B. PRESENTATIONS

SECTION B.1

PRINCIPLES OF RISK ASSESSMENT

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mai 28, 1998 version of the manuscript of the State of the Art Report for SIGA 98 entitled:

Geo-Environmental Risk: Assessment, Analysis, Management and Planning

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1.0 Introduction

Recent geo-environmental disasters, both natural and human-generated, have lead to increased demands for information and accountability. Details of government and industry risk management strategies, policies and procedures are no longer restricted to a few high-ranking officials. Rather, they are being sought after and challenged by the public, often with serious consequences for the organizations involved.

No wonder then that conferences and numerous seminars are being organized with the aim of increasing professional awareness on the implications of public demands and on the need to implement rational risk management plans. This paper, after reviewing the development of risk management practices in various fields of the industry, tackles the ambitious goal of presenting the basis of healthy geo-environmental assessment, analysis, management and planning. Risk-related disciplines are presented not only *per se*, but as important decision-making support. Crisis management—and in particular its necessary integration to risk management—is also included because in these last decades public behavior has noticeably changed.

There is indeed a strong and increasing demand by the public to know its level of exposure to risk, and the efforts being undertaken to mitigate those risks. At the same time, industry and public agencies struggle with shrinking human and financial resources, while attempting to maintain a level of practice compliant with internal and external (public) expectations. Public perceptions are often the result of irrational and emotional reactions to media reporting, a situation which often becomes more apparent in the aftermath of crisis events. When crises strike, organizations find themselves under public and media scrutiny, which often results in accusations, liabilities and business losses.

During a 1996 conference at a leading European engineering school, the keynote speaker, Neyrinck, addressed the growing distrust of science and technical progress that contributes to a general negative public perception. He noted that the emergence of opposing movements—such as consumerism, ethics and ecology—were considered to be the result of negative attitudes of the masses towards progress. Balancing these trends, however, is progress ideology, which projects a future of perfect happiness for humankind, brought on by the enhancement of scientific and technological knowledge. This happiness would be based on increased revenues and life expectancies, abolition of economic slavery, suppression of the death penalty and other utopian achievements.

But technical progress cannot be confused with progress through technology. Since the 1970s, opponents of technical progress, such as the ecological movement, have capitalized on an impressive series of human-generated mishaps to demonstrate the validity of, and justification for, their movements. These events have included:

- The Dioxin accident at Seveso, 1976
- The Amoco-Cadiz Oil Spill, 1978
- The Three Mile Island Nuclear Accident, 1979
- The Toxic Gas Release at Bhophal, 1984
- The Explosion of the Space Shuttle Challenger, 1986
- The Chernobyl Nuclear Accident, 1986
- Pollution of the Rhein river at Schweizerhalle, 1986
- Recent tailings spills and releases at Marcopper, Omai and Los Frailes mines (1995-1998)
- Recent deadly mud-flows in southern Italy (1998)

If, in most such cases, human error may be considered a root cause of the mishaps, it may still be proposed that technology should not be blamed. Many would argue that technology is not foolproof, and that all systems created by people are inherently imperfect, incomplete and potentially faulty. Professionals involved in the design of technological systems strive to reduce risks by increasing their knowledge, but they will remain incapable of independently defining the levels of risk that can be accepted by society at large.

Together with the concept of acceptability, however, comes risk sustainability. Over-exposure to risks has contributed to the bankruptcy of several insurance companies and large banking institutions in the last decade, and has generated new awareness among such organizations concerning risk management and exposure analysis.

Another author, Weber (1996), tries to explain how society has developed a high level of risk aversion by introducing the concept of "mankind increasing instruction." Enhanced instruction, he writes, allows each person to earn a living through a "learned profession," as opposed to the "environment-induced professions" that characterized cultures up to a few decades ago, at least in developed countries. Instead of being a farmer, a blacksmith or miner, people can make choices and take responsibility for their direction. Destiny no longer drives one's existence—*homo faber fortunae suae*—man is master of his destiny. Based on this enhanced knowledge, humans assume a central role: mastering their society and its fundamental nature.

The consequence of this shift is paradoxical, however, because people become more vulnerable. Catastrophes become unacceptable because they endanger the concept of "Almighty Human." An industrial or natural accident that would have been considered an act of God at the beginning of the century, now arouses public indignation, media attention and immediate scorn for the "usual suspects"—the authorities, the designers, the organizers or the scientists.

Interestingly, the conclusion may be reached quickly that risk does not exist by itself: it is a societal concept, and different cultural or religious backgrounds may come to widely diverging conclusions about what risk is and how it should be measured. Additionally, in all risk management approaches, there is an underlying assumption that people can shape their future, and, therefore, avoid or control tragic occurrences. Indeed, it is only if the future is considered as changeable through people's actions that avoiding natural hazards, or mitigating their effects, can be imagined. In the case of the opposite assumption, that is, if it is determined that the future cannot be changed, then there is no real interest in examining risk. This issue may be considered as trivial, but it should be remembered that only recently (in historical terms) have people abandoned fatalistic concepts and embraced an anthropocentric view of the world.

The result is that in order to meet the needs of a sophisticated society, geo-environmental specialists can not ignore irrational and subjective perceptions, nor can they fail to address psychological and sociological factors. They must, therefore, integrate the "engineering" approach with a "public relations" vision. (Oboni, Oldendorff, 1997). Accompanying this integration is the necessity to respond with enhanced acuity to qualitative and quantitative questions raised during the assessment, analysis, management and planning approaches to risk.

Risk must be recognized as being omnipresent, and considered as a day-to-day parameter in any human activity. Risk assessment (RA), risk-based decision making, risk-based evaluation of feasibility of projects, human error studies and the development of risk mitigative plans and crisis management plans for risks that both can and cannot be mitigated are becoming essential weapons in the arsenal of modern managers, generally grouped under the icon of Risk Management (RM).

1.1 Definition of Terms

When studying and practicing geo-environmental risk management (RM) and crisis management (CM), a common difficulty is encountered at the level of basic definitions. Confusion arising from varying interpretations of terms is often experienced (IUGS Committee on Risk Assessment, 1997). Clarity and strict compliance with well-defined interpretations are the only means by which a positive and constructive communication among interested parties may be maintained. For this reason, the principal terms used throughout this paper are defined in Appendix A.

1.2 General Considerations

In order to proceed with the study of a modern RM approach, it is important to remember that RM does not constitute an assurance that hazards and related accidents will not happen. RM deals with the need for sensible and sustainable risk reduction, not risk elimination. The goal of RM is to select those options that best balance the benefits of actions in response to real or perceived risks against the costs of reducing those risks.

RM must not be confused with Hazard Management (HM). In HM, hazards are identified and prioritized without accounting for the consequences (C) of a hazard event. A hazard map demonstrates only where the hazard potential is present, and may indicate a range of magnitude of the events, but not their potential consequences. All too often, mitigative strategies are influenced by perceived hazard magnitudes without a true appreciation of the actual risk involved. In a RM procedure, following identification of hazards, relative consequences are taken into account.

A risk graph, presented in Figure 1, plots the probability of occurrence *p* of a hazard and the cost of the consequences *C* of that hazard striking the potential target system in a log-log axis system. The log- log axis system allows readings of extremely low probabilities and extremely high costs simultaneously with other possible values.

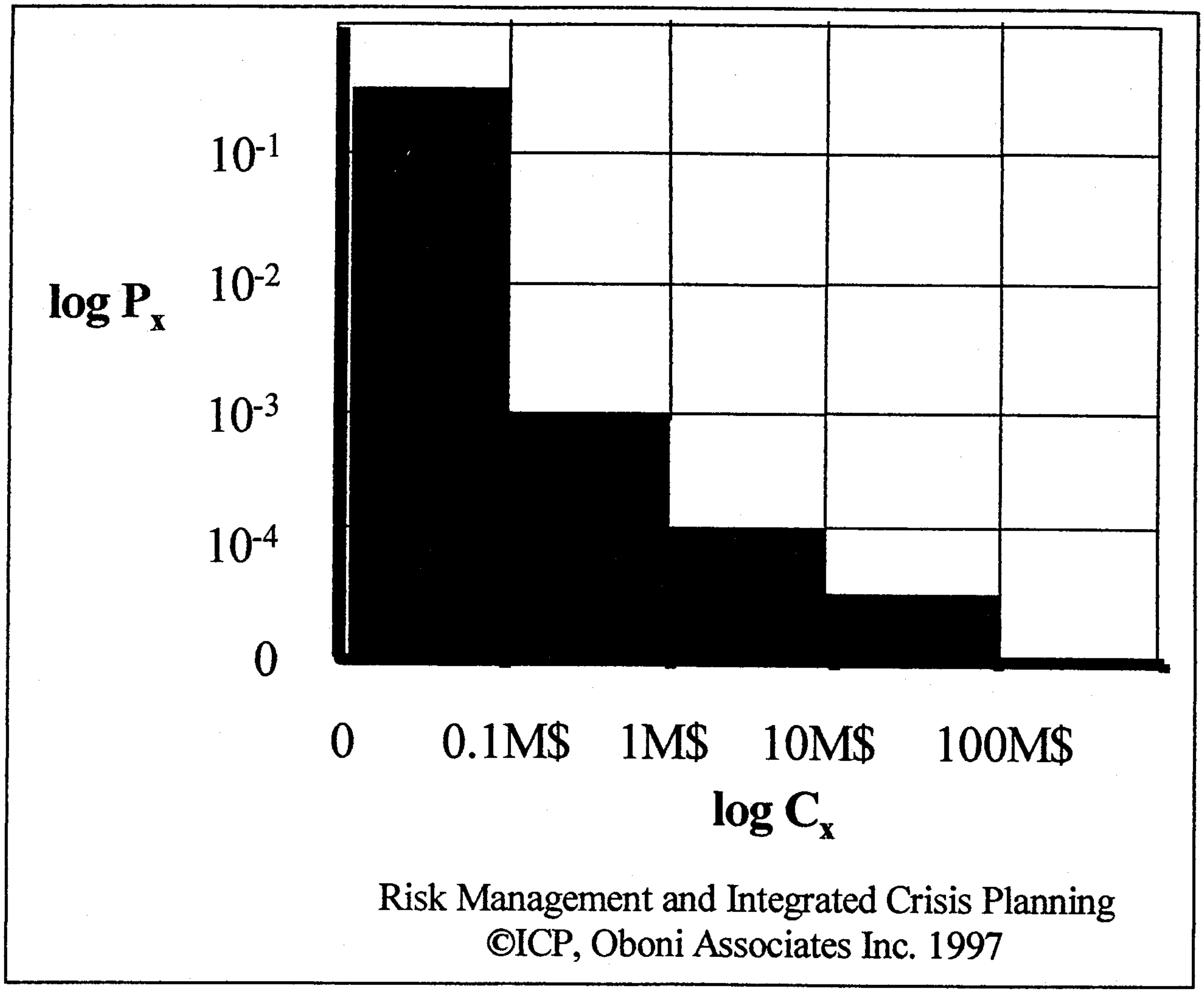


Fig. 1: A Risk Graph, where the Probability of Occurrence of the Hazard *p* and Cost of Consequences *C* are plotted in a *p-C* graph. Note the use of a logarithmic scale on both axes to increase readability and comparison of extreme values such as very high costs or very low probabilities of occurrence.

Fig. 2 presents the variation of mitigative costs as a function of risk reduction. In particular, the graph illustrates that threshold values exist beyond which further risk reduction can lead to uncontrolled escalation of mitigative expenses. RM incorporates careful consideration of the cost of consequences, and encourages refined management of a variety of different hazards. Used effectively, RM allows comparison of risks arising from different types of hazards. It is on the basis of such assessments that the foundations of organization-wide RM systems may be envisioned. Ultimately, application of RM techniques can facilitate effective allocation of funds, clearly demonstrate effective due diligence, and dramatically enhance communication of decisions to affected employees, managers, investors, regulators and to the public.

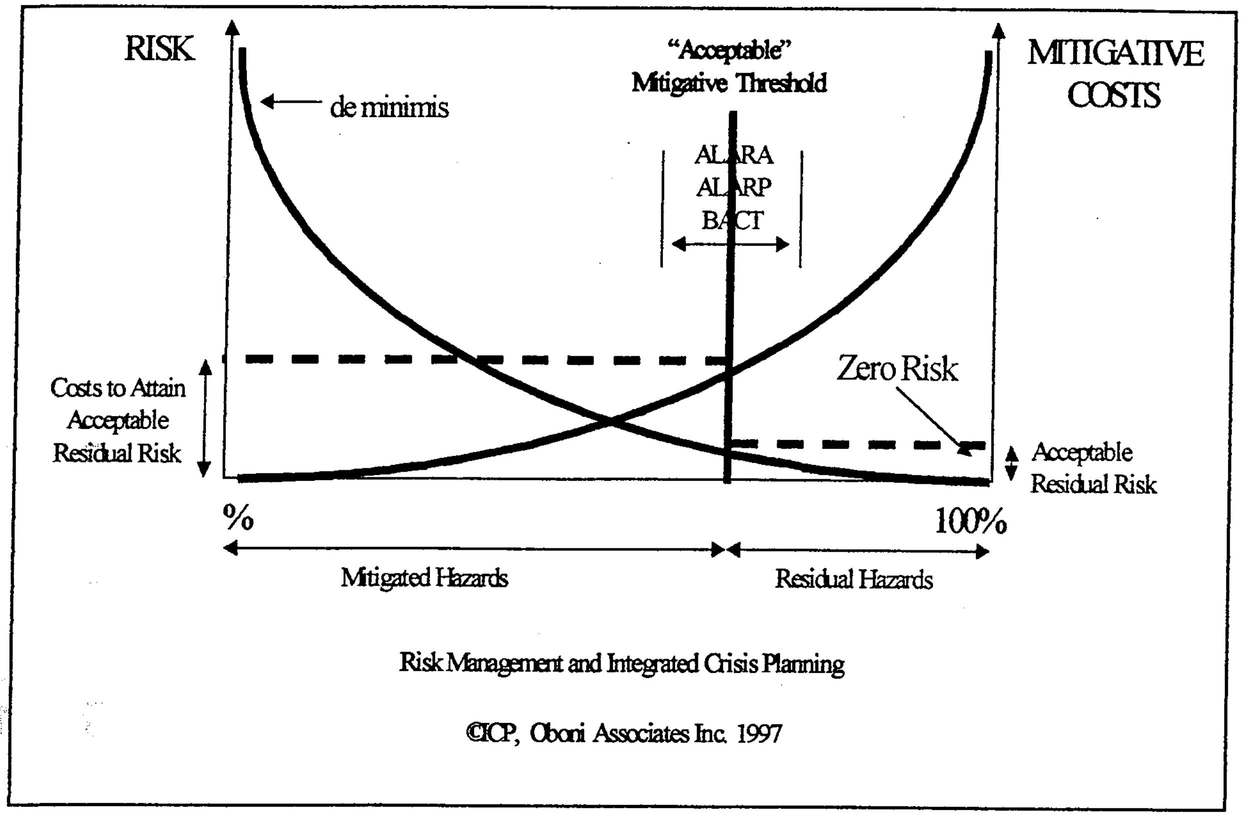


Fig. 2: Variation of mitigative costs as a function of risk reduction

Based on the results of sensible risk assessment (RA), practical RM measures may be taken, such as the installation of passive mitigative structures (e.g. protective nets for rockfall, barriers to hinder vehicle movement, automatic shut-off valves) or active ones (e.g. rock support structures, clearance screening, removal of the hazard source).

Each of these measures has some residual risk that should be carefully evaluated and entered in the "cost" side of the equation. It may therefore be seen that RM is actually a decision making science rather than another housekeeping tool to "keep the order."

2.0 Review Of Risk Management Methods And Models

2.1 From World War II to the Seventies

Before World War II, the study of risk mitigation was more of an art than a science, and most often these practices resulted in significant over-design of parts that were thought to be critical for performance. This approach was based on the idea that the weakest link in a chain or system is the driving parameter of the global resistance of the entire chain. But the insufficiencies of this approach became apparent at the beginning of the 1940s, in the development of the V1 rocket, lead by Wernher Von Braun. In the course of development of the V1, a pre-series of test rockets, about ten in all, had a failure rate of 100%; none flew for the expected duration. Rather, they exploded on the launch ramp or shortly after launch. The V1 was not a very complex machine and each component was subjected to a series of enhancements. But the failure rate did not decrease. Apparently, the V1 was weaker than its weakest component! It was decided that the failures were probably driven by the "system" rather than by its "components." It was E. Pieruschka, a mathematician on the project team, who found the key to solving the problem, thereby causing great confusion and consternation in the minds of many scientists. Pieruschka stated that the probability of failure of a system like the V1 is always higher than the probability of failure of its weakest component. As a result, the V1 was the first human system in which the design was modified on the basis of system reliability concepts.

With the start-up of the first nuclear power plants in the US (Shippingport, 1957, Yankee Rowe, 1960, Indian Point, 1962) safety and reliability analysis of complex systems assumed even more importance. The expansion of commercial aviation further reinforced this trend, and the first failure forecast studies, safety of assets, and physical person analyses were prepared, laying the basis of our modern RM procedures. Another challenge was space exploration, which culminated on July 20, 1969 when the first human stepped on the moon. The safety/reliability/RM developed during the early stages of the Apollo program are considered to have been essential in the success of that endeavor, even if residual failures occurred, as in the case of the Apollo XIII mission.

It was during the mid 1960s that the concept of maintainability, or the scientific planning of maintenance operations, was first presented. Then, as now, down time of complex and expensive facilities represented a risk that many organizations found intolerable. Maintainability was seen as a mitigative measure aimed at the abatement of that risk. And at the end of the decade, the first reliability databases were created.

The growth of nuclear energy, with its associated hazards and potentially catastrophic accidents triggered the development of potential problem analysis, failure forecasting and other techniques that are applied from the drawing board stage. Possible failures are classified by potential consequences and estimated frequency, and are derived by assuming pessimistic scenarios. For each accident scenario, the goal is to demonstrate that foreseen mitigative measures adequately consider safety thresholds for people and physical structures.

2.2 The Rasmussen Report

In 1975, the first complete, analytical, industrial risk report was published in the US (Reactor Safety Study—an assessment of accident risk in US commercial nuclear power plants, WASH-1400). Directed by Prof. Rasmussen the team completed the task in the equivalent of fifty man-years. Their report is generally referred to as the Rasmussen report. The study, based on the application of probabilistic evaluation of risk, allowed the assessment of a large spectrum of potential accidents, taking into account the possible consequences for people and properties. Failures of safety systems were examined, as were a multitude of triggering events. The results were presented in curves indicating the probable annual frequency of accidents as a function of the consequences (mortality rate), for 100 nuclear power plants of two considered types. The study concluded that the risk represented by these facility types was very low.
The Rasmussen report marked the passage from a deterministic to a probabilistic approach in the safety, reliability and risk studies. In 1977, a review group lead by Prof. Lewis criticized the Rasmussen report, arguing that uncertainty in the reliability of individual components had been underestimated. The "Lewis report," however, accepted the Rasmussen approach as correct, and recommended its further development and increased use. In 1979 the Rasmussen report again came under scrutiny when the then West German *Gesellschaft für Reaktorsicherheit* (Society for Reactor Safety) published a report, coined "the German Risk Study." Again the Rasmussen report was globally accepted, although some assumptions were criticized and some values were changed.

The Rasmussen report was comprehensive, to the point where it projected a simulated accident scenario which closely matched later events at Three Mile Island. Following that accident, a US presidential commission recommended the generalization of the Rasmussen report's methods to all nuclear safety studies. As a result, risk studies for nuclear power plants became standardized procedures, and by 1985, over twenty such studies had been completed.

2.3 Environmental Risk Studies from 1970 to the Present

At the end of the 1970s, in response to a ministerial request, the Health and Safety Executive in the United Kingdom launched a study of risks associated with a petrochemical facility at Canvey Island, located on the left bank of the Thames River, downstream from London. This constituted the first wide-spectrum example of a geo-environmental risk study.

The site covers an area of approximately fifty square kilometers, and hosts seven large facilities which employ over 3,000 workers. The neighboring region has some 33,000 inhabitants. The key task of the study was to evaluate the risks associated with Canvey Island and decide if authorization to run the facilities, originally given in 1973, should be maintained or revoked. In addition, since an expansion of the facility had been undertaken, the risk study was expected to assist in decision making, and allow a detailed study of possible mitigative options. As a result of the study, numerous modifications were introduced in the design, and a review conducted in 1981 demonstrated that the risk was acceptable, and the mitigative measures still adequate.

A similar large spectrum study was conducted at the beginning of the 1980s in the Netherlands, following a request by the "Commission for Safety of the Population of the Netherlands." The scope of the study was the region located between Rotterdam and the North Sea, which encompasses the largest harbor in the world, as well as a very high concentration of chemical and petrochemical facilities. Unlike the Canvey Island study, however, this analysis did not account for the effects of an accident in one facility on neighboring sites.

In the 1980s, risk studies were performed in the chemical, petrochemical, railroad, automotive and water treatment industries and today, communities, utilities, mining, forestry and almost all types of industry demonstrate strong awareness of rational RM.

During the past decades, characterized by the development of the RM "culture", a variety of different RM models have been proposed by agencies scattered all over the world. The most structured models appear to have originated in the field of environmental RM. The review of these models is not only important because of their historical value, but also because many of these models are still in use and correspond to well recognized standards. It is, moreover, extremely interesting to see how, in some of these models, preliminary integrations of RM and CM have been proposed. Among these "classic" models we can cite:

- Canadian Standard Association (CSA, 1991)
- Scientific Committee on Problems of the Environment (SCOPE, 1980)
- National Research Council (NRC, 1983)
- Royal Society (RS, 1983)
- Health and Welfare Canada; Health Protection Branch (HPB, 1990)

All these models are characterized by phases and subphases. Table 1 compares the various models to summarize the series of examples, to emphasize how each differs in comparison to the others and to note how definitions and syntax differ between organizations.

The most modern RM models recognize the requirement to consider the public dimension of risk. But, if on one hand, technical aspects of Hazard Identification and RM seem to be very regulated, and are divided into various tasks, on the other hand, the non-technical aspects of risk do not appear to be further explained or outlined. The emotional component of risk is also not clearly acknowledged, and techniques to mitigate this aspects of risk are not clearly defined. Thus, these models seem to ignore that over the years, the press has come to play an increasingly important part in reflecting or even shaping public opinion, and has assumed an instrumental role in crisis situations.

During the 1980s, the human factor was introduced in RAs for the first time from a qualitative, then, later, a semi-quantitative point of view (see § 7.2.2) . Likely motivations for this shift were the accidents at Three Mile Island, Chernobyl, Bhopal and the Challenger explosion. These events are some of the best known recent crises where human factors played a very significant role.

Table 1:A comparison of various RM models

	C.S.A.	SCOPE/ITC	NRC	RS	HPB
a	Hazard Identification			Risk Assessment	
	What can go wrong?		a1: Identification	a: Risk Estimation	a1: Hazard Identification
			a2: Dose response Assessment	a1: Identification	a2: Risk Estimation
			a3: Exposure Assessment	a2: Probability of Exposure	a3: Options
			a4: Risk Characterization		a31:Development of Options
					a32: Option Analysis
b	Risk Estimation			Risk Evaluation	Risk Management
	What is the likelihood of the hazard, what will happen and what areas will be affected?		b1: Development of Regulatory Options	b: Risk Evaluation	b1: Decision
			b2: Evaluation of Options	b1: Significance or Value	b2: Implementation
			b3: Decisions and Actions	b2: Public Perception	b3: Monitoring
					b4: Evaluation
					b5: Review
c	Risk Evaluation				
		c1: Significance	Not Described in this Manner		
		c2: Acceptability			
		c3: Consequences			

2.4 Recent Geo-Environmental Risk Management Examples

As we have seen in the prior section, chemical, electronics and nuclear industries have paved the way to geo-environmental RM practices with strictly controlled HM, reliability and safety processes, resulting in rigid operating environments characterized by small allowable deviations. Methods developed for these industries, however, have limited application and may even be inappropriate for the specific needs of heavy industries (such as transportation or mining) exposed to geo-environmental risks.

Additionally, organizations which are considering employing RM/CM techniques are faced with the challenge of developing RM/CM from relative infancy, phasing in its implementation so as not to compromise safety and reliability and to provide employees with a high level of confidence by demonstrating that new RM/CM approaches are, indeed, effective. In the following subsections two recent RM examples are reviewed.

2.4.1 Chardonne Model

This program was conducted since the early 1990s for a Swiss community threatened by rockfall from a series of unstable cliffs. From time to time, these rockfalls would impact houses and other assets.

The Chardonne Model is a rockfall risk management system designed to subjectively quantify risk to engineered structures in rockfall environments, and to propose monitoring or mitigative action through a event tree (see § 7.3) framework (Oboni, Angelillo, 1993).

In general, for each potential rockfall source area, subjective field evidence is converted to a probability of rockfall occurrence hitting a potential target. The probability of rockfall impact is multiplied by the related cost of a hit to generate a level of risk. Calculated risks are grouped into one of three risk classes (R1, R2, R3), and action is assigned to each level. An R3 level receives no monitoring and is considered as presenting insignificant risks, while an R1 level is either visually monitored, monitored with instruments, or immediate mitigative actions are recommended. An R2 level describes an intermediate risk situation that receives a "milder" monitoring/observation and long-term mitigative action in case of negative evolution.

2.4.2 CN Rockfall Management Program

Despite the existence of various rockfall hazard rating systems (BGC-OA, 1995), a very limited number of rockfall risk approaches have been developed to date. An international review was conducted to define the state of the art and practice in rockfall risk evaluation, particularly for linear transportation corridors (Abbott, Bruce, Keegan, Oboni, Savigny, 1998a). Following the review, a methodology for rockfall hazard and RA was developed by considering European and North American methodologies. The new methodology uses a strictly defined observational approach to assign probabilities to various topographic, geologic and anthropogenic features (Abbott, Bruce, Keegan, Oboni, Savigny, 1998b). Mitigative influences of signals, track circuits and remedial works are integrated. Referred to as the "CNRHRA," the methodology provides a hazard rating which, when linked with frequencies, creates a decision-making framework that guides the monitoring and the prioritization of mitigative works. Canadian National Railway has now implemented the new methodology in the Canadian Province of British Columbia.

3.0 From Problems To Risks

Safety can be defined as the ability of a system to avoid the occurrence, in a given environment, of critical or catastrophical phenomena. Safety is generally measured in probabilistic terms. The consequential costs of an unsafe situation, a hazardous situation or, a plainly hazard occurrence, combined with the probability of occurrence of that situation, provides an evaluation of the risk (Appendix A, Fig. 1, §1.2).

When dealing with hazards and hazardous situations, however, not only unsafe conditions are of interest, but also problems that may occur during the life cycle of a system that result in loss of performance and down time are of interest. For, when a problem occurs, a system stops providing its expected performance.

Problems may occur progressively (progressive loss of functionality) or abruptly, and may result in partial or total loss of serviceability of the system (e.g. the car finally starts, but can only be driven in first gear; a waste water treatment plant performs well only at 80% of its design rate). A problem which results in a abrupt and complete loss of serviceability is called a "cataleptic problem." A problem which is progressive and partial is known as a degrading problem. Problems also may be classified in order of increasing effect, as outlined in Table 2

Table 2: A possible classification of problems in order of increasing effect

Minor Problem	System does not work well, but causes only negligible damage to itself and its environment without endangering people
Significant Problem	System does not work well, and causes some damage to itself and its environment without seriously endangering people
Critical Problem	One or more vital functions of the system are lost; the system causes significant damages to itself and its environment, with a minor probability of wounding or death for people
Catastrophic Problem	One or more vital functions of the system are lost; significant damages to the system and its environment result with significant probability of wounding or death for people

As seen in Table 2, problems may have a wide range of consequences, and therefore produce widely scattered risks. Unfortunately, neither term of the risk equation—the probability of occurrence of a given problem or phenomenon and its associated costs of consequences—is easy to quantify, and that is particularly true with geo-environmental systems.

3.1 Types of Risks

Once the probability of a hazardous event has been determined, the resulting risk cost is obtained by multiplying the probability by the costs of consequences (i.e. the cost of an accident).

With this definition, risk can be expressed in monetary units (dollars) or in other units such as dollars per time unit, deaths per annum, accidents per mile per year, or as one of a range of other expressions.

Several authors have stressed the important distinction between monetary risk (risk cost, i.e. multiplying the probability of an accident by the expected cost(s) of that accident) and risk to life (probability of death occurring from an accident). Reducing risks only to those linked to death or disease is a modern phenomenon, most likely associated with the loss of a larger basis of spiritual values by a modern, pluralistic and materialistic society. A major concern conveyed by Fell (1994) and others (Sobkowizc, 1996) is determining the acceptable risk level, which generally differs depending on whether a phenomenon is natural or man-made. Some authors (Morgan, 1997) have considered risk management as a public interest issue and have promoted the idea that there may be an absolute upper cost limit, which no life-saving program can exceed without consuming more time and resources than it returns.

Ultimately, these considerations lead to the necessity of clearly stating a number of conventions whenever a RM study is considered (Renn, O., Kals, J., 1990):

- Defining what is "damage",
- Grouping certain types of damages (for example, cancer, genetic mutation etc.),
- Choosing the threshold separating "fate" or "Act of God" from the scope of the study,
- Choosing methodologies and processes,
- Choosing the unit of risk and,
- Expressing the risk, that is, as a product or as a pair of values (see Fig. 1, Appendix A).

3.2 Levels of Risk

The selection of such options can not be done by the analyst alone and represents a very important part of the documentation of each study. Ultimately, a point will be reached where acceptable risk levels have to be discussed, where it is decided what kind of consequences can be tolerated, and where the degree of acceptable uncertainty is defined, especially when dealing with high-consequence situations. Again, these are not decisions that can be made independently by analysts. Rather, communication, and social and cultural values have to be introduced and "allowed to act."

In recent years, however, "standardized levels of risk" have been formulated, and these definitions are now in common use among analysts. Four levels of risk are commonly defined, as follows:

Zero Risk
Today it is generally accepted that a state of "zero risk" is unobtainable, no matter what the mitigative budget may be. It is therefore rare to see any practical study based on this degree of acceptability.

As Low As Reasonably Achievable (ALARA) or As Low As Reasonably Practical (ALARP)
ALARA is an approach where risk is reduced as much as possible—within reason. Some measure of acceptability, however, is needed. "A decision rule is needed for specifying what is reasonable, a rule that ultimately depends on physical limits...and the cost of implementation." (Wilson & Crouch, 1982)

Best Available Control Technology (BACT)
BACT is an attempt to reduce risk-producing activity, but it is often not economically feasible to employ. Costs can be prohibitive, and opinions differ on what exactly constitutes BACT.

"De Minimis" Risk Concept
In this concept, low risks are seen to be trivial, and not worthy of management. The "de minimis" can be problematic due to lack of consensus on the nature of "trivial" (Health & Welfare, 1990).

In many cases, instead of comparing risks with threshold values, "risk/risk" studies are undertaken. In a "risk/risk" analysis, three types of comparative analysis may be conducted:

- natural or background levels of risk,
- risk associated with other comparable hazards and,
- risk of alternatives.

Some authors consider comparative risks to be problematic because they do not leave the public with a clear understanding of the level of risk under discussion, but it is generally recognized that when communicating risk to the public, the actual levels of risk are often less important than paying attention to perceived levels of risk. Thus it may be that relative or comparative risks are the only sensible solution for effective RM of real-world problems, where public perception plays an important role.

4.0 Modeling Uncertain Parameters

4.1 Uncertainty

Uncertainty has been identified and studied since humanity's earliest days. Among some of the most famous quotations concerning uncertainty are Pliny the Elder's *solum certum nihil esse certi* —"the only certainty is uncertainty"—found in his *Historia Naturalis*, and, "to know one's ignorance is the best part of knowledge" by Lao Tzu, in *The Tao*. Knowing one's ignorance suggests that ignorance can be quantified, measured, communicated to others by means of understandable parameters and must be modeled. When modeling relationships of uncertain parameters, analysts are usually consulted to define specific values of the parameters, such as the most likely value, the worst or the best value.

From humankind's beginning, however, decisions—sometimes critical ones—have been made without due consideration of uncertainty. Some researchers wonder, if only for the sake of dialectics, if uncertainty really matters (Granger, Henrion, 1990), but it is generally concluded that uncertainty *does* matter—for at least three reasons:

- It is important to identify (in a decision, a risk assessment or policy making process) factors and sources of disagreement. An explicit treatment of uncertainty forces a more careful review of such matters, including categorization and prioritization of factors, as well as planning for contingencies.

- It is difficult to rely on expert opinions, especially when experts may be difficult to understand and have diverging views. By forcing experts to develop and explain the uncertainty involved in their judgments, it is possible to enhance understanding of risks.

- Problems are rarely solved once and for all, and may resurface. As a result, the temptation is to use or adapt past decisions or policies. If uncertainties related to past problems have been explicitly qualified, this "projection" of the past into the future is easier to implement and increasingly applicable, as stronger confidence in using the past appropriately is generated.

Risk Managers, like all professionals, cannot escape varying degrees of uncertainty in their work. Much of the information on which they depend is imprecise, may be biased or censored, or may pertain to phenomena that are not fully understood, either in origin, or in their behavior and evolution.

In order to use such information effectively, it is helpful to understand the origins of uncertainty. The following elements are common sources of uncertainty:

- Subjective Judgment, Approximations, and Linguistic Imprecision.
- Measurements.
- Variability, Randomness and Unpredictability.
- Model Uncertainty.

Thus, uncertainty generally arises because of incomplete information or disagreements between information sources, but also because of linguistic imprecision and other factors such as cross cultural barriers. In addition, analysts often question the quality of their data sets, and they are often asked to express degrees of confidence in their model's result. The Rasmussen report was the first large-scale study to employ a formal treatment of uncertainty, and to deliver results in terms of probability of occurrence for a sequence of events leading to a specific consequence.

Techniques for numerically answering questions concerning data quality and confidence in model results are a part of statistical sciences. While the data sets available to the analyst are generally too small to enable the use of "high level" statistics, simple statistical approaches do help to condense data into meaningful "estimators" that can be used in numerical analyses (see definitions of the terms "statistics" and "probability" in Appendix A).

4.2 Probability and Frequency

Often the terms "Probability" and "Frequency" (see Appendix A) are used synonymously. Clarity and strict compliance with well-defined interpretations, however, are the only means by which a positive and constructive communication among interested parties may be maintained.

Within the frame of the term *probability* two interpretations are possible: in the *frequentist view* of probabilities, in which the probability of an event is defined as the frequency with which it occurs in a long sequence of similar trials. For example, in the toss of a coin, the frequentist approach says that the probability of heads is 0.5, i.e. that the long run frequency converges towards 0.5 when the number of tosses increases. In the case of a coin toss, few would question this definition, but if the analysis focuses on, for example, estimation of the occurrence of a unique event (a terrorist attack against a facility, the failure of a dam), the long-run aspect of this approach is clearly non-applicable. The *personalist (subjectivist)* or Bayesiann view considers the probability of a phenomenon's occurrence as the degree of belief that the event will occur, given the level of knowledge presently available. In this view, estimates are considered "first" or *a priori* estimates, to be perfected with updates whenever further information becomes available. It is this view of probability that is used throughout this report and in most of the author's work.

4.3 Judgmental Probabilities

Many assessment methods (Einstein, 1988, Morgan 1992) rely on judgmental or subjective probabilities. These probabilities are determined by employing the expert opinion of an individual or a consensus of highly qualified professionals. Probabilities obtained in this manner should be referred to as "judged" or "allocated" to avoid misunderstandings concerning their origin.

Judgmental probability assessment has long been the subject of research in the behavioral sciences, as comprehensively summarized by Hogarth (1975). When a subject thinks and makes a judgment in the presence of uncertainty, a set of heuristic procedures are generally used. Because these procedures are approximate at best, they can lead to bias or even to error.

The **heuristic of availability** drives the judgment by the ease of thinking about previous occurrences, or by the ease of the event occurring. For example, if one is asked to estimate the time it takes to eat lunch, life experience will provide a strong basis for a reasonable assessment of the time required, and this assessment will most likely be quite accurate unless something unexpected comes up during lunch. Memory, emotions and personal preferences may introduce severe bias and error in estimation of probabilities in this manner.

The **heuristic of representativeness** encompasses the tendency to expect details of an event to reflect a larger process, thus enabling the evaluation of the probability of a given event belonging to a certain class of events. The coin toss example works well here. Because it is expected that the phenomenon is random, it may be thought that a sequence of outcomes (chain) HTHTTH is more likely than both HHHTTT or HTHTHT, although all three chains are equally likely to occur. The same heuristic may lead to excessive attention to detail while ignoring background information.

The **heuristic of anchoring and adjustment** refers to the process of anchoring to a first estimate, and then adjusting as a function of receiving additional information. In general, the rate of adjustment is insufficient and the results are biased towards the "first impression" or anchor.

Mowen (1993) noted that people often attempt to find logical explanations for events that are quite evidently determined by chance. He called this phenomenon "creeping determinism" and considered it as a key factor behind many poor decisions.

Even if the heuristic biases are neglected, many find the estimation of probabilities to be difficult, particularly in extreme ranges, i.e. at values near 0 and 1 (very small and very large ends of the probability spectrum). The difficulty is most likely due to the delicate interplay of the various possible behavioral and psychological factors. Dushinsky and Vick (1996) found that the ability to explicitly specify a preference for one probability value over another diminishes rapidly below about 10^{-1} raising difficult defensibility issues for extreme value estimates. Furthermore, well-known effects of overconfidence and motivational bias (when the analyst has a stake in the outcome) may tend to artificially drive probability estimates toward the extreme ends of the scale.

Authoritative research has shown (Brown 1989; Fischhoff, Slovic, Lichtenstein, 1977) that people have a strong tendency to attribute excessive confidence to their estimates. Generally, when asked to develop "optimistic," "expected" and "pessimistic" forecasts, it is within the range of the pessimistic forecasts that the most accurate answers often are found. Studies have also demonstrated that people who receive frequent and precise feed-back are more likely to develop sound judgment, and lose their overconfidence bias. If it is considered that most risk-based decisions will probably be predicated on subjective probabilities, it may therefore be assumed that these probabilities will often be affected by overconfidence, or that their distribution will be systematically skewed or shifted towards more favorable areas.

The result of these and other factors can be variations in probabilities of several orders of magnitude between various individuals, even when they express no fundamental disagreement in verbal likelihood assessments. Recently, an encoding method has been developed for the definition of subjective probabilities that overcomes these difficulties by deconvoluting the determination of a subjective probability in a series of elemental questions (Oboni, Bruce, Aziz, Ferguson, 1997, 1998) and is particularly useful in relative risk (risk/risk, see § 3.2) approaches.

5.0 Risks And Crises Awareness: A Need

Crises and risks are always to be considered, whether a corporation or a project is successful or not. As noted earlier, geo-environmental risk is omnipresent and potential crises are part of the evolution of any human endeavor.

Global trends towards reduced financial resources require that industry and public agencies operate more efficiently and to do more with less, including maintaining levels of practice compliant with internal and public expectations.

At the same time, codes and regulations are being enacted that increasingly require organizations to demonstrated due diligence and make efforts to limit risk. In many instances, codes are even becoming probabilistic in nature, i.e. RM-oriented, as demonstrated by numerous examples (Loucks and Lynn, 1966).

In addition to the technical issues associated with regulatory codes, there is the question of public reaction to crises that occurs in the absence of RM and CM measures. When crises strike, organizations find themselves under public and media scrutiny which results in accusations, liabilities and business losses. Public perceptions are often the result of irrational and emotional reactions to media reporting or failed or non-existing risk communication efforts.

Therefore, any individual or organization that has physical or moral assets to preserve, and is cognizant of the possible impact of hazards and crises on these assets, is interested and concerned by crises and risks.

5.1 Aspects of Crisis

As outlined in Appendix A, a crisis is defined as a decisive moment, particularly in times of danger or difficulty. But crisis is more than a simple definition. A crisis touches people deeply, be it at the personal or corporate level. A crisis may leave both worlds changed, and it often alters individual behavior patterns.

When the Chinese character for the word *wei-ji* or crisis is examined, the word consists of two components, the first representing danger and the second opportunity. It may be the "danger" aspect of crisis that is dreaded and the second, the opportunity, that is often neglected.

Often, efforts are made to try to avoid crises, and further to avoid costs of consequences. But in both personal and corporate affairs, crises are inevitable. No matter how effective one's warning systems are, eventually a crisis will happen. It is at this point where CM may be employed to great effectiveness; it can represent the tool allowing to seek out the opportunity embedded in a crisis.

Often the opportunity a crisis offers is to learn and to grow, and a dangerous situation can become—if positively controlled and managed—a positive, beneficial one. However, not every crisis will be beneficial for the affected person or organization and, in fact, the opposite may be a more likely outcome. Ultimately therefore, crises may well be significant threats to the well-being, financial state and reputation of all involved. A CM strategy, a plan clearly stating which steps to take when a sudden unwanted event occurs, can help minimize the damages and loss of control.

5.2 Potential Victims of a Crisis

As indicated in the introduction, there is a strong and increasing demand from the public to know its level of exposure to risk and the efforts being undertaken to mitigate those risks.

Corporate responsibility is not only a buzz word. Society's expectations of companies have changed over the past three decades as corporate social responsibility and corporate environmental responsibility have become parameters of progressive business management. The public, stakeholders and government demand that corporations demonstrate responsibility for their actions and the consequences of those actions. This new reality becomes most apparent in crisis situations where damage to the environment has occurred or where people have been killed, injured or otherwise adversely affected due to corporate or governmental agencies interactions with geo-environmental systems.

The Institute for Crisis Management in Louisville, KY reports that the number of news stories on class action lawsuits against organizations increased five fold from 1991 to 1992 and coverage of business crimes increased three fold in the same one year period. According to the *Public Relations Journal* (June 1993), news coverage of business crises in 1992 rose by 45% over the previous year. The impression is that the media has increasingly focused on business scandals and crises as staple stories.

There are four classes of crises development (Public Relations Society of America, 1995):

Exploding Crises:	Well-defined, noticeable events with prompt impact.
Immediate Crises:	Events that catch people by surprise, but for which there is some time to prepare.
Building Crises:	Crises that can be anticipated.
Continuing Crises:	Chronic problems that take a long time to appear, are usually complex, and will not be resolved easily.

A crisis development, therefore, can be compared to a problem occurrence as developed in section 3.0.

The list of businesses prone to crises is endless and the variety of crises that may occur in each type of business is extensive because crises are not simply the results of accidents, natural disasters and fraud, but they can also result from miscommunication or the lack of communication with stakeholders (rumors, media campaigns, boycotts, etc.).

5.3 Crisis Preparedness

In order to maximize efficiency and cost effectiveness, CM must be linked with RM at an early stage, continuously over time. This close relationship offers the opportunity to take communications risk and crisis assessment to another level: the integrated combination of technical RM and public relations related CM.

Although both CM and RM are, if carried out professionally, already a comprehensive managerial strategy that integrates management, policy making and media relations, current practice must reach further to efficiently meet the needs of our increasingly sophisticated society. Neither CM nor RM approaches alone can offer satisfactory solutions to all crisis-related needs, but, when integrated, their effectiveness greatly exceeds the capabilities of each individual discipline.

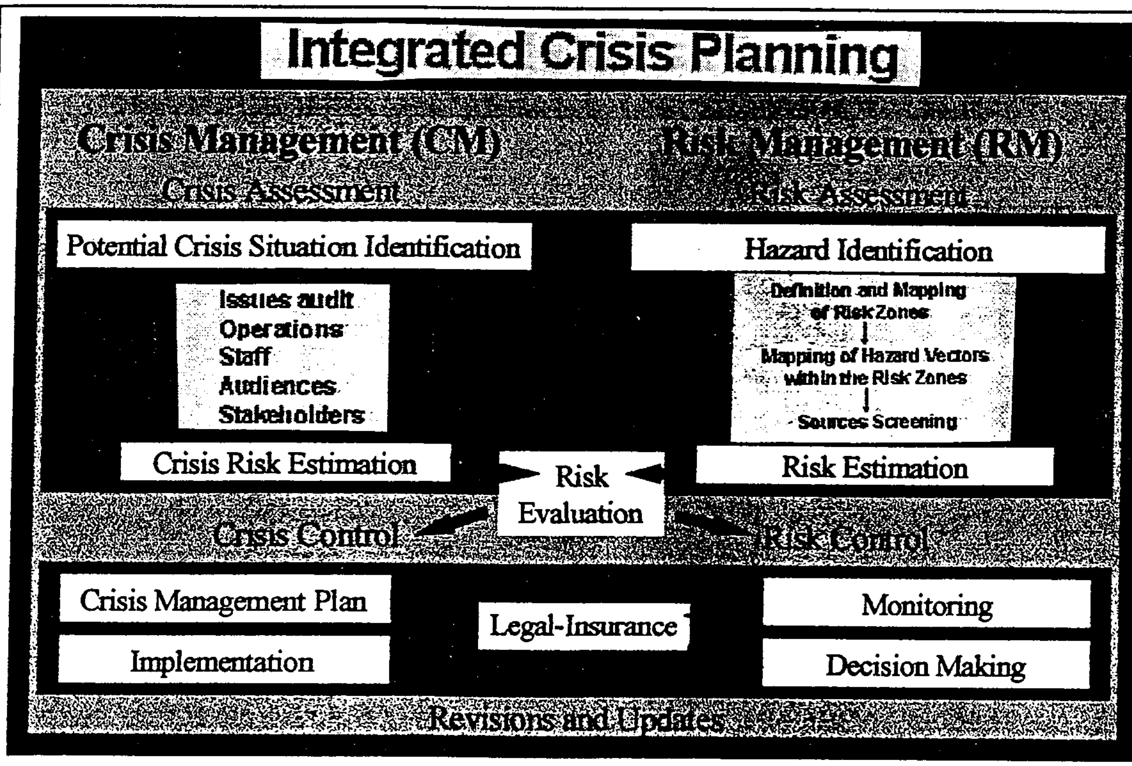
In current practice, RM and CM often stand alone, or are insufficiently linked because those that are called to implement such programs lack either a coherent conceptual framework, formal education in the fields, or cross-disciplinary experience. In addition, CM often begins at the end of the RM process, or after a crisis has happened.

Failure to pay particular attention to the PR side of crises may result in a loss of revenue and corporate image. Furthermore, the lack of an established CM plan may diminish a company's ability to react appropriately in the event of a crisis. In many cases a situation which represents a low risk from a technical point of view may be considered an unacceptable risk from a PR perspective and vice versa. This statement can be generalized to many aspects of corporate life and geo-environmental projects, where conflicting goals or very diverging definitions of what risk is (see § 3.1 and 3.2) may lead to deadlock.

To illustrate this last point one can consider as an example the life of a railroad company. The traffic department is always concerned with timetable and traffic reliability. This department faces a risk that trains may not run on schedule, which would result in an inability to deliver cargo on time, and, compounding the delays, potential loss of contracts. Frequently small geo-hazards along the line which could slow traffic are a major concern for the traffic department. For its own part, the safety department of the same railway is concerned with avoiding loss of lives and assets. Through the efforts of this department the crisis they are trying to avoid is the occurrence of a major geo-hazard related accident—such as a slide or wash-out of the line—with fatalities and environmental damages (derailment of toxic cargo in a waterway or lake, for example).

As a result, when these two parties discuss sharing next year's budget, a deadlock in their negotiations may occur. Safety personnel might be dedicated to major stabilization work in highly hazardous areas, while traffic department representatives would want to spend money on small but frequent hazards that delay trains, but which do not cause major accidents. Thus, only the comparison of the long term global risk, including "hard", technical risks and "soft", public relations-oriented risks will help to breach this deadlock.

Recently a model for the integration of CM and RM has been presented under the name of *Integrated Crisis Planning*, or ICP® (see www.oboni.com) (Fig. 3). ICP® reaches beyond the establishment of preparedness programs and crisis response because it employs both CM and RM at all times and at all levels of a given project.



Risk Management and Integrated Crisis Planning

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Fig 3 The ICP□ scheme

An ICP® plan consists of a number of strategic steps that structure the CM/RM integrated process aiming at the quantitative evaluation of the global risks.

5.4 Benefits of Risk Management

Today companies and organizations that are not willing to accept reasonable risks or to try new ideas leave themselves vulnerable to failure. For this reason, companies that want to succeed (even the large ones!) are beginning to accept increased levels of risks and are trying new ideas if there is a corresponding probability of more progress and greater overall success.

These innovative "higher risk" or "risk-based" decision opportunities are developed at strategic and tactical levels. Strategic decisions are *una tantum* or one-time decisions focusing on the development of larger goals and objectives. Once a strategy is defined, tactics are deployed to implement that strategy, and each tactic may constitute a new risk-based decision opportunity.

To support innovative attitudes and ideas, companies, organizations and individuals must follow processes that allow them to identify which risks are worth taking and which will result in overexposure.

In general, as the number of levels of management increases, the willingness to accept risks decreases. Organizational systems are known to be based on control and on preventing people from doing things (Harvey-Jones, 1993) . Of course, it is generally seen that when individuals and organizations perceive themselves to be in a losing or failing position, they tend to take riskier stances. This common approach is reflected in the popular phrase, "we had nothing to lose" which is used to justify risky attitudes or choices.

The applicability and meaningfulness of RM and CM for organizations exposed to geo-environmental hazards and the resulting risks, or ready to embrace transparency and rationality in geo-environmental decision making, are undoubtful.

It has been shown by sociologists specializing in catastrophe behavior (Kyoto University Research Centre for Disaster Reduction, among others) that the two most significant elements characterizing "fear"—unforseeability and uncontrollability—are eased when transparent and rational information is delivered. When organizations embrace RM/CM approaches, the level, transparency and rationality of information are increased, thus leading to the feeling of foreseeability and controllability of the present and future. When an individual or an organization feels that things are foreseeable and controllable, risk-taking, audacity and pugnacity increase. People work more calmly and creativity is enhanced.

6.0 Risk Assessment As Decision Making Support

The arena in which geo-environmental decisions are made is often so complex that precise cause effect relationships do not exist or cannot be detected (Mowen, 1993).

In addition to rational thought, many other factors and tools may enter into real-life decision making explicitly or implicitly. Without attempting to be exhaustive, the following list notes some factors which are encountered more often than others:

- Intuition
- Prestige
- Superstition
- Using Computers Models and Expert Systems
- Hazard awareness

For engineers, technical decisions may be made on the basis of lowest overall cost, possibly projected over the life cycle of the facility, or of the strategy, or based on other criteria. Costs expressed in a currency unit are easy to compare: most people can think in terms of dollars, and unit costs for various alternatives are often well-documented. Cost first can be expressed in a crude approximation as an expected value, or can be developed more sophisticatedly into a probabilistic formulation in such a way that probabilities of not exceeding a given amount can be delivered.

Other decision-making objectives or values which may or may not be structured to facilitate quantitative analysis of a decision may include the following:

- producing the highest quality product,
- minimizing liability,
- minimizing potential for loss of human life,
- enhancing environmental safety,
- pursuing a project for its strategic importance,
- improving corporate image or PR, and
- attaining prestige.

Any of the above criteria may be included in a quantitative objective function, but there is considerable danger associated with the complex problem of dealing with many different (and occasionally conflicting) consequence evaluation criteria.

One option often considered in real life decision making is to consistently assume worst-case conditions (for example, specify the highest possible flood, the smallest observed fatigue life of materials, etc.). Over-conservative, unsustainable decisions may be generated on this basis. It could be argued that from the standpoint of system performance and safety, this approach may be suitable. The resulting decision, however, could be too costly as a consequence of "compounded conservatism." On the other hand, an economical design may not ensure the desired levels of performance or safety, especially from the angle of public perception and expectations.

Decisions based on trade-offs between costs and benefits (tangible and intangible factors) are therefore necessary. Obviously, on the cost side of the equation, not only construction and maintenance costs, but also potential costs of accidents and mishaps should be comptabilized.

The most desirable solution is one that is optimal, in the sense of presenting minimum potential overall cost and/or maximum potential benefit. Thus, one can see that a well conceived Risk Assessment is an obvious component of rational decision making.

Obviously, since available information and evaluative models contain uncertainties, a trade-off or cost-benefit analysis should be carried out probabilistically in order to include the effects of such uncertainties on a given decision. Such an approach diverges significantly from "worse case" or the "expected value" analyses common in the past. Identifying hazards, studying risks and incorporating these concepts into decision making, which become therefore risk-based decisions, have proven to filter out the "creeping determinism", and to greatly improve the quality of decisions.

Another element of bias that is often introduced in decisions is the overconfidence bias (see § 4.3). This apparently negative factor, however, may in fact be a benefit. There are methods that allow development of quantitative feed-back (probabilities updates) from *a priori* estimates (based on the subjective probabilities), through the use Bayes' theorem (Einstein, 1988, Ang and Tang 1984). Despite the limitation associated with overconfidence bias, risk-based decision making can be used to "educate" analysts and enhance their ability to offer sensible forecasts by presenting regular and rational quantitative feed-back. Thus armed with quantitative feed-back for every decision they make, decision makers will not only be able to reduce emotional influences on their decisions, but will also learn to control the array of biases and errors they are exposed to.

As no methodology comes without secondary effects, risk-based decision making can also produce a set of undesirable results that are known, but extremely difficult to quantify. If mitigative options are implemented as a result of a Risk Assessment, the public reaction may be such that risks actually increase, because the mitigative action generates excessive confidence in the public, which soon "forgets" about the hazard.

In the following section, a conceptual framework for risk-based decision making is described. Although strategic and tactical decisions will not be specifically separated or identified in the section, the discussion is intended to address decisions that corporations or individuals do not wish to develop on the basis of simple heuristics, and which must be therefore based on rational justifications and values.

6.1 Characteristics of a Decision

Risk-based decision making allows comparison of alternatives based on risks generated by very different hazards or conditions, thus adding another dimension to the discussion. For example, how can corporate risks generated by continuous unfavorable conditions (minor work site accidents due to safety violations at a remote construction site) be compared, in relative terms, with risks generated by very rare hazards (such as an 100 year return avalanche that could strike the construction site)?

If risk-based decisions that are to be made involve such different alternatives as investing in more site inspectors, developing awareness among workers, or installing permanent avalanche protection, none of the standard qualitative methods of comparison would allow such a mixing of "apples and oranges."

Even when considering a single, apparently binary, alternative, a general geo-environmental decision problem is generally characterized by the following attributes:

- **Complexity**
  Generally, complex and sometimes contradictory sets of values underlie any decision. Keeney (1992) describes a list of "devices" to use in identifying objectives, including wish lists and goals, constraints and guidelines.

- **Rarely binary**
  Individuals and corporations often fall into the trap of binary decisions, i.e. decisions with *yes/no* answers, or *either/or* choices ("pick A or B"). Creativity and good sense should be used in generating as many alternative courses as possible.

- **Basic data can be enhanced with time and money**
  Before starting a mitigative program an agency may decide to invest in numerous studies in order to forecast how well the new measures will perform. Pitfalls associated with this type of approach include paralysis by analysis, and missing an opportunity to make an effective decision at the right time.

- **Involves risk and has secondary effects**
  When a mitigative program is decided, there may be hidden secondary effect on the geo-environmental field that may take years to show up.

- **Can result in a crisis (even in the case of success)**
  Ten years ago, a European battery producer decided to sustain a full spectrum of battery production, from tiny watch batteries to batteries designed for large vehicles. At the time, the battery industry considered the decision to be poor, because most battery suppliers were restructuring to specialize in a limited number of models. Recently, however, many of the specialized suppliers have filed for bankruptcy, leaving the full-spectrum producer as the sole company capable of meeting all market needs.

  In spite of the foresight which ultimately resulted in a good decision, the full-spectrum company recently faced a crisis: in order to meet increased production demands, a large stock of packing materials had to be ordered. These materials were stored at the producer's premises, and all possible space was used, including administrative offices, hallways and other locations. The fire extinguishing system, however, was not designed for such an increase in fire loading, and was even nonexistent in areas where there was now a clear need for a fire suppression system. A fire at that time could obviously have created a major crisis with the insurance company and the firemen; that situation would have erupted in the newspapers with accusations and screams of a "negligent" attitude.

6.2 Decision Models

Regardless of the complexity or degree of uncertainty inherent in the decision the most rational alternative is most likely to be selected when the analysts carefully, logically, and methodically analyze each alternative. Bazerman (1990) suggests the following model for decision making:

- Define the problem.
- Identify the criteria that will be used to evaluate consequences.
- Determine the relative worth of each criterion.
- Generate alternatives.
- Rate each alternative on each criterion.
- Identify the optimal alternative.

Of course, there must be more than one alternative to choose from for a decision to be made. Although minimizing the number of alternatives could be seen as simplifying the decision making process, this strategy is not recommended.

The *best decision* can only be made if the *best alternative* is among those being considered, and the best alternative may only be generated if the values are studied and explicitly defined (Keeney, 1992).

The various components of a complex decision problem may also be integrated into a formal layout called a *decision tree,* consisting of a sequence of elementary decisions. These decisions are actually the list of feasible alternatives, the possible outcomes associated with each alternative, the corresponding probability assignments, monetary consequences and utility evaluations.

Thus a decision tree integrates relevant components of the decision analysis in a systematic manner suitable for an analytical evaluation of alternatives. Probability models of engineering analysis and design may be used to estimate the relative likelihoods of the possible outcomes, and appropriate value, or utility models evaluate the relative desirability of each consequence.

Once a decision tree has been established based on existing information, with the probabilities of the possible outcomes and the consequences of all respective paths evaluated, the expected monetary value of each alternative may be computed by running successive multiplications of the values along each branch of the tree. A decision analysis based entirely on available prior information is called *prior analysis;* if this analysis is updated subsequently with additional new information, the latter is called *terminal analysis* (Ang, Tang, 1984).

7.0 Development Of RM Approach

The development of RM approach of complex facilities and complex potential failure phenomena relevant to any system requires a number of phases and steps are shown in Table 1. in Appendix A, in the subsections devoted to risk and hazard related terminology, the definitions of Hazard Identification, Risk Estimation, Evaluation and Control are presented as found in the Canadian Standards (CAN/CSA, 1991).

Obviously, because of space limitations, this paper will focus the attention only on some methodological aspects that the author deems of particular interest.

7.1 Bounding the System

The first step for studying the geo-environmental risks undergone by a facility, a system, a project or a strategy is to carefully and very precisely bound the system. Bounding is an operation that defines the limits or boundaries of a system in relation to its environment. In the RA of a facility, bounding is the operation that defines where the facility stops and where the environment begins.

In a RA for a railroad, for example, the RA boundary will most likely be beyond the right of way, and actually correspond to a location where the legal concept of proximity is also defined, i.e. the place beyond which a mishap, for example a rockfall, cannot be considered the responsibility of the RR company, but, rather, an Act of God. In a mine's RA the boundary may be defined at the exterior of the seepage collection ditches and at the outflow of the seepage treatment ponds.

A RA of an improperly bounded system will lead to wrong conclusions, loss of focus and, ultimately loss of money and time as well as poor decisions.

An effective RA initially requires identification of hazards and/or potential problems or failure modes (see section 3.0). Thus the development of a high quality Hazard Identification (HI) phase is fundamental to the quality of the whole RM approach.

7.2.1 Generic Hazards Review

HI is always a complex and difficult task, because industrial facilities are often constructed over long periods of time by a changing work force, and usually under changing design criteria; systems are complex, and include man-made components such as vessels, pipelines, controls and computers; they may consist of ponds, buildings, complex machines (each of which may be considered a subsystem and warrant a specific RA of its own) which interact with natural elements such as slopes, seismically active faults, precipitation and runoff. Previous operations can have an impact on newly built components; and industry containment methods are often process-specific and may be unique to each facility.

A comprehensive RA, therefore, must be based on a thorough HI accounting for all types of hazards and the affected components existing at a specific site or location. To be effective, the HI must be systematic, yet accommodate the varying spatial and temporal considerations of each considered site.

In order to assess as many failure modes as possible, a series of potential failure modes must be identified, whenever possible on the basis of previous historical data and creativity. Failure modes can generally be identified as elemental failure modes and compound failure modes. Elemental failure modes are those which cannot be subdivided further, and include, for example, the probability of a pipe bursting as a result of mechanical failure. A compound failure mode is a mode which could occur as a result of one series of possible elemental failure modes—a pipeline rupturing on top of a dam, for example, which could result from a series of elemental failures such as a collision with a truck, a snow removal accident, or over pressurization due to freezing.

A double listing such as Table 3 can be used to develop an initial set of possible hazards in an industrial facility (Hammer, 1972, Ericson, 1969, US Army, 1969), but unfortunately, there is no method ensuring that all possible hazards (and domino-compounding effects) will be gathered.

Table 3: Elements and possible hazardous situations. Each element can be linked to several Hazardous situations.

Elements	Hazardous Situations
Hydrocarbons	Fire, Explosion
Combustibles (including paper, wood etc.)	Fire
Chemical Catalysts	Heat, Temperature (including variations)
Vessels, pressurized vessels	Radiations (thermal, electromagnetic, UV, nuclear, ionization)
Batteries	Contamination
Generators	Toxicity
Revolving machines, Tools	Corrosion
Pumps	Chemical reactions
Ventilators, fans	Oxidation
Switches	Humidity, condensation
Springs	Leaks
Suspension systems	Pressure
Pressurized fluids	Acceleration
Objects that can fall	Falls
Objects that can slide, move	Shocks
Heating systems	Stress Concentration
Nuclear material	Vibrations and Noise
Reactors	Electricity
Energy (in any form)	

Table 4 presents a preliminary list of possible generic failure modes in industrial applications.

Table 4: Preliminary list of possible generic failure modes in industrial applications

Structural failure	Does not stop
Jamming	Does not start
Vibrations	Does not switch
Moves away from its position	Works too late
Does not open	Shorts
Does not close	Circuit is open
Fails when open	Losses of energy
Fails when closed	Leaks internally
Works intermittently, without command	Leaks externally
Shows wrong values	Goes above maximum limit
Flow is reduced	Goes below minimum limit
Starts by mistake	Wrong data input/output

7.2.2 Human Error as a Hazard: Review

In any RA human error must also be taken into account, particularly in those specifically addressing reliability of service. People are, in effect, present at each and every stage of a facility's life, from design to demolition, or reclaim/closure and original environment restoration. In fact, some authors address the Human-Machine system, where people are considered as a component—quite special ones indeed—of any system.

Humans are also obviously present in geo-environmental systems (tailings management, rockslopes maintenance, patrolling, developing forecast analyses etc.) and they influence decisions about the course of actions, the emergency procedures, the mitigative plans, meanwhile they are subject to the full spectrum of human emotions, perceptions and stresses.

In the industrial world, until the 1970s, it was generally felt that the human component was reliable, and almost error-free, particularly in relation to the high frequency of dysfunctions that occurred in other components (electrical, electronics, mechanical etc.). With recent and dramatic increases in the reliability of non-human system components, however, the human factor has been exposed as a significantly "hazardous" element, a sort of weak link in industrial processes. Analyses of failures and accident demonstrate that human error may be regarded as either a generating or a permitting factor in many geo-environmental cases too.

Statistics related to human error are not easily interpreted due to the variability of the psychological and physical state of subjects at the moment of accidents. Stress compounds these parameters, and stress levels may differ substantially between daily routine activities, maintenance and repair functions or accident/crisis status. As a result, numerical values related to human errors are simply estimates that can vary greatly as a function at least of the following factors:

- Available time to react,
- Ergonomy of facility (design of human-machine interface),
- Experience and level of instruction, and
- Stress.

In extreme situations it has been noticed that stress may induce "paralysis" of operators. Between 1973 and 1975, studies were conducted in some US nuclear power plants to investigate the probability of error versus the time available for reaction. Some quantitative models which allow definition of a probability of occurrence of a human error, and which are linked to a series of situation-dependent parameters (performance factors) have been developed by various authors (Swain & Guttermann, 1983). Tables 5 and 6 present examples of values derived through these methods

Table 5: Probability of omission in the case of written protocols, including lists of independent elements (no domino effect between elements)

Case	Type of List	Range of Probabilities
Protocol "check list" is well used	Short list (less than 10 elements)	$3\ 10^{-4}$ to $3\ 10^{-3}$
	Long list (more than 10 elements)	$1\ 10^{-3}$ to $1\ 10^{-2}$
Protocol "check list" is badly used or other procedures are used	Short list (less than 10 elements)	$1\ 10^{-3}$ to $1\ 10^{-2}$
	Long list (more than 10 elements)	$3\ 10^{-3}$ to $3\ 10^{-2}$
Task is well-known		$1\ 10^{-2}$ to $2.5\ 10^{-1}$

Table 6: Probability of error of selection for switches operated in a room

Potential Error	Range of Probability
Switch is clearly labeled, with no ambiguity, away from similar shape and dimension switches	$3\ 10^{-4}$ to $3\ 10^{-3}$
Switch is clearly labeled, in a group of maximum two switches of similar shape and dimension	$1\ 10^{-3}$ to $1\ 10^{-2}$
Switch is poorly labeled, away from switches of similar shape and dimension	$1.7\ 10^{-3}$ to $1.5\ 10^{-2}$
Switch is poorly labeled, in a group of two or more switches of similar shape and dimension	$3.0\ 10^{-3}$ to $3.0\ 10^{-2}$

This type of approach is well adapted to operations where time for reflection is not paramount, and where a single operator is at work alone. Some authors propose that human error may fall in a range between 10^{-5} and 10^{-3} (Sharp, 1984). In Table 7, data (Lees & Swain, 1980) are compiled to present an estimation of the probability of error in the case of a simple alertness test and complex diagnostic as a function of allowable reaction time.

Table 7: Estimation of the probability of error in the case of a simple alertness test and complex diagnostic versus allowable reaction time

Allowable Reaction Time	Alertness Test	Complex Diagnostic
60 seconds	10^{-1}	1
5 minutes	10^{-2}	$2\ 10^{-1}$
10 minutes	10^{-4}	10^{-1}
More than 10 minutes	10^{-5} to 10^{-6}	10^{-2}

7.2.3 Hazard Identification Techniques

Techniques such the Potential Problem Analysis (Kepner Tregoe; 1981) can also be used for HI. In a qualitative way, this technique allows to answer two basic questions:

- What could go wrong?
- What can we do about it now?

The first question corresponds to a typical HI activity, whereas the second one fits the description of a Hazard Control phase. The Kepner-Tregoe methodology encompasses four basic activities, the first two of which are typical of the HI phase of a RA:

- Identification of vulnerable areas of a design,
- Identification of specific potential problems within these vulnerable areas that merit preventative action,
- Identification of likely causes of these potential problems and identification of preventative actions, and
- Identification of contingent actions that can be taken if preventative actions fail or if they are impossible or disproportionate.

For a complex system, the adverse conditions or *faults* that could lead to the occurrence of one of the potential modes of failure may be numerous and involved, to the point that a systematic means of identifying various faults and their interactive effects (if any) on the failure event would become necessary. The fault tree diagram serves exactly this purpose.

A fault tree analysis may include a quantitative evaluation of the probabilities of the various faults or failure events (Roberts, 1981). This evaluation would lead, ultimately, to calculation of the probability of the main failure event (top event). Used in a quantitative form, fault tree analysis (FTA) is a valuable diagnostic tool. Aside from identifying all potential paths that could lead to failure, it may also serve to single out critical events that contribute significantly to the likelihood of failure of a system, and reveal the weak links, if any, in the system.

Examples of Hazard or Failure Mode Identification and in particular of Elemental Failure Modes can be drawn from reports on similar facilities (BGC-Oboni Associates Inc. 1996), publications (Oboni et Al. 1998, Savigny, Rinne, 1991), from nation-wide information resources (USCOLD,1994), and from other readily available sources.

7.3 Risk Analysis Methods

Once the hazards have been identified, a variety of techniques are available for analyzing "how bad it can get" and estimating a probability of occurrence, potential consequences, and finally, the risk. These include, but are not necessarily limited to, the following:

Failure Modes and Effect Analysis (FMEA) (US Navy, 1969, SAE Aerospace, 1967, Jordan, Marshall, 1972),
Hazard and Operability Study (HAZOP) (Lawley, 1974), or,
Event Tree Analysis (ETA) (Ang. Tang, 1984).

A *Failure Modes and Events Analysis* (FMEA) is primarily a qualitative technique which can be quantified to a degree. In an FMEA, the effects or consequences of individual component failure modes are systematically identified. The analysis is usually descriptive, and is organized using a worksheet or table to display the information. FMEA relates component failures modes and their causative factors, as well as their effects on the system, and presents them in a readable format. The major disadvantage of FMEAs are the difficulties they pose when dealing with generalized risks, and in the comparison of these risks with those obtained through other assessments to facilitate a ranking of risks.

A HAZOP is a form of FMEA which was originally created for the chemical industry. It provides a rigid and systematic way to identify hazards and operating problems throughout a facility. The objectives of the technique are to:

- produce a full description of the facility or process, including the intended design conditions,
- systematically review every part of the facility or process to discover whether deviations from the design have occurred, and
- consider how these deviations could lead to hazards.

The principles of HAZOP can be applied to systems under operation or in various stages of design.

A HAZOP study requires:

- a team, consisting of design, operating, and risk personnel,
- a collection of design documents, including operating and maintenance manuals,
- a definition of the scope of the study,
- identification and analysis of each major component in the system, and all supporting systems, and
- documentation of the consequences of deviations from design, and a summary of those deviations which are considered hazardous and credible. The documentation is usually done on HAZOP worksheets.

An *Event Tree Analysis* (ETA) is a technique, either qualitative or quantitative, that is used to identify possible outcomes and their probabilities given the occurrence of an initiating event. It is generally assumed that each event in the sequence is either a success or failure. An ETA is an inductive type of analysis, in which the question is addressed, "What happens if..?" (The ETA is conceptually similar to the decision tree described in Section 6.2)

The art of building sound ETA lies in the ability of the analyst to dissociate each failure sequence into smaller events that are more easily understood, and whose likelihood can be reasonably bounded within this range. Ravinder, et. al. (1988) show that even a moderate degree of decomposition substantially improves reliability of the aggregated probability result when judgments on the smaller components can be made with increased confidence. These two features of the PRA methodology limit the effects of some important sources of bias and contribute substantially to the successful application of the technique in practice. At the other end of the spectrum, deconstructing a problem into too many "elements" or branches may introduce errors and "dullness" into the tree.

The occurrence of a top event may or may not lead to serious or adverse consequence. A number of potential consequences may be possible, the relative likelihoods of which will depend on the conditions or subsequent events that follow.

7.4 Risk Evaluation

Risk evaluation is the phase at which values and judgments enter the decision process by including social, political, economic and environmental consequences (CAN Standards, 1991).

The most common approaches used to formulate values and evaluate risk include:

- Cost-Effect Analysis (CEA),
- Benefit-Cost Analysis (BCA),
- Risk Benefit Analysis (RBA),
- Socio-Economic Impact Analysis (SEIA),
- Environmental Impact Analysis (EIA), and,
- Regulatory Impact Analysis Statements (RIAS).

CEA:
This approach attempts to obtain a predetermined goal by the lowest possible monetary outlay, and, to achieve this end, examines all the aspects of the process under review. A RBA differs from a CEA in that there is no predetermined goal; rather, trade-off is the key.

The relationship between potential risks and anticipated (net) benefits that must be weighed.

BCA:
A BCA encompasses health risks, benefits and costs together with all alternative methods and their respective health risks, benefits and costs. Assessed competitively, a BCA assures a "market" model, and makes decisions based on market assumptions.

SEIA:
A SEIA extends the assessment of the BCA since it looks not only at one aspect of the market, but also at international trade, the rate of inflation, employment, distribution, and so on. The Canadian government's Health Protection Branch defines SEIAs as assessing:

- effects of market efficiency, in terms of production and consumption,
- distribution of income, and,
- market structure.

EIA:
An EIA assesses the effect of projects on the environment, and finally, the RIAS detail the course of actions previously undertaken, and/or considered and discuss the non-regulatory alternatives to regulatory action. The Treasury Board of Canada, for example, employs RIAs for all regulatory proposals, regardless of cost.

Obviously, in order to assess the impact of any potential failure on an item or party, potential receptors must be identified and characterized. Receptors will vary at and within each site. The potential receptors presented in Table 8 have been identified, in the course of a RA of mine tailing systems (BGC-OA, 1996), as items that could be harmed if a tailing dam failure were to occur at a specific site.

Table 8: Potential Receptors identified during a RA of tailings systems

Categories	Items
Human health and safety	public, site workers
Environmental damage	water quality
Socioeconomic factors	land use and property values aesthetics and quality of life
Infrastructure disruption	lines of transportation, utilities
Reputation and confidence	public, regulators, investors
Mine productivity	investors, workers

As pointed out earlier, risk evaluation from Public Relations related hazards is generally conducted in an informal manner, and is based on quantitative judgments. Only in recent years has leading-edge research been conducted into the formulation of quantitative approaches for "soft" risks. (Oboni, Oldendorff, 1997, 1988).

During the processes of risk evaluation and risk estimation, a number of strategic steps should be taken to structure the CM process:

- general corporate key messages are developed,
- spokespersons are assigned,
- specialists are contacted,
- crisis teams are established,
- information flow and decision making structures are installed,
- audiences (media, employees, community, government, distributors, known opposition, NGO's etc.) are identified, and
- contacts are established.

Media training which prepares spokespersons for interviews and comments to the media should be foreseen.

7.5 Risk Control

In this phase RM measures are decided, implemented and, if necessary, enforced, then cyclically re-evaluated. The array of possible technical mitigative measures is endless, and includes but is not limited to the following examples:

- moving an installation or facility elsewhere,
- moving penstocks from the surface into the mountain (well and gallery situation),
- installing alert systems,
- increasing security screening of new personnel,
- enforcing safety rules
- copying computer files to a remote location,
- installing deflagration walls for bombs,
- doubling or duplicating facilities, and
- doing nothing.

8.0 Costs Aspects

8.1 Cost of Mitigative Programs and Crisis Management

Costs related to the implementation of mitigative programs are generated by studies and engineering fees, construction costs, and the maintenance / repair / replacement costs that must be accounted for over the life or duration of the system. Remarkably, there are very few instances in which these costs have been formally incorporated as part of the decisions regarding mitigative structures.

The costs of RM/CM and preparedness depend on the amount of research conducted to assess risk, the comprehensiveness of the CM plan, and the thoroughness of implementation. RM/CM costs are ongoing costs that can be budgeted for. They reduce the ultimate costs of the consequences of a crisis and this should be accounted for.

8.2 Cost of Consequences

Cost of Consequences can be mitigated and proactively reduced through a RM and CM Plan. RM will help allot money to the most vulnerable areas of a system in order to implement risk reduction measures, acting either on the hazard source or on the cost of a hit of that particular hazard on a potential target within the system. CM will trigger the preparation of communication protocols and PR action that will help minimize the "public cost" of a crisis (Cohn, 1996)—the costs due to loss of business, boycotts, negative images and so on.

Crises in the form of disputes, protests or legal battles can result in immense costs for an organization. Grunig (1992) gives some geo-environmental examples of crises as a result of activism which, for the involved companies, are the equivalent of costly "accidents":

- An association of oyster growers fought a developer for seven years. The development company lost its battle to build a resort on disputed wetlands.
- A moratorium on building a sewage treatment plant led to the layoff of 115 employees and higher interest rates at the time of the actual construction.
- A resort was forced to spend $300,000 to improve its sewage system.
- A proposed basalt-mining operation never got off the ground after its small-town neighbors complained.

8.3 Life Time Risk-Crisis Cost of a Project

As mentioned earlier, risk is generally defined as the product (multiplication) of the probability of occurrence of a hazard by the cost of the undesirable consequences resulting from the occurrence of the hazard. As such, the first step in determining the risk is the determination of the probability of occurrence of the hazard generating that risk.

The probability of occurrence of a given phenomenon can be established by various analytical or qualitative methods (Ang, Tang, 1984, ANS, 1983). Once the probability p_x of a phenomenon x is determined, the cost of consequences C_x has to be evaluated in order to allow the estimation of the risk. Stated otherwise as:

$$R_x = p_x \cdot C_x$$

Cost C_x can be considered as a stochastic function resulting from a sum of—I—stochastic terms C_{xi}, each representing an *ith* component of the cost of the accident due to the phenomenon x (reconstruction, direct, indirect).

A detailed approach to the probabilistic evaluation of life-long costs of a mitigative option or a strategy has been recently presented by Oboni and Oldendorff (1998). The method can be generalized to study a system subject to an array of geo-environmental hazards—natural, human-made, industrial, boycott—and mitigative measures of various nature, including PR.

9.0 Two Examples Of Minimization Of Long-Term Global Costs Based On Risk Assessments

9.1 Landslide Damages Insurance Company

Following a number of sudden movements and reactivations of dormant landslides, an insurance company in an Alpine country became aware that, over the course of many years, its "landslide insurance" department had overexposed the company by insuring buildings for landslide damages located in dormant slide or unstable areas.

The first reaction of the company was to tighten the rules and "correct" its behavior by avoiding this type of contract, and to try to "get out" of old contracts that looked unfavorable. This reaction in turn triggered a number of events: potential clients approached competing companies, established clients were angry and displeased with the company, and within the company itself, various stakeholders became very vocal in arguing that the company was either failing in its commitment (mission statement) to help and protect the community, or that the company was losing too much business because of a "panic reaction after only a couple of "accidents."

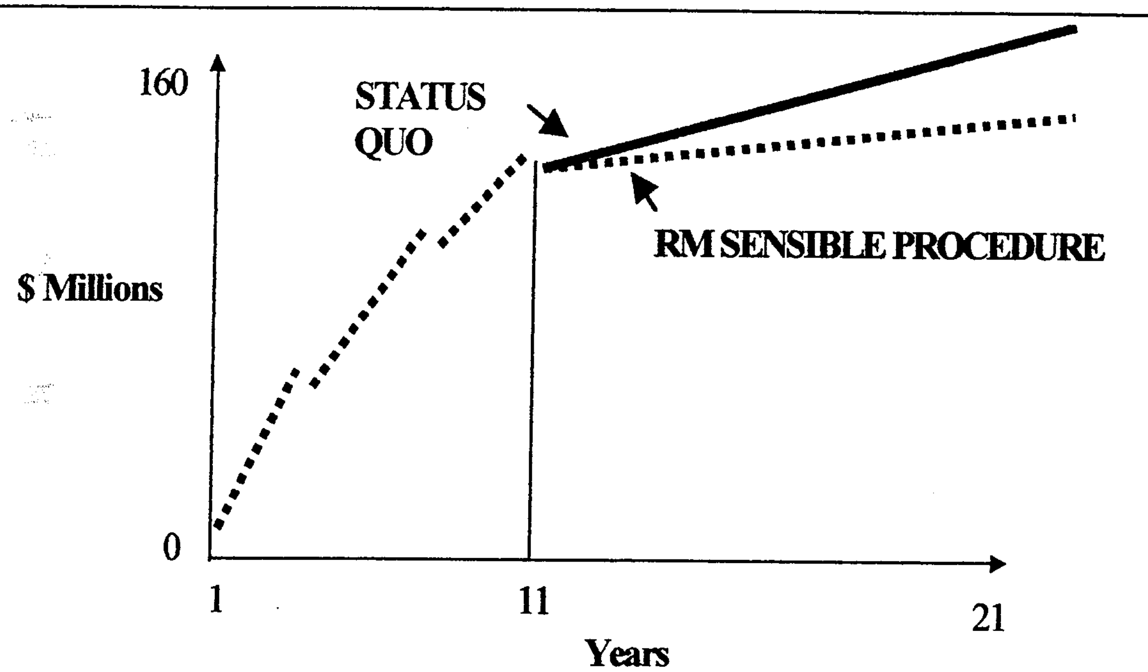
The impact of various mitigative scenarios was studied, among which the following can be cited:

- *Status quo*, i.e. continuation of company practices as conducted prior to the accidents.
- Continuation of the "hard core" protocols developed in the aftermath of the accidents.

- Development of a sensible procedure, widely published and delivered to prospective clients in such a way that they could themselves determine their level of risk. They would then be able to see how mitigative measures implemented on their structures would influence the risk, and therefore, the decisions of the insurance company.

In this case, parameters for the analysis were derived from the insurance company's database. Among these parameters, the average number of "overexposure" type of contracts per year and the average time to damage for these contracts may be cited.

Fig. 4 below illustrates the evolution of the NPV of the first (*status quo*) and the last (sensible procedure) alternative over the next twenty years. Note that the two alternatives deliver identical results up to the 11th year, as, in this particular evaluation, the average time to damage was found to be equal to ten years. After the 11th year, the two curves diverge, and at the end of the considered period the economy achieved by introducing the "sensible procedure" is evaluated at approximately 35M$, compared with a total cost of over 160M$ for the status quo scenario.



Risk Management and Integrated Crisis Planning
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Fig. 4: **Sensible procedure net present value (NPV) over the next 20 years**

The third alternative, i.e. the development of a sensible procedure, was finally chosen and implemented as follows:

1. A simple methodology based on scoring tables was developed to allow prospective clients to determine, together with their design team, a terrain hazard evaluation. This evaluation takes into account not only the geomorphology and possibly known physical parameters of the terrain, but also the level of available knowledge and the behavior of neighboring structures.

2. Another scoring table has been developed to determine the vulnerability of the structure, i.e. its tendency to be damaged by possible terrain movements.

3. The risk is evaluated as a score resulting from the multiplication of the terrain hazard score and the vulnerability score. If the risk score is less than a given threshold value, then insurance is warranted without further action or investigation.

4. If the risk scoring is higher than the limiting (threshold) value, then the owner, together with the design team, enters a phase where the effects of various risk mitigating options are evaluated in terms of risk score reduction. It is the owner's and the design team's responsibility to decide which mitigative option they choose. The insurance company is only interested in insuring a building that obtains, directly—or with the help of the selected mitigative option—a risk score lower than the threshold value.

The procedure described above is represented graphically by Fig. 5:

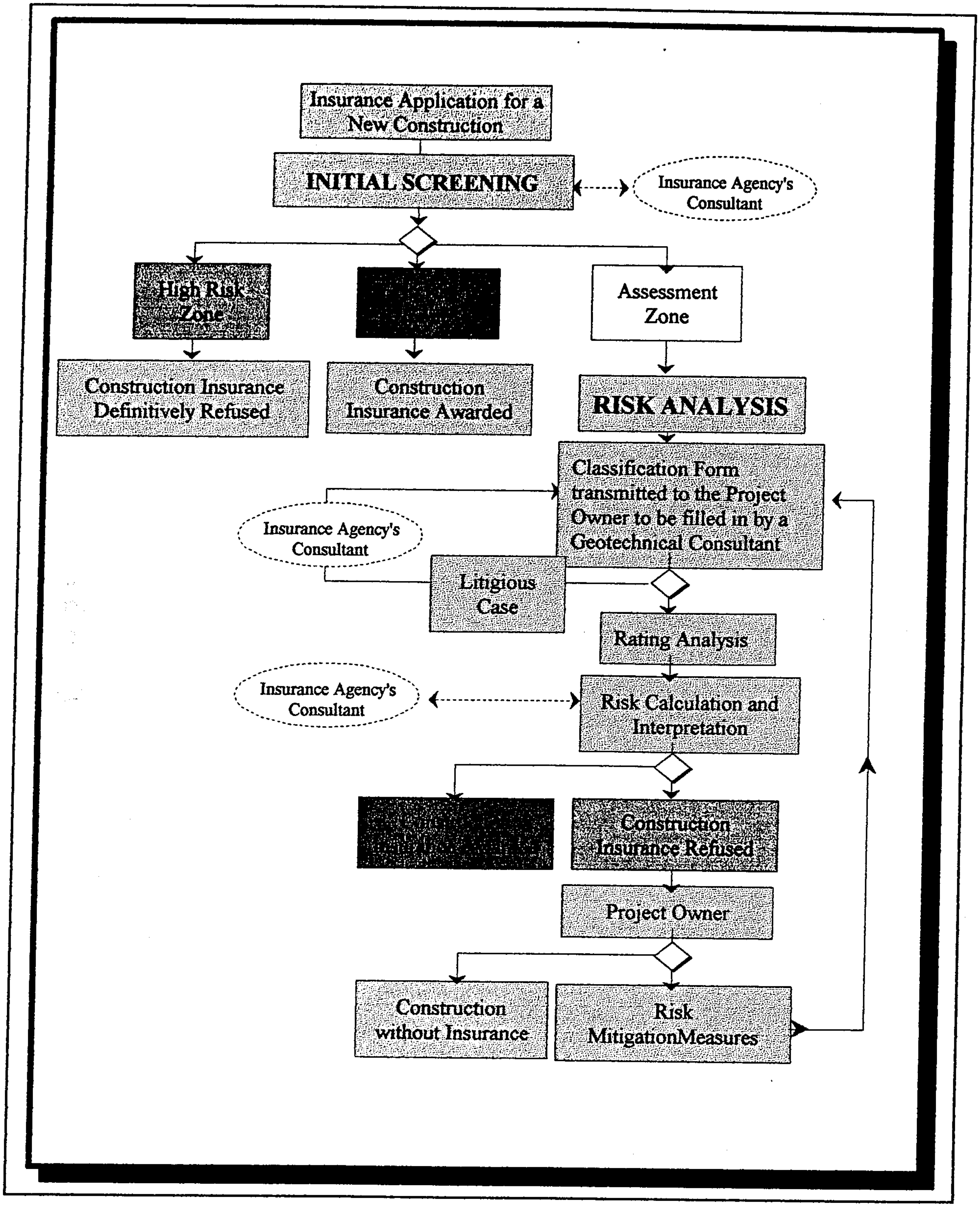

Fig. 5: Flow chart of the sensible procedure for Landslide Damages Insurance

9.2 Rockfall Mitigative Works Uphill of a RR

This analysis was performed on a section of a railroad track in North America, which is subject to rockfall.

On the considered stretch of track rockfall susceptible of derailing a train happened over twenty years ago, and then repeatedly, at the rate of approximately one per year in the last three years. The possible mitigative tactics were the following:

- no action,
- shed,
- rockfall nets,
- rockfall nets combined with alarm system,
- alarm,
- scaling

The twenty years NPV of the cost of each mitigative tactic was evaluated following the ICP® procedure, leading, for the specific section of track considered in this study to the results shown in Figure 6. (n.b. these results are site specific and should not be considered as general). In the figure one can see the NPV cost in the *y* axis and the expected number of rockfall occurrences over the next 20 years on the *x* axis. An entry of n=20 means that 20 occurrences are expected over the next 20 years, leading to a frequency of 1 event per year, whereas, for example a n=5 means that the expected frequency is 5/20=4, thus 1 event per every 4 years.

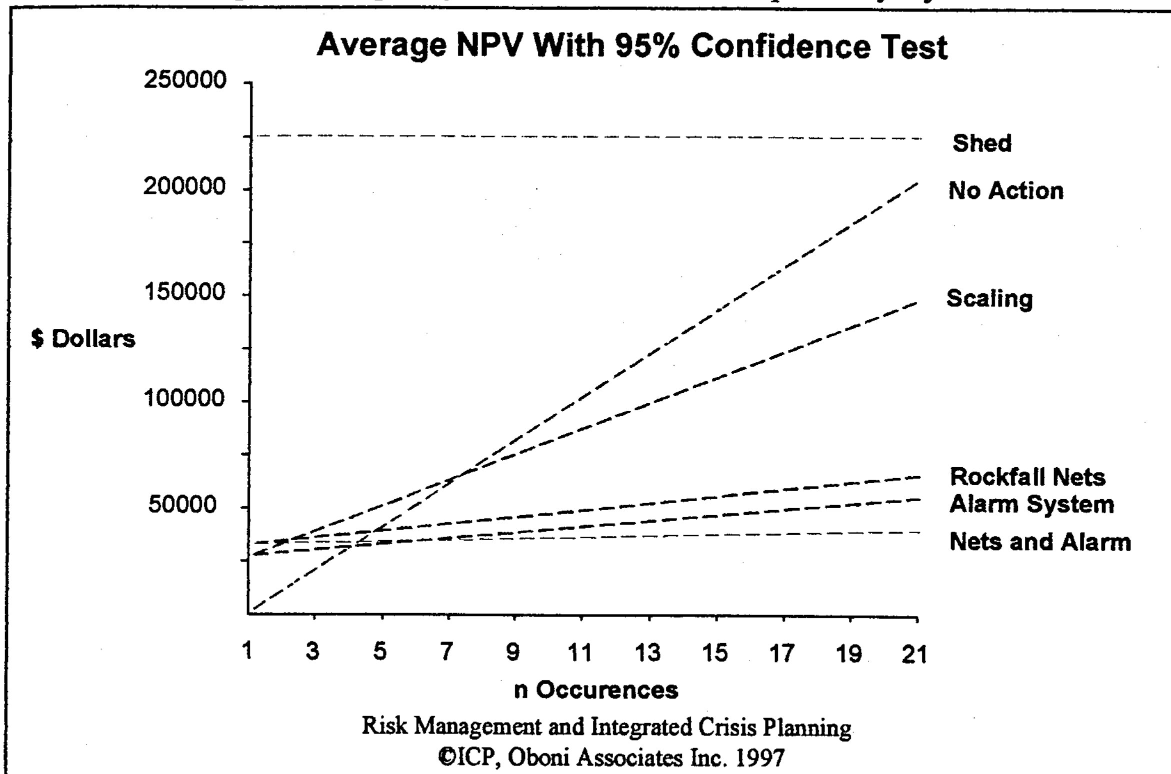

Fig. 6 Twenty years net present value of the global risk-cost of various mitigative tactics at the selected location. The 95% confidence value of NPV is plotted against the possible number of hazard occurrence.

The ICP© method can be used to test the "robustness" of a mitigative scenario versus the possible variation of the number of hits of the hazard. If the plot NPV *n* remains relatively horizontal for all possible *n*, as is the case for Rockfall Nets, Alarm Systems and Nets and Alarm System in Figure 6, then the mitigative scenario under scrutiny is extremely robust, i.e. very insensitive to one of the most uncertain parameters in the analysis, i.e. the expected number of occurrences of the rockfall.

Thus, when choosing among various candidate mitigative scenarios, one of the selection criteria may be to chose the more robust scenario over more sensitive ones. Note, however, that the robustness criteria cannot be used alone: in the case of Figure 6, the shed is the most robust solution (the graph is horizontal), but remains much more expensive than any other option for any value of *n*.

Based on the test data, an evaluation may be made that NPV'd cost depends linearly on the number of rockfall, and that there is a minimum point (with regard to *n*) for most mitigative measures beyond which the cost of no action is greater than implementation of any of the measures but the shed.

10.0 Conclusions

After reviewing the broad aspects of Geo-Environmental Risk, and its Assessment, Analysis, Management and Planning, this State of the Art paper has focused the attention on Risk-Based decision making, showing how risk should or may influence decisions and how corporations, governmental agencies and other private or public entities may include risk in their policies and decisions.

The constant link between risks and crises has been emphasized, with particular focus on the need for crisis preparedness and management.

A set of conclusions can be drawn by the analysis of the State of the Art of this field, as follows:

- When dealing with risk and crises, communication, taken in the broadest sense, is essential to proper assessment, management and planning

- An essential step related to RA is the bounding of the system. Severe under- or over-estimations of the risks can be achieved by improper bounding of the system

- There are no methods ensuring that all hazards or consequences are accounted for.

- Human error is a well known factor in industrial risks, but often and wrongly neglected in geo-environmental risks

- Geo-environmental data are by essence scarce and/or difficult to gather, specially when long-term risks are considered.

- Statistics can rarely be used. Rather, probabilities and specifically subjective probabilities are a common tool.

- Geo-environmental systems are dynamic, evolutive systems, with or without human action, and therefore risk studies should be cyclic and built around the cyclic reevaluation.

- In order to obtain a technical-economical optimum risk and crisis management have to be integrated and updated simultaneously

- Public perception is a "reality"—and is as important as reality.

Acknowledgments

The sections related to Crisis Management are extracted from *Risk/Crisis Management Systems Design*, a course manual developed in 1977 by Dr. Gitta Oldendorff (former Crisis Management expert at Oboni Associates Inc.) for the CM sections and Dr. F. Oboni for the Risk/Hazard Management aspects (©1977 Oboni, Oldendorff). The course manual is used for a three day program delivered by Dr. Oboni in cooperation with a leading Crisis Management expert at the University of British Columbia, Vancouver, within the frame of Continuing Education Program.

ICP® is a proprietary methodology for the Integrated Crisis Planning (©1977 Oboni Associates Inc.). ICP® is a management tool for decision-making that goes beyond traditional RM and CM. It opens avenues to comprehensive and cost-effective RM/CM. ICP® has applications in all types of crises, regardless of origin. Natural, industrial, or human-generated hazards and their related costs may all be quantified with the methodology. Hazards may include terrorism and, in some cases, political risk.

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Appendix A: Terminology and Definitions

General Terminology

Cost of Consequences	A monetary measure of the impact of a hazard on potential receptors, obtained as a sum of various components such as direct costs, replacement costs, indirect costs (loss of business etc.), social costs, political costs, public reaction costs etc.
Public Relations (PR)	A management function that helps to define organizational objectives and philosophies, and facilitates organizational change. Public relations practitioners communicate with all relevant internal and external publics in an effort to create consistency between organizational goals and societal expectations.
Problem	A doubtful or difficult matter requiring a solution; sudden deviation from an expected performance or the existence of a permanent deviation from an expected performance.
Accident	An event that is without apparent cause or is unexpected. Generally an unfortunate event, possibly causing physical harm or damage brought about unintentionally.
Incident	An event or occurrence that attracts general attention or that is otherwise noteworthy in some way.
Catastrophe or Disaster	A great and usually sudden "disruption of the human ecology which exceeds the capacity of the community to function normally, unless disaster preparedness and mitigative measures are in place."
Preparedness	Activities that take place before a catastrophe and which are geared towards ensuring that disaster managers have tools at hand to cope with crisis events when they occur.
Mitigation	Measures and activities implemented with the goal of reducing or eliminating the impact of the events (cost of consequences) or reducing the hazard (probability of occurrence).

Risk Related Terminology

Risk	The product (multiplication) of the probability of occurrence of a hazard by the cost of the undesirable consequences resulting

from the occurrence of the hazard. In some cases, the product is not expressed, and probability of occurrence p and cost of consequences C may be plotted as points on a p-C graph .

Risk Management (RM)	The complete process of risk assessment and risk control, i.e. the result of a rational approach to risk analysis and evaluation, and the periodic monitoring of its effectiveness using the results of RA as one input.
Risk Estimation	May be based on historical data, logical models (fault and event trees), or mathematical models. Probabilities can be assigned subjectively or objectively if an historical database is available. Risk estimation helps answer the questions, "What is the likelihood of the hazard, what will happen, and what areas will be affected?"
Risk Evaluation	The process of determining acceptable risk. There are upper and lower limits (or thresholds) to risk that need to be defined before risk control can take place. These thresholds are often influenced by society's level of accepted risk.
Risk Control	The process of deciding on measures to control risk and monitor the results of implementation. Decision theory can be used as a tool here. Risk control can answer the question, "What can be done to reduce the risk?"

Hazard Related Terminology

Hazard	A condition with the potential to cause undesirable consequences. The term "hazard" is often used to mean "source of a given magnitude" (for example, m^3 of sliding mass).
Hazard Management (HM)	The set of techniques used to define hazards and to rate them in terms of likelihood or magnitude.
Hazard Identification	Identifies the hazards and potential damages. Hazard identification answers the question, "What can go wrong?"

Crisis Related Terminology

Crisis	A decisive moment, particularly in times of danger or difficulty.
Crisis Management (CM)	A set of techniques that manages the public relations and media relations implications of crisis situations that have the potential to damage or destroy the image and/or function of an

organization. Crisis management is also an organizational discipline involving logistics experts, security managers and technical communications experts.

Issue Management (IM) A relatively new discipline that identifies and manages "issues" related to an organization. The tools are research (issue identification phase) and a variety of techniques designed to develop effective communication channels between the organization and its stakeholders. Issue management manages issues that are potentially detrimental to an organization's reputation or operations in such a way that the issues do not lead to crises

Risk Communication Part of the RM/CM process and, in a way, risk mitigation at the non-technical level. Stakeholder analysis has to be performed to prepare a risk communication campaign (the public does not care about facts from the technical RM process but about values and emotions).

Crisis Management Plan A CM Plan is the compass in the middle of the fog, i.e. a crisis. A CM Plan encompasses several components.

Media Training The media are an important stakeholder in a crisis and are often a key link to the public and other stakeholders. The development of key messages that reflect the knowledge that is acquired in the RM process and other important factors in a crisis (for example, compassion) is an important step in media training.

Probability And Statistics Related Terminology

Statistics The set of mathematical interpretative techniques to be applied to phenomena that can not be studied deterministically because of the number and complexity of their parameters. An example of such a phenomenon would be the duration of a flu-related sick-leave. There are dozens of driving parameters, including physical and mental fitness of the sick person, the environment and so on. There is certainly no deterministic "magic formula" to determine the duration of the required leave. As a result, it is possible to say only that a flu-related sick leave "lasts from three to ten days, with an average of five and a standard deviation of one."

Probabilities The set of mathematical rules used to evaluate the stochastic (uncertain, possible) character of an occurrence by evaluating the number of chances of the occurrence of the phenomenon over a total number of possible occurrences. In *De Natura Deorum*, Cicero wrote that "probabilities direct the conduct of the wise man." Evaluating chances, studying their consequences and opting for various courses of conduct are indeed the basic steps of modern Risk Management and risk-based decision making. As such, statistics are a *descriptive* discipline whereas probabilities are an *evaluative* discipline. If the flu example given above is addressed in terms of probabilities, for example, it may be seen that probabilities can be used to evaluate the chances that an ill person will still be on leave in two days time.

Probability

A measure of the likelihood of an event, expressed with numerical values ranging from 0 to 1, where 0 represents impossibility and 1 certainty. Probability is often interpreted as a subjective degree of belief (opinion, subjective interpretation). For purposes of this text, the frequency interpretation of probability, in which probabilities are understood as mathematically convenient approximations of long-run relative frequencies, will not be used.

Frequency

Frequency or **relative frequency**—a proportion measuring how often or how frequently something occurs in a sequence of observations.

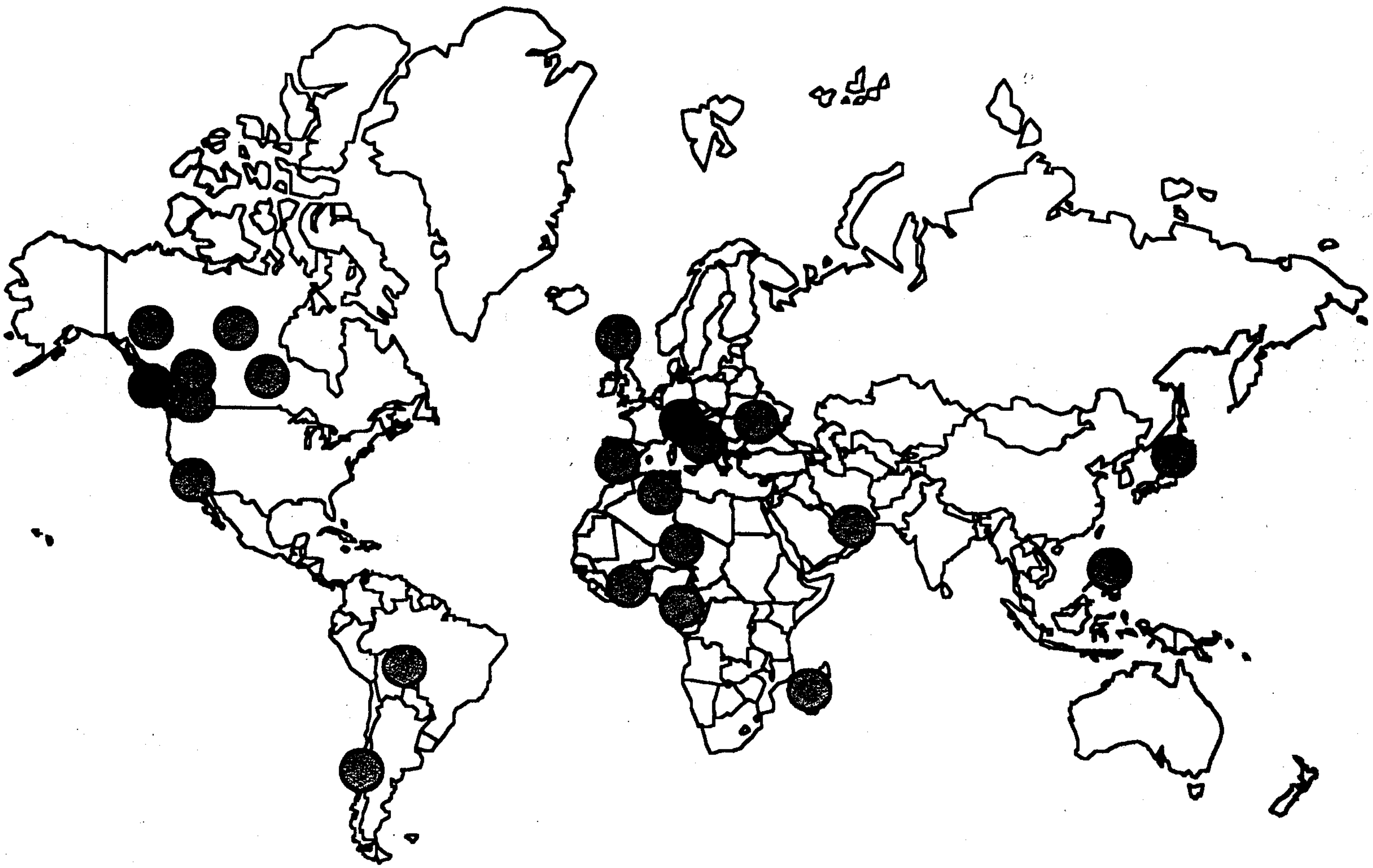
RISK MANAGEMENT
&
INTEGRATED CRISIS PLANNING (©ICP)

by

Oboni Associates Inc. (**OA**)

OBONI associates

EXPERIENCE INTERNATIONALE



Bureaux internationaux:

- **Lausanne, Suisse**
- **Vancouver, Canada**

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WHY RISK MANAGEMENT?

- Risk exposure and mitigation evaluation
- Information and accountability
- Shrinking human and financial resources
- Accusations, liabilities and business losses
- Irrational and emotional reactions

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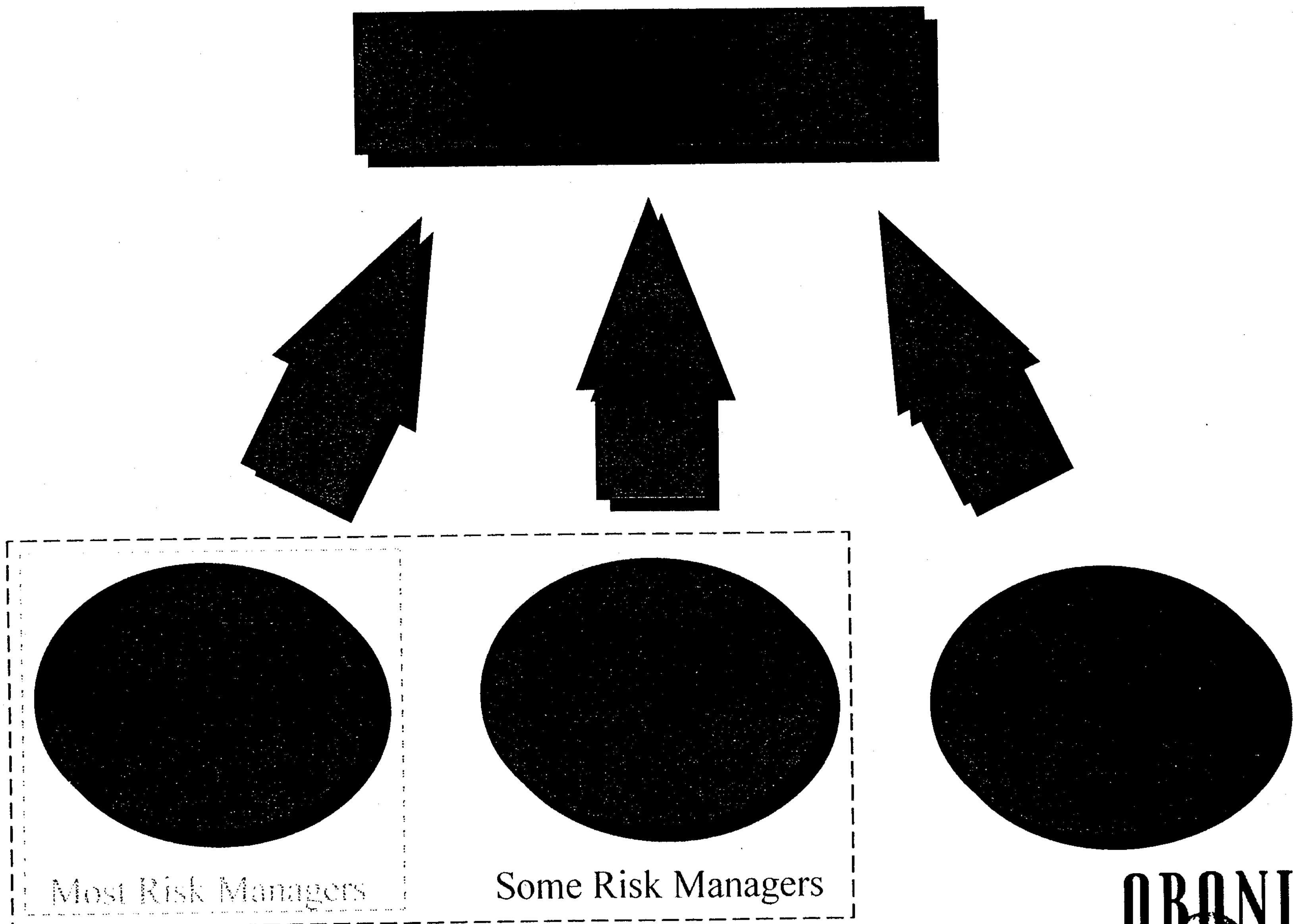

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“MANAGING” RISK

<u>Hazard Management</u> - based on likelihood or magnitude

<u>Risk Management</u> - based on cost of consequences as well as liklihood. RM and HM are not the same!

<u>Crisis Management</u> - manages public reactions to “situations”/hazards that can damage an organization

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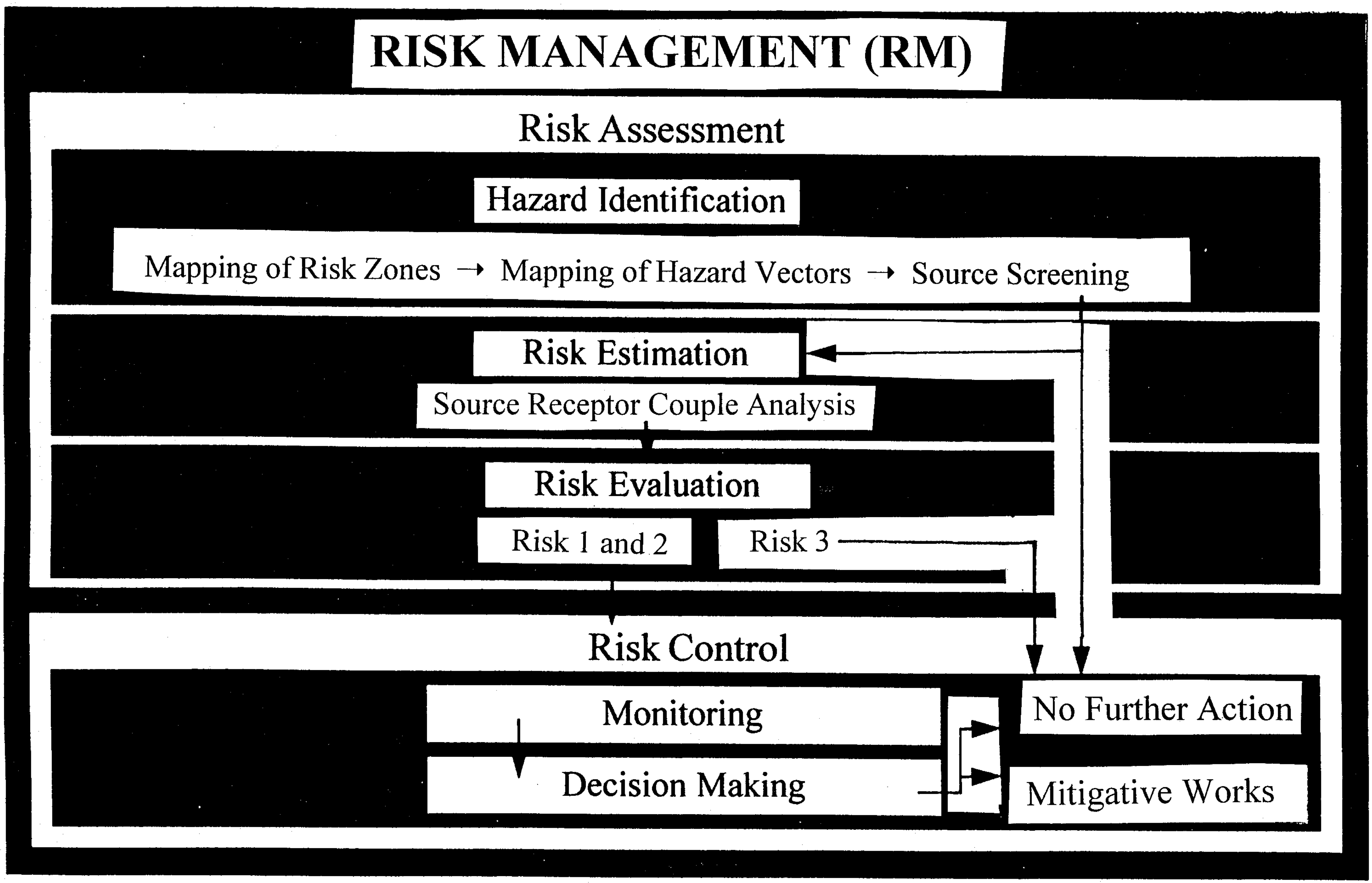
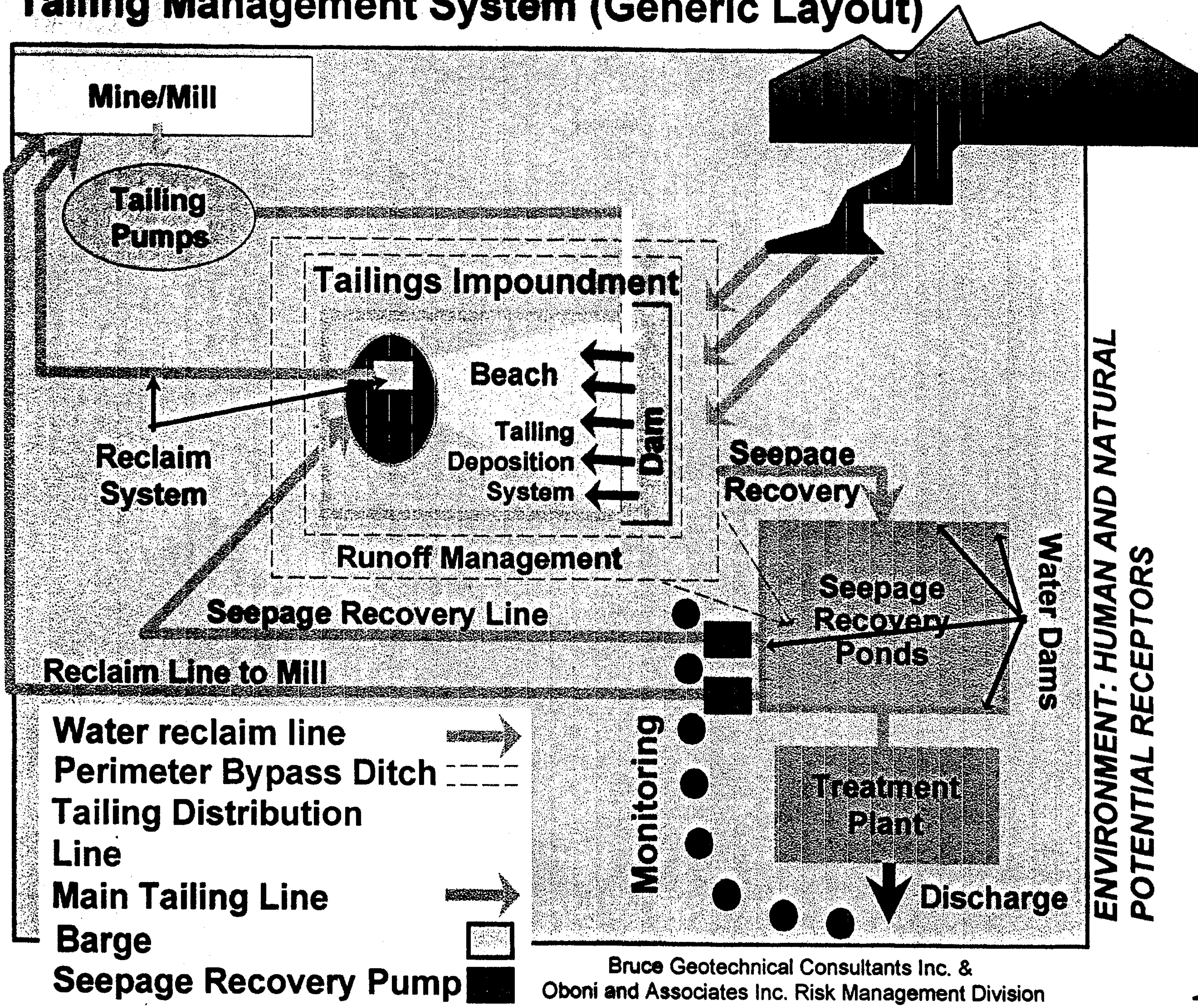


RISK MANAGEMENT (RM)
Risk Assessment
Hazard Identification
Mapping of Risk Zones → Mapping of Hazard Vectors → Source Screening
Risk Estimation
Source Receptor Couple Analysis
Risk Evaluation
Risk 1 and 2
Risk 3
Risk Control
Monitoring
Decision Making
No Further Action
Mitigative Works

Tailing Management System (Generic Layout)



Bruce Geotechnical Consultants Inc. &
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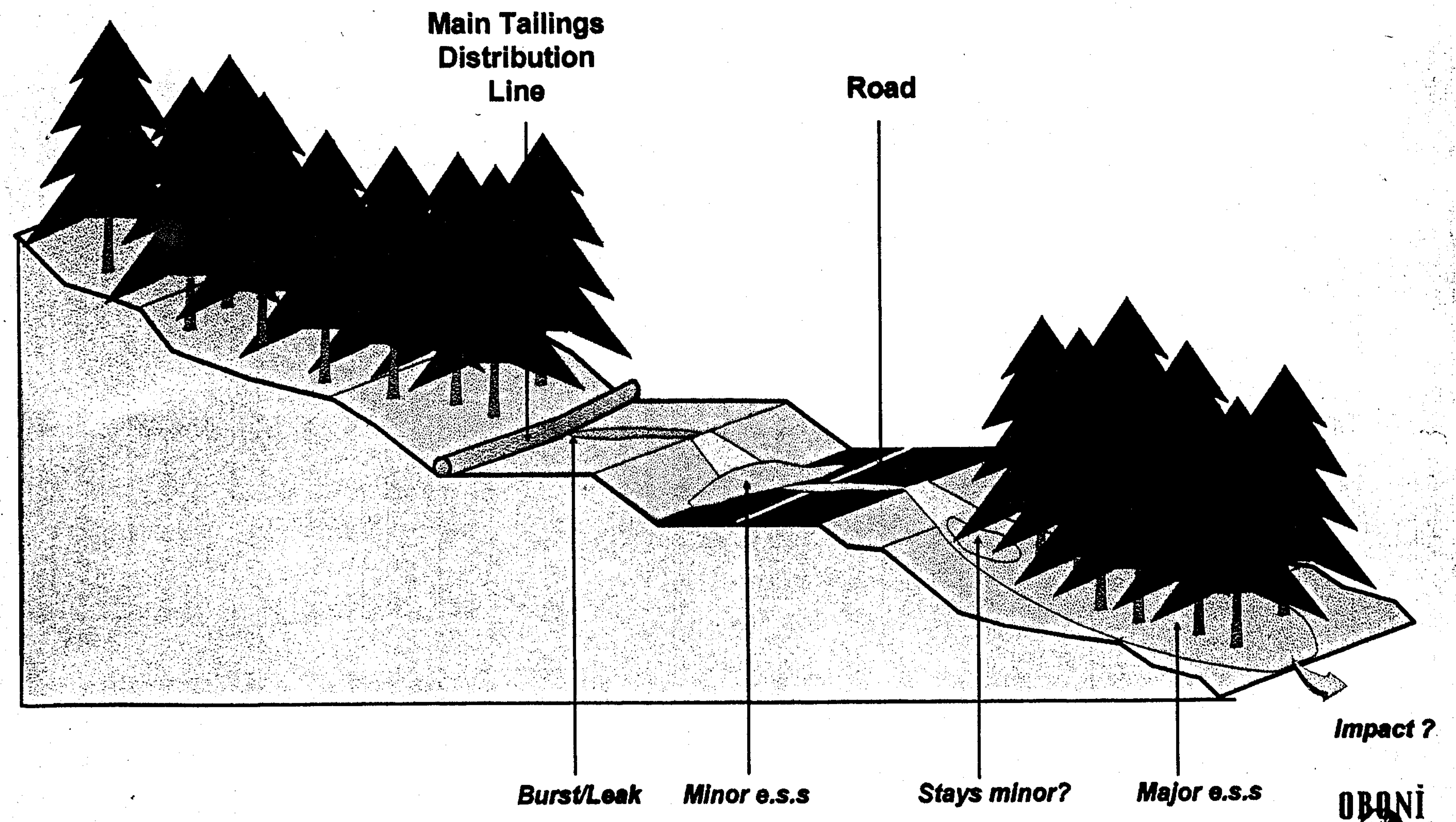
MAIN TAILINGS DISTRIBUTION LINE LONG/SHORT DURATION BURST/LEAK

FIGURE 3

not to scale



DETERMINING "RISK"

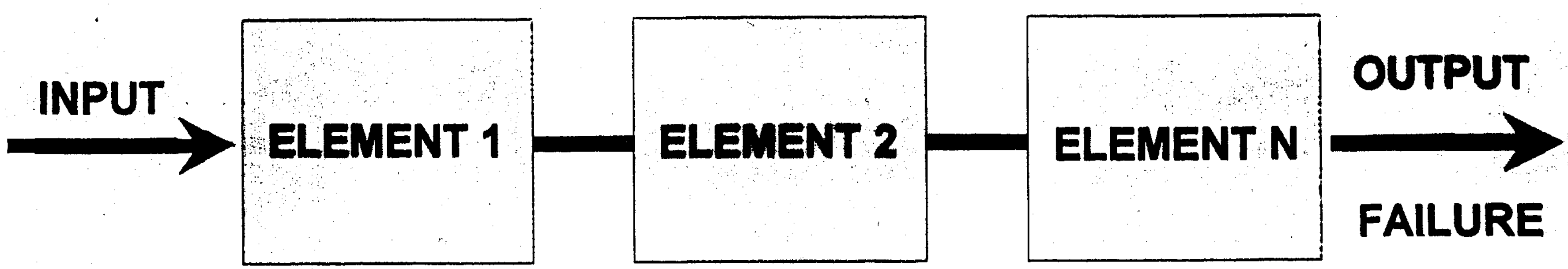
Probability - likelihood of an event (0 to 1)

Frequency - how often something occurs

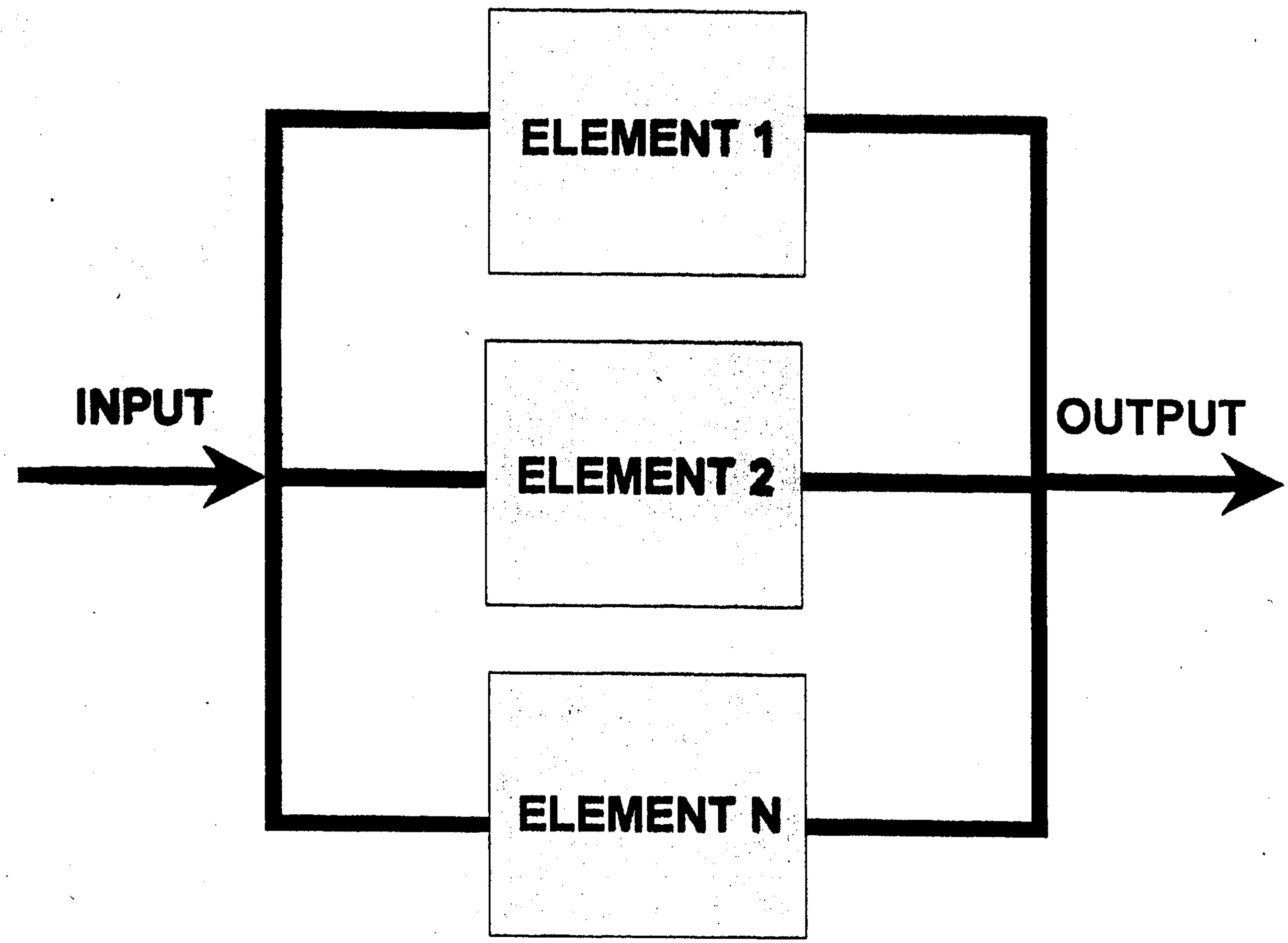
Hazard - condition with POTENTIAL to cause consequences

Cost of Consequence - measure of impact of hazard on potential receptors

SERIES SYSTEM



PARALLEL SYSTEM



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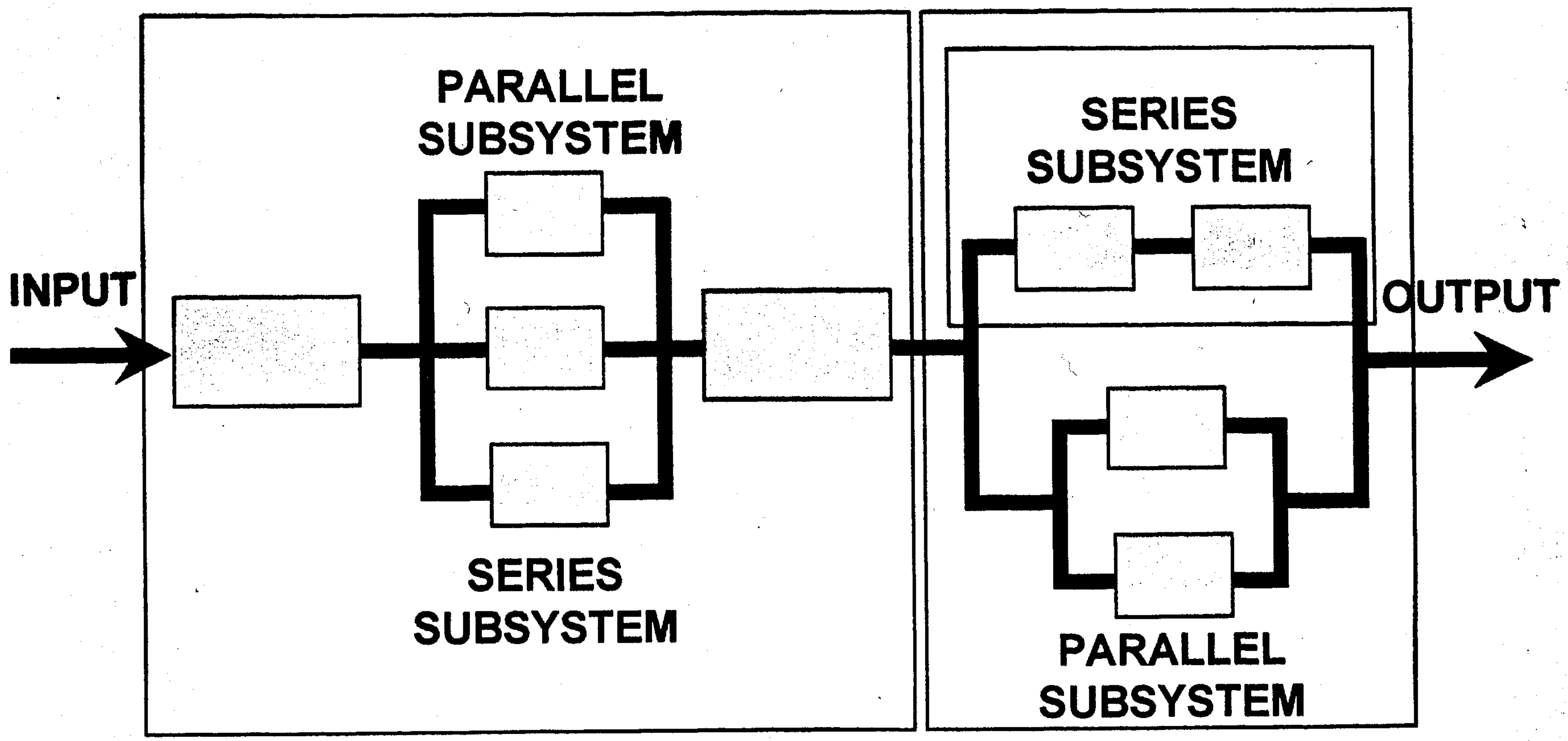
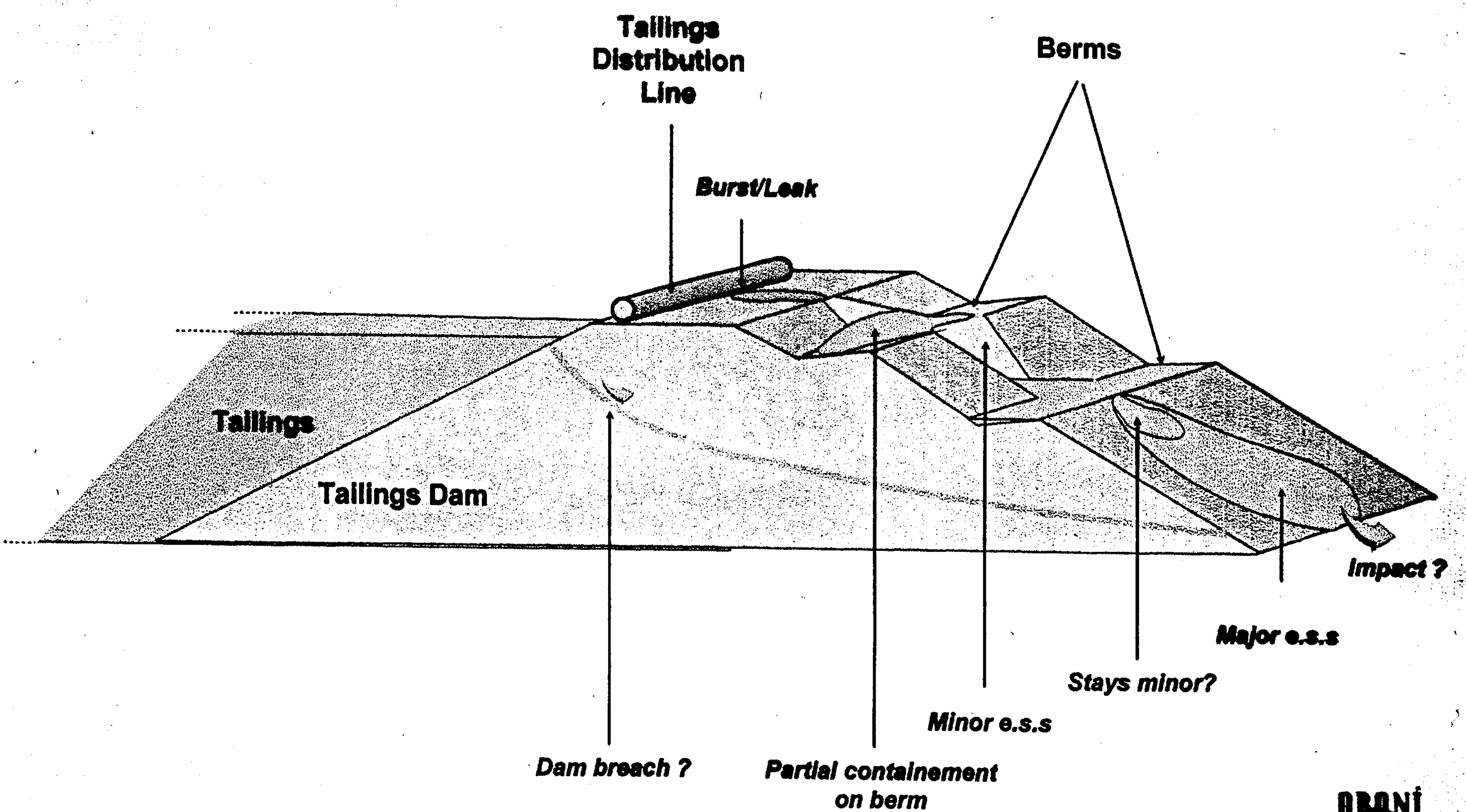
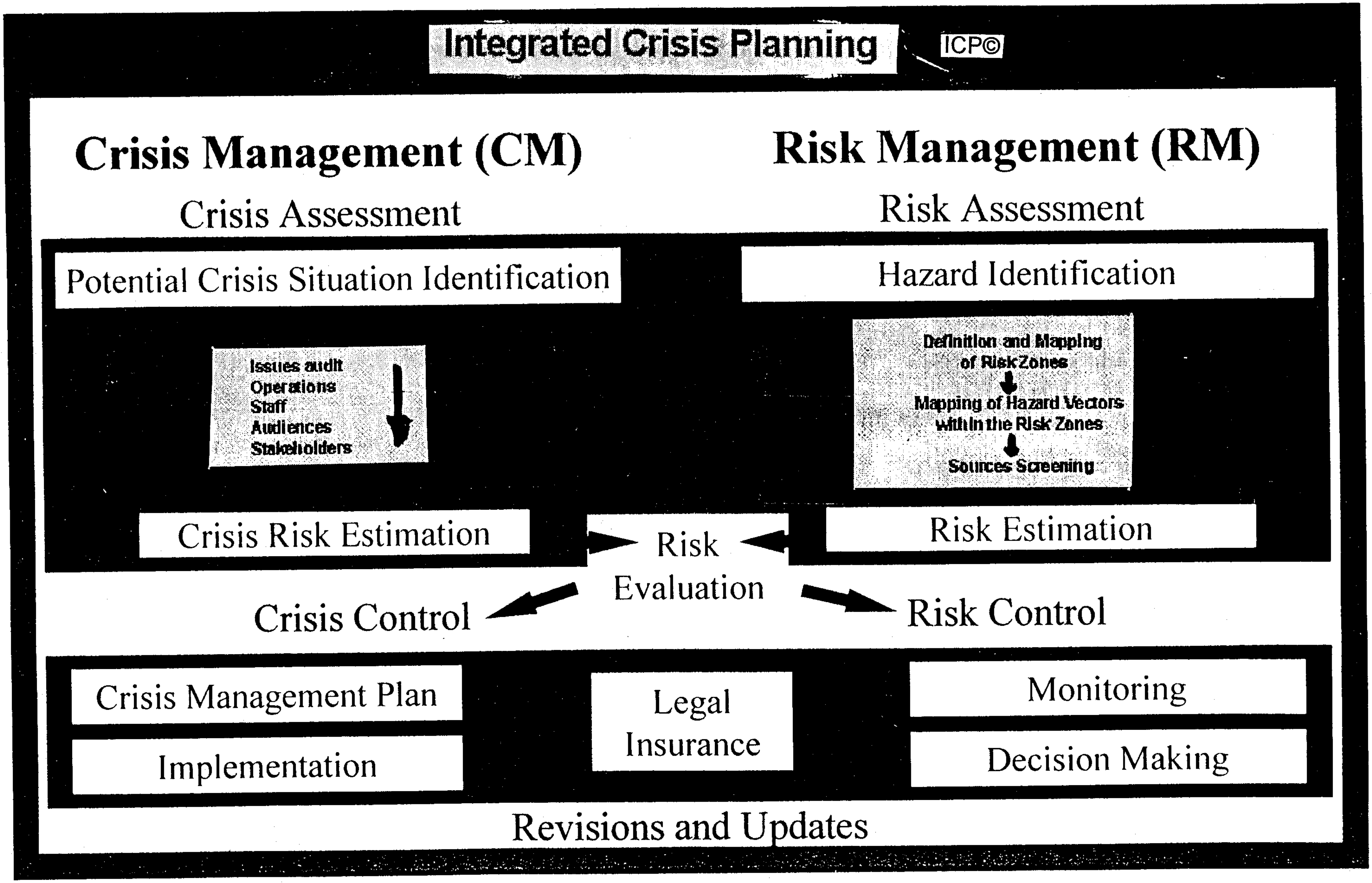
HYBRID SYSTEM



	TAILINGS DISTRIBUTION LINE LONG/SHORT DURATION BURST/LEAK AT THE CREST OF THE TAILINGS DAM	FIGURE 2
		not to scale





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LEVELS OF "ACCEPTABLE" RISK

- Zero Risk
- As Low As Reasonably Achievable (ALARA)
- As Low As Reasonalby Possible (ALARP)
- Best Availiable Control Technology (BACT)
- "de minimis"

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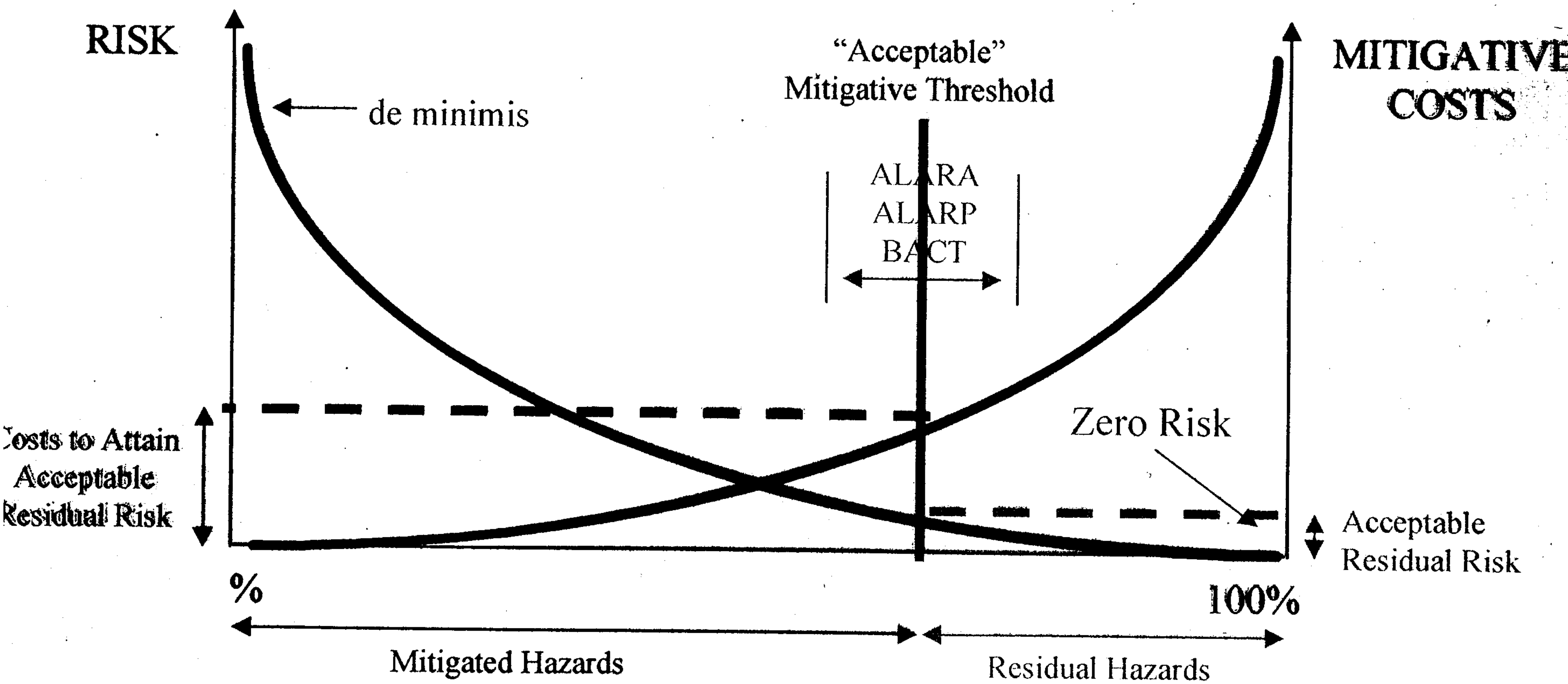
Mitigated Hazards and Residual Risk



BENEFITS OF RISK MANAGEMENT

- Clearly delineates priorities
- Enables efficient allocation of resources
- Enables rational risk mitigating choices
- Helps meet public expectations
- Provides a clear and defencible approach
- Enhances communication and transparency

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