing developments and new developments. This is in line with approaches overseas where different acceptability criteria for new and old facilities tends to be applied only for individual risk and not for societal risk.

The rationale behind this is that it becomes difficult in the societal risk calculations to take separate account of existing and new developments around a hazard site. They ultimately must all be added into the societal risk calculations. So one acceptability criteria is essential.

As suggested above, it is also proposed here that the societal acceptability criteria should not be as rigidly applied as the individual risk criteria. With more flexibility being applied to the application of the proposed societal risk criteria there should be no need to develop separate societal risk criteria for existing and new facilities.

OPTION Y

This option is given in *Figure 7.4b*. A line with slope of -1 is drawn at 2 orders of magnitude below the current recommended 'unacceptable' line. Risk falling this bottom line should be considered as 'broadly acceptable', within which no risk mitigation is required. The middle region is therefore the ALARP region. This is similar to the current PHI risk guidelines, except that (as for above option) we still have our criteria extending to 5,000 fatalities, with the 1000-5,000 region treated as an 'Intense Scrutiny' region.

7.5 *APPLICATION OF THE CRITERIA*

Having proposed the above acceptability criteria for individual risk and societal risk it is now important to discuss how the criteria should be implemented. There are a number of aspects to consider here, including:

- Interim Guidelines;
- Area of natural terrain for which the criteria should be applied;
- Consultation Zone;
- Cost-Benefit Analysis.

A brief discussion on likely implementation problems is also included below.

7.5.1 *Interim Guidelines*

It is recommended that the proposed risk guidelines for Individual Risk and Societal Risk should be viewed as Interim Criteria only at this stage. Only when they have been used in earnest for the assessment of QRA results from natural terrain landslides and boulder fall studies will any significant problems with practicability be identified. Further work could also be carried out to assess the tolerability of the public to such risks, by the use of opinion surveys and willingness-to-pay studies (see the cost-benefit section below which discusses willingness-to-pay).

7.5.2 *Area of Natural Terrain*

In order to be able to implement the societal risk criteria we need to define a "unit" measure of natural terrain for which the criteria apply. We must remember that the proposed criteria have been developed from the risk guidelines for PHI sites. We must therefore establish what constitutes an "area of natural terrain" which is equivalent to an actual PHI. Clearly this is not a straightforward task, which is further complicated by the fact that PHI sites themselves are widely varying in scale and extent of hazard which they present to the public, and yet the same PHI criteria are applied. For example, the same PHI risk guidelines are used for a large oil & gas terminal on Tsing Yi as would be applied for a small water treatment works with a few 1 tonne drums of chlorine.

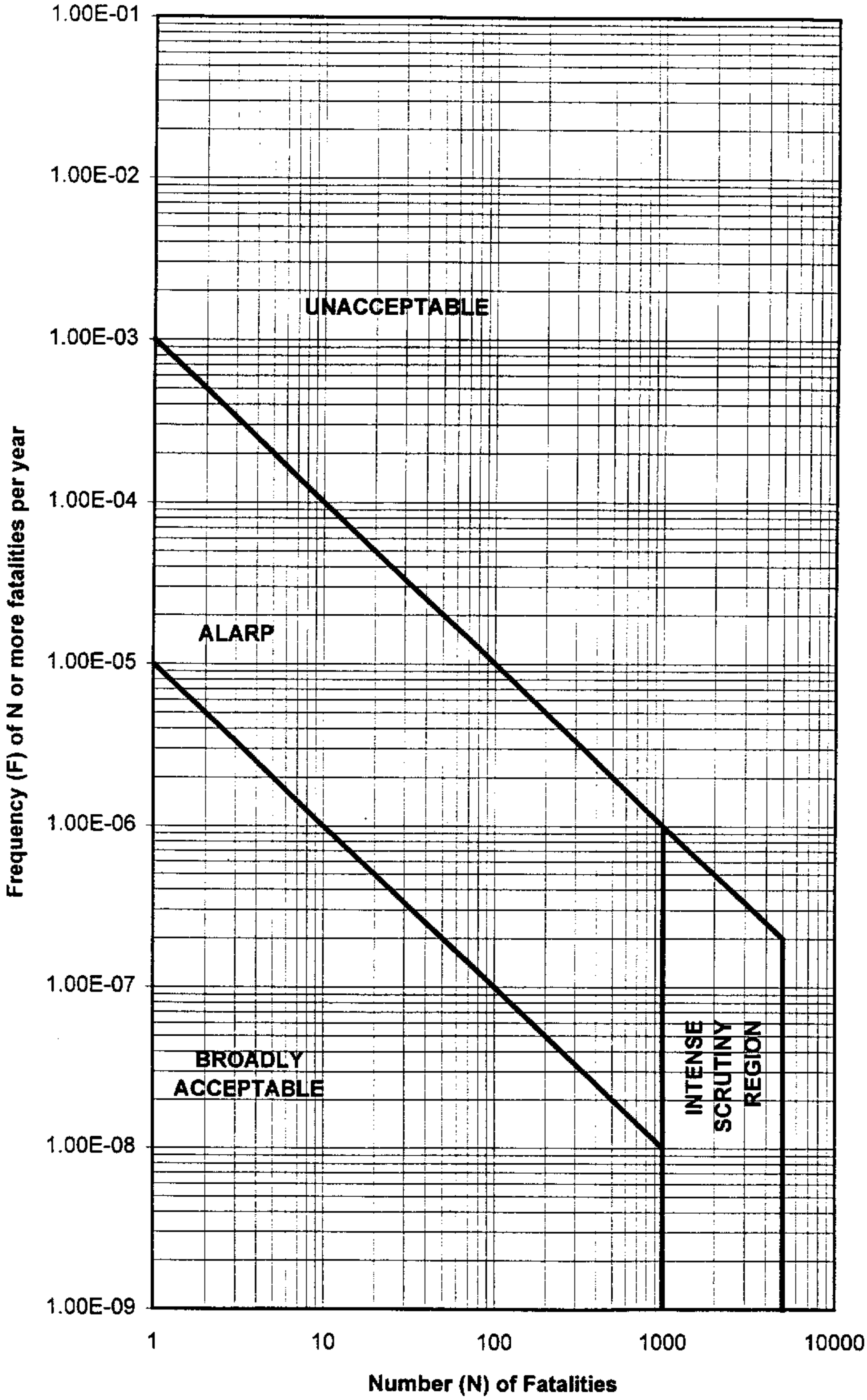
There is therefore no mathematically robust way to determine an equivalent area, or length, of slope. The approach proposed here is to base the calculation on the Consultation Zone (CZ) for a "typical" PHI. Once again, however, we meet difficulties here since different types of PHI sites have different consultation zones. The CZ for a water treatment works using chlorine in 1 tonne drums is usually 1 km (ie 1 km radius from the chlorine store), whilst that for an LPG site is usually about 150m. The CZ will represent the area around the plant where most of the risks are concentrated, but there may still be some risk beyond the CZ.

The intent here, however, is to consider the "community at risk" from natural terrain. We need therefore to find the type of PHI site that would place an equivalent number of people at risk (for the same types of development) to a new development within natural terrain.

Work to date on the Natural Terrain Landslide Study (NTLS) *[Ref. 49]* in GEO has provided information on 26,780 landslides from natural terrain, of which, 8,804 have occurred during the last 50 years. Of the 8,804 landslides, 199 (2.3%) have a runout distance of more than 150m, and 34 (0.4%) have a plan runout distance of more than 300m. It is understood that these distances refer to the horizontal distance travelled from the initiation point of the landslide (ie these are not distances from the toe of the slope). The majority of the landslides within the NTLS are shallow debris flows and slides of relatively small size.

From the NTLS work *[Ref. 49]* it is likely that the risks from natural terrain landslides are likely to be concentrated (at the most) within 150 to 300 metres

Figure 7.4b - Proposed Societal Risk Criteria for Landslides and Boulder Falls from Natural Terrain (Option Y)



from the toe of the slope, or indeed to developments on the slope itself. In reality many of the historical landslides in the NTLS would not have extended to such distances, since they would have started a certain distance up the slope. It is estimated here that a reasonable estimate at this stage, for the distance from the toe of the slope within which the risks are likely to be concentrated, is about 150m. This distance needs to be reviewed following landslide and boulder fall QRA studies for natural terrain areas. It should also be noted that some catastrophic landslides may also be capable of extending beyond this, but this is the case with the CZ for existing PHIs also (as noted above).

If a CZ of around 150m is eventually adopted for natural terrain (this can only be substantiated following QRA studies on natural terrain) then this would be similar in extent to that usually adopted for LPG PHI sites.

It is proposed to use a 150m Consultation Zone for an LPG PHI site as the basis for our comparison here. This 150m CZ would be drawn radially around the PHI site covering an area of about 70,700 m^2. We need to determine what length of slope (at the toe) this is roughly equivalent to.

Using a 150m distance, as the equivalent width of the CZ for natural terrain then we arrive at a distance of about 470m for the length of the toe of the slope which gives an equivalent 150m (circular) CZ. At this stage, bearing in mind the coarseness of the exercise, **it is suggested that a 500m length of natural terrain (which presents risk to the community) should be considered as the basis for the QRA. That is, a 500m length of natural terrain (toe of the slope(s)), which presents risks to the community, should be the maximum length used for application of the risk guidelines.** Should a development involve greater areas of natural terrain, such that this length is exceeded, then an appropriate linear scaling factor should be used. That is, if a very large development within a large natural terrain area is being considered, with (say) 5km of equivalent toe slopes (which presents risk to community) from natural terrain, then it follows that the risk guidelines for societal risk should be increased by an order of magnitude for that development [so this is, essentially, saying that such a large area of natural terrain is equivalent to 10 PHI sites].

If the development involve less than 500m equivalent toe slope from natural terrain, then the same criteria should still be used, ie the acceptability should not be scaled down.

The proposed societal criteria are applied to the results of QRA for 3 selected boulder fields to assess if the proposed criteria can be met or is difficult to achieve. The F-N curve for 3 selected boulder fields is plotted in *Figure 7.5a* along with the proposed societal risk criteria. These boulder fields are part of the SAR-wide study conducted previously by ERM [*Ref. 10*]. The selection of these 3 boulder fields from amongst 197 analysed in the study [*Ref. 10*] is arbitrary (the worst case has not been identified); however, these fields have a length of about 500m of threatened population and the affected facility includes road, temporary structure and modern building. It can be seen that the F-N curve for the individual boulder fields is within the "ALARP" region, and therefore it can be concluded that the criteria may not be impracticable to achieve.

Further refinement of the QRA model for boulder fall from natural terrain and further studies on QRA of landslides from natural terrain should provide additional confirmation on the practicality of the proposed societal risk criteria. It may be noted, however, that the FN curve for the 3 individual fields is close to the "unacceptable" line for single fatality events.

An alternate approach (to improve the practicality of meeting the criteria), adopted by some industries including the rail industry is to define societal risk criteria for fatalities greater than one only. This approach has been adopted since the frequency of events causing one fatality is usually very high (higher than 10^{-3}) resulting in an F-N curve in the "unacceptable region" for fatalities less than two. Since the objective of an FN curve is more to represent the high fatality-low frequency events rather than high frequency-single fatality events, such an approach is considered justifiable. However, in the calculation of PLL and individual risk, all the events are included.

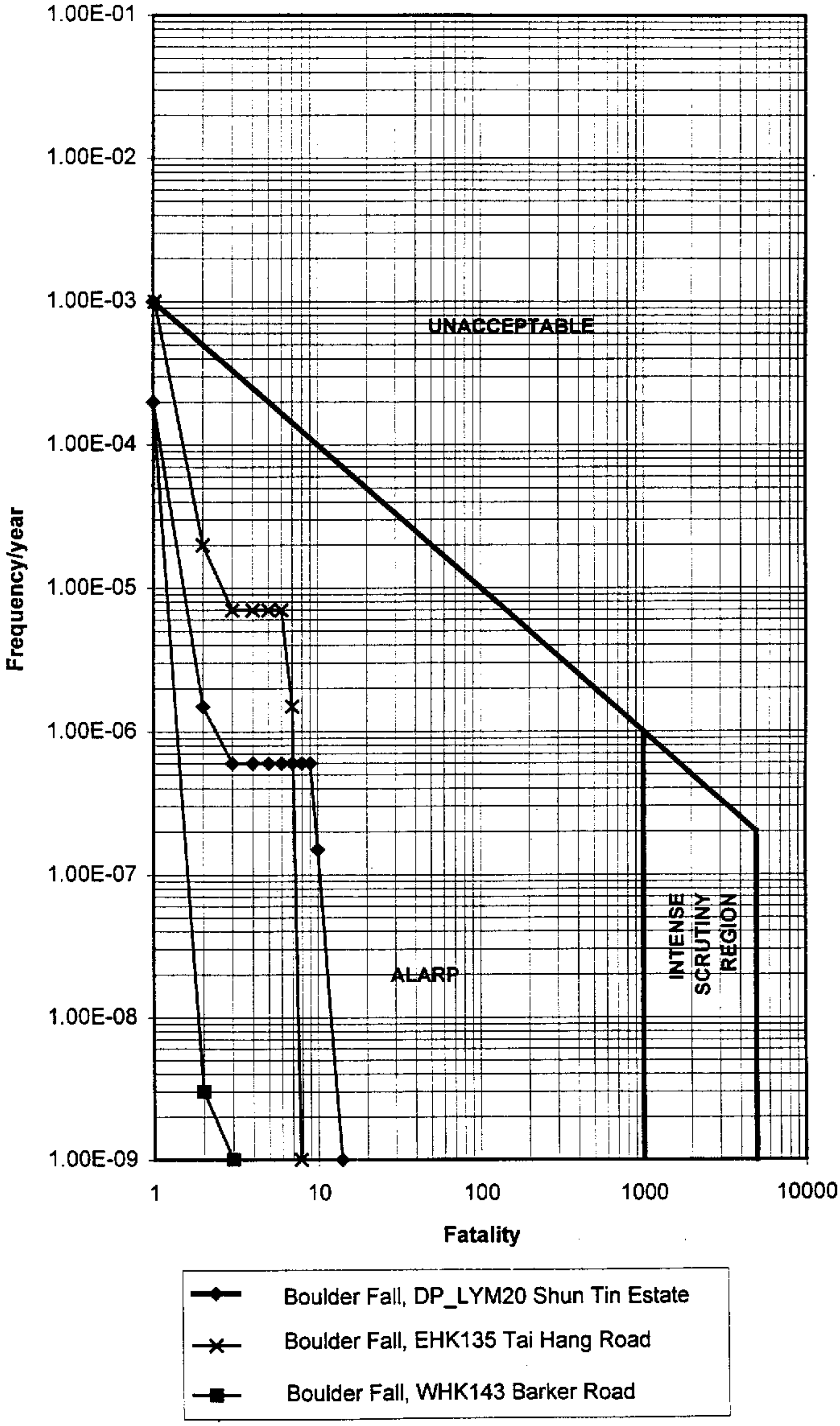
7.5.3 Consultation Zone

It is suggested that it will eventually be necessary to define Consultation Zones within steep natural terrain areas. A CZ, once defined within a particular location, restricts certain types of developments and requires developers to assess the risks associated with the additional development. Further work still needs to be done on carrying out QRAs on landslides and boulder fall hazards in order to provide a basis for estimation of the CZ. Different approaches have been adopted worldwide for the definition of CZs. For example, the Hong Kong Government adopts a hazard range approach for chlorine WTWs which store chlorine, whereby the 1 km CZ is the distance for about 1-3% fatality due to rupture of a 1 tonne chlorine drum (The Water Supplies Department is currently undertaking a reassessment of the chlorine hazards using more recent and advanced dispersion models based on which a review of the Consultation Zone will be carried out). Such an equivalent approach for natural terrain may result in a CZ which extends about 150m from the toe of the slopes, but includes the actual slopes themselves up to the summit(s).

The best Consultation Zone approach to be adopted for landslides and boulder falls from natural terrain in Hong Kong needs much discussion, and is best attempted following a number of QRA and land-use planning studies for natural terrain. A firm recommendation on the best approach would therefore be premature in this study, although an approach based on risk levels rather than hazard ranges is preferred.

Reference should be made to *Annex B* for a discussion on how consultation zones, and landuse planning zones, are defined overseas. An approach similar to the UK could be adopted where 3 zones are defined, based on IR levels. Certain types of developments are then restricted within certain zones.

Figure 7.5a - Calculated Boulder Fall F-N Curves for 3 Selected Fields & Comparison with Proposed Criteria



8 COST-BENEFIT ANALYSIS

8.1 OVERVIEW OF COST-BENEFIT ANALYSIS METHODOLOGY

In order to assess the cost-effectiveness of the identified risk mitigation measures it is necessary to carry out a Cost-Benefit Analysis (CBA). The ALARP ('As Low As Reasonably Practicable') principle implicitly includes the undertaking of a CBA in order to assess cost effectiveness of an identified risk mitigation measure, since the term 'reasonably practicable' implies a balancing of costs and benefits. Should the CBA indicate that the costs of a particular risk mitigation measure (or group of measures) are grossly disproportionate to the reduction in risk obtained by implementation of the measure then it would not be 'reasonably practicable' to implement the measure and the measure should be rejected. More simply put it can be said that it is not cost-effective to implement the measure. As noted by Marin [*Ref. 58*], the optimum level of safety will be when risks have been reduced up to the point where the cost of any extra reduction just equals its benefits, but to go no further. In economists' terminology, risks should be reduced until the 'marginal cost equals the marginal benefit'. As noted below, this is a somewhat idealistic view since, in reality, there will be other factors such as the uncertainty in the risk results and in the estimated costs (of the mitigation measures, and, indeed, in the 'value of life' figure used also) which can significantly affect the conclusions of the cost-benefit analysis.

The question remains as to how it is determined whether a risk mitigation measure is cost-effective. The most common approach tends to be for the societal risk measure, Potential Loss of Life (PLL) to be used as a basis, since this is a single figure which represents the complete range of risks to society as a whole. However, in certain circumstances, such as where a particular individual, or identified population group, has been identified (in the QRA) as being exposed to a higher risk than the rest of the community, then it may be preferable to also base the CBA on Individual Risk, or Collective Risk (where Collective Risk would represent the societal risk to the identified population group).

For the undertaking of CBA for landslide and boulder fall QRA it is considered that the most appropriate measure of risk, upon which to base the cost-effectiveness of the candidate risk mitigation measure, is usually the PLL. The advantage of using the PLL is that it represents the risks to society (ie the community at risk from the identified hazards) and will include the complete range of hazard events which affect that community. The candidate risk mitigation measures can therefore be chosen on the basis of the identified most significant contributors to the PLL, ie from the output of the QRA.

The overall approach for the CBA is therefore:

- *Identify Significant Hazard Events:* identify the hazard events which contribute significantly to the PLL;

- *Identify Candidate Risk Mitigation Measures*: choose a number of candidate risk mitigation measures which would reduce risks from the identified significant hazard events. These risk mitigation measures can be considered individually or they can be grouped into separate groups of measures (eg group A, group B etc) with the risk reduction and costs associated with each group of measures then assessed;

- *Calculate Risk Reduction for Each Risk Mitigation Measure:* calculate the risk reduction achieved by each identified risk mitigation measure, by re-running (which may include revision of) the QRA model;

- *Determine Cost-Effectiveness of Each Risk Mitigation Measure:* the cost-effectiveness of each risk mitigation measure (or group of measures) now needs to be determined. This requires a comparison of the cost of implementation of the measure with the associated risk benefit (ie the reduction in risk) achieved. We therefore need to have a uniform basis upon which to make this comparison and the current approach is to base the comparison on 'cost'. We therefore need to express the risk benefit in terms of cost. If we are expressing risk in terms of 'risk to life', as is the case with landslide QRA, then we have to determine the 'value of life', or more precisely, the 'value of a statistical life'. The approach adopted for determination of cost-effectiveness of the risk mitigation measures is discussed in more detail below;

- *Recommend Risk Mitigation Measures for Implementation:* the CBA results can now be used to recommend which risk mitigation measures should be implemented. Where the risk benefit (expressed in monetary terms) achieved is clearly much greater than the cost for implementation of the risk mitigation measure then the measure is deemed to be cost-effective (or 'reasonably practicable') and should therefore be recommended for implementation. Where the cost for implementation of a measure is grossly disproportionate to the risk benefit achieved, say, by an order of magnitude or more, then the mitigation measure would not be cost-effective, and would therefore not be recommended on cost-benefit grounds (there may be other socio-political or technical reasons for still implementing the risk mitigation measure). However, where the difference between cost and benefit is not so great (for a risk mitigation measure) then judgements on whether to implement the measure will need to be made, taking into account factors such as uncertainty in the risk results and estimated costs, and socio-political and technical factors.

8.2 *VALUE OF LIFE*

8.2.1 *Background*

Despite concern by various authors on moral issues relating to assigning a cost to human life, it has been recognised by a number of government bodies and experts in the risk assessment field [*Refs. 50-58*] that such cost-benefit decisions relating to safety need to be made and, anyway, are inevitably being made daily throughout the world in many walks of life, although the decisions on the costs being assigned to safety, ie 'value of life' (or cost of injury), are usually implicit in nature.

It has been recognised that the determination and use of a 'value of life' figure in a cost-benefit analysis permits a government or organisation to assess in a consistent manner the costs and benefits of different projects in various sectors. For example, a government can apply such an approach in assessing the costs and benefits for a new project to develop a new large dam, and apply the same approach in assessing another scheme relating to the construction of a new water treatment plant. For the dam project the potential risks associated with flooding resulting from dam failures can be assessed and mitigated in a cost-effective way, using a particular 'value of life' figure. Similarly so, a consistent approach can be adopted for optimisation of the risks arising from potential chlorine releases on the new water treatment works. Such an approach should help to ensure that government resources for safety are assigned in a consistent manner across a number of sectors.

It is important to note here that the 'value of life', as used in CBA associated with risk assessments, is more accurately termed the 'value of a statistical life'. For example, a 'value of statistical life' of HK$10 million is just another way of saying that a reduction in death of 1 in 100,000 per year has a value of HK$100 per year. Hence, even if an apparently high 'value of a statistical life' figure is used it does not necessarily mean that enormous amounts of money will need to be spent to achieve optimal safety, since if the actual risk levels are already reasonably low then the CBA may indicate that it is not worth spending that much on further risk mitigation. For simplification the term 'value of life' will be used hereafter.

Marin [*Ref. 58*] explains that there has been two main approaches adopted in determining a 'value of life' figure, ie

- Human Capital approach;
- Willingness-to-Pay approach.

8.2.2 *Human Capital Approach*

Initially the most common method was the 'human capital' or 'foregone earnings' approach. This approach considers a person's earnings and treats the present value of those earnings as the economic value of the person concerned. The main problems with this approach are:

- it implies that a person who has no earnings has no economic value, ie a zero 'cost of life' would be applied to the unemployed, the young, old or infirm, and housewives etc;

- it takes no account of factors such as pain and suffering (although some attempt has been made by some to add such factors on).

The human capital approach was initially used by government transport departments such as the UK Transport Department, for use in assessing road schemes, who used this approach from 1968 before changing to the willingness-to-pay approach in 1988, upon recognition that the human-capital approach did not adequately reflect what the public were prepared to pay on safety. Governments that use human capital numbers may spend less on safety than their citizens would like. Germany, which still uses a human-capital approach, crudely boosts its sums by not discounting the future value of lives saved [*Ref. 56*].

8.2.3 *Willingness-to-Pay Approach*

The normal approach in a conventional cost-benefit analysis study is to base valuations on what the goods or services are worth to those affected directly or indirectly by the process or project. As Marin [*Ref. 58*] importantly explains, *the relevant question [for risk assessment studies] is how much people will pay for a very slight reduction in their chance of premature death or how much compensation they would require to accept a slightly higher risk, when the probability of death is still very far below one.* It is now widely accepted that the willingness-to-pay approach is the correct way to determine the 'value of life' for use in risk assessment cost-benefit analyses. Many countries, including USA, UK, Sweden and New Zealand, have abandoned the human-capital approach in favour of willingness-to-pay (WTP) for improved safety. WTP studies assess what people would pay for very small changes in risk and then calculate a value for 'one statistical life'. WTP studies place a much higher value on life than the human capital approach. Before switching to WTP, New Zealand's transport ministry used a figure that was only about 10% of the new valuation from WTP [*Ref. 56*].

8.2.4 *Examples of "Value of Life" Figures*

Most government transport departments in developed countries have tried to estimate the value of life (see *Table 8.2a* below). There is wide variation, ranging from US$2.6M in the USA to US$20,000 in Portugal.

As reported by Technica [*Ref. 1*] there are wide variations in the figure assigned to 'value of life', ranging from £0.5 to 5 million from UK studies (*Ref. 59* - Dalvi, 1988), and £0.1 to 12M from US and UK studies [*Ref. 60* - Jones-Lee, 1989]. Jones-Lee considered that the most reliable studies gave values in the region of £2 million (1987 prices).

A more recent review [*Ref. 58* - Marin, Royal Society, 1992] concluded that there are strong reasons for adopting a value of £2 to 3 million (presumably at 1992 prices). Marin actually expressed this as: *there are strong reasons to suggest [based on the author's review of willingness-to-pay studies] that a value of £200-300 for each change in the risk of mortality of 1/10,000 would be a sensible minimum value* [this was then converted a more conventional 'value of a statistical life' figure to give £2 to 3M].

Latest information from HSE is that the £2M figure still tends to be used in the UK, with no inflation added. It is based on 1991 (or earlier). In the rail sector in the UK, Railtrack use a 'Value of Preventing a Fatality' of between £0.89M to £2.49M, depending on whether the risk is near the 'upper limit of tolerability' or 'where accidents may involve many fatalities' [*Ref. 72*].

The table below gives a summary of selected value-of-life figures from various countries and sectors. An attempt has been made to revise these figures to HK$ equivalent at 1997 prices, with a 5%/annual increase allowed for - this is a somewhat coarse attempt since the actual year for the given value of life figures in the various references was not always stated (when in doubt the year of the reference has been used) and the 5% is somewhat arbitrary.

It can be seen that the variation is extremely wide, from as low as HK$180,000 for road transport projects in Portugal to a value of life of about HK$100M used by BP in the offshore industry. Apart from a few exceptions, and neglecting the values determined by the human-capital approach, the value of life figures tend to fall in the HK$10M to $100 M range with an average of about HK$46M. The most relevant value-of-life is probably the £2M determined for the ACDS dangerous goods transportation study in the UK [*Ref. 50*] - this has been the basis for value-of-life figures used to date on PHI studies in Hong Kong, and it is estimated that the value would be equivalent to about HK$33M at 1997 prices.

Table 8.2a *Examples of Value-of-Life Figures Used Worldwide*

Country/Sector	Value of Life	Value of Life (HK$M equiv)	Year Applicable	Value of Life (1997 equiv) (HK$M)	Ref	Notes
Transport Depts						
USA	US$2.6 M	20.1	1993	24.4	56	WTP basis
Sweden	US$1.24 M	9.56	1993	11.6	56	WTP basis
New Zealand	US$1.15 M	8.89	1993	10.8	56	WTP basis
Britain	US$1.1 M	8.51	1993	10.3	56	WTP basis
Germany	US$0.93 M	7.18	1993	8.7	56	Human-capital basis
Belgium	US$0.4 M	3.09	1993	3.8	56	Human-capital basis
France	US$0.35 M	2.71	1993	3.3	56	Human-capital basis
Holland	US$0.13 M	1.01	1993	1.2	56	Human-capital basis
Portugal	US$0.02 M	0.15	1993	0.18	56	Human-capital basis
DG Transportation						
UK	£2 M	26.0	1991	33.2	50	ACDS study - DoT figure of £0.5M used with gross disproportion factor of 4. In one instance a further factor of 20 was used (to allow for aversion to high fatality events)
Offshore Oil & Gas						
BP	£0.6 to 6 M	7.8 to 77.9	1995	10.0 to 99.4	1	Fleishman & Hugh recommended £200K to 3M & this was updated by Beamont (1995)
Shell	£5 M	64.9	1993	78.9	61	

Country/Sector	Value of Life	Value of Life (HK$M equiv)	Year Applicable	Value of Life (1997 equiv) (HK$M)	Ref	Notes
Railway Industry						
UK (London Underground)	£2 to 5 M	26 to 64.9	1993	31.6 to 78.9	61	
UK (BR)	£0.75 to 4 M	9.7 to 51.9	1993	11.8 to 63.1	61	
France	£4 M	51.9	1993	63.1	61	
Germany	£1.3 to 2.1 M	16.9 to 27.3	1993	20.6 to 33.2	61	
Netherlands	£0.3 M	3.9	1993	4.7	61	
Switzerland	£0.7 M (1 to 10 lives)	9.1	1993	11.1	61	
	£50 M (>10 lives)	649		789.2		

8.2.5 *"Value of Life" Used in Hong Kong QRA Studies*

As discussed above, the use of cost-benefit analysis to support QRA studies is common practice in Hong Kong. The approach adopted to date on PHI Hazard Assessments has generally been to use the £2M figure from the UK, derived in the ACDS study by HSE [*Ref. 50*]. This has generally been converted to about HK$24M equivalent.

The recent DG transportation (chlorine, LPG, chemicals, hydrocarbons, etc) HA studies carried out by Technica [*Ref. 1, etc*] and the studies carried out by ERM for WSD (chlorine hazards) [*Ref. 52*] and for EMSD (LPG hazards) [*Ref. 4*] all used a value of life figure of HK$24M.

Although the ACDS value was determined some years ago, the basic (UK) value of £2M is still used in Hong Kong [*Ref. 1, 52*] - it is not clear whether this is also still the case in the UK. As noted above, the current (1997) value would be about HK$33M, adjusted for inflation.

A recent study for Geotechnical Engineering Office on 'QRA for the Squatter Villages in Lei Yue Mun' determined a value of life of HK$13M for residents in the squatter village, who were at risk from landslide hazards.

8.3 *AVERSION FACTORS*

From the above *Table 8.2a*, it is evident that an 'aversion factor' is also sometimes applied for large multiple fatality accidents. This is done to represent society's strong aversion to large multiple fatality events, as indicated by the media coverage and public outcry which accompany such events. A chemical plant incident which causes (say) more than 2000 fatalities (as was the case for the Bhopal disaster) is the type of event which society is extremely averse to. It is far worse, in societal acceptance terms, for an event to cause 2000 fatalities 'in one go' compared to events that cause fatality 'one by one', as tends to be the case for most car accidents. Similarly railway and air transportation accidents which cause many fatalities receive much media and public attention.

An interesting case is the rail industry in Switzerland, which uses a (HK$ equivalent, 1997) value of life of HK$11.1M for fatalities in the range of 1 to 10, but a much higher value of about HK$790M for higher multiple fatality incidents involving greater than 10 fatalities. This is equivalent, it is suggested here, to applying an aversion factor of about 70 for large multiple fatalities. It is also important to note that they apparently do not apply an aversion factor for fatalities in the 2-10 range. Hence the aversion factor has only been applied for high multiple fatality accidents.

The use of an aversion factor for multiple fatality accidents is common in Hong Kong for Hazard Assessments on Potentially Hazardous Installations (PHIs). An aversion factor of up to 20 [*Refs. 4, 52*] tends to be used for societal risk cost-benefit analysis, with the HK$24M value of life figure multiplied by this factor of 20, to give an equivalent value of life of HK$480M. This aversion factor has been applied by ERM for all QRA studies, ie the value-of-life of HK$480M is used in the cost-benefit analysis against the PLL determined for the PHI plant being studied.

Technica [*Ref. 1*] have proposed an approach (for DG transportation studies) whereby the value-of-life of HK$24M should be used for low risk situations (where the risk is in the ALARP area and is near the acceptable region), but a higher value-of-life of HK$480M should be used when the risk is unacceptable or is very nearly unacceptable, ie high in the ALARP region. This type of aversion to 'high risk' has been explored by Horowitz [*Ref. 53*] who followed up earlier work by Jones-Lee [*Ref. 60*] who suggested that an individual's willingness to pay for a reduction in mortality risk increases with the level of risk, ie the "baseline risk". The important conclusions of the Horowitz study were:

- *The value of life that is appropriate for valuing small risk changes is not necessarily the same for all risks, but instead is higher for higher risks;*

- *It remains an open question, however, just how large this effect is and whether it can be used to rationalise existing differences in the implicit cost per life saved in society.*

So whether an aversion factor of 20 for 'high risk' can be justified is not clear. Technica [*Ref. 1*] did, however, also review some previous decisions involving high risk operations which tended to indicate that an aversion factor of up to 20 has in fact been (implicitly) applied in the decision-making process.

It is also important to note that the Hong Kong Government has exhibited their own willingness-to-pay for cost-benefit analysis outcomes in Hazard Assessments on PHIs which have used an aversion factor of 20 against a value of life of HK$24M. Due to the relatively low risks usually determined for such installations the use of HK$480M for value-of-life is not prohibitive.

This is not necessarily the case for landslide QRA studies, wherein for certain circumstances the risk levels could be much higher than those usually experienced from PHI sites. One such example can be found in the Atkins-Haswell study carried out for GEO on "Quantitative Landslide Risk Assessment for the Squatter Villages in Lei Yue Mun" [*Ref. 3*]. That study used a value of life of HK$13M with no aversion factor applied. The study concluded (for squatters in the ALARP region) that a maximum of HK$71,000 per dwelling (HK$12,000 per resident) should be spent to re-house the squatters, and that: *this [HK$71,000 per dwelling] figure represents a grossly insufficient sum for rehousing. Therefore, rehousing for the individual risk ALARP zones is not a cost-effective risk mitigation option.*

Had an aversion factor of 20 been used then a figure of HK$1.42M per dwelling would have been derived, which then may have indicated that re-housing was cost-effective. Such a high expenditure may have been outside of the government's willingness-to-pay, or ability to pay.

It should be noted, however, that an obvious contradiction to this 'high risk' aversion factor is where individuals voluntarily expose themselves to extremely high risk situations in the pursuit of sport recreation activities such as mountain climbing and hang-gliding. The key concept here is "voluntary" which generally does not apply to the type of risks we are mainly concerned with in this study, ie risks to the public from PHI sites are not voluntary risks. Risks from landslides are generally not voluntary, although it could be argued that there is a strong element of voluntariness for squatters who reside in areas with well-known landslide risks. Such considerations would tend to validate the Atkins-Haswell approach in not applying an aversion factor.

8.4 *Recommended "Value of Life" for Use in Landslide & Boulder Fall QRA/Cost-Benefit Analysis Studies*

From the above discussion it is concluded that the most appropriate value-of-life figure for use on landslide cost-benefit analysis is about HK$24M. This value is consistent with the value-of-life figures used to date on most of the QRA studies in Hong Kong. However, this is based on the original UK ACDS £2M and therefore may be updated to the 1997 value to account for inflation.

It may noted that the Steering Committee for a current WSD project on Re-assessment of Chlorine Hazards from 8 Existing Water Treatment Works has endorsed the approach suggested by ERM to consider a value of HK$33M for cost of life based on current prices.

8.5 *Recommended "Aversion Factor" for Use in Landslide & Boulder Fall QRA/Cost-Benefit Analysis Studies*

The discussion above indicated that an aversion factor of up to 20 is often used in Hong Kong PHI cost-benefit analyses associated with risk assessments, and that this factor is applied against the "value-of-life" to give an equivalent much higher value-of-life. The aversion factor is applied to take account of:

- society's aversion to high multiple fatality accidents;
- an individual's aversion to high (involuntary) risk.

Where there is a strong element of 'voluntariness' it is suggested that an aversion factor should not be applied. It is thought, however, that this is unlikely to be the case for people who move into a newly designed residence in steep natural terrain. They would most probably assume that the government and developers have 'done their job' and ensured that the buildings are safely constructed and safely located.

So the question remains on what aversion factor (or factors) should be applied against the value-of-life and how should it be applied. The following approach is suggested:

Apply an aversion factor of greater than one for 'high risk' situations, ie when the F-N curve is 'within one order of magnitude' of the unacceptable region', or the 'intense scrutiny' region.

An aversion factor of up to 20 is recommended for the 'intense scrutiny' region.

The above approach has been developed for landslide QRA and is considered to be a practicable development from the current approach for PHIs and that it should be tested out on landslide and boulder fall QRA studies. The approach is less conservative, but more rational, than that currently used for many PHI QRA studies. The practicability of the approach can only be demonstrated, however, if the cost benefit analysis yields results which are within the Government's (or a developer's) willingness-to-pay, or indeed, ability to pay.

8.6 *MAXIMUM JUSTIFIABLE EXPENDITURE ON RISK MITIGATION*

The maximum justifiable expenditure on risk mitigation can be calculated by using the following equation:

Maximum Justifiable = Total PLL x Value-of-Life x Aversion Factor
Expenditure

Example Calculation

With a total PLL of 5E-3 per year for a particular site exposed to landslide risks (ie one fatality every 200 years) this gives the following justifiable cost of mitigation:

Maximum Justifiable Expenditure = 0.005 x HK$ 24M x Aversion Factor

A value of HK$24M has been considered here for illustration.

If the F-N curve is within the 'intense scrutiny' region, then an aversion factor of say, 20 is used, and the maximum justifiable expenditure is:

Maximum Justifiable Expenditure = 0.005 x HK$24,000,000 x 20
= HK$2.4 million per annum

Assuming that the cost of mitigation may be borne within a single year with a benefit stretching over many years, the "once-off" justifiable cost would be calculated as follows:

If the risk mitigation measures would be effective for up to 40 years, then:

Maximum Justifiable ("Once-Off") Cost = HK$2,400,000 x 40
= HK$96 million

If the F-N curve is not within the 'intense scrutiny' region or within one order of magnitude of the 'unacceptable' or 'intense scrutiny' region then, since no aversion factor is required, the maximum justifiable cost is calculated as HK$120,000 per annum. The 'once-off' justifiable cost (for a 40 year measure) would then be HK$4.8M.

8.7 *IMPLIED COST OF AVERTING A FATALITY*

The Implied Cost of Averting a Fatality (ICAF) provides a means of ranking and selecting the candidate risk mitigation measures according to their benefit in cost terms. The ICAF for a particular risk mitigation measure is calculated as follows:

$$\text{ICAF} = \frac{\text{Cost to Implement Measure}}{(\text{PLL Risk Reduction}) \times (\text{Lifetime of Measure})}$$

A measure is deemed to be cost-effective if it has an ICAF which is less than:

HK$24M: if the F-N curve is not within one order of magnitude of the 'unacceptable' or 'intense scrutiny' region or within the 'intense scrutiny' region
HK$480M: if the F-N curve is within the 'intense scrutiny' region

Example Calculation

If the F-N curve is within the ALARP region, and if the risk mitigation measures A, B and C have been identified, with the PLL reduction and costs for each measure calculated as:

Table 8.7a *Risk Mitigation Measures*

Measure	PLL Reduction	Cost of Implementation (HK$)	Lifetime of Measure
A	0.001	5,000,000	40
B	0.0007	200,000	40
C	0.002	2,000,000	40

Then the ICAF is calculated for each measure as:

Table 8.7b *Calculated ICAFs for Risk Mitigation Measures*

Measure	ICAF (HK$)
A	125,000,000
B	7,143,000
C	25,000,000

Therefore, with no aversion factor applicable then, for a value of life of HK$24M, measure B is cost-effective but measures A and C are not.

Had an aversion of 20 been applicable for measures A and C (say that these measures are associated with mitigation of events in the 'intense scrutiny' region) then all three measures would be deemed cost-effective.

The selection of a particular mitigation measure would therefore depend on cost-benefit analysis including consideration of aversion factors as well as other considerations such as environmental acceptability etc.

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Annex A

Natural Hazards

A1 *INTRODUCTION*

According to United Nations estimates, the last decade of this century was expected to experience tens of thousands of damaging landslides, earthquakes, and tornadoes; 100,000 floods; and several hundred to several thousand tropical cyclones and hurricanes, tsunamis, droughts, and volcanic eruptions [*Ref. 37*]. Large natural disasters have killed an estimated 3 million people in the past two decades [*Ref. 33*], with on average about 14,000 deaths per year due to earthquake disasters alone [*Ref. 34*]. It can be expected that many hundreds of thousands more will perish worldwide within the next decade.

In order to address natural hazards and the disasters they cause some 150 nations joined together in a United Nations resolution designating the 1990s the International Decade for Natural Disaster Reduction.

This Annex reviews incident data on natural disasters worldwide and the societal risks arising from such events. *Section A2* describes the types of natural hazards which have resulted in high fatalities, with the tables at the end of this Annex giving brief details of selected natural disasters. *Section A3* reviews the historical frequency of natural disasters and presents societal risk F-N curves.

It should be noted that any reference to financial losses here are given in US dollars.

A2 NATURAL DISASTERS - GEOPHYSICAL & HYDROMETEOROLOGICAL

The following type of natural disasters are reviewed within this Annex.

- Earthquakes;
- Tsunamis;
- Windstorms (typhoons, hurricanes, cyclones, tornadoes);
- Floods;
- Volcanic Eruptions;
- Mass Movements (landslides, rockfalls, avalanches, mudslides) - these tend to be synonymously referred to as "landslides" within some of the figures and various reference sources.

There is much variation in the literature on the number of people killed/injured/affected in some incidents. Where differing numbers of fatalities etc were reported the highest figure has usually been reported for this study. It is also important to note that incidents such as earthquakes can result in other disaster phenomena such as tsunamis and landslides, and, similarly, typhoon disasters can lead to flooding disasters. The tables presented in this Annex will therefore include some events which appear under different disaster classes, with the data presented here possibly duplicated and sometimes even inconsistent since different data sources may have been used. There has been no attempt made here to rationalise the data, since the main purpose of this Annex is to present examples of the scale of natural hazard disasters for subsequent use in the main text to support in the development of risk acceptability criteria for landslides from natural terrain.

Descriptions of the above type of natural hazards are provided below.

A2.1 EARTHQUAKES

An earthquake is the sudden motion of the earth caused by an abrupt release of slowly accumulating stress. Earthquakes have the potential for causing great sudden disasters, with whole cities or part of a city potentially destroyed within minutes.

The severity of an earthquake is defined in terms of its magnitude and intensity. The more objective is the magnitude, which is a measure of the total energy in the seismic waves. A scale for the representation of the magnitude of an earthquake is the Richter scale. The Richter scale is logarithmic, and henceforth a magnitude which is 1 higher on the scale represents an earthquake which is 10 times greater in magnitude.

Intensity is a measure of the severity of an earthquake experienced at a given location. Thus an earthquake of a given magnitude may have different intensities at different locations. The most widely used intensity scale is the Modified Mercali scale, as given in *Table A-2.1a* below.

At least 35 countries face a high probability of loss from earthquakes [*Ref.* 35]. Regions of particularly high seismic activity include California, US, Japan and China. The number of earthquakes which occur in or near Japan represent approximately 10% of those which take place worldwide. Some of these earthquakes are of a major scale. It is estimated that a magnitude 8 earthquake attacks Japan about every 10 years, with a magnitude 7 striking every year [*Ref. 42*].

During this century California has experienced over 30 earthquakes of magnitude 5 to 8.3 [*Ref. 40*], with the most recent earthquake occurring at Northridge in 1994. The most prone area is in the hills of central California, southeast of Monterey, where the town of Parkfield lies. This area has been hit by (recorded) earthquakes in 1857, 1881, 1901, 1922, 1934 and 1966. The 1857 great Tejon quake is estimated to measured at about 8.3 magnitude. It has been estimated that there is a 60% chance of a major quake hitting southern California within the next 30 years.

Table A-2.1a ***The Modified Mercali Intensity Scale*** *[Ref. 32]*

Intensity	Description
I	Not felt. Marginal and long period effects of large earthquakes.
II	Felt by persons at rest, on upper floors, or favourably placed.
III	Felt indoors. Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognised as an earthquake.
IV	Hanging objects swing. Vibration like passing of heavy trucks; or sensation of a jolt like a heavy ball striking the walls. Standing motor cars rock. Windows, dishes, doors rattle. Glasses clink. Crockery crashes. In the upper range of IV, wooden walls and frame creak.
V	Felt outdoors; direction estimated. Sleepers awakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutter, pictures move. Pendulum clocks stop, start, change rate.
VI	Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken. Knickknacks, books etc. off shelves. Pictures off walls. Furniture moved or overturned. Weak plaster and masonry D cracked. Small bells ring (church, school). Trees, bushes shaken (visibly or heard to rustle).
VII	Difficult to stand. Noticed by drivers of motor cars. Hanging objects quiver. Furniture broken. Damage to masonry D, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices (also unbraced parapets and architectural ornaments). Some cracks in masonry C. Waves on ponds; water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.
VIII	Steering of motor cars affected. Damage to masonry C; partial collapse. Some damage to masonry B; none to masonry A. Fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on sleep slopes.
IX	General panic. Masonry D destroyed; masonry C heavily damaged, sometimes with complete collapse; masonry B seriously damaged. General damage to foundations. Frame structures, if not bolted, shifted off foundations. Frames cracked. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in ground. In alluviated areas sand and mud ejected, earthquake fountains, sand craters.
X	Most masonry and frame structures destroyed with their foundations. Some well-built wooden structures and bridges destroyed. serious damage to dams, dikes, embankments. Large landslides. Water thrown on banks of canals, rivers, lakes etc. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.

Intensity	Description
XI	Rails bent greatly. Underground pipelines out of service.
XII	Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown into the air.

Masonry A	Good workmanship, mortar, and design; reinforced, especially laterally, and bound together by using steel, concrete etc.; designed to resist lateral forces.
Masonry B	Good workmanship and mortar, reinforced, but not designed to resist lateral forces.
Masonry C	Ordinary workmanship and mortar; no extreme weaknesses like failing to tie in at corners, but neither reinforced nor designed against horizontal forces.
Masonry D	Weak materials, such as adobe; poor mortar; low standards of workmanship; weak horizontally.

The direct effects of an earthquake include:

- ground shaking;
- ground lateral displacement;
- ground uplift and subsidence.

Whilst the indirect effects include:

- ground effects;
- soil liquefaction;
- slope failure: avalanches, landslides, mudslides;
- floods (due to failure of dams, dykes or levees, or tsunami or seiche);
- tsunamis and seiches (a seiche is a standing wave on the surface of water such as a lake);
- fires (due to destruction of buildings, ruptured gas mains, damage to industrial facilities etc).

Earthquakes have caused major loss of life in this century, mainly as a result of building damage/collapse (sometimes leading to large fires, such as in the Kanto, Japan earthquake in 1923 where some 143,000 were killed, mainly due to fires). The devastating effects can extend over a very large area, and can also seriously affect infrastructure such as roads, railways, airports, pipelines, water supply and sewage systems, and power supplies, as was the case in the Loma Prieta, California earthquake in 1989. Dam failures can also result from an earthquake, with potential for large loss of life due to flooding. The tables at the end of this Annex include earthquake disasters in *Table A-3.2b*. Reference to *Table A-3.2c* shows that earthquakes can also result in tsunamis. Earthquakes can also result in volcanic activity (see *Table A-3.2e*) and large landslides (*Table A-3.2f*).

Earthquakes have killed over 10,000 people each in Chile, Guatemala, Mexico, Nicaragua, and Peru [*Ref. 36*].

A2.2 *TSUNAMIS*

Tsunamis are large ocean waves generated by impulses from geophysical events occurring on the ocean bottom or along the coastline, such as earthquakes, landslides and volcanic eruptions.

Tsunamis cause significant damage and loss of life in many regions of the world. About 6,000 people were killed by tsunamis in the 1980s alone.

Tsunamis can travel great distances at high speed and cause massive damage at hundreds of kilometres from the epi-centre of a submarine earthquake. For instance, the 1960 earthquake near Concepcion, Chile generated a tsunami that travelled across the Pacific Ocean at about 800 km/hr with significant consequences in Hawaii and Japan.

Tsunamis are a major threat to 22 countries along the Pacific rim, although they have occurred elsewhere such as in the Mediterranean.

It is recognised that mitigation of the destructive impacts of tsunamis can be achieved by the construction of barrier walls and other diversions but the costs of such projects and the negative visual environmental impact restricts their use. Land-use zoning of coastal areas, together with effective early warning systems are the preferred mitigation options [*Ref. 35*].

A2.3 *WINDSTORMS*

Windstorm-related disasters worldwide cause an average of 30,000 deaths and $2.3 billion in damage each year [*Ref. 35*]. Severe tropical storms (called hurricanes in the Atlantic, Caribbean, and eastern Pacific; typhoons in the western Pacific; and cyclones in the Indian Ocean), tornadoes, blizzards, and other storms affect every country worldwide.

Table A-3.2d lists a number of major disasters caused by windstorms worldwide.

Disasters associated with severe tropical cyclones can cover hundreds of square kilometres, lead to hundreds of thousands of casualties, and cause billions of dollars in economic loss. Such storms are characterised by:

- winds approaching 350 km/hr;
- rains exceeding 800 mm in a few days;
- storm surges of up to 8 metres or more.

High death tolls have resulted in the Asia-Pacific region, with the United States suffering mainly widespread property damage from such windstorm events. In the US Hurricane Hugo, in 1972, caused nearly $2 billion in damage [*Ref. 35*]. In 1906 some 10,000 people were killed in Hong Kong due to a tidal surge resulting from a typhoon.

Tornadoes are common in the United States, although they have also been reported in Canada, Argentina, Australasia, Bangladesh, India and Europe. In 1974, 149 tornadoes struck from Canada to the Gulf of Mexico in 36 hours, killing more than 200 and causing $1 billion of damage [*Ref. 34*]. Outbreaks of such storms affecting large areas (hundreds of square kilometres) are common in the US.

A2.4 *FLOODS*

Floods happen more frequently than any other natural hazard. They occur annually in every season of the year from heavy rainfall, often in association with thunderstorms, typhoons/hurricanes/cyclones, and tornadoes and in the US alone cause direct losses of about $4 billion per year [*Ref.* 34].

Flooding is any abnormally high water flow that overtops the natural or artificial confining boundaries of a waterway. The effects of flooding on lives and property worldwide increases each year, mainly due to the increasing trend of urbanisation near low-lying waterways or coastal areas.

Bangladesh and China in particular have suffered greatly from flooding disasters, with the Bangladesh flood of 1991 causing 100,000 deaths.

In the United States alone, rainstorms and their resulting flooding (including mud and debris flows) caused 63% of disasters between 1965 to 1985 with 1,767 deaths [*Ref.* 34].

A2.5 *VOLCANOES*

Volcanic eruptions have claimed more than 266,000 lives in the past 400 years [*Ref.* 35]. Fatalities occurred in about 5% of all eruptions, with 1 out of 6 of the world's active volcanoes having caused death [*Ref.* 35]. Eruptions have immediate catastrophic effects through ash falls (such as buried the city of Pompeii), surges of lethal gas, blasts, mudflows or lahars, and lava flows. The largest and most dangerous eruptions occur from volcanoes that lie dormant for hundreds of years between periods of activity. Such prolonged inactivity leads to the potential hazard being ignored during the planning and development of the surrounding area. A prime example is the large population which have settled in the hazard zone of the volcano Vesuvius near Naples, Italy. Another example is the eruption of Mount Pinatubo, Philippines, in 1991, which killed 300 people. The volcano had been dormant for 600 years prior to this eruption.

A2.6 *MASS MOVEMENTS*

Mass movement disasters include landslides, rockfalls, avalanches, and mudslides. They can occur on natural terrain in most countries and can be caused by: heavy rains, melting snow or ice, earthquakes, volcanoes, and human activities. The consequences of large and sudden mass movements include direct impact on persons and building damage/collapse which result in fatalities and injuries. Such events can also affect transportation systems (road and rail) and lead to severe damage to infrastructure.

Landslides in the United States cause at least $1-2 billion in economic losses and 25-50 deaths each year [*Ref.* 35, 34].

In Europe, the long-term average for fatalities from snow avalanches is about 100 avalanche deaths per year [*Ref.* 49]. In military history there has been very high fatalities due o snow avalanches, for example, in 1916 up to 10,000 men were killed in 2 days on the Austrian-Italian front, with the whole campaign accounting for at least 40,000 avalanche deaths.

The worst disaster due to land movement occurred at Mount Huascaran, Peru (1970) where an earthquake triggered a massive landslide which buried the nearby towns of Yungay and Ranrahirca. Over 18,000 were killed in Yungay, with over 60,000 fatalities obtained in total.

The largest mass movement (best described as a rockslide/debris flow) on record occurred at Mayunmarca, Peru (1974) where a 1 billion cubic metres volume landslide descended 1500 vertical metres in just 4 mins. Some of the debris was estimated to have reached speeds up to 1000 km/hr. Over 450 people were killed in this incident.

A3 SOCIETAL RISKS

A3.1 HISTORICAL DATA ON NATURAL DISASTERS

The Agency for International Development's (A.I.D) Office of US Foreign Disaster Assistance (OFDA) provides relief and rehabilitation in responses throughout the world, and also provides support for disaster prevention, mitigation and preparedness (PMP). In order to plan for resources OFDA have collated and analysed historical natural disaster records worldwide since they started operations in 1964. Heyman [*Ref. 44*] provides an analysis of the data for 1964 to 1989. This data source and other data sources have been used in *Section* 3 of this Annex as the basis for assessment of societal risks worldwide from natural hazards.

The major disaster types in the OFDA data are as follows:

- CS/DP: civil strife, displaced persons, expellees, emergencies and refugees;
- DRIFS: drought, food shortages, famine and infestations;
- GEO-P: (Geophysical) - includes earthquakes, landslides, volcanic eruptions, tsunamis and unusual phenomena;
- HYDRO: (Hydrometeorological) - includes hurricanes, cyclones, typhoons, storms and floods;
- OTHER: accidents, epidemics and fires.

The three OFDA regions are:

- LAC: Latin America and the Caribbean;
- ASP: Asia and the Pacific;
- AFR: Africa.

Table A-3.1*a* below provides a summary of worldwide Geophysical and Hydrometeorological disasters worldwide.

Table A-3.1a Worldwide Disaster Statistics, Geophysical & Hydrometeorological (1964-89)

Classification	Number of Disasters	Killed	Affected
GEO-P	315	497,000	42,023,615
HYDRO	1,109	536,820	845,462,237

Analysis of the above table indicates that, on average, 12 geophysical type disasters occur worldwide each year, with an average number of fatalities of about 1500. Hydrometeorological disasters occur with more frequency worldwide, although they tend to result in less fatalities on average, they occur at a frequency of over 40 disasters each year, producing on average less than 500 fatalities.

Figure A-3.1*a* shows data from the Swedish Red Cross [*Ref. 48*], this presents the annual average number of disasters worldwide by disaster type. It can be seen that floods and storms occur most frequently (15-25 per year), followed by earthquakes (about 15 per year). Landslides occur at a similar frequency to "accidents" (major chemical/petrochemical accidents etc) at about 4 each year [the 1980s data is neglected here since it only represents 2 years incident data]. Volcanic eruption disasters tend to occur at about 3 to 4 events each year.

Within the Asia Pacific region the OFDA data from [*Ref. 44*] gives the following equivalent table to that above.

Table A-3.1b Asia Pacific Disaster Statistics, Geophysical & Hydrometeorological (1964-89)

Classification	Number of Disasters	Killed	Affected
GEO-P	184	353,665	25,123,377
HYDRO	657	500,154	786,443,023

Analysis of the above table for the Asia Pacific region disasters indicates that, on average, 7 geophysical type disasters occur each year, with an average number of fatalities of almost 2000. Hydrometeorological disasters occur with more frequency, although they tend to result in less fatalities on average, they occur at a frequency of over 25 disasters each year, producing on average about 750 fatalities.

It can be seen from the above tables that the Asia Pacific region has had a large proportion of the worldwide experience for these types of disasters, ie Geophysical (58%) & Hydrometeorological (59%). It follows therefore that the public living in the region (who either have personal experience of disaster or who have access to modern communications such as TV, radio, newspapers etc) should have knowledge of many such disasters from within their own and/or other countries.

The data for each of these disaster types are now summarised below for each country (see *Tables A-3.1c & A-3.1d*). It can be seen that (for the period analysed) Hong Kong is well down the list for 'disaster-prone' countries within the region. The countries most prone to geophysical disasters are China, the Philippines and Pakistan, although it is known from incident records over a greater time period that Japan is particularly prone to earthquake disasters. The countries most prone to hydrometeorological disasters are Bangladesh, India, the Philippines, Vietnam and China. It is known that China has experienced flooding incidents which have resulted in very high fatalities but these are not included within the time period for the OFDA data.

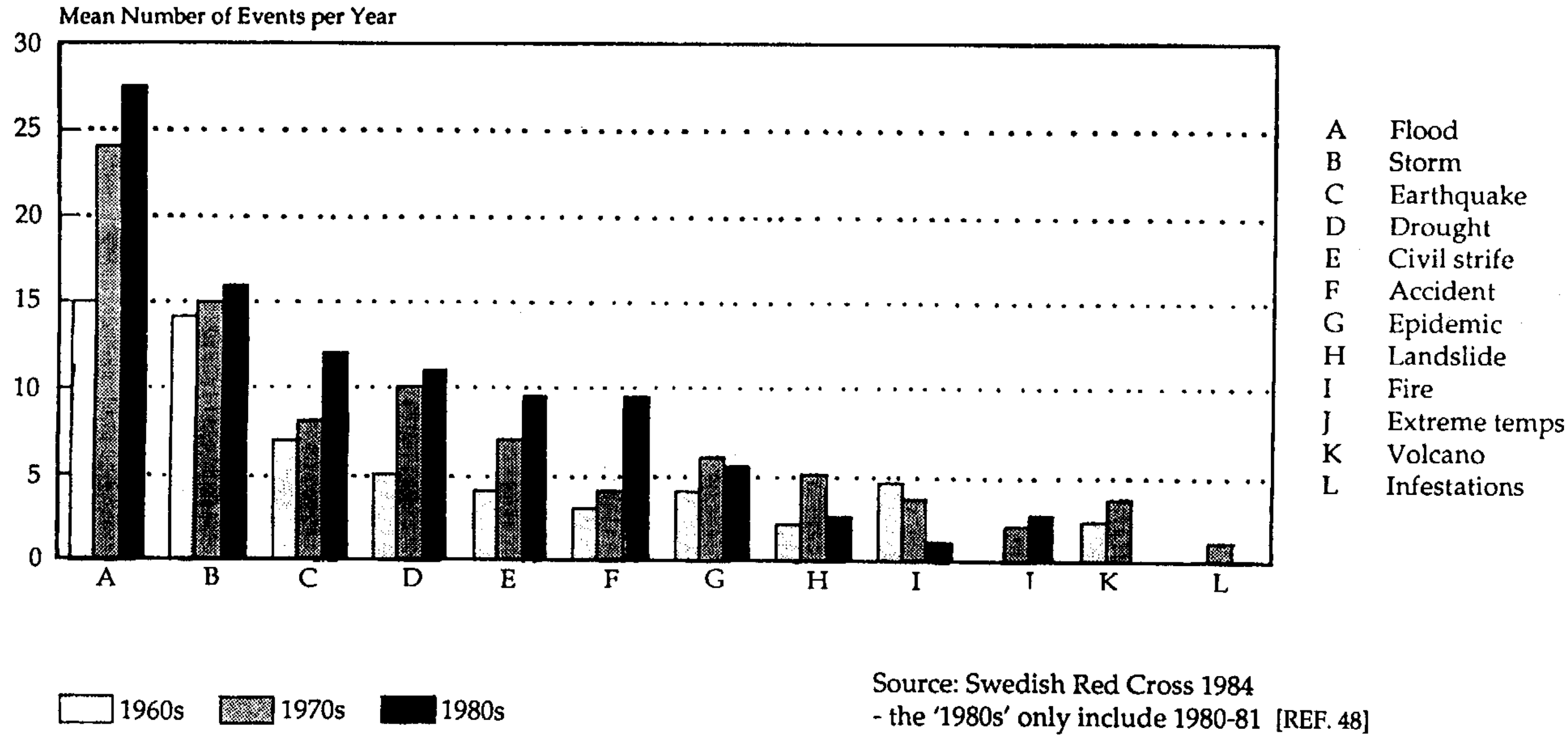


FIGURE A-3.1a - AVERAGE RECORDED ANNUAL NATURAL DISASTER EVENTS - WORLDWIDE

Table A-3.1c Geophysical Disasters - Asia Pacific (Selected Countries) (1969-89)

Country	Killed	Affected
China	257,251	1,135,919
The Philippines	7,055	475,500
Pakistan	4,982	30,000
India	1,401	20,055,100
Indonesia	224	1,131,366
Taiwan	134	37,106
Hong Kong (SAR)	100	1,000

Table A-3.1d Hydrometeorological Disasters - Asia Pacific (Selected Countries) (1969-89)

Country	Killed	Affected
Bangladesh	391,541	217,431,405
India	53,672	271,873,049
The Philippines	12,416	35,856,007
Vietnam	10,609	21,294,957
China	9,608	194,296,500
Korea, Rep of	3,411	2,302,753
Pakistan	2,834	15,013,427
Indonesia	2,320	2,440,526
Japan	2,083	3,614,659
Sri Lanka	1,700	5,501,347
Burma	1,486	2,244,319
Thailand	1,391	8,230,261
Taiwan	683	82,100
Hong Kong (SAR)	204	13,761
Malaysia	189	783,576

It is important to note that OFDA data covers natural disasters with specific criteria, ie

- disasters which warranted a US government response, and declared as such;
- non-declared natural disasters which met the following criteria:
  - earthquake and volcanic disasters which killed at least 6, or the total killed/injured was 25 or more, or at least 1000 were affected, or damage was $1M or more;
  - weather disasters except drought (flood, storm, cyclone, typhoon, landslide, extreme temperatures, etc) which killed/injured at least 50, or left 1000 or more homeless or affected, or damage was at least $1M;
  - drought disasters were included if the number affected was substantial

(although "substantial" was not defined by OFDA).

Exceptions to the above criteria have been permitted for small island economies, wherein a relatively small natural disaster could have a significant impact on that country's economy.

The OFDA data therefore does not fully represent all natural disasters in countries which resulted in multiple fatalities. Incidents which resulted in relatively low fatalities, with only a relatively low number of others affected, would probably not be included in the data.

A further weakness of the data arises from the short time frame of the disaster data, since data covering only 25 years will not be representative of the potential vulnerability to catastrophic geophysical disasters such as major or great earthquakes and volcanic eruptions.

The tables at the end of this Annex list selected natural disasters for a range of geophysical and hydrometeorological disasters. These incidents have been reported in a variety of reference sources and are not necessarily included in, or consistent with, the OFDA data.

A3.2 *SOCIETAL RISKS F-N CURVES*

Parfitt [*Ref. 45*] has produced a series of F-N curves from the OFDA data, plus other data sources. OFDA does not include US data, so the US data was obtained from the Natural Hazards Research and Applications Information Center, Institute of Behavioural Science, University of Colorado (NHRAIC). Incident data on major accidents in the chemical and petrochemical industries was obtained from the MHIDAS database, a database collated by AEA Technology and the UK Health & Safety Executive.

The following F-N curves from the Parfitt report are reproduced at the end of this Annex:

Figure A-3.2a:	Frequency of accidents for selected categories causing fatalities worldwide
Figure A-3.2b:	Frequency of accidents by origin in the chemical and petrochemical industries causing fatalities (worldwide, 1966-89): analysis by industry type
Figure A-3.2c:	Frequency of accidents in the chemical and petrochemical industries (UK and worldwide, 1966-89)
Figure A-3.2d:	Frequency of occurrence of selected natural hazards causing fatalities (worldwide, 1964-90)
Figure A-3.2e:	Frequency of earthquakes causing harm (worldwide, 1964-90)
Figure A-3.2f:	Frequency of floods causing harm (worldwide, 1964-90)
Figure A-3.2g:	Frequency of cyclones, hurricanes, and typhoons causing harm (worldwide, 1964-90)
Figure A-3.2h:	Frequency of volcanic eruptions causing harm (worldwide, 1964-90)
Figure A-3.2i:	Frequency of landslides causing fatalities (worldwide, 1964-90)

Each of these F-N curves are now discussed below, with emphasis on the geophysical and meteorological natural hazards, ie reference to the data on droughts is omitted since such events are not as relevant for this study. It is also important to note that (as already discussed above) the data is only for a limited time period of about 25 years, and as such, may not include some low frequency/catastrophic consequence events for certain hazard types.

Natural Disasters vs Man-Made Disasters Worldwide

Figure A-3.2a presents the worldwide F-N curves for various natural disasters and man-made disasters, ie

- Natural Disasters: floods, cyclones, earthquakes, drought
- Man-Made Disasters: chemical, aircraft

It can be seen that the most frequent events (in this data set) are aircraft disasters, with about 23 events each year resulting in 10 or more fatalities. Flood disasters are the next most frequent with about 12 disasters each year resulting in 10 or more deaths. The frequency of earthquake disasters which result in 10 or more fatalities is similar to that of chemical disasters, each at about 6 to 7 per year.

The societal risks, however, vary in terms of the potential for large numbers of fatalities from these types of disasters. The F-N curve for aircraft disasters is the steepest (ie they have the least potential for higher fatalities compared to the other events), with the maximum number of fatalities at about 600, at a frequency of 8E-2 per year, ie 8 such events expected in a 100 year period. The potential for high fatality chemical disasters similarly decreases more than for natural hazard disasters, with up to about 3000 fatalities at about 4E-2 per year.

The natural hazard events have the greatest consequence potential (compared to the man-made hazards), with earthquakes having the greatest consequence potential with up to 800,000 fatalities at a frequency of about 4E-2 per year [see later note on the validity of this particular high fatality number]. Cyclones have resulted in up to 300,000 fatalities at a frequency of about 4E-2 per year (presumably most deaths were due to the associated flooding, such as in the Bangladesh disasters). Floods have resulted in up to 30,000 fatalities at a frequency of about 4E-2 per year. [Please note this author's reservations about the validity of the F-N curves in [*Ref. 45*] for the (apparent) maximum fatality events, which do not seem to correspond with other data sources].

The overall conclusion from this data set is that natural disasters (worldwide) occur at a similar frequency to man-made disasters but the potential for catastrophic consequences is much greater for natural disasters.

Chemical and Petrochemical Disasters

Figure A-3.2b gives the F-N curves for the various industry sectors which contributed to the "Chemical & Petrochemical" data for *Figure A-3.2a*. The societal risks tend to be dominated by disasters which occur in the chemical and petrochemical industries. The chemical industry data would include events such as Bhopal disaster which killed about 2500 people, and this is presumably the event which is the highest fatality event in the data.

The F-N curve for "total" accidents can be interpreted as:

- chemical accidents (refers to "total" figures on *Figure A-3.2b* and "chemical" on

Figure A-3.2a) which kill 10 or more people have occurred about 7 times per year;

- every year a chemical disaster has resulted in over 50 fatalities, with over 10,000 people affected in total (see *Figure A-3.2c*);

- the worst chemical disaster (in the time period for the data set) resulted in up to over 2500 fatalities. This is presumed to be the Bhopal disaster which also affected over 200,000 people.

Natural Hazards Disasters

Figure A-3.2d shows the F-N curves for various natural hazards, ie floods, storms, cyclones, earthquakes and drought. The data is the same as presented in *Figure A-3.2a*, with data for storms added. As noted above, earthquakes have the greatest consequence potential, followed by cyclones and then floods. Reference to *Figures A-3.2h* and *A-3.2i* indicates that the consequences of volcanic eruptions and landslides tend to be even lower, although higher fatality events are known to have occurred.

Earthquake Disasters

Figure A-3.2e presents the F-N curves for earthquake fatalities, injuries and affected (homeless). It can be seen that the number of (serious) injuries obtained tends to be a little higher than the number of fatalities, but the number of people left homeless can be much greater. For example, the data can be interpreted as:

- earthquakes which kill 10 or more people have occurred about 7 times per year;

- each year an earthquake has occurred which resulted in over 1000 fatalities, together with over 3000 injuries and more than 100,000 left homeless;

- the worst earthquake killed up to 800,000 people, with over 1,000,000 left homeless.

Note: There appears to be some inconsistency here with historical disaster data. It is thought that this highest fatality event for earthquakes represents the Tongshan, China (1976) earthquake disaster. Other data sources, however, report a maximum of about 250,000 fatalities (although some data sources report up to 650,000 fatalities). The apparent discrepancy here could be due to differences in data sources for the OFDA data, or possibly even due to the method of construction of the F-N curves.

Flood Disasters

Figure A-3.2f gives the F-N curves for flood disasters in terms of fatalities, injuries and homeless. Interestingly, the higher frequency flood events tend to produce more fatalities than injuries (although this could be due to incomplete data due to under-reporting of injuries - this probably applies to all "injury" curves presented here). The curves can be interpreted as:

- floods which kill 10 or more people have occurred about 13 times per year;

- each year a flood has occurred which resulted in about 700 or more fatalities and over 1000 injuries, together with 1,000,000 or more people left homeless;

- Up to 30,000 people have been killed in a flood disaster, with up to 30,000,000 people being left homeless [outside of this time-period it is known that over 100,000 died in Bangladesh floods in 1991].

Cyclone, Hurricane and Typhoon Disasters

Figure A-3.2g indicates that similar numbers of fatalities to injuries can be expected for cyclones, hurricanes and typhoon disasters, with much higher numbers of people also affected (homeless). The curves can be interpreted as follows:

- cyclone/hurricane/ typhoon disasters which kill 10 or more people occur about 10 times per year;

- each year a cyclone/hurricane/ typhoon disaster has occurred which has resulted in about 800 or more fatalities, with a similar number of injuries, but with 100,000 or more people also left homeless;

- the worst cyclone/hurricane/ typhoon disaster event killed up to 300,000 people, with up to 5,000,000 left homeless. [It is suspected that this is the 1990 Bangladesh event, although other data sources give fatalities there at 500,000].

Volcanic Eruption Disasters

Volcanic eruption events have occurred with lower frequency and also have lower consequence potential than the above natural hazard disasters. *Figure A-3.2h* indicates that:

- a volcanic eruption event which results in over 10 fatalities occurs 4 times in every 10 years;

- once every 10 years a volcanic eruption disaster has occurred which resulted in over 400 fatalities with over 900,000 people left homeless.

- the worst volcanic eruption event killed up to 1000 people and left up to 300,000 homeless. [It is known that volcano events such as at Mount Pele, Martinique (1902) and Columbia (1985) killed about 29,000 and 22,000, respectively - the Columbia incident should have been in the OFDA data set].

Landslide Disasters

Of the natural hazard disasters considered here, landslide disasters have the lowest consequence potential but are relatively frequent. *Figure A-3.2i* can be interpreted as:

- landslide disasters which kill 10 or more people have occurred about 3 times per year;

- every year a landslide has occurred which has killed over 100 people;

- landslide disasters have killed up to 600 people (in this data set - it is known that some landslides have killed higher numbers). [The Mount Huscaran, Peru (1974) landslides killed tens of thousands, although OFDA may have classified this under earthquake, which was the initiating event. Other landslides have killed up to 5000 to 20,000 people].

The above interpretation of the F-N curves are now summarised in *Table A-3.2a.*

Table A-3.2a ***Summary of Societal Risks from Natural Disasters and Man-Made Disasters - Worldwide***

Disaster Type	Frequency of Events with 10 or more fatalities (per year)	Annual Event Maximum (N or more)			Worst Event (in 25 years) (Number, N)			Notes
		Fatal	Injured	Affected	Fatal	Injured	Affected	
Earthquake	7	1000	3000	100,000	800,000	>1,000,000	>1,000,000	The worst known earthquake in this time period was at Tongshan, China with 250,000 fatalities, although some reports state up to 650,000 killed.
Flood	13	700	1000	1,000,000	30,000	100,000	30,000,000	Outside of this time period over 100,000 were killed in Bangladesh flood of 1991.
Cyclone/ Hurricane/ Typhoon	10	800	800	100,000	300,000	600,000	5,000,000	The Bangladesh cyclone of 1970 resulted in 500,000 fatalities.
Volcanic Eruption	0.1	-	-	10,000	1000	-	300,000	Columbia (1985) should have been included with 22,000 fatalities.
Landslide	3	100	-	-	600	-	-	Mount Huascaran, Peru (1974) killed tens of thousands.
Chemical	7	50	300	10,000	3000	200,000	250,000	Worst event presumed to be Bhopal (1984) with over 2500 fatalities.
Aircraft	23	200	-	-	600	-	-	

Table A-3.2b Selected Earthquake Disasters

Date	Location	Fatalities	Injuries	Affected	Damage (US$M)	Notes	References
1906	San Francisco, CA Fire loss	700			24 500	Magnitude 8.3 and Intensity XI . Large numbers of fires	32
1908	Messina, Italy	75 000				Magnitude 7.5.	34, 35
1915	Avezzano, Italy	32 600				Magnitude 7.5	34
1920	Kansu, China	200 000				Magnitude 8.5. Earthquake/landslide.	32, 34, 35
1923	Tokyo-Yokohama (Kanto), Japan	143 000			350 000 houses destroyed in Tokyo.	Magnitude 8.3. Tokyo and Yokohama almost completely destroyed. High death toll mainly due to fire. Firestorm in Tokyo, with near-total destruction of an area of 90 by 50 miles - the most costly fire in recorded human history. In Yokohama a trainload of schoolchildren slid down a slope into the sea.	32, 34
1927	China	40 900				Magnitude 8.0	34
1932	Kansu, China	70 000					32
1935	Quetta, India	60 000				Magnitude 7.5	32, 34
1939	Erzincan,Turkey	32 700				Magnitude 8.0	34
1939	Chillan, Chile	30 000	58,500		920	Magnitude 8.3	32, 34, 36
1939	Erzincan, Turkey	23 000					32
1948	USSR	100 000					35
1949	USSR	20 000				Earthquake/landslide	35
1957	Mexico City					Magnitude 7.5. Notable for damage to buildings standing on bad ground. The old lake bed area of the city experienced intensities of VII, in other locations the intensities were V or less.	32
1960	Agadir, Morocco	14 000				Relatively low magnitude (5.8) but very destructive since epicentre was close to the town. Area was not previously regarded as a major seismic risk zone.	32

Date	Location	Fatalities	Injuries	Affected	Damage (US$M)	Notes	References
1960	Chile, Concepcion	6 000	3 000		550	Magnitude 8.9. Most severe earthquake recorded.	36
1962	North-western Iran	14 000					32
1963	Skopje	1 200				Relatively low magnitude (6.0) but very destructive since epicentre was close to the town.	32
1964	Alaska and US West Coast				500	Magnitude 8.4. Notable for long duration (3 mins earth shake) and long reach. Ground fissures occurred at 725 km from the epicentre. 75 houses were destroyed in Anchorage, when the ground they were built on failed in a large landslide. The tsunami which was produced destroyed waterfront areas in Crescent City, California, over 2500 miles away.	32, 34
1968	North-eastern Iran	11 600					32
1970	Mount Huascaran, Peru	70 000	150 000	3 million	530	Magnitude 7.8. Triggered major avalanche and mudflow, burying the town of Yungay with 25,000 killed. 83,000 sq km affected. 3 million people affected, 186,000 homes lost.	32, 34, 35, 36
1971	San Fernando, CA				553	In localised areas the intensity was assessed as high as XII.	32
1972	Managua, Nicaragua	12 000	20 000	400 000	845	Magnitude 6.2. Three quarters of population homeless.	32, 36
1976	Guatemala City	24 000	77 000	3.8 million	$1 billion	Magnitude 7.5. Affected the poor rural highlands and slums of Guatemala City. 14 towns destroyed, 1.2 million homeless. The region had been free of any noticeable seismic activity for several decades.	32, 33, 35, 36, 41
1976	Tangshan, China	250 000	800 000			Magnitude 7.6. The region was previously not considered susceptible to major earthquakes, although many small tremors had been experienced. The earthquake consequences were high since the epicentre was at the city at shallow depth.	32, 34, 41
1978	Iran	25 000					35

Date	Location	Fatalities	Injuries	Affected	Damage (US$M)	Notes	References
1985	Mexico City	20 000	30 200		$6 billion	Most of death toll in Mexico City, some 400 km from the epicentre. Particularly heavy damage to buildings between 9 to 13 stories high. Over 1000 inhabitants killed in 1 collapsed tower block, similar number in a high rise hospital.	33
1988	Spitak, Armenia	100 000	19 000	500 000 homeless	$16 billion	Magnitude 6.7	33, 34
1989	Loma Prieta, California	62	3757	8000 homeless	$6 billion	Magnitude 6.9. Much of the damage was due to poor ground conditions in the Marina district, which was built upon artificial fill and sand.	34

Table A-3.2c Selected Tsunami Disasters

Date	Location	Fatalities	Injuries	Affected	Damage (US$M)	Notes	Reference
1707	Houei, Japan	4 900				80 ft high.	38
1750	Lisbon, Portugal					50 ft high tsunami destroyed Lisbon, triggered by 2 earthquakes.	34
1792	Ariake, Japan	12 000				33 ft high.	38
1854	Ki-i	3 000				40 ft high.	38
1867	Caribbean					60 ft at Gouadeloupe. Widespread damage throughout the Caribbean.	34
1868	Hawaii Island	81				60 ft on southeast coast of Hawaii Island. 2 villages swept away. Local tsunami.	34
1883	Sunda Strait	36 000				135 ft at Mera, Java. Resulted from explosion of Krakatoa volcano.	34
1896	Sanriko Coast, Japan	27 122				80 ft high. 10 600 houses swept away.	34, 38
1918	Mindanao, Philippines	100				24 ft at Mindanao.	34
1922	Coquimbo, Chile	1 000				30 ft at Chanaral.	34
1923	Kwanto, Japan	160				35 ft in Sagami Bay. 868 houses swept away.	34
1933	Sanriko coast, Japan	3 000				96 ft in Ryori Bay. 4100 houses swept away.	34, 35
1944	Tonankai, Japan	998				33 ft in Owase. Over 3000 homes swept away.	34
1945	Pakistan	4 100				Triggered by 8.3 earthquake off the coast.	34
1946	Aleutian Islands	173			27	25 ft in Hawaii. 500 buildings destroyed.	34
1946	Nankaido, Japan	1 500				22 ft on Kii Peninsula. 2000 houses swept away.	34
1960	Chile	2 061			22 in Hilo.	35 ft at Hilo, Hawaii. 18 ft at Japan. 61 killed in Hilo. 2000 killed at Valdivia, Chile.	34
1964	Kodiak, Prince William Sound, Alaska	119				60 ft on Kodiak Island. Damage sever and widespread along coastline.	34
1964	Crescent City, northern California					Tsunami triggered by the Alaskan earthquake over 2500 miles away.	34

Date	Location	Fatalities	Injuries	Affected	Damage (US$M)	Notes	Reference
1976	Celebes Sea, Philippines	7 000		90 000 homeless		30 ft local tsunami.	34
1983	Sea of Japan	103				30-40 ft at coast. Thousands of homes and boats destroyed.	34

Table A-3.2d Selected Windstorm Disasters

Date	Location	Fatalities	Injuries	Affected	Damage (US$M)	Notes	Reference
1900	Galveston, Texas, USA	6 000				Hurricane	35, 34
1906	Hong Kong	10 000				Typhoon	35
1928	South Florida, USA	2 400				Hurricane	34
1959	Japan	4 600				Typhoon	35
1963	Bangladesh	22 000				Tropical cyclone.	35
1965	Bangladesh	17 000				Tropical cyclone	35
1965	Bangladesh	30 000				Tropical cyclone	35
1965	Bangladesh	10 000				Tropical cyclone	35
1970	Bangladesh	500 000				Tropical cyclone. Sea surge coincided with heavy rain and high winds.	35, 34
1971	India	25 000				Tropical cyclone	35
1974	Fifi, Honduras	8 000		600 000	540		33, 36
1977	India	20 000				Tropical cyclone	35
1985	Bangladesh	10 000				Tropical cyclone	35
1989	Hurricane Hugo	28			$10 billion	Early warnings & effective evacuation procedures reduced fatalities.	34
1991	Bangladesh	125 000			10	Cyclone hit low lying area Chittagong on the coast.	34

Table A-3.2e Selected Flood Disasters

Date	Location	Fatalities	Injuries	Affected	Damage (US$M)	Notes	Reference
1889	Johnstown, USA	2 209			150	Heavy rains and partially caused by failure of dam. worst flood disaster in USA history.	34
1936	North-eastern states, USA	>80			>400	80 died in Pensylvania alone. Heavy rains and warm temp caused rapid melting of 14" snow cover.	34
1938	Sichuan, China	2 429				Flood from landslide dam failure	62
1949	China	57 000					35
1953	North Sea coast	1 800					35
1954	China	40 000					35
1963	Vaiont Reservoir, Piave Valley, Italy	2 500			600M	Flood due to landslide dam failure	62
1991	Bangladesh	125 000				Cyclone hit the low lying Chittagong on the coast. 95% of houses destroyed in coastal towns. Over 100,000 fishermen died at sea.	33, 34
1992	USA	117				Caused by Hurricane Agnes	34

Table A-3.2f Selected Volcanic Eruption Disasters

Date	Location	Fatalities	Injuries	Affected	Damage (US$M)	Notes	Reference
1902	Mount Pele, Martinique	29 000				Volcanic eruption. Pyroclastic flows and surges (very hot gases and particles) caused most fatalities. St Pierre destroyed.	35, 36
1902	Guatemala	6 000				Volcanic eruption	35
1919	Indonesia	5 200				Volcanic eruption	35
1951	Papua New Guinea	2 900				Volcanic eruption	35
1963	Indonesia	1 200				Volcanic eruption	35
1980	Mount St Helens, Washington State					Eruption triggered by an earthquake which caused the entire north slope of the volcano to fail in a massive landslide.	34
1982	El Chichon, Mexico	1 700				Volcanic eruption. Pyroclastic flows and surges claimed most lives.	35
1985	Nevado del Ruiz, Columbia	22 000				Volcanic eruption. Fatalities due to mudflows (lahars) which buried Armero.	33, 35, 36
1991	Mount Pinatubo, Philippines	300		100,000		Volcanic eruption and mudflows. Volcano had been dormant for 600 years. Some (informal) reports give much higher fatalities.	47

Table A-3.2g Selected Mass Movement Disasters

Date	Location	Fatalities	Injuries	Affected	Damage (US$M)	Notes	Reference
1916	Italy	10 000					35
1920	Ningxia, China	100 000				Earthquake-triggered loess slides	62
1921	Kazakh, USSR	500				Debris flow.	62
1933	Sichuan, China	2 429				Flood from landslide dam failure	62
1935	Huili, China	250				Rock and debris slide	62
1938	Kobe, Japan	505				Debris flows destroyed over 100,000 houses.	62
1941	Taiwan	350				Earthquake-induced landslides	62
1941	Huaraz, Peru	5 000				Lahar destroyed most of Huaraz.	36
1949	Tadzhikistan, USSR	20 000				Earthquake/landslide. Fatalities due to landslide not known.	35, 62
1951	Taiwan	154				Failure of dam due to landslide	62
1958	Shizuoka, Japan	1 094		19,754			62
1962	Mount Huascaran, Peru	5 000				Destroyed 9 towns. Began as a gigantic ice fall. Approx volume of landslide of 13 million cubic metres. Killed about 4000 in city of Ranrahirca.	35, 49
1963	Vaiont Reservoir, Piave Valley, Italy	2 500			600M	A high speed rock avalanche caused a reservoir wave that overtopped the dam.	35, 62
1965	Yunnan, China	444				Rock slide	62
1966	Rio de Janeiro, Brazil	350		4 M		Landslide, 4 million affected.	36
1969	Virginia, USA	150				Debris avalanching and floods. Most fatalities thought due to debris flow.	62
1970	Mount Huascaran, Peru	66 800 (total)	143 000	3 M		Landslides caused by magnitude 7.8 earthquake. Mudslides buried the nearby towns of Yungay and Ranrahirca. Over 3 million affected. Landslide in the order of 100 million cubic metres killed above 18,000 in Yungay. Some of the debris accelerated to about 1000 km/hr. Some boulders weighing several tonnes were hurled up to 4 km through the air.	35, 36, 49

Date	Location	Fatalities	Injuries	Affected	Damage (US$M)	Notes	Reference
1974	Mayunmarca, Peru	310			21	The most massive rockslide on record buried several villages in the Mantaro Valley. 1 billion cubic metres of sandstone and marl descended 1500 vertical metres in 4 mins. Initial failure thought to have been influenced by normal groundwater pressure. Average velocity of slide 120 to 140 km/hr. Total travel distance of about 8 km.	36, 49
1974	Andes	450					62
1975	Gansu, China	>500				Loess slide caused by flooding	62
1980	Hubei, Yuanan, China	284				Rock slide and avalanche	62
1983	Pan American Highway, Ecuador	150					62
1984	Sichuan, China	>300				Debris flow	62
1985	Armero, Columbia	21 800			1 billion	Lahar from volcanic eruption.	33, 36
1987	Sumatra, Indonesia	132				Failure of a natural slope with quarry workings at the toe.	62
1987	Reventador, Ecuador	5 000			1.5 billion	A magnitude 6.9 earthquake, following a month of heavy rains, precipitated landslides on slopes of Mount Reventador. Event also ruptured the trans-Ecuador oil pipeline, causing massive financial loss to Ecuador.	35
1988	Gansu, China	277				Loess slide	62

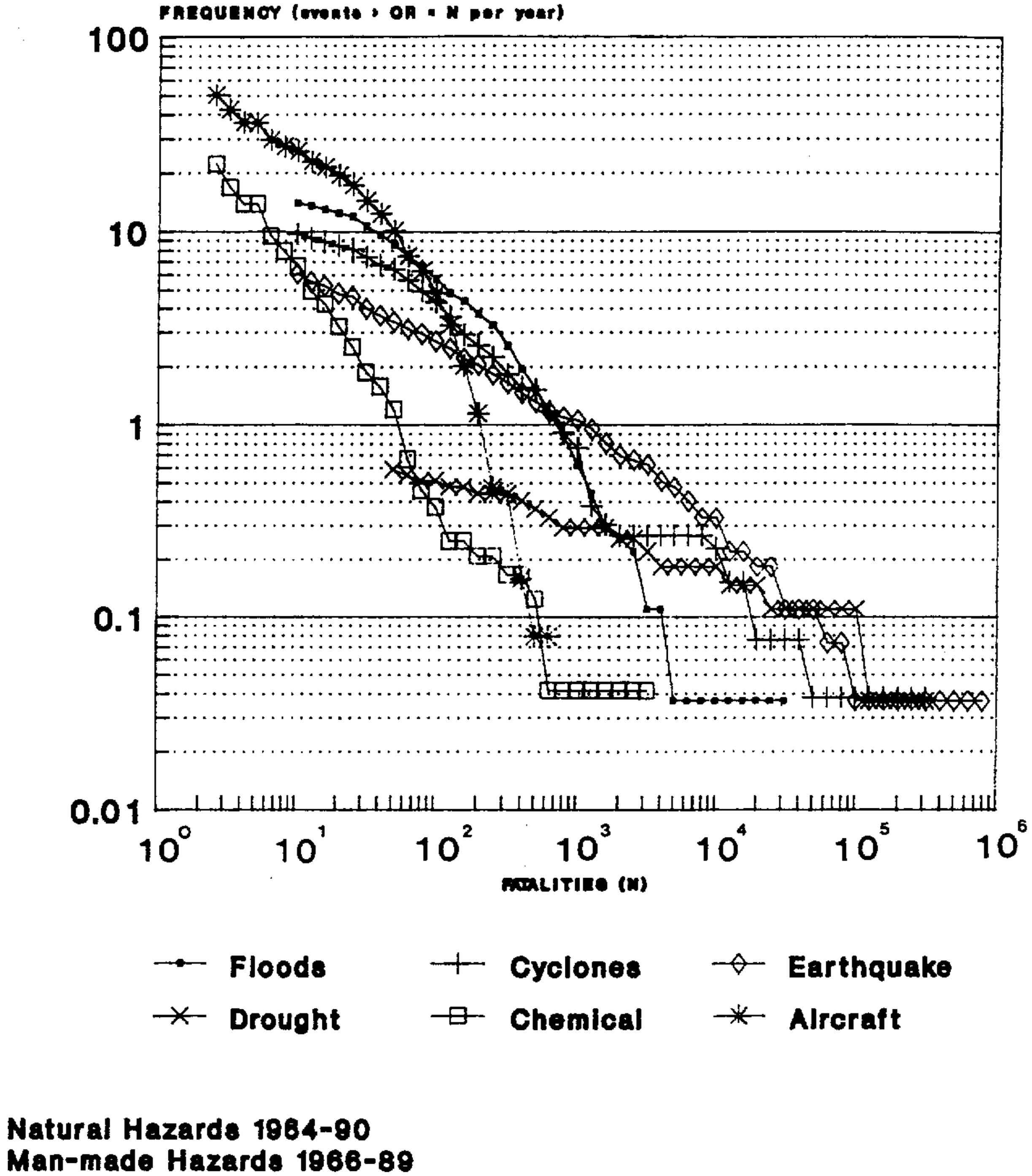


FIGURE A-3.2a - FREQUENCY OF ACCIDENTS FOR SELECTED CATEGORIES CAUSING FATALITIES WORLD-WIDE

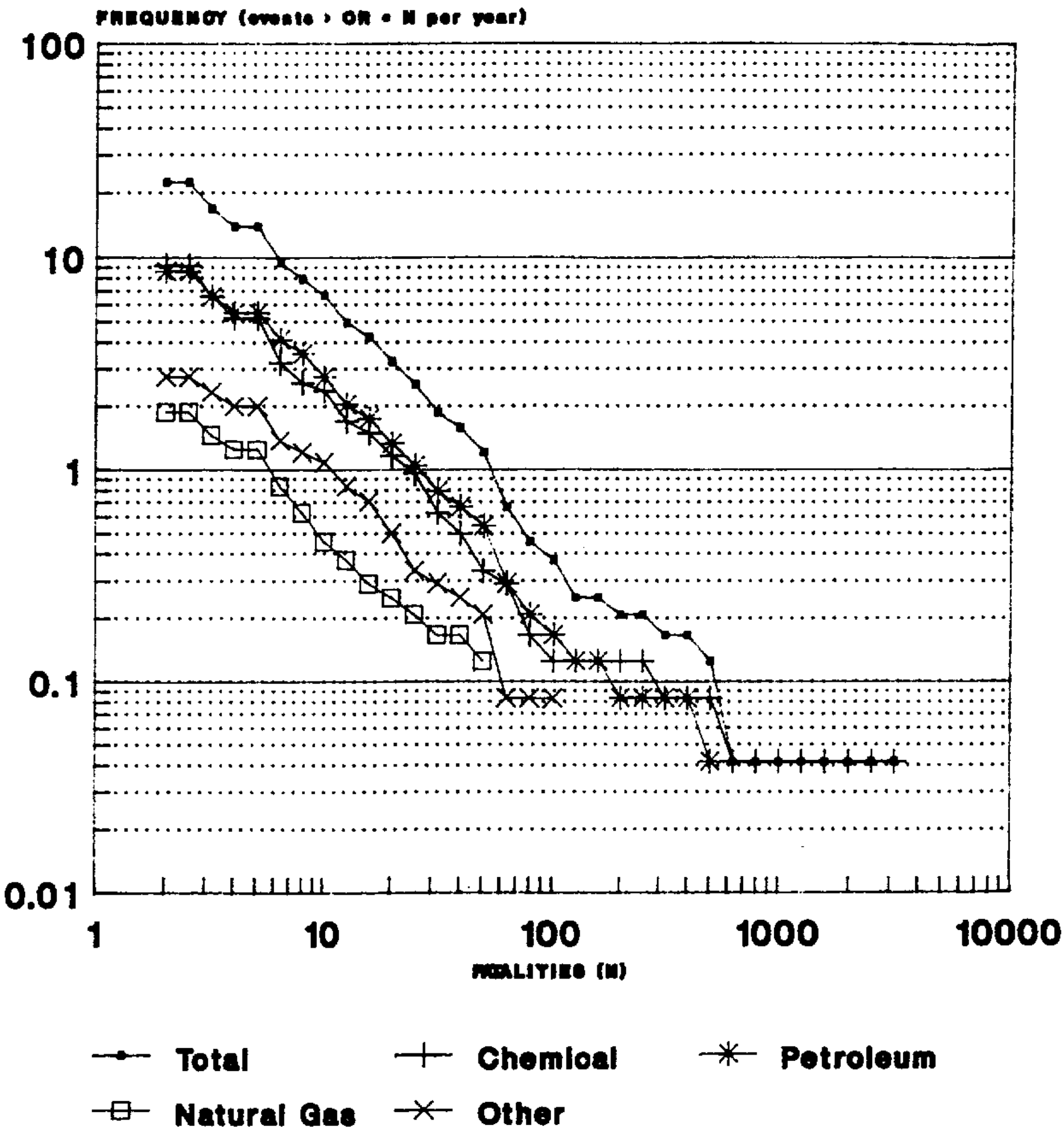


FIGURE A-3.2b - FREQUENCY OF ACCIDENTS BY ORIGIN IN THE CHEMICAL AND PETROCHEMICAL INDUSTRIES CAUSING FATALITIES (WORLD-WIDE, 1966-89): ANALYSIS BY INDUSTRY TYPE

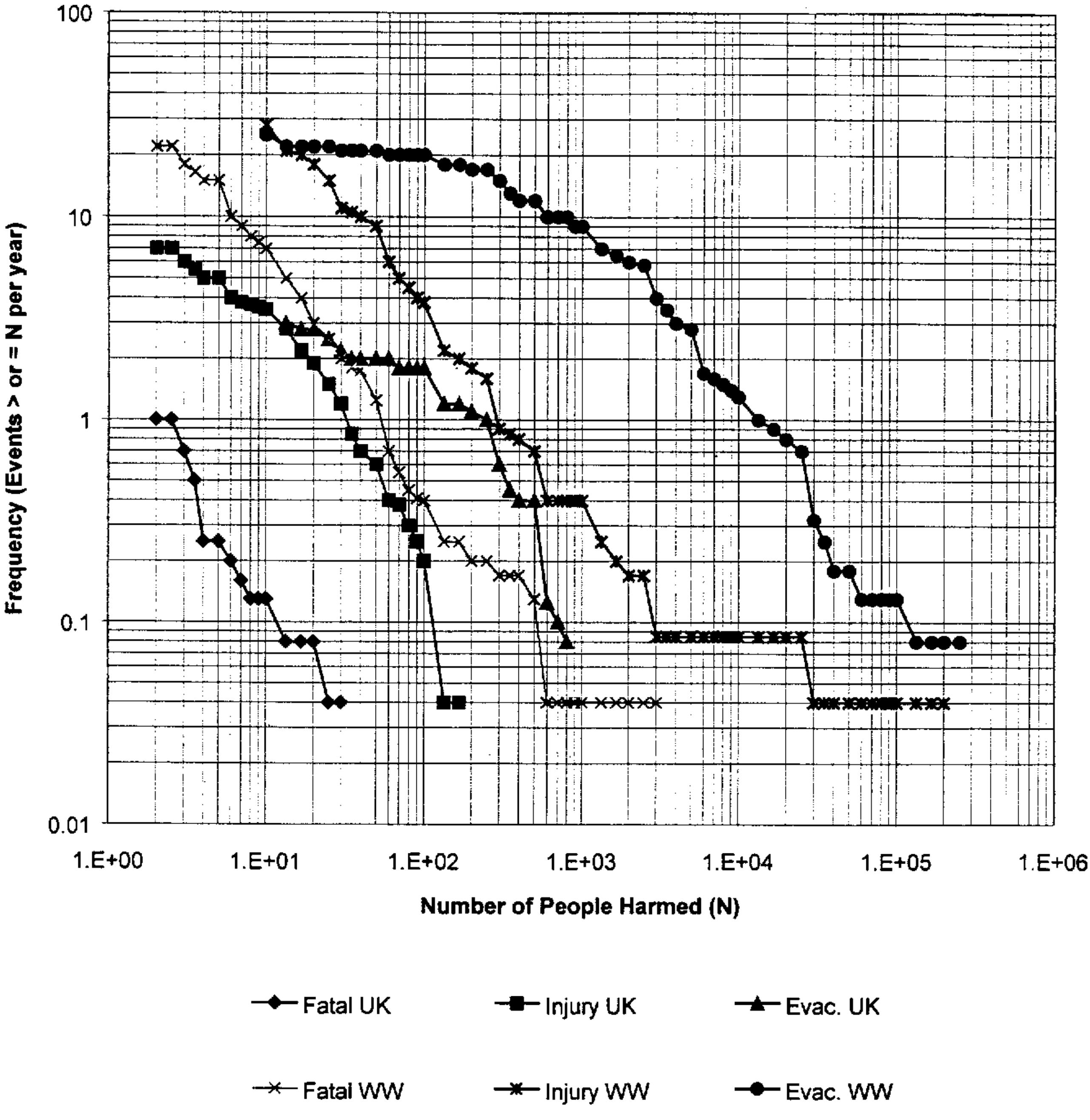


Figure A-3.2c - Frequency of Accidents in the Chemical and Petrochemical Industries (UK and World-Wide, 1966-89)

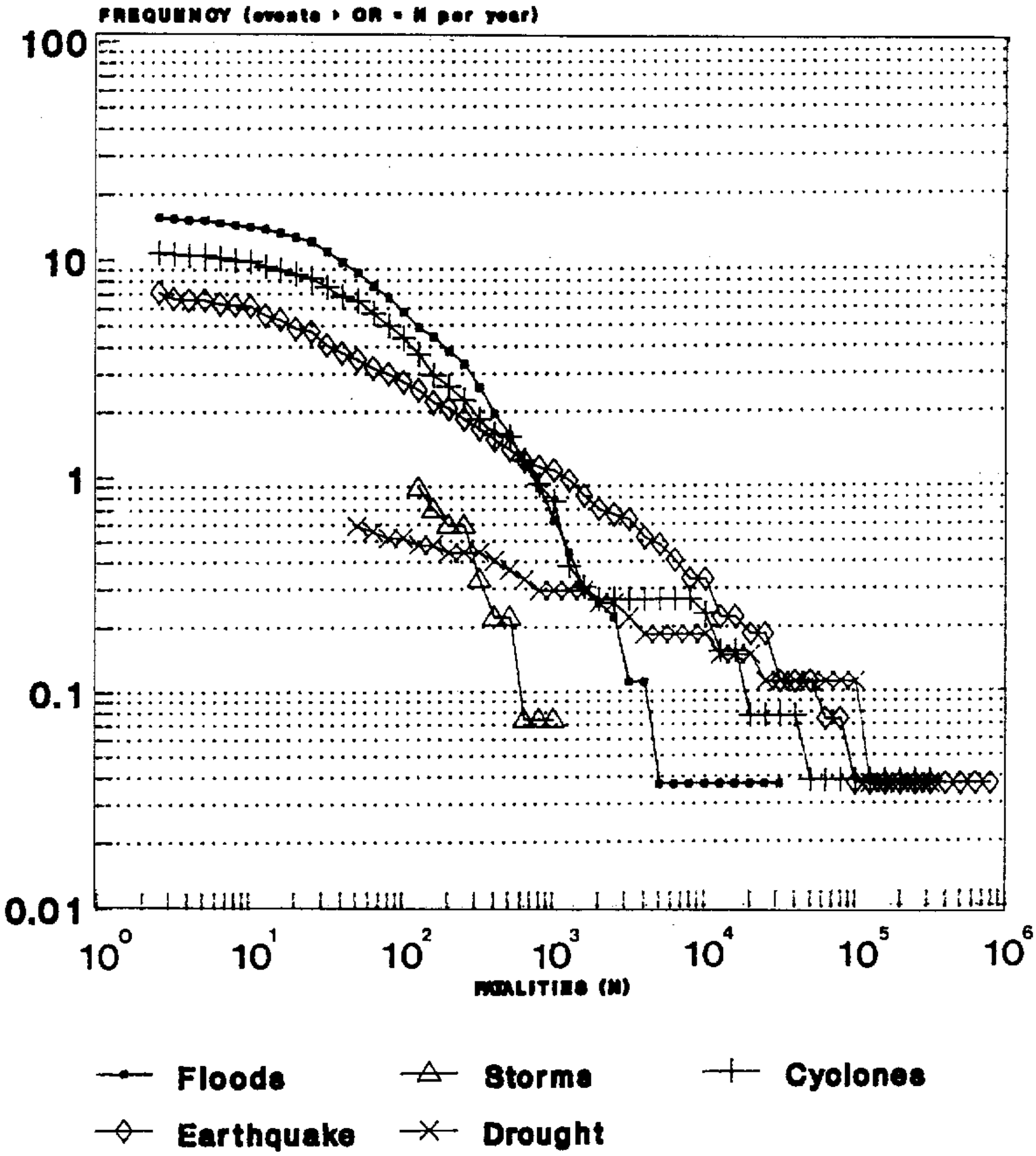


FIGURE A-3.2d - FREQUENCY OF OCCURRENCE OF SELECTED NATURAL HAZARDS CAUSING FATALITIES (WORLD-WIDE, 1964-90)

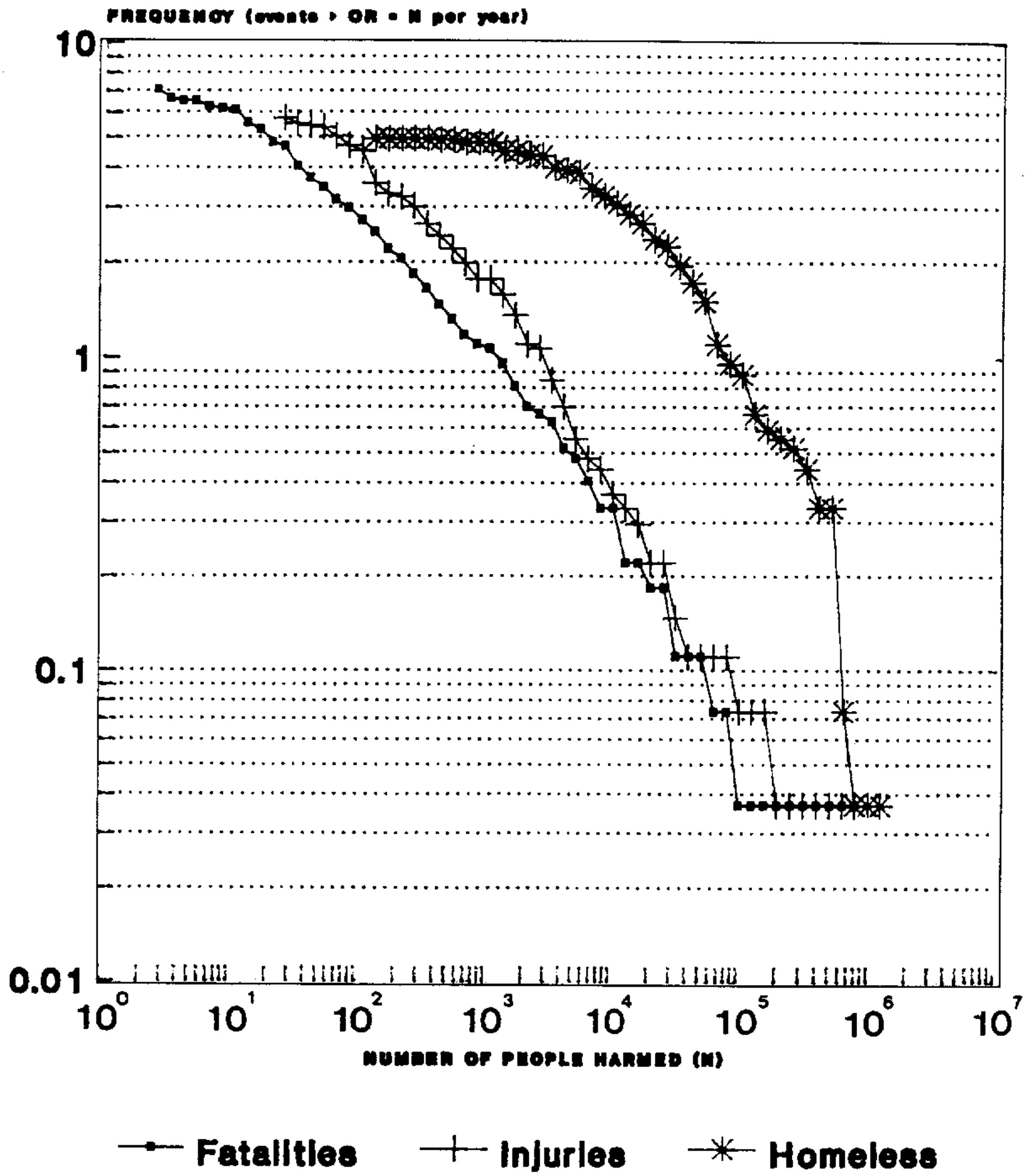


FIGURE A-3.2e - FREQUENCY OF EARTHQUAKES CAUSING HARM (WORLD-WIDE, 1964-90)

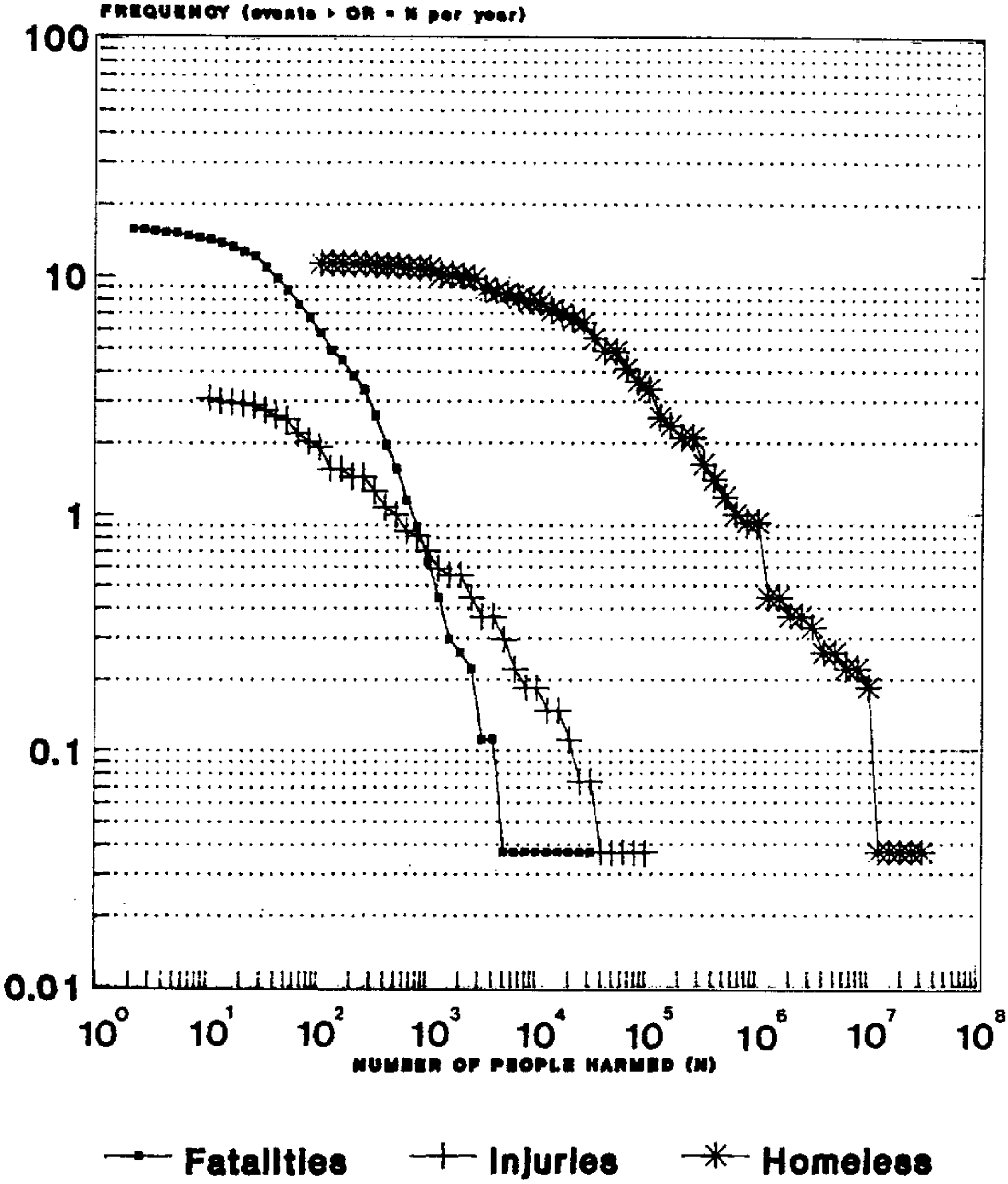


FIGURE A-3.2f - FREQUENCY OF FLOODS CAUSING HARM
(WORLD-WIDE, 1964-90)

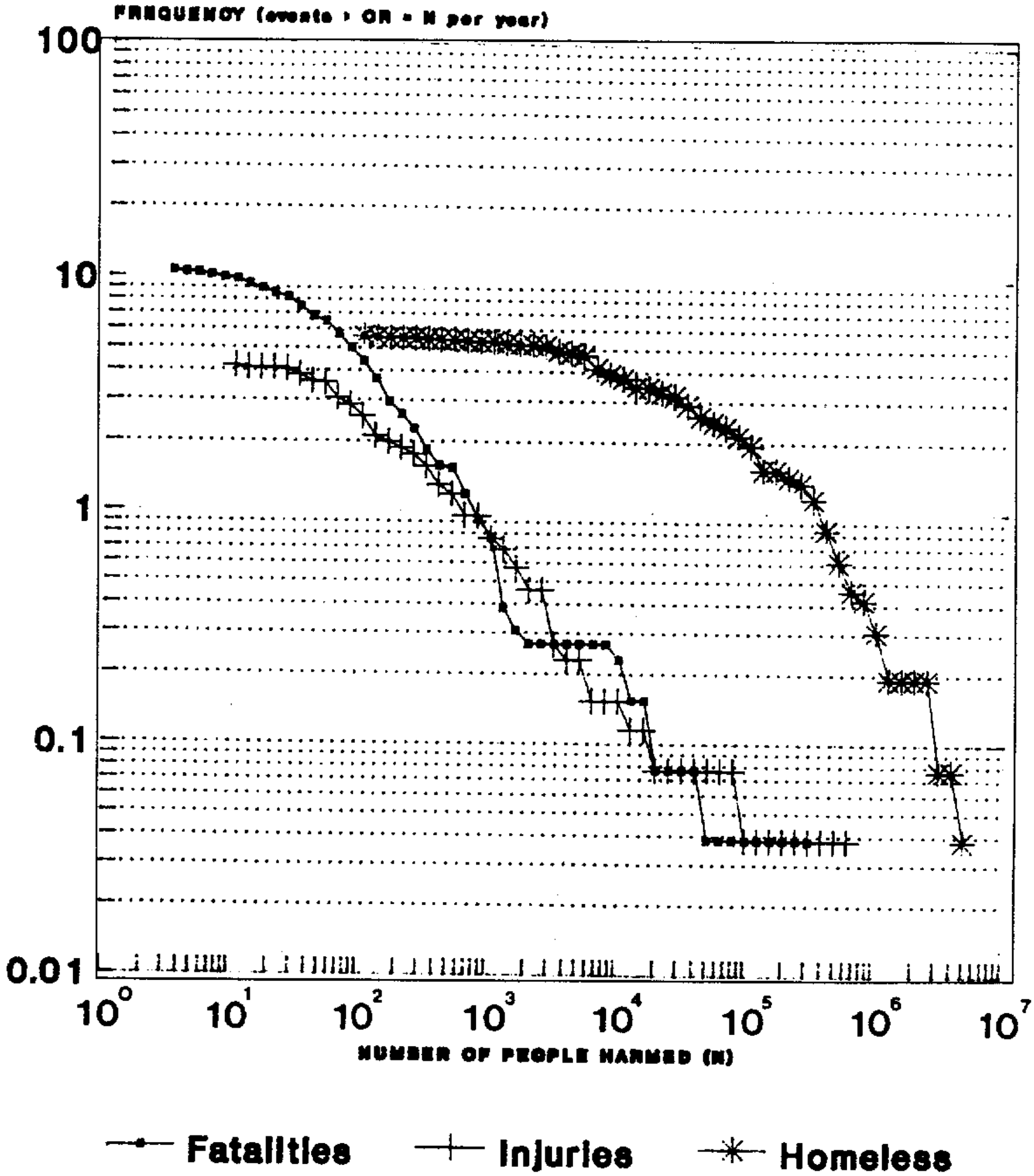


FIGURE A-3.2g - FREQUENCY OF CYCLONES, HURRICANES, AND
TYPHOONS CAUSING HARM
(WORLD-WIDE, 1964-90)

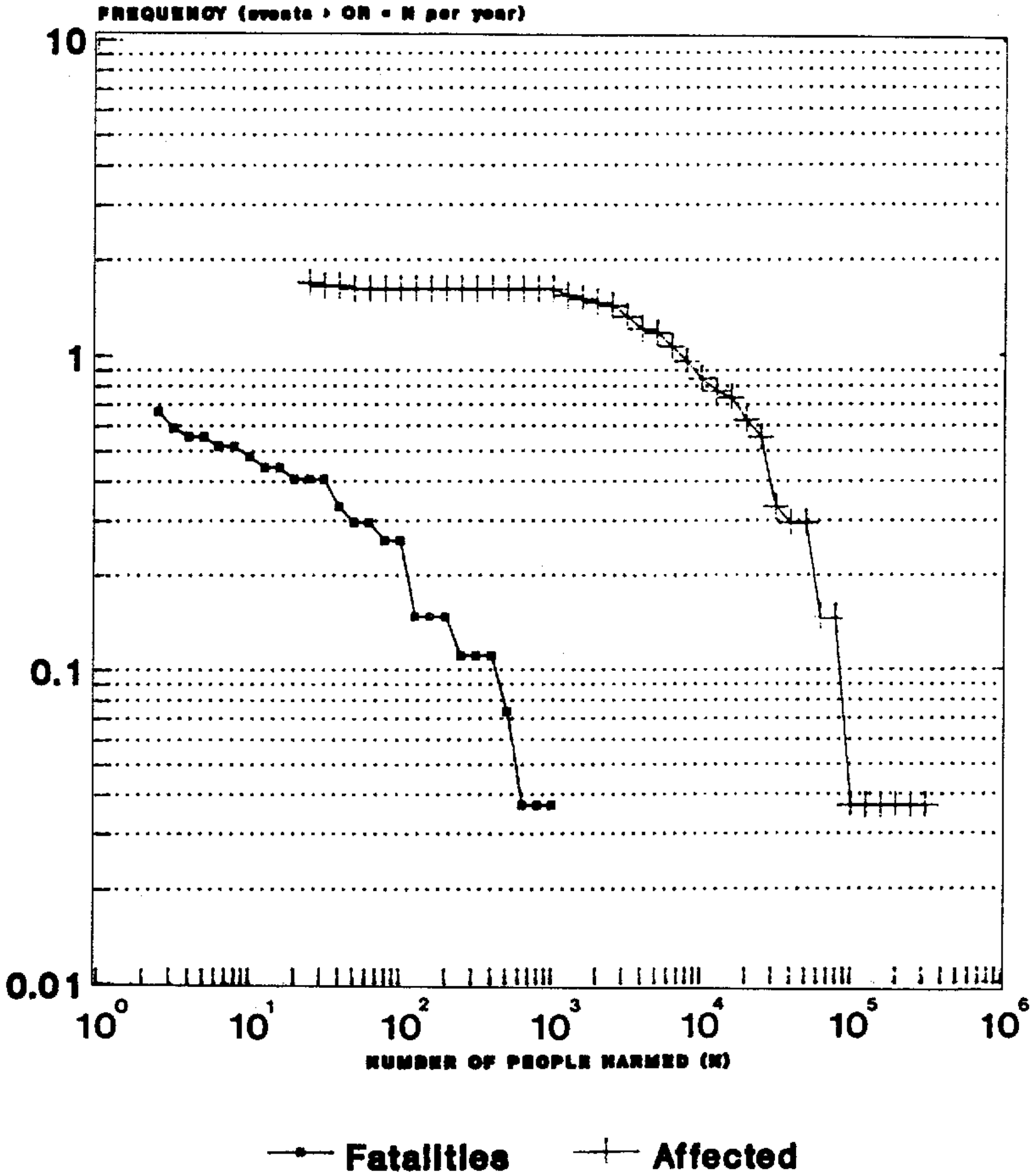


FIGURE A-3.2h - FREQUENCY OF VOLCANIC ERUPTIONS CAUSING HARM
(WORLD-WIDE, 1964-90)

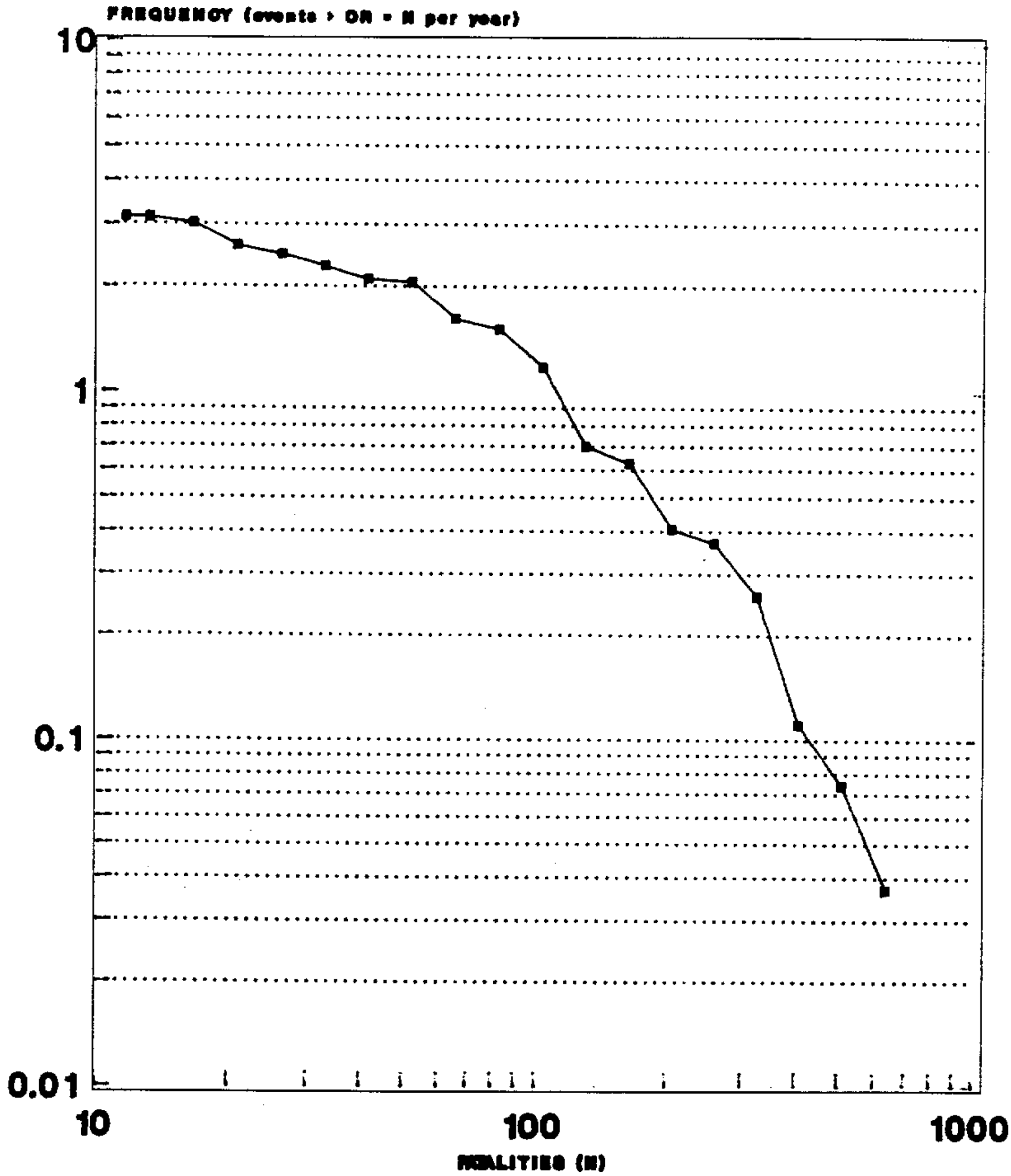


FIGURE A-3.2i - FREQUENCY OF LANDSLIDES CAUSING FATALITIES
(WORLD-WIDE, 1964-90)

Annex B

Approaches Adopted in the Development of Risk Acceptability Criteria Overseas

B1 *INTRODUCTION*

The use of Quantitative Risk Assessment (QRA) techniques for the evaluation of risks from serious accidents associated with hazardous industries and the effect on the surrounding population was first brought to the fore in the UK in June 1978 with the publication of the first Canvey Report. In parallel with this, the Dutch authorities in Groningen formulated a criterion for societal risk in 1979.

A European Community Directive for the safety of the public located in areas in the vicinity of an installation involving hazardous substances was subsequently issued on 24 June 1982 with a requirement for member states to implement national standards by 8 January 1994. This was known as the Seveso Directive. The national standards required all operators of hazardous activities within the particular country to demonstrate to the regulatory authority that they had identified the major accident hazards associated with their operations and had adopted appropriate safety measures (risk controls).

In cases where threshold quantities of specified substances are exceeded, the site operator had to submit a notification. The notification had to include the following:-

- a description of the safety important sections of the establishment and details about the dangerous substance(s);

- information relating to major accident situations of sufficient detail to allow off-site emergency plans to be prepared.

The Directive has had subsequent minor revisions, but there was no mention of a requirement to introduce QRA techniques or to have criteria for judging the acceptability, or otherwise, of the off-site risks imposed by the facility. It is understood that by implication this was left to the member states to decide upon. A major change to this legislation (Seveso II) is currently being prepared (see *Section B-6).*

Each member state of the EU has addressed the Directive and some of these have been reviewed by Pikaar and Seaman [*Ref. 17*]. The most notable approach to the Directive is that of the Netherlands who use standardised QRA techniques for evaluating risk levels associated with hazardous industries and established criteria for judging acceptability/tolerability of the calculated risks. A review of the criteria adopted by some countries in Europe is given below, starting with the UK, where the definitions of criteria and their interpretation is readily available from well known government publications. The approach adopted in Australia (NSW) for major hazard plants is also reviewed.

The countries which are reviewed here are: UK, The Netherlands, France, Switzerland, and Australia (NSW).

B2 *UNITED KINGDOM*

B2.1 *USE OF QRA AND THE ALARP PRINCIPLE*

In the UK, the Health and Safety Executive (HSE) uses both deterministic and probabilistic methods of assessment, but with an increasing use of the latter in the form of Quantified Risk Assessment (QRA). The deterministic approach, when used, would usually be for the consequences of fires and explosions, although there is still inevitably a probabilistic element in the events that are chosen to be credible. The probabilistic approach is favoured by the HSE since it permits account to be taken of both the likelihood of an accident and the consequences in making decisions on land-use.

The HSE and other government departments in the UK are continuing in the process of developing their approach to the whole subject of QRA and the use of criteria. Various documents and reports on the subject have already been published [*Refs 2,19,20,21,22,23*].

The original 'criteria' developed by HSE was for use with nuclear power stations and this was published in 1987 [*Ref 20*]. In 1989, further documents were published relating to the use of QRA techniques in decision making [*Ref. 22*] and for the application of risk criteria for land use planning in the vicinity of major industrial hazards [*Ref. 21*]. A further document on the tolerability of risk from nuclear power stations was published in 1988 and revised in 1992 [*Ref. 20*] which indicates that the criteria should also apply to large industrial plant in any industry.

There are some very interesting points given in the document regarding risk and acceptability/tolerability and the rationale behind the HSE's criteria, and some of these are reproduced below for ease of reference.

"Hazards and risks differ from industry to industry and some are arguably more readily acceptable, and the associated risk more tolerable, than others".

"Tolerability does not mean acceptability. It refers to a willingness to live with a risk so as to secure certain benefits and in the confidence that it is being properly controlled. To tolerate a risk means that we do not regard it as negligible or something we might ignore, but rather as something we need to keep under review and reduce still further if we can. For a risk to be acceptable on the other hand means that for purposes of life or work, we are prepared to take it pretty well as it is."

"The main test to be applied in regulating industrial risks are very similar to those we apply in day to day life. They involve determining:

a) whether a given risk is so great or the outcome so unacceptable that it must be refused altogether;

b) whether the risk is, or has been made, so small that no further precaution is necessary;

c) if the risk falls between these two states, that it has to be reduced to the lowest level practicable, bearing in mind the benefit flowing from its acceptance and taking into account the costs of further reduction."

In fact, the legal interpretation of point (c) above is that risks must be reduced to a level which is "As Low As Reasonably Practicable" (the so called ALARP principle). The meaning of "reasonably practicable" is well established in English case law:

"Reasonably practicable" is a narrower term than "physically possible" and seems to me to imply that a computation must be made by the owner in which the quantum of risk is placed on one scale and the sacrifice involved in the measures necessary for averting the risk (whether in money, time or trouble) is placed in the other, and that, if it be shown that there is a gross disproportion between them - the risk being insignificant in relation to the sacrifice - the defendants discharge the onus on them." (Judge Asquith, Edwards v. National Coal Board, All England Law Reports Vol.1, p.747 (1949))."

This ALARP principle was adopted in the Health and Safety at Work Act (1974), and is the basis of the approach adopted by the HSE in its regulation of the major hazard industries, including the nuclear, chemical and offshore oil and gas industries. It has also been adopted in the Railways (Safety Case) Regulations (1994). The scheme distinguishes three levels of risk: an upper level above which risk is intolerable; below this a region in which risk is tolerable providing it has been reduced to a level which is As Low As Reasonably Practicable (ALARP); and finally a lower level below which risk is broadly acceptable, so long as precautions are maintained, because it is very small. This concept is shown in *Figure B-2.1a*.

If the risk level is in the top band, it must be reduced, or the activity must cease. If the risk level falls in the ALARP region, cost may be taken into account when determining how far to go in the pursuit of safety.

In simple terms this reflects the fact that whilst almost any system can be made safer with additional expenditure on safety measures, beyond a certain point it becomes extremely inefficient use of resources. Ultimately society is not prepared to pay large sums to reduce risks which it believes to be extremely small.

The HSE does not formally require a full QRA, with the calculation of risk levels, to be carried out as part of the CIMAH Safety Report (for 'top-tier' major hazard sites). The use of QRA, however, has been encouraged by HSE, since it may make the safety arguments more convincing. HSE has asked for QRA to be carried out, however, in circumstances where it was considered indispensable for arriving at an informed judgement of the suitability of an installation. Such circumstances included installations located within densely populated areas, with large quantities of dangerous substances such as chlorine stored. HSE have judged the acceptability of such risks against established criteria for individual risk, as discussed below.

B2.2 *INDIVIDUAL RISK*

The values proposed by UK Health and Safety Executive for Individual Risk in their tolerability document [*Ref 20*] for the upper and lower boundaries of the ALARP region are 10^{-4} and 10^{-6} per year respectively (that is to say, the upper level of tolerable risk of fatality is set to be a chance of 1 in 10,000 per year and the lower, (broadly acceptable) level 1 in a million). These values are proposed for members of the general public living close to a nuclear power station or other

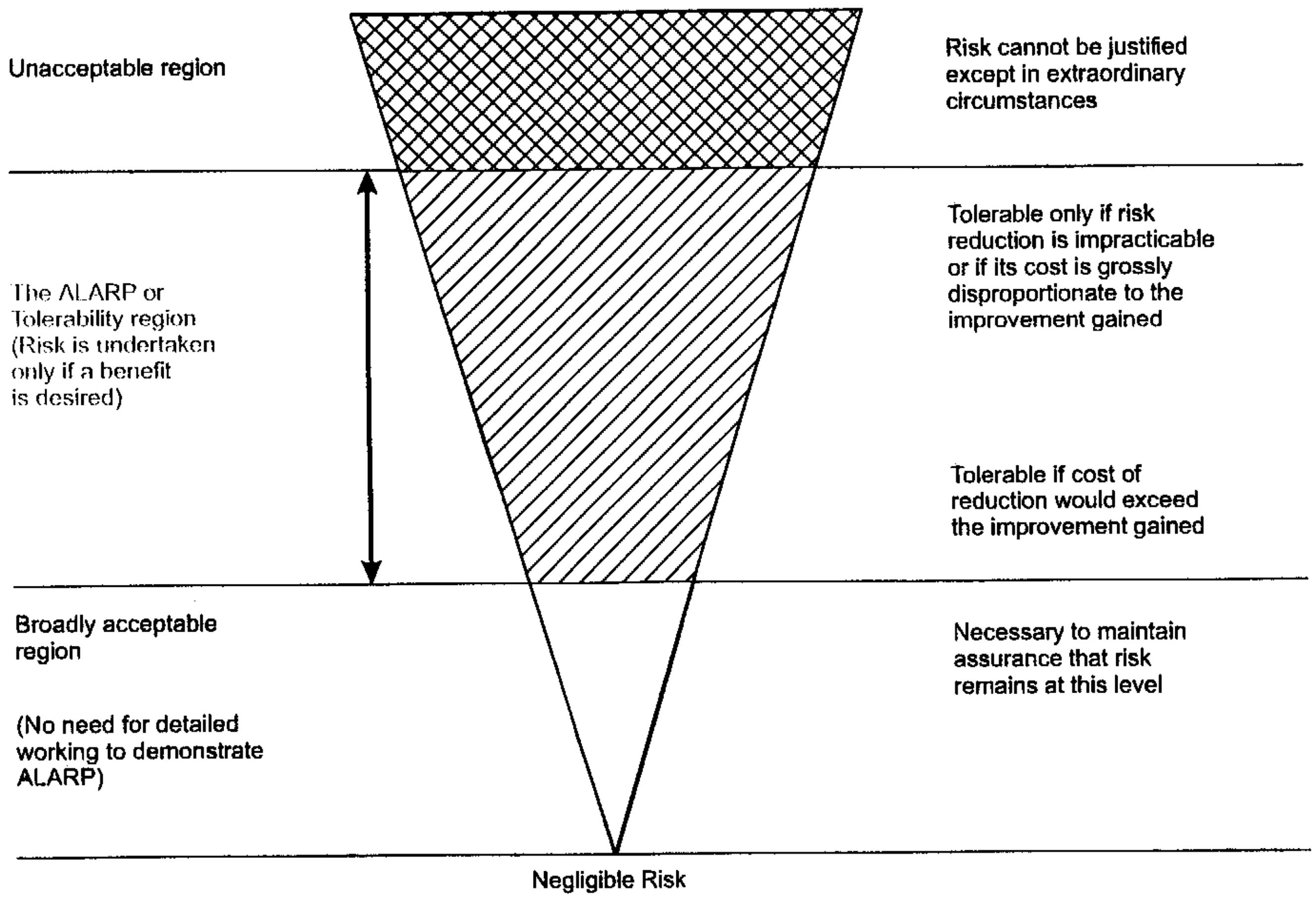


FIGURE B-2.1a - UK HSE RISK CRITERIA FRAMEWORK major hazard facility.

It is important to note that HSE do take account of factors such as occupancy, escape and protection indoors in their risk calculations, and the consequent decisions on landuse planning. They also take account of safety systems on the plant, including containment systems to mitigate releases, when calculating risk levels.

Table B-2.2a *Individual Risk Zones For Land-Use Planning*

	Individual Risk (per year) of HSE Dangerous Dose
Inner Zone	$10^{-5} \leq IR$
Middle Zone	$10^{-6} \leq IR < 10^{-5}$
Outer Zone	$3 \times 10^{-7} \leq IR < 10^{-6}$

The criteria are not used for judging acceptability of new installations or existing developments. They are based on concept of a 'dangerous dose' and not fatality, ie, a dangerous dose is a level of harm at which all the following injurious effects may be expected:

- severe distress to almost everyone;
- a substantial fraction requiring medical attention;
- some serious injuries requiring prolonged treatment;
- some highly susceptible people may be killed.

The dangerous dose is probably equivalent to a likelihood of fatality of between 1% to 3% for an average cross-section of community [*Ref. 21*].

B2.3 CONTROL OVER LAND-USE WITHIN THE VICINITY OF MAJOR HAZARDS

As noted above, the HSE uses both deterministic (ie consequence-based) and probabilistic methods (risk-based) of assessment, but with increasing tendency towards the latter.

B2.3.1 *Consultation Distance*

A Consultation Distance (CD) is defined for all major hazard installations, within which HSE must be consulted by local planning authorities (LPA) for advice on planned developments. The CD is usually defined by the 3×10^{-7} per year individual risk contour for the dangerous dose, or by the 500 Thermal Dose Unit (TDU) or 70 mbar consequence-based criteria for fire and explosion hazards. That is, the limit of the "outer zone" from either *Table B-2.3a* or *Table B-2.3d* is used to define the consultation distance.

In order to avoid unnecessary repetition on hazard analysis for planning advice, HSE have determined standard (consequence-based) consultation distances for various chemicals. For example, the consultation distances used for LPG in above-ground 'bullets' are presented in *Table B-2.3a* below [*Ref. 71*].

Table B-2.3a *Consultation Distances for Bulk Pressurised LPG*

Tank Size (te)	Consultation Distance (m)	Middle Zone (m)
6-10	150	125
11-15	175	150
16-25	250	200
26-40	300	250
41-80	400	300
81-120	500	400
121-300	600	500

For larger vessels and spheres a 'catch-all' consultation distance of 1000 m is used.

HSE originally adopted a consultation distance of 1 km for a typical chlorine plant with, say, one or two 30 te vessels, with a larger distance used for large process plants such as chlorine manufacturers, and a smaller distance used for smaller hazards such as drum users. They found, however, that this approach tended to be too conservative and overly-restrictive for land-use planning. HSE have increasingly adopted QRA for assessment of toxic installations, and found that QRA is very useful in helping to refine consultation distances.

B2.3.2 *Categories of Development*

Table B-2.3b shows the categories of development which HSE have defined for consideration on land-use planning issues.

Table B-2.3b *HSE Categories of Development*

Category	Development Type
A	Housing (10 or more houses), hotel or holiday accommodation
B	Factories, warehouses, offices, farm buildings, non-retail plant nurseries (all for <100 occupants)
C	Retail, community, leisure, etc. This category also includes cases not covered by A, B or D, eg housing with less than 10 units.
D	Highly vulnerable, or very large facilities. This includes hospitals, homes for the elderly, schools, etc. It also includes very large examples of category C.

It should be noted that the above classification is much simplified. HSE provide a more comprehensive classification for application by land-use planners.

It can be seen that category A is the 'housing' category which forms the basis of HSE's approach. Category C cases are assumed to be similar in significance to Category A, so that relatively small C developments will be given similar advice to small A (ie about 10 houses), while large C are given the same advice as large A (ie over about 30 houses). HSE adopt a 'common-sense' approach to deduce the equivalencies shown in *Table B-2.3c* in making judgements about cases where the risk is mainly societal:

Table B-2.3c *HSE Equivalencies for Developments*

Housing	Retail	Leisure (daytime), restaurant, pub, etc	Holiday/hotel
10 houses	100 people	100 people	25 people
30 houses	300 people	300 people	75 people

B2.3.3 *Acceptability Criteria for Land Use Planning*

At present the HSE does not use formal standard societal risk criteria for fixed installations in a decision making process. However, it does consider societal risk in a simplified way for housing developments near existing installations. Some qualitative judgements are made for land use planning decisions using some surrogate judgements based on the individual risk criteria and a three dimensional matrix with zones. Three zones i.e. inner, middle and outer (see *Table B-2.2a*) are utilised based upon individual risks of $1x10^{-5}$/yr, $1x10^{-6}$ /yr and $3x10^{-7}$/yr. The $3x10^{-7}$/yr figure is the level used in general to define the land-use planning consultation distance.

The inner, middle and outer zones are defined by either the distance to individual risk levels (for a dangerous dose), as detailed in *Table B-2.2a* above, or by distances to specified thermal radiation dose or overpressure criteria. *Table B-2.3d* below details the "consequence criteria" which are used. For thermal radiation and overpressure the dangerous dose is set at 1000 TDU (thermal dose units) and 140 mbar (corresponding to a fatality level of about 1%) and to 500 TDU and 70 mbar for more susceptible members of the population.

Table B-2.3d *Consequence-Based Criteria for Land-Use Planning*

	Inner Zone	Middle Zone	Outer Zone
Thermal Radiation Dose	Fireball radius	1000 TDU	500 TDU
Overpressure	600 mbar	140 mbar (2 psi)	70 mbar (1 psi)

Note: 1 TDU (thermal dose unit) = 1 $(kW/m^2)^{4/3}$.s

B2.3.4 *HSE's Decision Matrix for Land Use Planning Decisions*

HSE's general approach to land-use planning issues around major hazard sites is summarised in *Table B-2.3e* below. It can be seen that the decision-making process is based on individual risk, but with qualitative account being taken of societal risk issues by considering the various types of development. For housing, HSE's advice will be based on the criteria for individual risk shown above. The element of societal risk is allowed for by using a harsher judgement for larger (or more vulnerable) developments in the middle zone of the criteria.

HSE may also not advise against a development in circumstances where it is a small addition to an existing population at risk. Such an example would be for an extra couple of houses in an area which is already built up.

HSE adopt the following decision matrix for land-use planning decisions, with the zones defined by use of either the risk-based criteria or consequence-based criteria.

Table B-2.3e *HSE's General Approach to Land-Use Planning Decisions*

	Inner Zone	Middle Zone	Outer Zone
A (housing)	Not Acceptable	Maybe/Not	Acceptable
B (commerce/ industry)[a]	Acceptable	Acceptable	Acceptable
C (community/ leisure)[b]	Maybe/Not	Maybe/Not	Acceptable
D (sensitive)	Not Acceptable	Maybe/Not	Maybe/Not

(a) includes small housing developments >10 houses
(b) includes small housing developments <10 houses

It should be noted the above table is very much a simplified summary of HSE's overall approach to land-use planning decisions. In reality, many additional factors need to be taken into account as part of the complex land-use planning decision-making process.

Within the inner zone HSE usually advise against all but industrial land-use, small retail or leisure development or small housing development (for not more than 25 people) which is not likely to set a precedent for further development. Less restriction is placed on land-use in the middle zone but HSE advise against developments where people are very vulnerable, large retail or leisure developments or housing developments for more than 75 people. In the outer zone HSE would only consider advising against developments where the inhabitants are unusually vulnerable or the development is extremely large.

B2.4 *SOCIETAL RISK*

As noted above, at present the HSE do not use formal standard societal risk criteria for fixed installations in a decision making process. However, they do consider societal risk in a simplified way for housing developments near existing installations.

HSE have, however, developed societal risk acceptability criteria for the transportation of dangerous goods. A transportation study [*Ref. 2*] undertaken by a sub-committee of the Advisory Committee on Dangerous Substances (ACDS) on behalf of the HSC (Health & Safety Commission) in 1991 derived and applied societal risk criteria. The criteria were used for evaluating port activities and were derived as follows:-

The starting point was the second 'Canvey Island' risk assessment [*Ref. 31*], where after a searching process of technical and sociopolitical assessment, including Public Inquiries and Parliamentary debate, the risks were deemed to be just below the borderline of tolerability. This allowed a benchmark to be set for the upper limit of societal risk to a local community, using an F-N curve with a slope of -1 through $F = 2x10^{-4}/yr$ and N = 500 fatalities.

A "broadly acceptable line" was set at a level three orders of magnitude below the 'Canvey' related line and with the same slope.

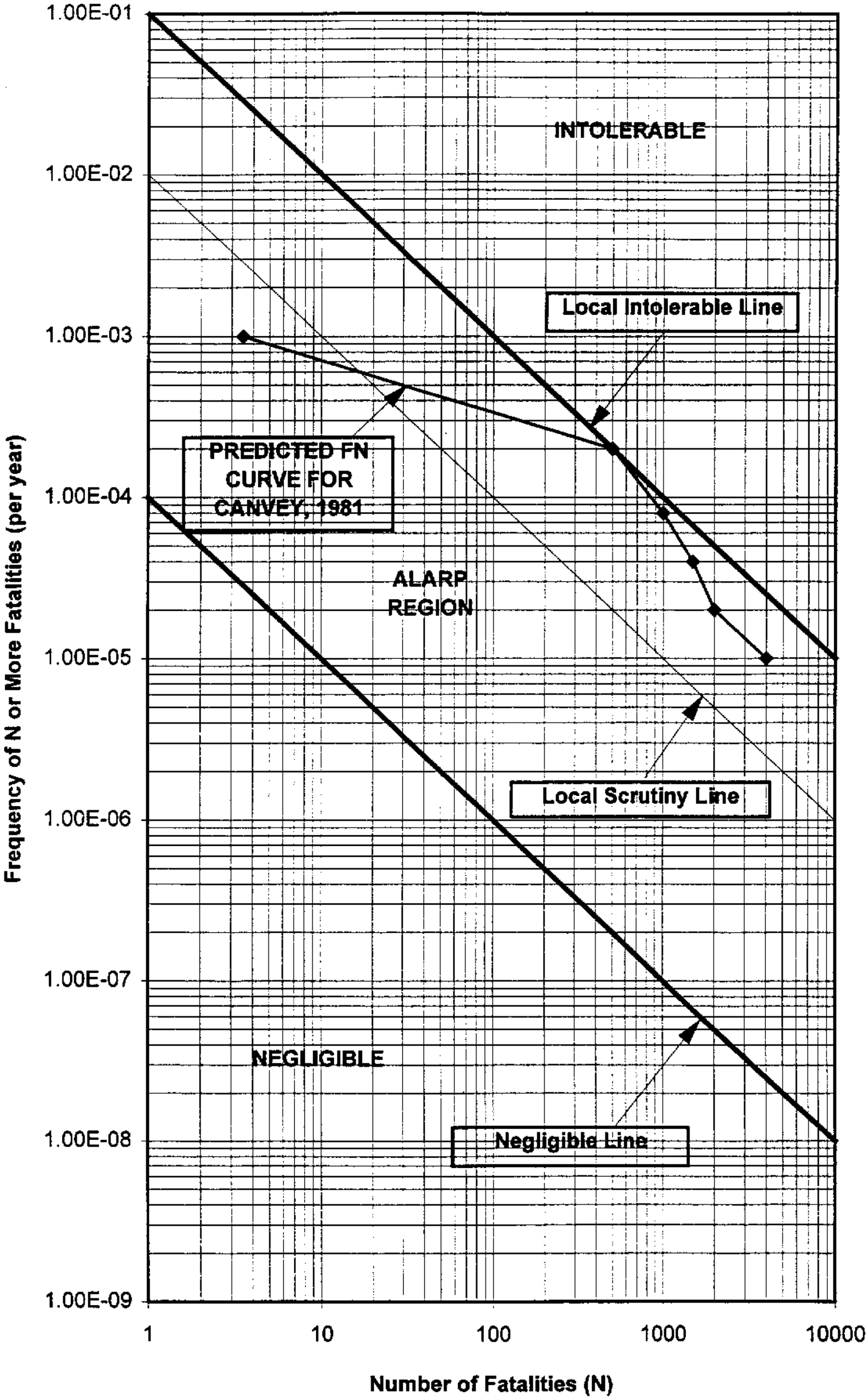
The lines were used as an initial benchmark for judgement against three seaports individually assessed.

For ports where the tonnage of hazardous substances might be substantially less than at Canvey, the frequency would be adjusted downwards pro rata to tonnage per year to give a 'scrutiny' level, a level above which particular effort may be needed to reduce the risks. This scrutiny level is not as severe as a "tolerability level" but well up the ALARP region.

Inbetween the "intolerable" and "broadly acceptable" level, the ALARP principle applies. A cost of 2 million pounds sterling per fatality averted is used in the calculation of which risk reduction measures are considered to be "reasonably practicable".

The F-N criteria are shown in *Figure B-2.4a* with a scrutiny line for 300,000 tonnes/yr trade.

Figure B-2.4a - Basis for HSC Port Criteria



B3 THE NETHERLANDS

In the external safety policy of the Netherlands [*Refs. 1,17,18,19*], hazardous industrial activities are evaluated with respect to their off-site risks, both in terms of individual risk and societal risk. For activities described as dangerous, these risks are compared with acceptability criteria. If risks are found to be unacceptable, risk reducing measures or zoning (or both) are applied to bring the risk to an acceptable level.

The external (or off-site) risk assessment is QRA based and the parameters used in the risk control policy are as follows:-

Individual Risk (IR): This is shown on a map around the facility as contours at which a hypothetical individual staying at that location, unprotected and for twenty-four hours per day, would be subjected to a defined probability of fatal harm per year due to exposure to hazards induced by the industrial activity.

Societal Risk: This is the annual frequency of simultaneous death of a defined number of people, who need not be specifically identifiable. As noted earlier, societal risk can be graphically represented by the annual frequency (F) of accidents killing more than a specified number (N) of people.

The current criteria values adopted are as follows:

Table B-3.1a Individual Risk Criteria

	Maximum Permissible Risk
New Situations	10^{-6} /yr
Existing Situations	10^{-5} /yr

Table B-3.1b Societal Risk Criteria

	Directional Value
> 10 deaths	10^{-5} /yr
> 100 deaths	10^{-7} /yr
> 1000 deaths	10^{-9} /yr

The societal risk criteria gradient is at a value of minus 2 which shows strong risk aversion (or more correctly, high consequence aversion) and this is shown on *Figure B-3.1b*. For example, in this approach, one incident involving 1000 or so fatalities is considered less tolerable than 10 events involving 100 or so deaths in the same period, since a slope of -2 implies that a single event involving 1000 fatalities is no more tolerable than one hundred incidents which each involve 100 fatalities. The supporting argument is that accidents causing large numbers of fatalities have, by comparison with less severe accidents, a disproportionately disruptive impact on society.

It should be noted that the societal risk criteria have been revised during recent years to eliminate the lower "acceptable" line. That is to say, the risks are either "unacceptable" (ie, "intolerable") or fall within the ALARA (As Low As Reasonably Achievable) region, wherein, if ALARA is demonstrated then they are deemed to be "tolerable".

For IR > 10^{-5}/yr immediate steps are required to correct the situation. For risks below 10^{-5}/yr measures are required to reduce risks as far as achievable through technical means. The basis of ALARA is 'best available technology'. In interpreting what is reasonable the authority takes the view that the following are relevant:

- The economic situation in the sector and state of art in that sector. Note that the economic situation in a particular facility is not a factor;

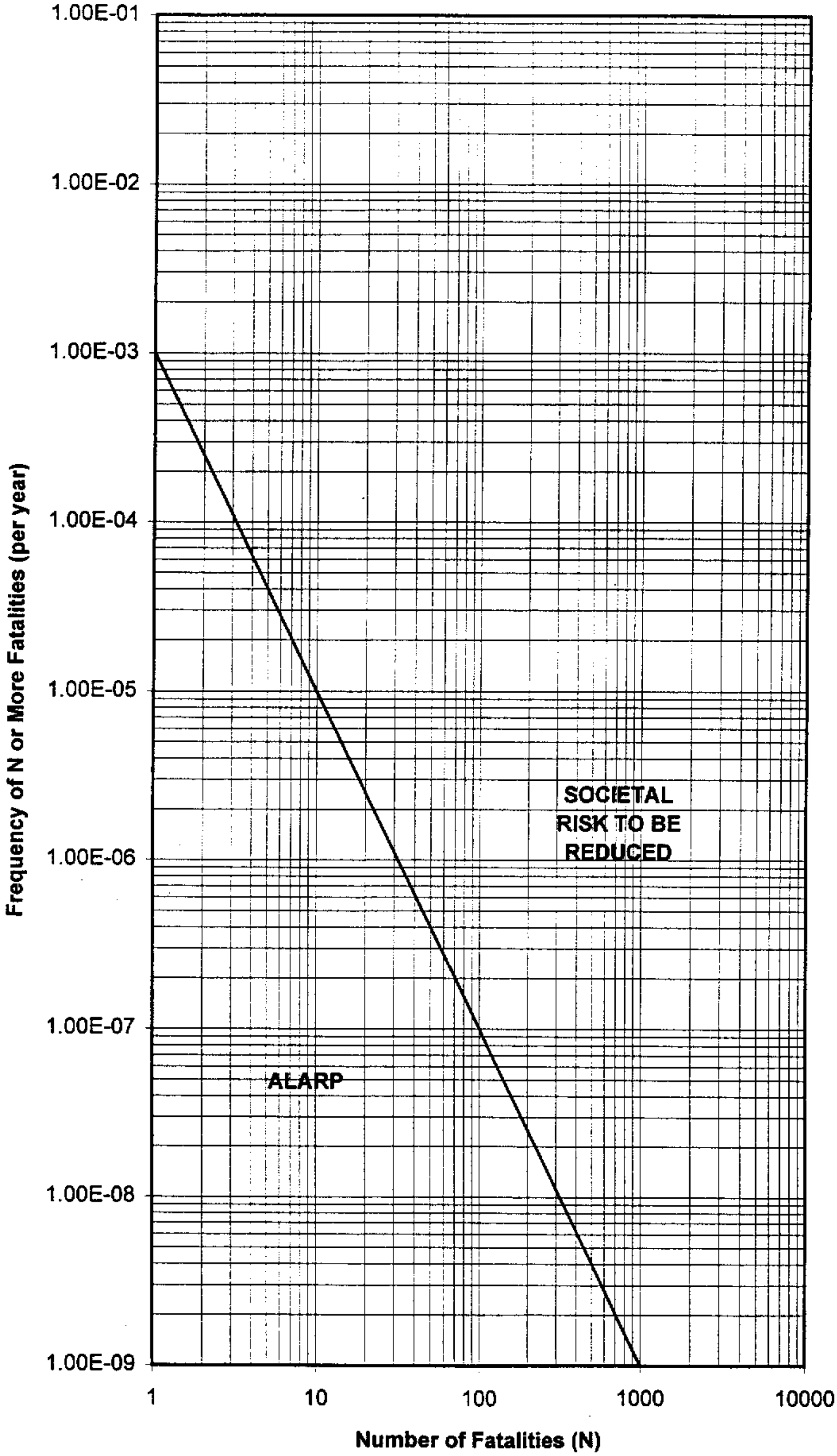
- Where the maximum IR value is exceeded greater levels of control are required even though the costs may be substantial;

- Where the perceived risk is high , e.g. nuclear, compared with a more acceptable risk, e.g. LPG, the authorities will take less account of the cost of controls.

Notwithstanding the above, the Courts in the Netherlands have not yet elaborated on the application of the ALARA principle as it is a relatively new concept in the Dutch system. It could be looked on as roughly equivalent to the ALARP principle in the UK, although the use of Cost-Benefit Analysis is more explicit with ALARP.

The land use policy requires that development plans within the neighbourhood of an existing installation should respect the risk levels and no new buildings are permitted inside the 10^{-6}/yr contour except in special circumstances, e.g. replacement of existing dwellings, provided that they are not located in the 10^{-5} per year contour.

Figure B-3.1b - Dutch Societal Risk Criteria for Fixed Installations



B4 *FRANCE [Ref. 64]*

B4.1 *LEGISLATION*

Major hazards legislation is divided into two groups. The first is concerned with the implementation of the main provisions of the Seveso Directive, and the second, implementation of the provisions on emergency planning, warning and information for the public. The main law on major hazards is the Act of 19 July 1976.

Under the "Law of 19 July 1976" a top-tier major hazard installation must provide a Safety Report to the Prefect. Assessment of the Safety Report is under the control of DRIRE but subject to direction by the Prefect. Ministry for the Environment has a special accident bureau, BARPI (Bureau for the Analysis of Risks and Industrial Pollution) who may also be consulted by other bureau or by the DRIRE.

B4.2 *ASSESSMENT OF HAZARD AND RISK FROM MAJOR HAZARD INSTALLATIONS*

Although the authorities recognise the validity of probability as a valid parameter in the assessment of risk, the regulations are centred on safety distances that result from maximum effect calculations of major hazard units. QRA studies could be requested by a local authority, but the basis on which the results would be judged is unclear.

The approach adopted involves the consideration of a range of accident scenarios and the maximum effect, taking account of protective control features considered at the installation. The accident scenarios and reference criteria are derived from experience of past industrial accidents. The approach is a deterministic one for a given list of scenarios chosen on probabilistic considerations.

The reference scenarios provide the basis for determining the planning zones around the installations. Six different scenarios are used, each being associated with a particular type of hazardous installation as follows:

Scenario A: BLEVE: for liquefiable combustible gas installations (fixed, semi-mobile or mobile);

Scenario B: Unconfined VCE: for liquefiable combustible gas installations (fixed, semi-mobile or mobile);

Scenario C: Total instantaneous loss of containment: for vessels containing liquefied and non-liquefied toxic gases;

Scenario D: Instantaneous rupture of the main piping system: for toxic gas installations when the containment is designed to resist external damage or internal reactions due to the products concerned:

Scenario E: Fire affecting the largest tank in a group, explosion in the vapour phase for fixed roof tanks, and fireball and projection of burning product due to boilover: for large vessels containing flammable liquids;

Scenario F: Explosion of the largest mass of explosives present, or explosion due to a reaction: for storage and use of explosives.

Threshold for toxicity, heat radiation and overpressure are used to characterise the effects of these hazards. The size of the zones are then determined. These zones are used to set the planning zones where control of urban development is necessary. The zone calculations are detailed below in *Table B-4.2a.*

Table B-4.2a Zone Calculations

Scenario	*Zones*	*Example*
Scenario A BLEVE	Radius of fireball: for 1% deaths due to burns, and for significant burns level. Initial lethal effects from shock wave (140 mbar). Initial damage and serious injuries due to shock wave (50 mbar)	BLEVE of a $500m^3$ propane sphere gives 1% fatality due to burns at 580m, and the risk of significant burn levels up to 680m. The envelope for the zone is therefore defined by a radius of 680m around the installation.
Scenario B Unconfined VCE following rupture of a main pipeline. The explosion is assumed to occur when the mass of gas within explosive range is at a maximum.	Initial lethal effects from shock wave (140 mbar). Initial damage and serious injuries due to shock wave (50 mbar).	The rupture of a 100 mm diameter line from a propane vessel gives two zones, 200m for lethal effects, and 450 m for initial damage and serious injuries. This is for an explosion involving 8,280 kg of propane, and results in a zone radius of 450m. If the same line had an automatic isolation valve installed, with a limited discharge of 780 kg predicted, then a zone radius of 210 m would result.
Scenario C Total instantaneous loss of containment, for vessels containing liquefied or non-liquefied toxic gases. Unfavourable conditions for dispersion are assumed.	Initial deaths by inhalation. Initial irreversible damage to health.	Catastrophic failure of a 1 tonne chlorine vessel, resulting in a cloud of 300 kg of chlorine, gives initial lethal effects up to 800m, and irreversible damage to health up to 1600m.
Scenario D For toxic gas installations when the vessel is designed to resist external damage or reactions between products: the scenario is guillotine rupture of main liquid pipeline.	Initial deaths by inhalation. Initial irreversible damage to health.	The rupture of a 40 mm diameter line discharging for three minutes will give an envelope of 3,940 m radius.

Scenario	Zones	Example
Scenario E Associated with large volume storage vessels for flammable liquids, such as fire affecting the largest tank, explosion in the vapour phase for fixed roof tanks, and fireball and projection of burning product due to boilover.	Radius of fireball. Distance to heat flux of $5 kW/m^2$ Distance to heat flux of $3 kW/m^2$ Initial lethal effects from shock wave (140 mbar). Initial damage and serious injuries due to shock wave (50 mbar). Zone of projection of missiles.	A large (100 m square) tank gives a zone of radius 130 m for initial lethal effects due to heat radiation, and 110 m to initial burns. Explosion in the vapour phase of a 20,000 m^3 fuel oil tank gives 100 m to initial lethal effects, and 110 m to initial damage and notable injuries.
Scenario F An explosion of the largest mass of explosives present or explosion due to a reaction.	Initial lethal effects (140 mbar). Initial damage and serious injuries (50 mbar). Projection of missiles. 1% deaths due to burns. Significant burns level.	The detonation of 50te of TNT gives 300 m to initial lethal effects, and 810 m to initial damage and notable injuries.

B4.3 *ACCEPTABILITY CRITERIA FOR NEW DEVELOPMENT*

As discussed above, the hazard assessment considers six different scenarios, as relevant to the installation under study. Threshold criteria for toxicity, heat radiation and overpressure are used to characterise the effects of these hazards and to determine zones for the purpose of land-use control.

Two zones are defined within which developments are restricted. The zones are determined by the procedures described in *Table B-4.2a* above. The first zone, zone Z1, is the nearest zone to the hazardous installation, and the second zone Z2 is the most distant.

The criteria by which the two zones are determined are LC1% (lethal concentration at which 1% of the exposed population will suffer fatality) for zone Z1, and IDLH (the concentration/dose which is considered to be imminently dangerous to life and/or health of the exposed population) for zone Z2, which corresponds with the appearance of irreversible damage to health and notable injuries.

Proposed developments are categorised into six categories as follows:

A High rise buildings
B Establishments receiving the public
C Sports areas, no structure receiving the public
D Residential structure with limited site occupation factor (<0.08)
E Extensions limited to $20m^2$ overall not forming accommodation
F Modifications to existing residential or office buildings, with no extension or change of use

Establishments receiving the public and high rise buildings are prohibited in both zones because of the potential number of casualties and the difficulties of evacuation.

In zone 1 authorisation is given for developments in categories E and F which do not result in any increase in density. Houses, other residences and establishments receiving the public are prohibited.

In zone 2 authorisation is given for developments in categories C, D, E and F with limitations on density.

Industrial installations may be permitted in these zones, subject to certain conditions, such as the distribution of gas masks to people combined with suitable training.

B5 *SWITZERLAND*

The Federal and Kanton (state) criteria [*Ref. 17*] address only the frequency and seriousness of accidents, i.e. societal risk. There is no mention of risk contours or individual risk criteria in the published documents.

The Federal guidelines give a maximum and minimum societal risk criterion consisting of two lines with a gradient of -2 on a log-log plot of Annual frequency against Number of fatalities, with vertical extension of the lines at both ends as indicated in *Figure B-5.1a*. The vertical extension of these lines (at both ends) have been interpreted by Pikaar & Seaman [*Ref. 17*] as follows:-

- Accidents below a certain size do not fall within the intent of the relevant law concerned with Major Accidents;

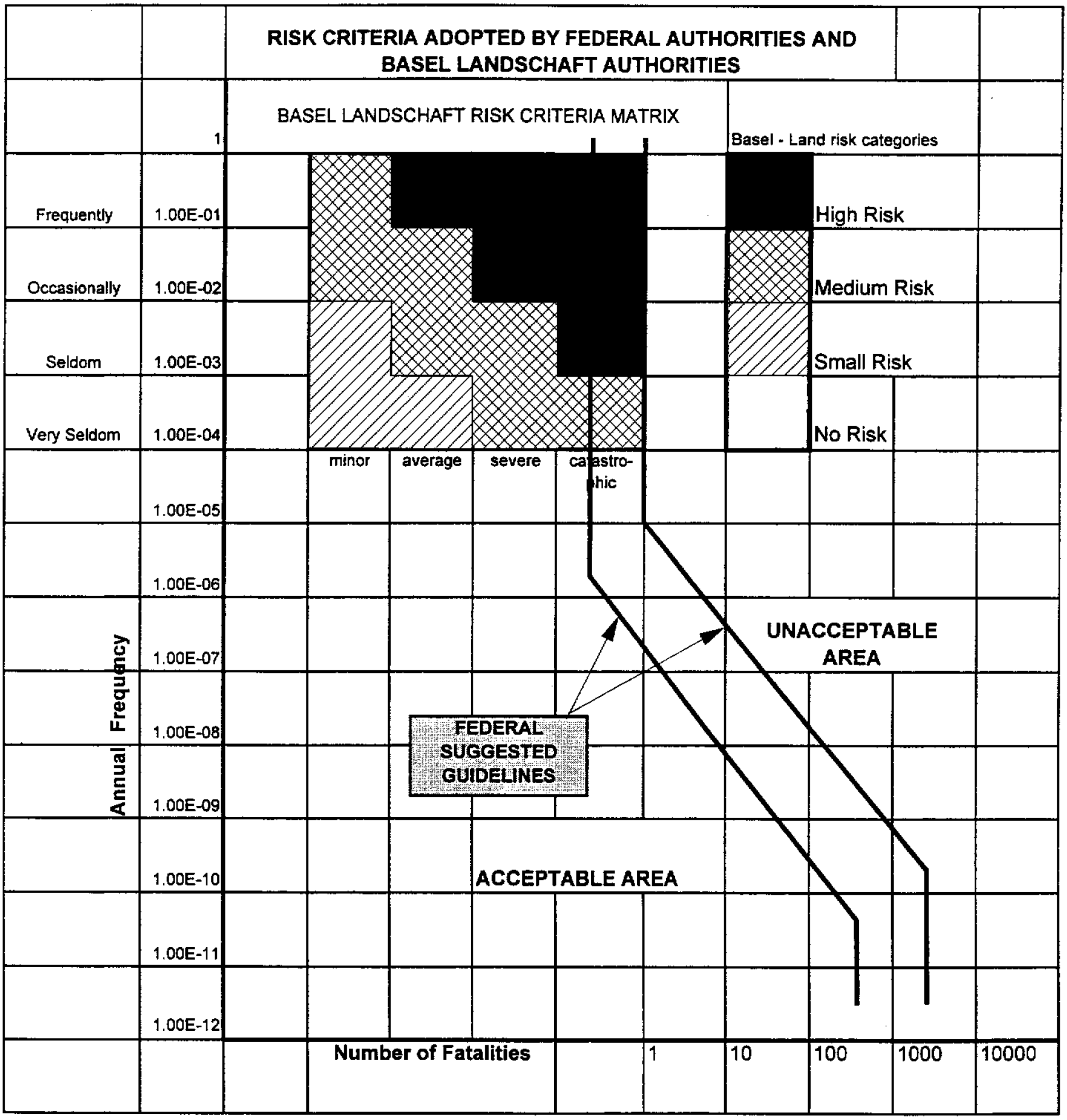
- Accidents producing more than a certain consequence (ie approximately 2000 deaths) will **never** be acceptable. Circumstances that could produce such consequences cannot be permitted.

The guideline criterion of Kanton Basel Landschaft authorised in 1993 is shown in the upper part of *Figure B-5.1a*. The quantitative positioning of the consequence along the N axis is an interpretation of the explanatory notes of the matrix. This ranges from 'no harm', through 'temporary reversible harm' to 'irreversible harm' and fatality with the corresponding risk categories which are applied for each.

For proposed installations that impose risk levels that remain intolerable after all risk reduction possibilities have been exhausted, decisions have to be made at a political level. The authority can prevent industrial development which is too close to housing but the converse is not covered by law.

According to Pikaar & Seaman [*Ref. 17*], the Swiss situation (nationally) is still "fluid", with many parties still having to decide how they will proceed and what type of criteria to adopt i.e. whether to adopt guidelines or to impose firm limits to the risk levels.

Figure B-5.1a - Swiss Societal Risk Criteria



B6 *OTHER EUROPEAN COUNTRIES & SEVESO II*

The other European countries do not use specific criteria linked to QRA techniques for judging acceptability of hazardous industries or developments within their vicinity. Other means are adopted for ensuring safety. For example, the Federal Republic of Germany adopt a standards-based approach, whilst France adopts a consequence-based approach for land use planning controls.

Due to the need to reflect the considerable advances in thinking on major hazards issues that have taken place since 1982, a fundamental review of the Seveso Directive has been carried out. The review was so far-reaching that a new Directive has been required: the Council Directive on the Control of Major Accident Hazards involving Dangerous Substances (COMAH), also known as Seveso II Directive. The Seveso II Directive applies for all CEC member countries and was adopted on 9 December 1996, and needs to be implemented by law in the UK by February 1999. The main features of the new Directive are [*Ref. 65, 66*]:

- Application will depend solely on the presence of the threshold quantity of the dangerous substance, with no distinction between processing and storage;

- There will be more use of generic categories, eg "highly flammable" to define the application, cutting the number of named substances to 37. The categories are defined by the directives for the classification of dangerous goods for supply;

- An "ecotoxic" category will be introduced to cover substances that may harm the environment, without necessarily threatening people;

- The duty to notify the presence of a dangerous substance has been switched from top to bottom tier sites;

- The increased emphasis on safety management systems is reflected at both the top and bottom tiers. Bottom tier sites must have a major accident prevention policy (MAPP). This policy forms part of the safety report for top-tier sites;

- The required contents of safety reports will be set out more precisely, for example, making it clear that hazard and risk assessments should cover the whole range of potential accident scenarios;

- Land-use planning requirements will be introduced, largely based on the UK's system, but with a need to take into account risks to the environment;

- On and off-site emergency plans will still be required, with additional duties to test those plans and put them into effect and to include measures to be taken for remediation and clean up of the environment;

- Information to the public has been extended by making safety reports available to the public;

- Criteria for the reporting of major accidents are included to improve the consistency of reporting from member states to the European Commission;

- The duties and powers of Competent Authorities (CA) will be extended to prohibit dangerous activities. That is, the CA will have the power to prohibit start-up or continued operation where there is evidence that the measures taken for the prevention and mitigation of major accidents are "seriously deficient". There will also be a requirement for member states to set up a system for inspecting installations;

- There is a new requirement on CA to designate establishments which might give rise to domino effects.

One of the most notable new features of the proposed revision is the requirement for a land use policy that includes among its objectives the prevention of major accidents and the limitation of their consequences. In addition to the requirements for siting new installations there will have to be provisions for controlling new developments surrounding existing facilities. Member states will have to inform the Commission of the siting and land-use planning criteria which are applied for the purposes stated. If the revision is adopted, it is expected that the matter of risk acceptability criteria will become more explicit in the future.

B7 AUSTRALIA (NSW)

B7.1 LEGISLATION

Most States and Territories in Australia consider the risk impacts of proposed industrial developments early in the development application stage. This process ensures that risk levels from industrial developments are not unacceptable in relation to the existing land uses in the vicinity. Similarly, risk is a consideration when planning non-hazardous developments in the vicinity of existing industries, to ensure that risk levels are not unacceptable for the proposed land use. In New South Wales (NSW), a series of guidelines have been published on the procedures to be adopted for the assessment of risk from industrial developments [*Ref. 67, 68, 69, 70*]. This includes procedures for the identification of 'potentially hazardous industries' (PHIs).

For existing industries, a National Standard for the Control of Major Hazard Facilities has been developed. This Standard provides a methodology for the identification of 'major hazard facilities', and specifies requirements for such facilities. The other states and territories are increasingly adopting this Standard.

Note that 'potentially hazardous industries' and 'major hazard facilities' are not one and the same, as they are terms used in different context, as outlined below.

In New South Wales, Australia, the Department of Urban Affairs and Planning introduced *State Environmental Planning Policy No. 33 - Hazard and Offensive Development (SEPP 33)* on 13 March 1992 [19]. SEPP 33 ensures that the safety and pollution impacts of an industrial development are assessed at an early stage of the development application process. SEPP 33 does not apply to existing developments unless a new development application is required for the site, eg due to modification of existing facilities or the development of new ones. Through the SEPP 33 policy, an assessment procedure is introduced which links the permissibility of a proposal to its safety and pollution control potential. Procedures and guidelines for the application of SEPP 33 are well documented in a number of government publications. A fundamental aim of the policy is to ensure that the merits of development proposals are properly assessed (in relation to off-site risk and offence), with proper account being taken of locational and design considerations.

For development proposals classified as 'potentially hazardous industry' the policy establishes a comprehensive test by way of a preliminary hazard analysis (PHA) to determine the risk to people, property and the environment. Should the risk exceed the criteria of acceptability, the development is classified as 'hazardous industry' and may not be permissible within most industrial zonings in NSW.

SEPP 33 applies to any proposal that falls under the policy's definition of 'potentially hazardous industry'. Certain developments may involve handling, storing or processing of materials that in the absence of locational, technical and operational controls may create an off-site risk to people, property or the environment. Such activities are defined as 'potentially hazardous industries'. A risk screening procedure is provided to establish whether a development proposal would fall into such definitions and hence come under the provisions of the policy.

B7.2 *RISK SCREENING*

Risk screening is undertaken for all industrial development proposals. The aim of risk screening is to determine whether the proposal would fall under the definition of 'potentially hazardous industry'. The factors considered in risk screening are:

- the nature of materials stored on site;
- the quantity of each material stored;
- the location of storage areas; and
- the separation distance between individual storage area and the site boundary.

Locational, technical and operational control measures are not considered at this stage. By not considering control measures at this stage, in essence this procedure establishes whether there could be significant off-site consequences in the 'worst-case' scenario, i.e., a scenario in which no safeguards exist. This is consistent with the definition of 'potentially hazardous industry', which is any industry which, in the absence of control measures, may create an off-site risk. Development proposals that are not 'potentially hazardous industries' are permissible, whereas those that are 'potentially hazardous' require further assessment.

The main steps in the risk screening procedure are:

1. Identify Hazardous Materials and the Type of Hazard
2. Group and Total by Class, Activity and Location
3. Compare with Screening Thresholds
4. Consider Transportation Issues
5. Determine Whether the Site is Potentially Hazardous Industry

These steps are discussed below.

B7.3 *CONTROL OVER LAND-USE WITHIN THE VICINITY OF MAJOR HAZARDS*

The State of New South Wales adopt a risk-based approach to land-use planning for potentially hazardous industry, as outlined in SEPP 33. In their guidance document "Risk Assessment" (Hazardous Industry Planning Advisory Paper No.3 - Environmental Risk Impact Assessment Guidelines) the Department of Urban Affairs and Planning (NSW) clearly state their view with regards to the use of risk assessment for land use planning as follows:

Land use safety planning is an integral part of risk management and these guidelines have been prepared on that basis .... this integrated assessment approach .... has been useful in securing safer plants at safer locations, in optimising resources and in ensuring the complementary implementation of the various safety regulations and requirements. Early consultation with the consent authority, and use of the risk assessment approach at the initial stage of site selection and project formulation, will maximise its benefits to all parties.

Potentially hazardous industry are permitted in zones where industry or storage establishments are permitted, unless they are already prohibited as a class of development in the land-use plan. The implication of SEPP 33 is, if industrial development is permissible, that a merit-based assessment is required for development applications. This assessment must occur before it can be refused or approved on public safety or environmental impact grounds.

B7.4 ACCEPTABILITY CRITERIA FOR NEW DEVELOPMENT

B7.4.1 Criteria for Risk Screening Process

The requirements for risk screening and preliminary hazard analysis (PHA), with the need to satisfy certain criteria have been outlined above. The published guidelines for SEPP 33 detail the criteria for establishing whether an installation should be classified as 'potentially hazardous industry'. Screening threshold quantities are defined for each DG class and quantity-distance graphs also provided for the risk screening procedure. The graphs provided for flammable and explosive substances are based on the following thermal and overpressure criteria at the site boundary:

- thermal criteria: 12.6 kW/m^2 for 30 secs
- overpressure: 7 kPa

In Australia the states of New South Wales [*Ref. 68*], Western Australia and Queensland have formulated and implemented risk criteria for use with hazardous industries and land use planning in their vicinity.

B7.4.2 Risk Acceptability Criteria

In their guidance document "Risk Criteria for Land Use Safety Planning" (Hazardous Industry Planning Advisory Paper No.4) the Department of Planning (now the Department of Urban Affairs and Planning) detail the criteria by which the acceptability of risks associated with potentially hazardous installations are assessed.

Acceptability criteria are given for individual risk only. Although the operator is required to also present societal risk levels in the form of an F-N curve, the department have not set criteria for societal risk. They state their reservations on societal risk as follows:

The Department of Planning's experience with implementation of the societal risk criteria F-N approach is that much more research is needed before adopting that approach here. As societal risk acceptability is specific to each society, it is very important that allowance be made to reflect differences between societies and cultures.

Further, the F-N approach is a complex one which does not lend itself to easy implementation. It may not be possible in practice, for example, to account for small but incremental increases in population over a period of time which may eventually have significant implications on a cumulative basis.

In view of these considerations and pending further refinements to the f-n approach (if applicable to NSW conditions), the department suggests that judgements on societal risk be made on the basis of a qualitative approach on the merit of each case rather than on *specifically set numerical values.*

The individual risk criteria for the New South Wales State (NSW) are given below and the other states apply similar levels. Additional criteria are used in NSW relating to heat radiation, explosive overpressure and toxic exposure for evaluating injury levels.

Table B-7.4a ***Individual Risk Acceptability Criteria in Australia (NSW)***

Land Use	Suggested IR Criterion Values (per year)
Hospitals, schools, child care facilities, old age housing	$5x10^{-7}$
Residential, hotels, motels, tourist resorts etc.	10^{-6}
Commercial developments including retail centres, offices and entertainment centres	$5x10^{-6}$
Sporting complexes and active open space	10^{-5}
Industrial (this risk contour should be contained within the boundaries of the site)	$5x10^{-5}$

Similar to The Netherlands, the IR contours are calculated taking no account of occupancy, escape or protection factors. That is, for example, the 10^{-6} criterion assumes that all residents will be at their place of residence and exposed to the risk 24 hours a day and continuously day after day for the whole year. In practice this is not the case and this criterion is therefore conservative.

With regards to societal risk the NSW Department of Planning are aware of other countries' criteria but do not publish their own because they are of the view that much more research is needed before adopting specific criteria for societal risk. They consider that acceptability of societal risk is specific to each society and that it is important that allowances are made to reflect this and the differences in culture. They do however use a qualitative approach for making judgement on each case by evaluating risk contours around the facility and taking into account vulnerability of the public and types of development. This is similar to the approach adopted in the UK .

B7.4.3 Injury Risk Levels

The Department of Planning have also set criteria for the risk of injury (as opposed to risk of death) since they consider that:

- Society is concerned about risk of injury as well as risk of death;
- Fatality risk levels may not entirely reflect variations in people's vulnerability to risk. Some people may be affected at a lower level of hazard exposure than others.

The table below summarises the established criteria for the risk of injury.

Table B-7.4b ***Injury Risk Levels***

	Frequency per year	Injury Criteria (not to be exceeded)	Injurious Effects
Heat Radiation	$5x10^{-5}$	4.7 kW/m^2 at residential areas	Will cause pain in 15-20 secs and injury after 30 secs exposure (at least 2nd degree burns)
Explosion Overpressure	$5x10^{-5}$	7 kPa at residential areas	Probability of injury is 10%. No fatality.
Toxic Exposure	10^{-5}	No specific criteria set.	Toxic concentrations in residential areas should not exceed a level which would be seriously injurious to sensitive members of residential community, following relatively short duration of exposure.
	$5x10^{-5}$	No specific criteria set.	Toxic concentrations in residential areas should not cause irritation to eyes or throat, coughing or other acute physiological responses in sensitive members of the community.

B7.4.4 Risk of Property Damage and Accident Propagation

The Department of Planning have also set criteria for the risk of property damage and accident propagation, ie

- Incident heat flux radiation at neighbouring potentially hazardous installations or at land zoned to accommodate such installations not exceed a risk of $5x10^{-5}$ per year for the 23 kW/m^2 heat flux level.

- Incident explosion overpressure at neighbouring potentially hazardous installations or at land zoned to accommodate such installations or at nearest public buildings should not exceed a risk of $5x10^{-5}$ per year for the 14kPa (2 psi) explosion overpressure level.

The above criteria have been set to avoid the potential for an accident on one site causing damage to buildings and propagating to an neighbouring industrial operation, and hence initiating further hazardous incidents (the so-called "domino effect").

B8 WORLDWIDE SUMMARY

Cassidy [*Ref. 19*] has reviewed the world-wide situation with regards to the national practices on the use of QRA and associated criteria in the issue of operating licenses for land based non-nuclear installations. *Table B-8.1a* is based on this information, with Hong Kong and Singapore also added here.

Table B-8.1a Summary of Approaches Worldwide

Country	Class'n of Install'n	Hazard Identification	Partial Quantification	Probabilistic Assessment	Quantitative Objectives
Belgium	Yes	Mandatory	Sometimes	No	No
Canada	No	No	Rare	Some	No
Denmark	Yes	Mandatory	Rare	Some	Some Cases
Finland	Yes	Mandatory	Sometimes	Some	Some Cases
France	Yes	Mandatory	Frequent	Rare	Occasional
Germany	Yes	Mandatory	Sometimes	No	Occasional
Greece	Yes	Mandatory	Not Known	No	No
Hong Kong	Yes	Mandatory	Frequent	Yes	Yes
Italy	Yes	Mandatory	Not Known	No	No
Japan	Yes	Mandatory	Rare	Rare	No
Luxembourg	Yes	Mandatory	Not Known	No	No
Netherlands	Yes	Mandatory	Frequent	(By Law) Yes	(Official) Yes
New South Wales	Yes	Yes	Yes	Yes	Yes
New Zealand	Yes	Not Known	Not Known	Some	No
Norway	Yes	Mandatory	Sometimes	Some	Some Cases
Singapore	Yes	Yes	Yes	Some	No
Sweden	Yes	Mandatory	Not Known	No	No
Switzerland	Yes	Mandatory	Sometimes	Some	Some Cases
UK	Yes	Mandatory	Frequent	Some	Some Cases
US*	Yes	Yes	Yes	Some	No

* At national (Federal) level

B9 *SUMMARY OF ACCEPTABILITY CRITERIA*

Table B-9.1a and *Table B-9.1b* below summarise the risk acceptability criteria and consequence criteria adopted by various countries for land use planning purposes around major hazard sites.

Table B-9.1a Summary of Individual Risk Acceptability Criteria

Country	Acceptability Criteria (per year)					IR or PIR calc*	ALARP applied	Notes
	Site boundary	Industry/ Commerce	Community /leisure	Residential	Sensitive			
UK	-	- -	- 10^{-6} lower	10^{-5} upper 10^{-6} lower	10^{-5} upper $3x10^{-7}$ lower	PIR	Yes	Dangerous dose criteria. 'upper' indicates max permissible limit. 'lower' indicates "broadly acceptable".
		- -	- *$3x10^{-7}$*	*$3x10^{-6}$* *$3x10^{-7}$*	*$3x10^{-6}$* *10^{-7}*			*Calculated (equivalent) fatality criteria [9]*
Netherlands	-	-	-	10^{-6} (new) 10^{-5} (exist)	- -	IR	Yes	Criteria represent 'maximum permissible risk'
Hong Kong	10^{-5}	-	-	-	-	PIR	No	Single maximum limit of 10^{-5} set.
Australia (NSW)	$5x10^{-5}$	$5x10^{-5}$	$5x10^{-6}$	10^{-6}	$5x10^{-7}$	IR	No	

* IR - the calculation of individual risk assumes that a person is at a specific location for 100% of the time, all year round, with no mitigating effects allowed for such as escape out of cloud, or being indoors.

PIR - the calculation of individual risk takes account of occupancy factors, and mitigating effects such as escape out of cloud, or being indoors.

Table B-9.1b ***Summary of Consequence-Based Unacceptability Criteria for Land Use Planning***

Country	Criteria Specified	Unacceptability Criteria		Frequency per year	Notes
UK	Yes	Thermal:	Inner Zone: Fireball radius Middle zone: 1000 thermal dose units (TDU) Outer Zone: 500 TDU		See *Table B-2.3e* above for HSE's advice for each zone.
		Explosion:	Inner Zone: 600 mbar (8.8 psi) Middle zone: 140 mbar (2 psi) Outer Zone: 70 mbar (1 psi)		Within the inner zone HSE usually advises against all but industrial land-use, small retail or leisure development.
Australia (NSW)	Yes	Thermal:	23 kW/m^2 at site boundary (property damage) 4.7 kW/m^2 at residential areas	$5x10^{-5}$ $5x10^{-5}$	
		Explosion:	2 psi at site boundary (property damage) 1 psi at residential areas	$5x10^{-5}$ $5x10^{-5}$	
		Toxic:	Toxic concentrations in residential areas should not be seriously injurious to sensitive persons.	10^{-5}	No specific toxic criteria set.
			Toxic concentrations in residential areas should not cause irritation to eyes or throat to sensitive persons.	$5x10^{-5}$	No specific toxic criteria set.
France	Yes	Thermal:	Inner Zone: 1% fatality thermal dose Outer Zone: Significant burn levels		In inner zone no authorisation to residential developments, sports areas, establishments receiving the public and high rise buildings. In outer zone authorisation given to all developments except establishments receiving the public and high rise buildings. Industrial developments may be permitted in both zones.
		Explosion:	Inner Zone: 140 mbar (2 psi) Outer Zone: 50 mbar (1 psi)		
		Toxic:	Inner Zone: Initial lethal effects Outer Zone: Initial irreversible damage to health		

Annex C

Rail Transportation Risk Criteria

C1 INTRODUCTION

There are a limited number of precedents for the setting of risk criteria in the railway industry, essentially because risk assessment has only been used to any significant degree in the past few years. Those which do exist relate primarily to rail operations in the UK, partly influenced by the 1994 Railways (Safety Case) Regulations, and to railway systems in Hong Kong where the regulatory regime closely follows that adopted in the UK.

A brief review of relevant aspects of the 1994 UK Railway Safety Case Regulations is presented below, and a summary of the approaches adopted by various railway operators is given. The advantages and disadvantages of the two key approaches are discussed.

UK Railways (Safety Case) Regulations

The UK Railways (Safety Case) Regulations, 1994, do not mandate the setting or risk criteria as such. They require an operator to formulate a clear and testable safety policy which includes the setting of risk targets, ie

- Reducing risk levels to below a specified figure;
- Reduction in accident rates (or, for a new operator, achievement of specified levels).

This contrasts with HSE's general approach of specifying risk criteria in the form of an upper level of tolerable risk; a broadly acceptable level of risk; and a cost-benefit ratio for gross disproportion, which, if the risk lies between these two levels, can be used to determine if the risk is nonetheless tolerable (ie, ALARP).

C2 *RISK CRITERIA ADOPTED BY RAILWAY OPERATORS*

There are essentially two approaches adopted by railway operators to defining risk criteria.

- Simple adoption of the criteria defined by HSE in relation to nuclear or chemical *process plant,* and taking these to apply to passengers on the railway;
- By reference to the level of risk currently tolerated for existing systems providing a comparable type of *service* to passengers.

Risk criteria have been developed and adopted by Eurotunnel, Railtrack, London & Continental (formerly Union Railways) and London Underground Limited (LUL) regarding the Jubilee Line Extension Project. The approach adopted by the MTR Corporation and Kowloon-Canton Railway Corporation in Hong Kong for new railways is described later.

Taking the first approach above, many rail operators have simply adopted the values proposed by HSE as being applicable to their passengers (ie, they have assumed that the upper and lower boundaries of the ALARP region for individual risk are defined as 10^{-4} and 10^{-6} per year respectively).

However, there a number of problems associated with applying these figures within a railway environment, and more specifically a new rail extension. One anomaly associated with applying these figures within a railway context, is that whereas a nuclear or chemical facility is *"there all the time"* permanently exposing the surrounding population to the risks of an accident, for a transport system, a passenger is only at risk when they travel. The total risk to which a passenger is exposed thus increases with their use of the service, and therefore the natural units of risk are *"per use"* and not, as for process plant, *"per year"*. This consideration is not applicable to the question of landslides and boulder falls, where the specification of risk criteria and calculation of risk in units of per year are considered to be appropriate.

One generally tolerates greater risk for greater benefit, and for railways the primary benefit is the distance travelled, evidenced by peoples' willingness to pay more for longer journeys. It is generally important that criteria take this into account. Considering this for railways, if the individual risk criteria do not increase with increasing benefit (ie, distance), it will generally mean that it is much easier to meet the criteria if the system provides short journeys with no interchanges, than for a system providing long distance journeys involving interchanges.

To the individual, the analogy with landslides and boulder falls could be, for example, the proximity to place of work, or reduced travelling costs, as the benefit of living near a slope. For squatter areas in steep natural terrain, even though the residents are knowingly exposing themselves to high levels of risk, they gain large personal benefits by living in cheap or free accommodation and in close proximity to their work.

Considering railways again, and the simple adoption of the HSE values for process plant, how does one know that the upper level of risk of (1 in 10,000 or 10^{-4} per year) is tolerable for someone regularly travelling by rail? The nature of the risk from rail travel is so very different from nuclear power or other major hazard plants - there is a big difference in terms of voluntariness between choosing to travel by train (in preference to travelling by car or bus for example) and choosing to live near a nuclear power station or chemical plant. Similarly to the above point, there is also the more general question of how to compare the benefit of nuclear power to the individual, with that of travelling as a rail passenger. Moreover, as HSE point out,*"people tend to view risk differently according to whether they can judge the hazard directly from experience, or whether the danger is not well understood or is particularly dreaded"*. Whereas people's fear of radiation may be due to the fact that it can harm without being felt, or that it can cause cancer or harm an unborn child, railway accidents are more readily understood from experience.

For railways, the key question is whether it is reasonable to assume that one would tolerate an average risk of 1 in 10,000 per year (if a regular commuter) when it is a level almost 10 times higher than we are currently exposed to on any modern railway, and equivalent to the average risk of being killed in a road accident. The figure was criticised at Hinkley Point as being too high and a figure of 1 in 50,000 or 100,000 considered more appropriate for nuclear facilities.

The second approach (deriving criteria by reference to the level of risk currently tolerated for existing systems) therefore has distinct advantages. It is interesting to note that the UK Health and Safety Commission (HSC) noted in its publication "Major hazard aspects of the transport of dangerous substances" [*Ref.* 2] that the upper (maximum tolerable) limit of risk (for individual or societal risk) *"is not set by some scientific calculation, but by observation of what contemporary society at present tolerates"*. It is therefore a socio-political rather than a scientific matter. However, direct measurement of this risk level is not a simple matter, although it is nonetheless an important matter, as HSE points out, *"in weighing the cost of extra safety measures the principle of reasonable practicability applies in such a way that the higher or more unacceptable the risk is, the more, proportionately, employers are expected to spend to reduce it"*.

An indirect method is to observe the level of risk to which passengers are currently exposed when they travel by rail, and to argue that this cannot be intolerable: if it were intolerable, there would be a public outcry about safety standards, and the railway would be boycotted. The upper level of tolerability must therefore be at least as high as the current level of risk.

A further consideration is that the public reasonably expect a new railway or an extension to an existing railway to be safer than an existing railway providing a comparable service.

It is the above two general aspects (reference to existing levels of risk and expectations as regards new developments) which have potential applicability to the question of the tolerability of risks from landslide hazards.

For railways, both considerations can be accommodated by setting the upper level of tolerability for a new railway or an extension equal to the highest level of risk experienced on a existing system offering a comparable type of service to passengers.

Based on the premise that the public will not expect new extensions to be less safe than on the operating railway, criteria can then be derived based on the estimated maximum risk currently tolerated (as estimated by historical data and

QRA, the latter to account for rare events which may not be included in the historical record). From inspection of a network layout, and knowledge of passenger travelling patterns, the maximum number of interchanges regularly undertaken by commuters as part of their journey can be established.

Annex D

Risk Acceptability Criteria Developed in Hong Kong

D1 *INTRODUCTION*

The use of QRA, and the application of risk criteria to assess the acceptability of risks to the public, is well-developed in Hong Kong. For many years QRA and risk acceptability criteria have been applied to PHI sites and more recently for other facilities, to include:

- Potentially Hazardous Installations (PHIs), i.e. installations which store, process or use more than specific (significant) inventories of dangerous substances, i.e. Chlorine, LPG, Hydrocarbons, Explosives, Industrial gases and chemicals, etc;
- Rail industry - KCRC and MTRC have recently developed risk criteria for their respective operations (public transportation);
- Dangerous Goods (DG) Transportation, i.e. DG transport operations associated with the PHI sites.

Risk criteria have also been proposed for a previous QRA study (in order to assess the acceptability of risks from landslides) for GEO, i.e. the Atkins Haswell Study which assessed the landslide risks to Squatter Villages in Lei Yue Mun [*Ref.* 3], wherein the existing PHI risk criteria were used as a basis for the development of criteria for the squatter areas.

The following sections give an overview of the risk criteria which have been developed in Hong Kong for PHI Sites and DG transportation. The risk criteria developed by KCRC and MTRC are discussed in *Section 4* of this Annex.

D2 RISK GUIDELINES FOR PHI SITES IN HONG KONG

The Hong Kong Government has established both individual and societal risk guidelines for planning applications around Potentially Hazardous Installations (i.e. those installations that either store or process large quantities of toxic or flammable substances). The guidelines are published in the Hong Kong Planning Standards & Guidelines, Chapter 11.

D2.1 INDIVIDUAL RISK

The individual risk criterion specifies that the risk of fatality to an off-site individual should not exceed 10^{-5} per year. There is no distinction between different types of individuals, i.e. whether a member of the general public in residential accommodation, or a worker in an adjacent industrial site. The 10^{-5} criterion therefore applies to any off-site individual and, in effect, the criterion specifies that the 10^{-5} per year individual risk "contour" should not extend off-site.

No ALARP region has been specified for individual risk, and risks are regarded as intolerable above and tolerable below this figure.

D2.2 SOCIETAL RISK

The societal risk criteria established by the Hong Kong Government are shown in *Figure D-2.2a* in the form of an F-N curve (Frequency vs Number of fatalities). An F-N curve provides a measure of the likelihood of multiple fatalities by plotting the (cumulative) frequency of accidents which affect various numbers of people. There are three (3) regions indicated on the figure, i.e.

- Unacceptable region;
- ALARP region;
- Acceptable region.

The guidelines were originally intended for application to new PHIs or expansion of existing PHIs. They have, however, been applied to all PHIs in Hong Kong, i.e. those in existence preceding the introduction of the risk guidelines, and to all other new PHIs and expansions to PHIs. The guidelines are not rigid criteria. They are intended for use as guidance in the complex decision-making process involving planning for and around PHI sites, although it is probably fair to say that in reality the criteria have been applied fairly rigidly.

D2.3 INTERPRETATION OF THE GUIDELINES

For planning applications involving a new PHI or expansion to a PHI, the site owner needs to demonstrate that the individual risk contour of 10^{-5} does not extend off-site and that the societal risk (F-N curve) is below the "unacceptable" region, i.e. the F-N curve should either be within the "acceptable" region or the "ALARP" region, or possibly partly within both regions. If the F-N curve falls wholly beneath the "acceptable" line then the societal risks to the public are deemed to be acceptable (as noted earlier, the "public" in Hong Kong includes all types of off-site population, i.e. general public in residential accommodation, industrial employees off-site, etc.) and the site owner need not implement any risk mitigation measures to further reduce societal risks. If the F-N curve lies wholly or partly within the "unacceptable" region, the site owner should implement risk mitigation measures to reduce the societal risks such that the revised F-N curve lies below the "unacceptable" region. If this cannot be achieved then the PHI site may not be permitted to operate.

If the F-N curve lays wholly or partly within the "ALARP" region then the site owner has to implement risk mitigation measures to reduce the risks to "As Low As Reasonably Practicable". To demonstrate achievement of ALARP it is normal practice in Hong Kong to carry out a cost-benefit analysis to help identify those risk mitigation measures which are cost-effective. An important aspect of ALARP is that the cost of risk mitigation measures should not be grossly disproportionate to the risk benefit which they help to achieve. It is important to note that the demonstration of ALARP does not necessarily require that the F-N curve needs to eventually lie either wholly or partly within the "acceptable" region, i.e. it could still lie wholly or partly within the ALARP region.

Figure D-2.2a indicates that there is a "high fatality" unacceptable line at 1000 fatalities. This indicates that no incident at a PHI site should have the potential to cause more than 1000 fatalities, unless the cumulative frequency for this severity of accident on the F-N curve is less than 10^{-9} per year, which is considered to be such a low frequency that it is effectively non-credible.

For the consideration of new developments, within the vicinity of PHIs, the risk guidelines are applied in a different manner. For example, if a new housing development is proposed near an existing PHI (i.e. within the "Consultation Zone"), and if the development constitutes a significant population increase, then the developer should carry out a Hazard Assessment (which includes a QRA) to demonstrate that the risks to the new development lay within the "acceptable" region. By definition (of individual risk) this does not require consideration of the individual risk to the public to be redemonstrated, since the additional population will have no impact on the individual risk results. The developers are, however, required to demonstrate that the societal risk to the actual development (i.e. the specific F-N curve for the development only) lays wholly within the "acceptable" region. For a significant increase in population there may also be the potential for the overall F-N curve for the PHI to be raised higher up into the high ALARP or even the "unacceptable" region - this would need to be taken account of during the land-use planning process.

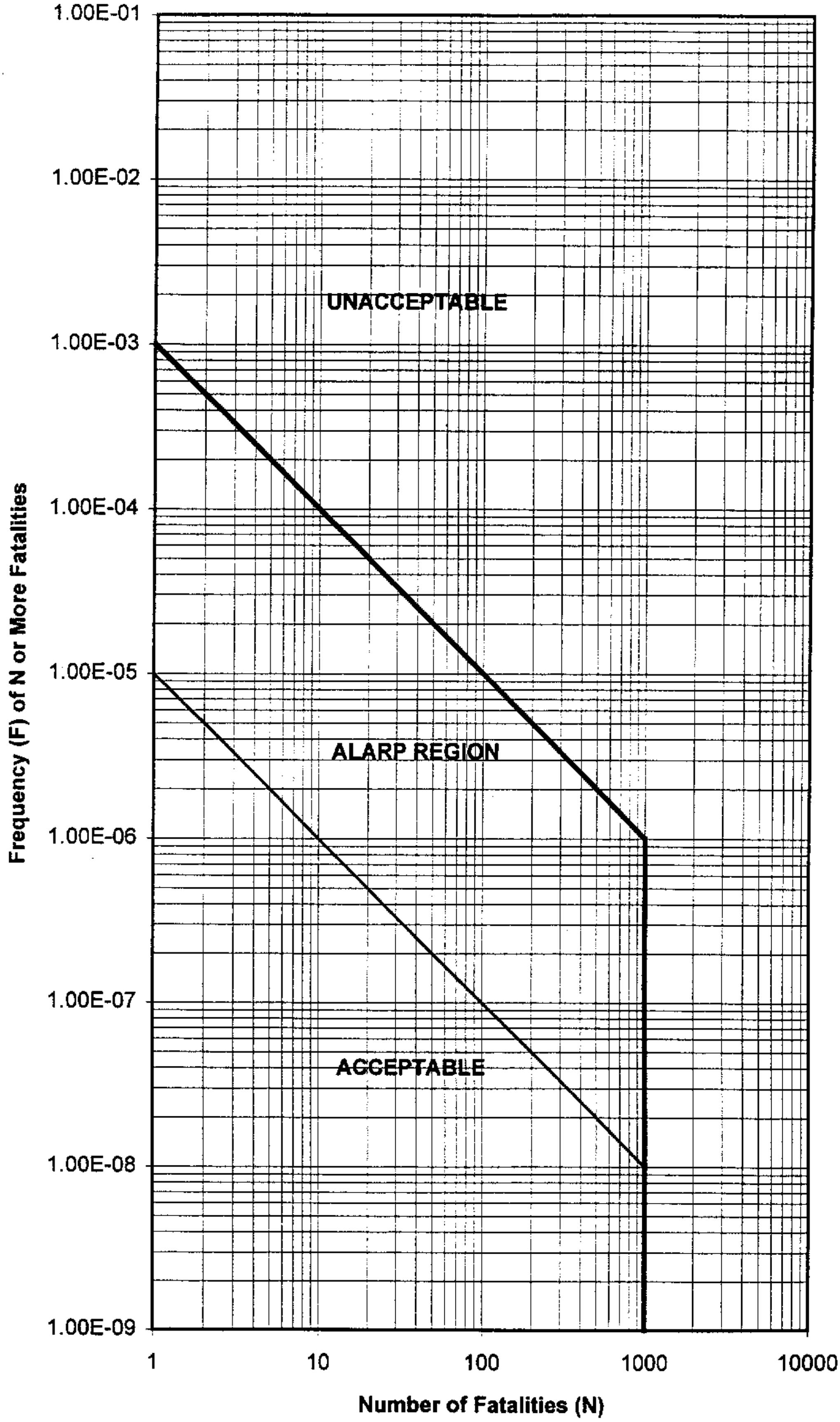
Also, the following important aspects should be noted for interpretation of the guidelines:

- The guidelines refer to risks from a single PHI;

- The guidelines are explicitly taken to refer to only off-site risks (i.e. they are not applied to workers at the PHI generating the risk);

- The risks are normally calculated taking into account realistic occupation or presence factors, with the individual risk applied to the most-exposed person (ie, those in the vicinity for the greatest proportion of the time). For residential areas it would normally be assumed that at least some people are continuously present. For an adjacent industrial facility, however, the occupation factor for the most exposed individual would probably only be equivalent to about 8 hours in every 24 hours, with days off also needing to be taken into account. The risk calculations usually adopt realistic probabilities

Figure D-2.2a - Hong Kong Government PHI Societal Risk Criteria



of escaping, evacuation, or protection from the effects of the incidents.

This is a different approach to (say) the risk acceptability criteria in The Netherlands, where it is assumed for individual risk that a hypothetical individual is located at a particular point 100% of the time, with no protection or escape factors applied.

The individual risk determined in Hong Kong is termed (overseas) as "Personal Individual Risk" (PIR), whilst that determined in QRAs in The Netherlands is "Individual Risk" (IR).

- Average vulnerabilities are normally assumed for persons exposed to the incident, with no special consideration given to "sensitive" population such as the young (e.g. in Kindergartens), the old or the infirm. Recent QRA projects in Hong Kong are beginning to consider the risks to more sensitive population;

- Only on-site transport activities for the dangerous goods related to the PHI are presently included in the assessment for comparison against the PHI criteria. However, proposal for including related off-site transport in risk assessments for PHIs are currently under consideration by the Government.

D3 *RISK ACCEPTABILITY CRITERIA FOR DG TRANSPORTATION*

A number of QRA studies [*Ref. 1,5,6,7,8,9*] have recently been carried out on DG transportation in Hong Kong. These studies included consideration of non-fuel gas dangerous goods (i.e. Chlorine, Explosives, Hydrocarbons, Industrial Gases and Chemicals) and also fuel gas transportation (i.e. LPG and Naphtha).

The studies included the development of interim risk criteria to be used as guidelines for DG transportation in Hong Kong. The interim criteria were developed such that they were, as far as possible, consistent with the existing PHI risk guidelines in Hong Kong, and risk guidelines overseas.

D3.1 *INDIVIDUAL RISK*

The Technica Study [*Ref. 1*] included a review of risk criteria worldwide and concluded that no reasons had been identified for having different individual risk criteria for DG transport risks and DG site (storage, production and usage) risks. It was therefore concluded that the individual risk acceptability criteria for risks imposed on members of the public by hazardous activities should be independent of the activity to which they apply. Henceforth it was concluded that the same individual risk criterion of 10^{-5} per year should be used for fixed PHI installations and transport.

Technica also considered a number of options for applying the criterion in a practical manner, i.e.

- *Option 1* - the interim 10^{-5} individual risk criterion should cover the risks from all DGs transport activities. Only on-site transport activities for the dangerous goods related to the PHI are presently included in the assessment against PHI criteria. However, proposals for including off-site transport in risk assessments are currently under consideration by the Government;

- *Option 2* - The interim 10^{-5} individual risk criterion should cover the risks from the movements of all DGs travelling to/from all PHI sites;

- *Option 3* - The interim 10^{-5} individual risk criterion should be for the movements of all DGs to a single PHI. This would mean that PHI hazard assessments would need to include consideration of the risk of off-site transportation activities associated with the PHI;

- *Option 4* - the interim 10^{-5} individual risk criterion should be applied to the transport of the DG material groups used in the [Technica] transport studies.

At the time of the studies it was concluded that Option 4 was the most appropriate for assessing the tolerability of the individual risk for the DG transport trades. This was seen as practical, but only a starting point.

Option 1 was seen as the ideal option to get a true picture of the risks to which DG transportation imposes on individuals living or working near transport routes, although it was concluded that this was not a practicable option in the near future.

Option 3, which proposed that the 10^{-5} criterion should be applied for the movement of all DGs to a single PHI, was proposed as the most appropriate option for the future. It was also suggested that where several PHIs were closely grouped then the Government could sum the risks to aid land-use planning decisions.

Thus, it can be seen from the above that whereas the development of the criteria is straightforward, the application of the individual risk criteria for DG transportation activities is complex. Each of the above options would be expected to produce different risk results for comparison against the criteria.

D3.2 SOCIETAL RISK

Technica [*Ref. 1*] also developed societal risk criteria for DG transportation to and from PHIs, i.e. separate criteria for the following materials: Chlorine, Explosive, Hydrocarbons, Industrial gases and Chemicals, LPG, Naphtha. The proposed interim guidelines were based on the PHI guidelines using frequency scaling factors to determine the configuration of the three regions [on the F-N curve] specifying acceptability limits. These frequency scale factors equate to the number of PHI sites in the transport network. This approach is consistent with the approaches adopted for the development of DG transportation risk acceptability criteria in the Netherlands, UK and Australia.

It was recommended that the interim societal risk criteria should be applied to members of the public, including road users, but excluding workers involved in the transport activity.

The criteria developed shows 3 regions, ie Intense Scrutiny, ALARP and Acceptable. The application of the criteria requires inspection of the F-N curve for the DG transportation, where risks falling within the above regions are interpreted as follows [*Ref. 1*]:

Intense scrutiny	The risks are significant. They are acceptable if, after they are intensely scrutinised, it can be demonstrated that they are ALARP using an Implied Cost Of Avoiding a Fatality (ICAF) of HK$480 million and the benefits to society justify the risks of the activity.
ALARP	The risks are significant. They are acceptable if it is demonstrated that they are ALARP, using an ICAF of HK$24 million.
Acceptable	The societal risks are so negligible that they can be accepted without the necessity to undertake any additional actions to minimise the risks further.

Hence, it can be seen that there is no "unacceptable" region within these proposed criteria. This is presumably in recognition of the (current) necessity for DG transportation in Hong Kong, although a higher ICAF is proposed for evaluating measures to reduce risks which fall in the "intense scrutiny" region. Within the ALARP region an ICAF of HK$24 million (£2M) is proposed, which is the normal ICAF used for PHI sites in Hong Kong. This use of a range of values for assessing the cost effectiveness of risk mitigation measures is consistent with approaches adopted elsewhere world-wide.

D4 *MTRC & KCRC RISK ACCEPTABILITY CRITERIA*

As described earlier, there are essentially two approaches adopted by railway operators to defining risk criteria.

(i) Simple adoption of the criteria defined by HSE in the UK in relation to nuclear or chemical *process plant*, and taking these to apply to passengers on the railway (factored down where applicable for application to new railways).

(ii) By reference to the level of risk currently tolerated for existing systems providing a comparable type of *service* to passengers

The Kowloon and Canton Railway Corporation (KCRC) has adopted the first of these approaches in defining risk criteria for its new West Rail project [Asia Rail 97]. The precise values for the new railway are understood to be taken as an order of magnitude reduction in the criteria for KCRC's existing operating systems. These in turn are essentially based on the precedents established by HSE (10^{-4} and 10^{-6} as the boundaries of the ALARP region). The criteria are defined for passengers, staff and the general public living in the vicinity of the railway as follows:

Passenger fatality risk upper limit	1×10^{-5} per year
Passenger fatality risk lower limit	1×10^{-7} per year
Staff fatality risk upper limit	1×10^{-4} per year
Staff fatality risk lower limit	1×10^{-7} per year
Public fatality risk upper limit	1×10^{-5} per year
Public fatality risk lower limit	1×10^{-7} per year

The figures derived for the passengers suffer from many of the drawbacks described in *Annex* C. That is, they do not vary in according to the distance travelled (ie, the benefit), and are unspecific about the particular journey to which they relate. They are specified on a per annum basis which has been argued previously as inapplicable for a service industry, where risk increase in proportion to use of the service. The greatest criticism is that ultimately the defined risk levels derive from the risks to which roof workers, mine workers and offshore workers in the UK are exposed, arbitrarily reduced by a factor of 10 as suggested by HSE for third parties off-site for a chemical or nuclear facility, and reduced further by a somewhat arbitrary factor of 10 for a new development (as suggested by HSE). Whilst an order of magnitude improvement for passengers might be achieved through technology advances (platform edge doors, automatic train protection systems, and in any case the 10^{-4} level is higher than to which passengers are currently exposed on modern railway system), this level of improvement in staff risk may be extremely difficult to achieve (as a new railway is likely to be very similar in terms of the hazards to which staff are typically exposed).

By contrast, the MTR Corporation has derived criteria for the upper level of tolerability for a planned new extension based on the levels of risk currently tolerated on the railways (the MTR network) by the travelling public in Hong Kong. This is a far more robust and defensible approach. MTR's criteria comprise an overhead risk associated with entry and exit to the systems and boarding and alighting of trains (set equal to the maximum regularly tolerated for a journey involving the maximum number of interchanges), and a component which varies with distance travelled (benefit). In this way criteria can be defined for any journey on the new railway. The precise values are not yet in the public domain.

Annex E

Options for Development of Societal Risk Criteria

E1 *INTRODUCTION*

In setting societal risk F-N acceptability criteria for landslides and boulder falls from natural terrain the following aspects need to be considered:

- should a 3-tier approach be adopted for the criteria, with an "unacceptable", ALARP (ie "tolerability" region), and "unacceptable" region adopted;
- the slope of the F-N "unacceptability" line (and "acceptability" line, if one is adopted). A slope of -1 has been adopted for Hong Kong PHIs;
- should there be a high fatality vertical "high fatality" level and, if so, at what number of fatalities should it be applied. An "unacceptable" high fatality level of 1000 is used for PHI sites in Hong Kong, ie it is unacceptable to kill 1000 people or more in a single incident, unless the associated frequency is less than 10^{-9} per year (which is considered as non-credible).

Each of the above features for an F-N acceptability criteria are considered further below, but first we must consider the feasibility of development of such criteria based on the current Hong Kong PHI criteria, or other approaches. Five possible approaches are considered in *Annex E*, ie

- Option A Develop risk criteria for landslides from natural terrain based on using the PHI criteria for fixed installations. Determine the number of PHI sites and scale up the criteria to determine the effective overall PHI criteria for the territory. Use this overall criteria as the basis for the development of natural terrain criteria by scaling up or down as necessary to give a territory - wide natural terrain criteria. Using the 'number of natural slopes' (ie based on consideration of the area of the slopes), scale down the territory-wide criteria to give societal risk criteria natural terrain, i.e. for a particular "slope" or feature.
- Option B As for Option A, base the risk criteria on the PHI criteria but also take into account the risk criteria for transportation of DGs in Hong Kong. Scale up to determine territory-wide societal risk criteria for PHIs/DG transportation. Use these as a basis for the development of the natural terrain criteria as described in Option A.
- Option C Use the PHI societal risk criteria for a fixed installation as a direct basis for the development of criteria for landslide from a specific "natural slope". Scale the PHI criteria up or down as appropriate.
- Option D As for Option C but also take into account the DG transportation associated with the PHI.
- Option E Develop the societal risk criteria from 'first principles' by assessment of the risks from all types of landslides and boulder fall in Hong Kong and determination of the public's tolerability to landslide and boulder fall risks. Assess the relative contribution to societal risk from landslides and boulder falls from natural terrain, and the publics' tolerability (as compared to landslides from man-made slopes), to

determine the societal risk criteria for landslides and boulder falls from natural terrain.

Each of the above options are discussed below with Option C being the preferred option identified for further consideration in this study. The need for the application of a scaling factor against the PHI criteria is also discussed.

E2 *CONSIDERATION OF OPTIONS*

E2.1 *OPTION A - SOCIETAL RISK CRITERIA BASED ON TERRITORY-WIDE PHI CRITERIA*

This option involves the development of societal risk criteria for landslides from natural terrain by using the PHI criteria for fixed installations, but scaled up to represent an equivalent criteria for PHIs across the whole territory. The territory-wide criteria can then be developed into a territory-wide societal risk criteria for landslides from natural terrain by the use of an appropriate scaling factor if necessary. The criteria for a single natural terrain feature could then be determined by scaling down from the territory-wide criteria, say, using an "area of terrain" basis.

Advantages

- The PHI societal risk criteria have already been established and applied in Hong Kong over many years;

- If equivalent territory-wide criteria can be developed for PHIs then this could provide a useful basis for determination of an equivalent territory-wide criteria for landslides from natural terrain. This would provide a one-to-one comparison between the different hazards, with the public's [possible] different tolerability to the different hazards used as a basis for the estimation of a suitable scaling factor;

- Territory-wide PHI criteria could be estimated by scaling up the PHI criteria for a fixed installation by the number of PHI (plus non-PHI LPG installations) sites in Hong Kong. The overall number of "PHI type" sites is 174;

- If a scaling factor can be developed (if needed) for PHI risks versus natural terrain landslide risks then a good basis for the development of criteria for landslides from natural terrain (individual) features can be developed.

Disadvantages

- There are no data available of the public's relative tolerability to landslides from natural terrain versus risks from PHI sites;

- There have been no recorded fatalities to date in Hong Kong due to incidents involving either of these hazards and therefore no historical basis for comparison of risks or the public's tolerability to the disparate hazards;

- Although the overall (predicted) risks from PHIs can be estimated from previous Hazard Assessments there is still no basis for comparison against natural terrain risks, since there has been no study to date in Hong Kong which estimates the (predicted) risks from natural terrain landslides;

- PHIs do not represent all the DG storage risks. It is thought that if there is a valid basis for (a territory-wide) comparison of natural terrain landslides against chemical (storage) hazards, it would probably be on the basis of All Chemical Risks vs Natural Terrain Landslides. Even this comparison may be too restricted since the public may not tend to distinguish between natural terrain landslides and all landslides. The best basis for (territory-wide) comparison of the public's tolerability to risks may be All Chemical Risks vs All Landslide Risks. Even if this comparison could be made (a detailed public opinion survey in Hong Kong may be required), the subsequent exercise to convert this to a tolerability comparison (for the scaling factor) for natural terrain landslides vs PHI hazards would still be difficult to achieve, with a significant element of uncertainty.

- In any territory-wide comparison of DG risks vs landslide risks, the public's perception of the risks from chemicals may not just be restricted to storage hazards (as at the PHIs), rather the public may see the risks from chemicals in terms of the overall cycle of operations involving the transportation, storage and use of the chemicals. Hence the basis of the (territory-wide) comparison for DGs vs landslides may need to include DG transportation also;

- The proposed approach for the determination of the natural terrain criteria with this option is based on the use of the criteria for PHIs and the number of PHIs. There is the problem as to how many sites are classed as a "PHI". The overall number of actual PHIs is as follows:

- Chlorine	14 PHIs
- LPG	12 PHIs (7 domestic LPG sites plus 5 LPG terminals)
- Hydrocarbons	2 PHIs (town gas sites using naphtha)
- Industrial gases & chemicals	1 PHI
- Explosives	2 PHIs

Therefore there are 31 sites classified as PHIs. There are however a further 143 LPG installations serving residential communities with piped LPG. Most of these installations are located close to dense population and may present a significant risk to the public. The only reason that they are not classified as PHIs is because they store less than 25 tonnes of LPG. This inventory threshold is somewhat arbitrary, however, and in recognition of the potential for risks to the public being significant, the Hong Kong Government has required QRAs for many of these non-PHI installations (eg see the ERM studies on QRAs for 18 LPG sites [*Ref.* 4] which were all non-PHI sites);

The question remains as to which figure should be used for determination of the overall PHI risks (assuming that it is the "PHI criteria" which we are adopting as a basis for scaling up)? Whilst the actual number of PHI sites is 31 it could be argued that any realistic basis for comparison on a territory-wide basis should also include the rest of the LPG installations, thereby giving a figure of 174 "PHI type" sites. There may also be other DG storage sites in Hong Kong that store large inventories of chemicals, and produce significant risks to the public, but fall below the threshold level for classification as a PHI.

From the above it can be seen that the proposed approach for using the PHI criteria as a basis for scaling up to a territory-wide equivalent criteria for PHIs is not as straight-forward as it may first appear. Determination of the actual number of "PHIs" or "PHI type sites" remains a problem area;

- Data is available on the overall PLL from chlorine PHIs, but not for other PHIs. LPG installations are a particular problem area, since there are relatively few PHIs, but a large number of other LPG installations which may still present significant risks to the public. QRAs have not been carried out on most of these installations. The development of a "best estimate" for the overall PHI risks in Hong Kong would a time-consuming task and is beyond the capabilities of this study. The usefulness of such an estimate is also questionable, since it would still provide no further data on the public's "tolerability" to PHI risks - since there have not been any fatalities due to PHIs;

- Following on from the above problems with the number of sites to use as a basis for scaling up of the PHI criteria, another problem is that the number of PHI sites is likely to change due to:

  - revision of threshold storage inventories for DGs in Hong Kong (eg the threshold for chlorine (in 25 kg cylinders) is currently 10 tonnes. If this is reduced to (say) 5 tonnes then a number of water treatment works (using cylinders only) would then become PHI sites);

  - new sites could be constructed, eg a new water treatment works using 1 tonne chlorine drums would be classified as a PHI;

  - revision of the regulations for the control of sites storing and using dangerous substances could result in other types of sites be classified as PHIs, eg the regulations could be revised in the future to be compatible with the forthcoming COMAH Regulations in the UK. Sites such as chemical warehouses and warehouses storing LPG in disposable cylinders could then be classified as PHIs.

- Thus, the fundamental problem with scaling up from the PHI criteria to produce territory-wide criteria for PHI sites (for use as a basis for conversion to a territory-wide criteria for landslides from natural terrain) is that, in addition to the problems with the number to use for the existing PHIs, the number of PHI sites can, and is likely to, change. Does this then imply that criteria originally developed on this basis for natural terrain landslides must be changed also each time the number of PHIs change? Why should the public's tolerability to landslides change simply because the number of PHIs have changed? Clearly this is not a practicable approach and is not logically robust.

- Even if an equivalent territory-wide criterion for landslides from natural terrain can be produced it would still be necessary to scale down the criterion to produce criterion for individual areas. It is not immediately obvious how this could be achieved, although data arising from GEO's Natural Terrain Landslide Study (NTLS) may provide a basis.

Conclusions

Option A was the initial approach favoured for the development of risk criteria for landslides from natural terrain, but this has since been rejected for the reasons outlined above. The proposed approach has no firm mathematical or logical basis and would not produce any defensible criteria.

E2.2 *OPTION B - SOCIETAL RISK CRITERIA BASED ON TERRITORY-WIDE PHI/DG TRANSPORTATION CRITERIA*

This option is an extension of Option A to also include the consideration of the risks from DG transportation in the territory to provide equivalent territory-wide societal risk criteria for PHIs/DG Transportation. As for Option A, this could then be used as a basis for the determination of criteria for landslides from natural terrain.

Advantages

In addition to the advantages discussed above for Option A this option also has the following advantages:

- Studies have already been carried out in Hong Kong [*Refs 1, 5, 6, 7, 8, 9*] on the risks to the public from DG transportation. The transportation risk criteria developed from these studies could be added to the territory-wide PHI risk criteria to determine the equivalent overall risk criteria for PHIs/DG transportation. This may provide some measure of the public's overall tolerability to PHIs/DG Transportation risks in the territory.

- It could be argued that the use of the territory-wide criteria for PHIs/DG Transportation may provide a more sound basis (compared to Option A) for comparing the public's relative tolerability between PHIs/DG transportation vs Landslides from Natural Terrain.

Disadvantages

All of the disadvantages discussed for Option A also apply for this option, with the following additional problem areas;

- The Technica studies highlighted that the development of risk criteria for DG transportation is a difficult area, and the criteria developed to date are only interim criteria;

- The current DG transportation studies in Hong Kong do not take into account all DG transportation, it has been estimated in [*Ref. 1*] that only about 50% of the DG transportation has been represented in the studies. The studies therefore do not provide the data for the proposed comparison (here) of PHIs/DG Transportation vs Landslides from Natural Terrain;

- DG transportation in Hong Kong is likely to change over the years, for example, should the policy on the use of chlorine on water treatment works change at sometime in the future, then this would have a dramatic impact on the amount of associated DG transportation. Similarly, should there continue to be an increasing tendency for town gas supply for housing estates then this would continue to decrease the amount of LPG transported by road. As for the arguments above in Option A, with DG transportation being included in the basis for the development of risk criteria for natural terrain, then such a change in DG transportation could then imply that the criteria for natural terrain would need to be modified accordingly which is not defensible.

Conclusions

This option has been rejected for the equivalent reasons to those for Option A. Indeed, this option would be far too complicated an undertaking, with too many variables (more so than for Option A), and is not considered to provide a sound basis for the development of suitable criteria for landslides from natural terrain.

E2.3 *OPTION C - SOCIETAL RISK CRITERIA BASED ON PHI CRITERIA*

This option proposes to use the PHI societal risk criteria for a fixed installation as a direct basis for the development of criteria for landslides and boulder falls from an area of steep natural terrain. The PHI criteria could be scaled up or down as appropriate to account for any perceived differences between the public's tolerability to landslides from natural terrain compared to PHI hazards.

Advantages

- The PHI societal risk criteria are already well established in Hong Kong with many years application in QRA/land-use planning studies;
- Provides a simple and defensible basis for development of the criteria - the public may consider there is a general similarity at a particular location from hazards from nearby steep natural terrain and hazards arising from a nearby PHI.
- If a scaling factor can be developed (if needed) for PHI risks versus natural terrain landslide risks, then a basis for the development of criteria for landslides from natural terrain (individual) features can be developed;
- This option avoids the complications of scaling up and down on a territory-wide basis. It is far more defensible to make the comparison on the basis of a particular community which is at risk from specific types of hazards.

Disadvantages

- There are no data available of the public's relative tolerability to natural terrain landslides versus risks from PHI sites;
- There have been no recorded fatalities to date in Hong Kong due to incidents involving either release of chemicals from PHIs or landslides/boulder falls from natural terrain and therefore there is no historical basis for comparison of risks or the public's tolerability to the disparate hazards.

Conclusions

This option provides a sound basis for the development of risk criteria for landslides from natural terrain, although problems still exist, particularly so with the public's tolerability to landslides and boulder falls from natural terrain compared to PHI hazards. These difficulties, however, apply for all options A to D.

This is the preferred option from this study.

E2.4 *OPTION D - SOCIETAL RISK CRITERIA BASED ON PHI CRITERIA/DG TRANSPORTATION*

This option is an extension of Option C to also include the consideration of the risks from DG transportation associated with a particular PHI to provide an equivalent societal risk criteria for PHI/DG Transportation. As for Option A this could then be used as a basis for the determination of criteria for landslides from natural terrain.

Advantages

The advantages listed for Option C above also apply for this option, with the following additional advantages:

- The DG transportation studies [*Ref. 1*] have already proposed an approach for establishing the tolerable risks for DG transportation activities associated with a PHI. Technica has proposed that the risks from the DGs transportation activities associated with a PHI should not exceed the risks from the storage and use of the DGs at the PHI. The overall PHI/DG transportation criteria which are developed would then be twice the PHI criteria. This could provide a basis for the development of risk criteria for landslides from natural terrain.

Disadvantages

The disadvantages for Option C also apply here, with the additional following disadvantages:

- A PHI in a particular location presents risks to the local community from the storage activities in addition to the associated risks (to public along the transportation route) due to the DG transportation to the site. The risks arising from steep natural terrain would only affect the local community. It could be argued therefore that the basis for development of the tolerability criteria from PHI criteria should only take account of the storage activities associated with a PHI;

- The approach proposed by Technica for establishing the tolerability of societal risks for DG transportation activities associated with a PHI (ie that the risks from the DGs transportation activities associated with a PHI should not exceed the risks from the storage and use of the DGs at the PHI) is still at the draft stage and has not yet been fully accepted by Government. The current proposed criteria could therefore be revised.

Conclusions

Natural terrain would only present a risk to the nearby population, and there is therefore no equivalence to the transportation risks associated with a PHI. It follows therefore that for land-use planning decisions, the establishment of a PHI should include both storage and transportation, whilst natural terrain is only equivalent to the storage activity at a PHI. The previous option (Option C) is therefore preferable to this option.

E2.5 *OPTION E - SOCIETAL RISK CRITERIA FROM 'FIRST PRINCIPLES'*

This option proposes the development of the societal risk criteria from 'first principles' by assessment of all types of landslide and boulder fall risks in Hong Kong and determination of the public's tolerability to such risks. The relative contribution to societal risk from natural terrain landslides and boulder falls would need to be determined. The public's tolerability to such incidents would need to be assessed, and the societal risk criteria for landslides and boulder falls from natural terrain then developed from this basis.

This approach would first involve an estimation of the risk to people (eg, to various residential groups) from landslides and boulder falls from natural terrain. This would need to be based on QRA techniques, as there are generally insufficient historical data on fatalities to give a robust estimate of the underlying risk from landslides. Secondly, an assumption could be made that the upper level of risk to which the individuals (or society) would tolerate must be at least as high as this level (ie, it is assumed that the calculated level of risk is tolerated). It could then be argued that any new development should not expose individuals to a risk greater than the calculated value.

Advantages

- This option may be the most defensible in terms of its direct applicability to landslide risks, with no associated problems in consideration of aversion factors between PHI risks compared to landslide risks.

Disadvantages

- There will inevitably be uncertainty in the results obtained from any QRA results on landslide hazards, with the uncertainty range possibly being greater for QRA results for landslides and boulder falls from natural terrain. The level of uncertainty could be particularly high for high fatality events. This may not provide a defensible basis for the determination of society's tolerability to multiple fatality events;

- Some may argue that the current level of risk may not be tolerable. However, although the choices may be stark, it could also be argued that there is always an opportunity for individuals to re-locate if they truly believed that the risk to which they were exposed was outweighed by the benefit of residing in their location;

- The Hong Kong Government currently allocates very large sums of money to reduce existing risk from landslides from man-made slopes. This could tend to indicate that the current risk levels from (man-made slope) landslides cannot be considered as "acceptable" or "tolerable". When risk criteria for societal risk were first developed from the Canvey Island study [*Ref.* 31] the approach was to take the (predicted) F-N curve and draw the "unacceptable" line as a tangent to the existing F-N curve. The basis then used was the concept that *the existing societal risk level is not unacceptable, but on the limit of unacceptability*.

  It is by no means certain that the same concept could be adopted for (man-made slope) landslides in Hong Kong. There are indications that the risks from man-made slopes in Hong Kong may possibly fall into the equivalent "unacceptable" region of the F-N graph. For example, the UK Government (at the time of Canvey) were certainly not spending (or insisting that the chemical companies should spend) the amount of money on risk mitigation which the Hong Kong Government is currently spending on landslide risk mitigation.

  It could follow therefore that there is currently no firm basis for determination of what the limit of unacceptability for societal risk from landslides is, other than to conclude from the above that the current level of societal risk is probably not "acceptable". This seems to be supported by the fact that the community has been pressing for further reduction in risk (LegCo, District

Boards etc), with presumably additional expenditure.

Alternatively, one could also suggest that the Government may be spending disproportionately in Hong Kong to the levels of risk which the public are exposed to, ie the risks may well be "tolerable" but they are spending too much on risk mitigation.