Bridging the gap between field operations and risk management

Mark Leir, M.A.Sc. P. Eng., P.Geo., BGC Engineering Inc., Vancouver, BC, Canada

Introduction

Pipeline operations and engineering personnel in Canada are under increasing pressure from regulators, legal precedent, insurance providers, and standard of care guidelines to manage their risk from natural hazards in a systematic and proactive manner. This requires that pipeline operations personnel transition from a traditionally reactive hazard management approach to a more proactive approach using hazard and risk assessments. In response to these pressures, in the last decade, more Natural Hazard and Risk Management (NHRM) systems have been adopted by multinational corporations [1-6].

In accordance with sound risk management frameworks [7, 8] some corporations begin by building a hazard inventory across their system that include geotechnical (ground movement hazards such as landslides), hydrotechnical (river), and/or seismic hazards. Some corporations then apply qualitative (subjective) hazard and risk estimation methodologies to the inventory while others elect to use fairly quantitative techniques. Regardless of the approach, demonstrating risk reduction should be an important objective. This paper provides insight into how to strengthen the link between the Risk Control and Risk Estimation phases of the framework so that risk reduction can be demonstrated from the outset of the program. It discusses how the design of risk management systems should simultaneously consider, at the outset, the Risk Control phase of risk management, the project scale, how the system will demonstrate risk reduction, and the qualifications of those collecting re-assessment data. Specifically, emphasis is on a new approach of designing systems from the "field up" so simple and practical observations made during regular field inspections can be used to qualitatively or quantitatively update the hazard, vulnerability, and risk.

This paper and presentation should be of interest to those involved in geohazard management, specifically pipeline operations field personnel, operations engineers, integrity personnel, risk management personnel, and consultants designing and implementing hazard and risk systems.

Risk Management Frameworks

Awareness of the risk management framework is necessary during the design stage in order to incorporate the full cycle of risk management and ensure the system can eventually demonstrate risk reduction. The NHRM requirements for identification, assessment, and management are met in the systematically organised framework shown in Figure 1. Five Phases for implementing a risk management program, revisited by Porter *et. al.* [6], adopts this framework. Of importance to this discussion is recognising that the linkage between Risk Control and Risk Estimation is required to demonstrate risk reduction. Risk Control includes field based re-inspections that allow new observations about the hazard and vulnerability to be collected. Risk Estimation uses those new observations to re-estimate the risk. Comparison of risk from one inspection to the next allows management to determine if the risk is increasing or decreasing at the hazard site and to adjust their inspection frequency and action plan accordingly. Problems from failing to incorporate this linkage into risk management systems are discussed throughout this paper.

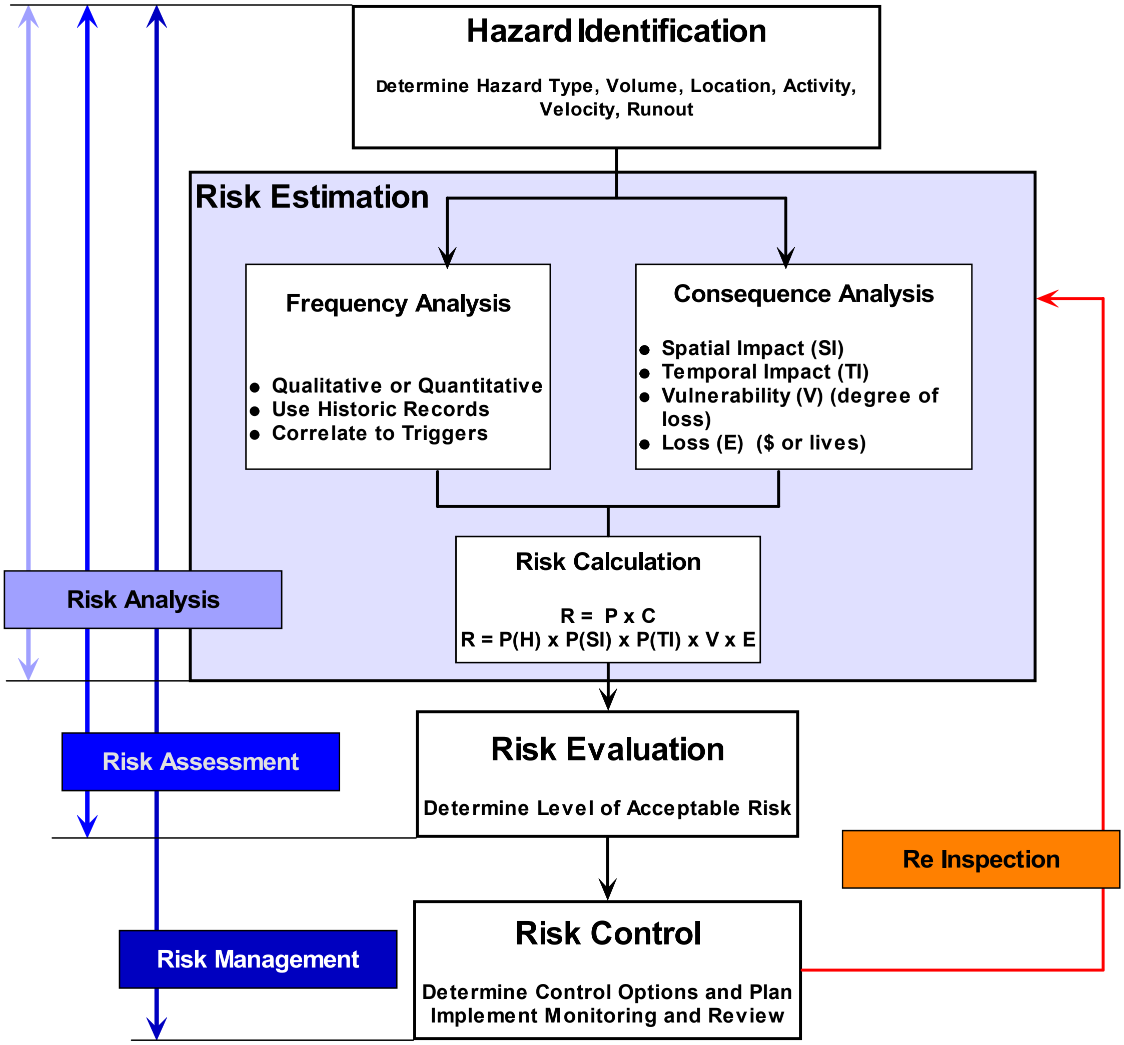

Figure 1. Natural hazard and risk management framework. Adapted from [7, 8]

Awareness of a Staged Approach

Figure 2 shows a staged approach where the risk management framework is re-applied to larger project scales in order to seek greater detail and clarity on the high risk sites identified in previous stages.

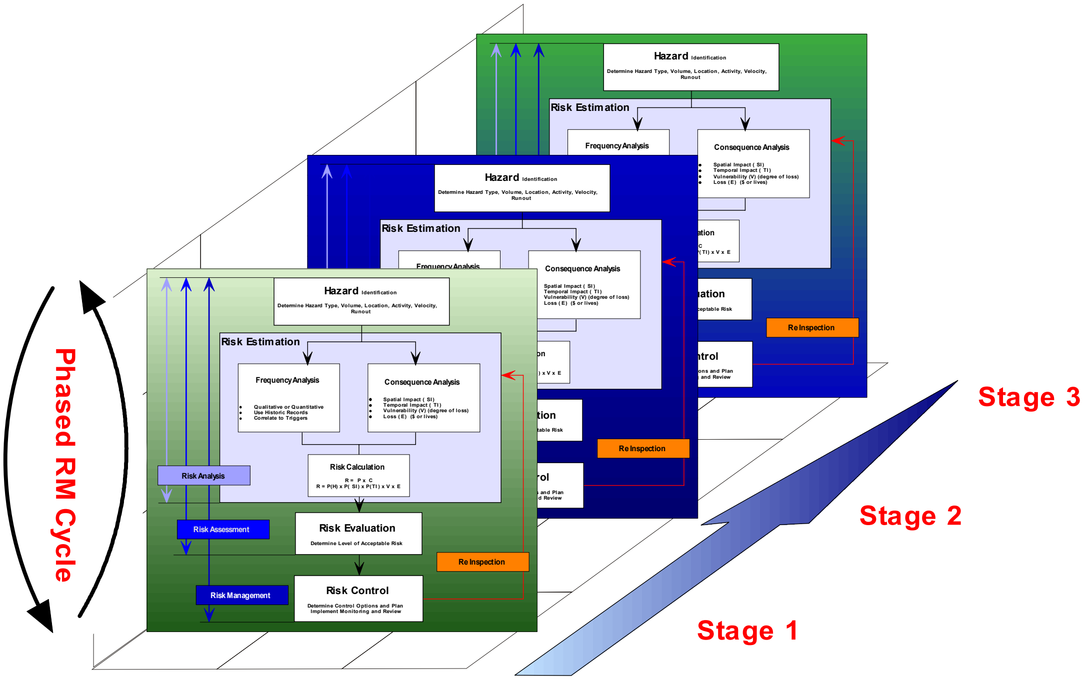

Figure 2. Risk Management framework applied in Stages of increasing study scale.

It is necessary to add this third dimension to Figure 1 for two reasons. Firstly, the staged approach helps scope the resources for risk assessment projects and convey the scale-dependent limitations of the assessments to designers, clients, owners, and users of the system. A key risk estimation factor may be impractical to obtain at Stage 1 and resources may be better spent collecting that key factor, or refining it, at a more detailed Stage 3 study. Understanding the scale limitations will help put these types of decisions in perspective and maximise the best use of project resources.

Secondly, during design, attempts should be made to maximise the number of risk assessment factors that can be estimated and refined through a range of study scales. For example, river bank armouring may be generally evaluated from airphotos at Stage 1 as “present” or “absent”. However by Stage 2, the assessment of the armouring can be refined with a subjective field inspection to determine if it is “effective”, “damaged” or ‘ineffective”. At Stage 3 site-specific deterministic or empirical models can actually quantify the effectiveness of the armouring. This approach of refining risk estimation factors through the stages benefits the economics of the project and provides continuity to risk estimation and risk reduction because factors can be re-used and refined instead of adding entirely new factors to the calculations. The concept of refining estimation techniques for different study scales is well described by Soeters and van Westen [9] and Aleotti and Chowdhury [10].

Each Stage is described below. Table 1, (adapted from [9]) provides additional guidelines for the typical study scale and accuracy level for each Stage.

Stage 1 Stage 1 is typically a 1:50,000 scale or smaller (regional or national) screening level study that is often conducted in the office. Hazard susceptibility and vulnerability is assessed within regions, mainline valve, or chainage segments rather than at specific sites. Risk is typically estimated using 3 x 3 risk matrices.

Stage 2 Stage 2 focuses on a selection of high risk areas identified in Stage 1. Hazard inventories are typically constructed in this stage from airphotos at large scales of 1:15,000 to 1:50,000 scale. Stage 2 includes brief site visits to carry out the first site inspection and obtain site photographs and GPS locations. Site visits allow the vulnerability to be assessed in more detail. Risk is assessed using a blend of risk matrices and more quantitative risk formulae.

Stage 3 Stage 3 studies assess the risk at a 1:500 to 1:15,000 scale (detailed scale) for purposes of monitoring and/or mitigation design. Detailed fieldwork, dendrochronology, site surveys, lab testing, and deterministic/probabilistic modelling are often introduced in this Stage. Detailed pipeline parameters such as wall thickness and coating may be included in Stage 3 vulnerability assessments. Uncertainty in hazard and vulnerability estimates is further reduced as better information is obtained. Depending on the availability of historical data some probabilities may be absolute instead of relative.

Table 1 – Scale dependent Stages of risk management (adapted from [9])

Stage	Class	Map Scale	Study Area (sq. km)	Spatial Accuracy (m)
1	National	< 1:1,000,000	> 1000	> 500
1	Regional	1:50,000 to 1:500,000	< 1000	+/- 50 to 250
2	Medium	1:15,000 to 1:50,000	< 500	+/-8 to 25
3	Large	1:5,000 to 1:15,000	< 50	+/- 5 to 8
4	Detailed	1:500 to 1:5,000	< 5	+/-0.025 to 2.5

Risk Assessment Principles

NHRM includes quantifying risk using probabilities and mathematical equations. A review of some standard terminology and principles is required here to appreciate that risk is comprised of a number of dynamic components and each component can be independently estimated (and re-estimated) in the field during Risk Estimation. The following is summarised from a collection of key technical publications [11-17].

In the context of risk analysis for natural hazards and pipelines, risk is commonly defined as the product of the annual probability of a hazard impacting the pipeline P, and the consequences of the impact, C.

$$R = P \times C \tag{1}$$

Consequence, C – The outcomes or potential outcomes arising from the occurrence of a hazard expressed qualitatively or quantitatively, in terms of loss, disadvantage or gain, damage, injury, or loss of life.

Risk, R – Risk is a measure of the probability and severity of an adverse effect to health, property or the environment. Risk is often estimated by the product of probability and consequences. Risk is formally expressed as a net present value monetary terms. (i.e. dollars) but may be expressed as a probability, frequency, or likelihood depending on the accuracy, and scale of the study or if monetary consequences are not defined.

Probability and consequence can be subdivided into more descriptive terms as follows;

$$R = P(H) \times P(S{:}H) \times P(T{:}H) \times V \times E \tag{2}$$

Hazard, P(H) – Hazard is a description of the geotechnical or hydrotechnical event. When quantified, hazard is the annual probability of a hazard of a certain magnitude (i.e. energy) occurring in a certain location. Hazard may be expressed quantitatively as a frequency, relative or absolute probability between 0 (certain not to occur) and 1 (certain to occur), or a hazard likelihood term. Large databases of historical hazard events are used to develop frequency-magnitude relationships [16].

Spatial Impact, P(S:H) – This is the probability of spatial impact on the element given the hazard has occurred. Spatial impact depends on the location of the hazard relative to the element potential travel distance, and velocity of the hazard.

Temporal Impact, P(T:S) - The probability of temporal impact given that spatial impact has occurred. Temporal impact depends on how long the element is in the path of the hazard. If the element is a pipeline, the probability of temporal impact is set at 1 (certain), because the pipeline does not move.

Vulnerability, V – The degree or proportion of total loss suffered when the hazard occurs. It is expressed on a scale between 0 (i.e. no loss, damage, or injury) to 1 (i.e. total loss, complete destruction, or death). For property, the loss may be measured in monetary terms; for persons, it will be the probability that a particular life (the element at risk) will be lost, given the person(s) is affected by the hazard.

Element, E – The population, buildings, and engineering works, economic activity, public services utilities, infrastructure and environmental features in the area potentially affected by the hazards. When quantified, the element(s) may be expressed as the value, or net present value, in monetary terms (i.e. dollars) when assessing property, or the number of lives affected by the hazard, when assessing risk to individuals.

The goal of risk estimation is to define, within the limits of the project scale and resources, the terms in Equation 2 as accurately as possible. The techniques to define the terms in Equation 2 can be refined from one stage to the next as long as each term is addressed at every project Stage.

All of the terms in Equation 2 are, to some degree, dynamic and therefore require re-assessment during every field inspection. For pipelines, P(H), P(S:H), and V are often the most dynamic terms and can be assessed in the field using factors listed in Table 4 and Table 5.

Risk reduction can be demonstrated by reducing the contribution from each term in Equation 2. For example, measures that reduce the likelihood of the hazard occurring P(H), reaching the pipeline P(S:H), or minimise the amount of damage V, will reduce the risk R at the hazard site. Conversely, evidence that a hazard is increasing in size or frequency P(H) should also translate into a higher risk.

Focus on Risk Control

Of importance to this discussion is the relative position of Risk Control – the stage at which field inspections and review of the management plan are carried out. In Figure 1, Risk Control is located at the bottom of the framework and is positioned outside the scope of risk analysis and risk assessment. Accordingly, it is often neglected in the initial system development, or considered late in the development and execution of a risk management program after hazard identification, risk estimation, or risk evaluation is well underway.

When the corporation logically graduates to an inspection program they often find deficiencies in the risk management system used for the initial site prioritisation. Gaps between what observations a pipeline inspector can be reasonably expected to collect in the field and what the risk management (essentially office based) system requires are often revealed. The gaps can be so substantial that the relatively new risk management system requires significant resources to redesign, or worse, may be rendered obsolete after the inspection program is well underway.

Furthermore, the corporation may find that the hazard causal factors and vulnerability inputs they used to initially carry out the risk estimation cannot reflect the deterioration or improvements that may have occurred to the hazard and risk, say after significant mitigation work was done to the site. Under these static conditions risk reduction is difficult to demonstrate. The risk management program may be stalled until observations from field inspections can be adapted or re-assessed to reflect the dynamic nature of each hazardous site.

A Typical Risk Management Scenario

A typical scenario is provided below to demonstrate how a well intended risk management program may run into problems during re-inspection if risk control is not the focus of the initial system design.

A simple Stage 2 risk assessment of debris flow hazard is started on 300 km of pipeline traversing mountainous terrain. The owner wishes to know the relative risk of pipeline exposure from debris flows in order to prioritise the sites for future action. At this time the owner is uncertain as to the scope of action that may be required. Airphotos and corporate records are used to build a preliminary inventory of 70 potential sites and, over a course of three days, a team of engineers and geoscientists follow up by visiting each of the potential sites in the field (Hazard Identification). The team agrees, prior to going into the field, that the causative factors that reflect the risk at each site are the following (Table 2):

Table 2 – Example causative factors for debris flow hazard and vulnerability

Hazard	Vulnerability
drainage basin size	location of the pipeline on the deposition fan
channel gradient	depth of burial of pipeline
average precipitation	
potential source volume	

The factors in Table 2 were selected because the data is readily available or relatively easy to understand and assess/collect in the field. Back in the office the field observations are combined in a logical manner, qualitatively or quantitatively, to produce a relative assessment of hazard and vulnerability for each site. In accordance with simple risk principles in Equation 1, the hazard and vulnerability are then combined to produce a relative risk of pipeline exposure from debris flows (Risk Estimation). The owner then determines an acceptable level of risk, assigns risk thresholds (Risk Evaluation), and selects the sites that require future inspection, monitoring, or mitigation. Berms are constructed at some of the high risk sites, monitoring hubs to monitor channel aggradation or degradation are installed at others, and some sites are scheduled for Stage 3 studies (Risk Control). An inspection program is set up for all of the sites and the inspectors are sent out to the field to re-inspect the sites to see if the Risk Control measures have been effective (Re-Inspection).

Unfortunately, despite the cost of the berms, monitoring hubs, and re-inspection, management cannot quantify a reduction in the risk at each site because the initial determination of risk by the team was based on the factors in Table 2 that do not change significantly from one inspection to the next nor reflect the changes to the hazard and vulnerability when site improvements are made. To jump-start the NHRM program, management must now develop a new inspection criteria that addresses these changes and conduct another baseline inspection or attempt to salvage the original baseline data. Either choice results in a complete or partial backtracking and redesign of the program.

This backtracking could have been minimised if the owner and the team had;

- developed the Risk Estimation methodology with Risk Control as the goal,
- considered the initial airphoto interpretation and field visit as the <u>first</u> of many site inspections, and,
- Selected causal factors that are dynamic and can be used across many project stages.

In this example the factors listed in Table 3 may have been better choices for assessing risk. These factors can be economically assessed from airphotos or in the field across a variety of stages. They are easily quantified or subjectively assessed by technical and, with minimal training, non-technical personnel. They are dynamic and the changes they exhibit from one inspection to the next can be related to the improvement or deterioration of hazard, vulnerability, and therefore, risk.

Table 3 – Dynamic causative factors for debris flow hazard and vulnerability

Hazard	**Vulnerability**
channel width	depth of cover
presence of aggradation	changes to armour
presence of overbank deposits	distance to the pipeline
presence of new channels	

Estimating Hazard and Risk in the Field

The following discussion provides additional explanations and examples of how hazard and vulnerability factors can be selected and incorporated into the calculation of risk (Eq. 2) so that change detection and risk reduction is possible and straight forward.

Estimating Hazard P[H], in the Field

The AGS [8] provides an excellent introduction into the techniques for estimating probability of hazard occurrence. Techniques include using historical records, correlation with triggers, probabilistic techniques, deterministic modelling, and, most relevant to this paper, relationships to geomorphology and geology. The challenge is to select factors that are useful, practical to collect in the field, and reflect the changes that are likely to occur onsite. A lengthy list of factors that contribute to the occurrence of landslides is available in the literature [9, 18, 19]. A few of these factors are categorized in Table 4. In practice Table 4 may be considerably larger and adapted to suit different geotechnical, hydrotechnical, and seismic hazard types.

To use these factors in the assessment of hazard frequency, we assume, in accordance with the concept proposed by Popescu [19], that the greater the number of these factors seen in the field the greater the likelihood of a hazard occurring, P[H]. The cumulative influence of causal factors contributes to a progressive deterioration of the hazard to the point of failure, or in the case of hydrotechnical and seismic hazards, occurrence. It is important to use very specific wording so inspectors to can report, as objectively as possible, that the hazard's likelihood of occurrence is changing. A tremendous amount of time can be spent selecting words and phrases that promote both objectivity from the field inspector and utility for trained technical professionals.

As shown in Table 2 causal factors may be grouped based on their influence on the hazard's occurrence or stability. For example, slope angles greater than 20° contribute a steady and progressive "long term" shear stress on the slope. However water being suddenly introduced to the slope, say during a storm or from broken irrigation pipes, adds a sudden shock to the slope. The slope may not be able to equilibrate to this new deteriorating condition. The cumulative effect of all the factors on site plus this "new shock" may cause the slope to finally fail. Accordingly, in relative terms, slope angle is considered a "slow" influence and water diversion/leakage is considered a fast influence on the slope stability. This relative influence determines their position in Table 4. The greater number of "bad actors" observed in the field the higher the P(H) becomes. The construction of a Geotechnical Field Inspection Tool that combines these concepts in a probabilistic framework to quantitatively assess the likelihood of hazard occurrence is currently in progress. In the interim, hazard frequency may be approximated by subjectively assessing hazard activity [12, 20] in the field or from airphotos [21]. The implementation of a similar Hydrotechnical Field Inspection tool is discussed by Leir *et. al.* [2, 22].

Table 4 – A few causative factors that contribute to the occurrence of landslides

Class	**Increasing influence on the landslide occurrence/stability** →				
Human	-	vegetation removal by forest harvesting	changes to surface water flow	excavation of slope toe	water leakage/diversion
Physical	changes in average rainfall	revegetated landslide scars	groundwater springs present	fresh debris at base of slope	intense rainfall > 10 mm/hr
Morphological	steep slope angles > 20 degrees	Anti-scarp slopes	noticeable joint dilation	fresh tension/ground cracks	-
Geological	closely spaced discontinuities	weathering bedrock	-	-	-

Estimating Vulnerability in the Field

Table 5 categorises some of the factors that contribute to the vulnerability of pipeline exposure from hydrotechnical hazards. Again, these factors are useful, objective, and easy to assess by inspectors whose hazard assessment experience may differ.

As with the assessment of hazard, the inspector makes some simple measurements or estimates and then selects the appropriate conditions from Table 5. The algorithm in the underlying database counts the number of selected factors in each group and uses this count as a multiplier in the determination of vulnerability. The more factors that are present the higher the vulnerability. For example, when an inspector returns to the site after some mitigation work was completed, the inspector may see that placement of an engineered berm and rip rap has increased the distance from the hazard to the pipeline, improved the depth of cover, and made the armouring "effective". All else being equal, the vulnerability has decreased, and accordingly, so has the risk. Risk reduction through field inspections has been demonstrated.

Table 5 – A few factors that contribute to hydrotechnical hazard vulnerability

Increasing relative influence on vulnerability to pipe exposure

depth of cover	> = 2 m	> 1.5 m	> 1 m	> 0.3 m	< = 0.3 m
distance to pipeline	> = 75 m	> 50 m	> 25 m	> 10 m	< = 10 m
armouring	effective		damaged	ineffective	required
control structures	effective		damaged	ineffective	required

Conclusions and Recommendations

Bridging the gap between field operations and risk management systems requires that:

- NHRM systems are designed from the "field up", instead of theory, in anticipation of supporting a field inspection program.
- NHRM systems are designed to demonstrate and quantify risk reduction at every Stage of a program.
- System designers consider the initial assessment of the hazard as the first of many field inspections.
- Designers scrutinise why certain causal factors have been selected for field inspection. Separate the "nice to know" information from the information that helps demonstrate risk reduction.
- Causal factors are practical to assess in the field by non-technical inspectors.
- Casual factors are not expensive to collect or maintain. Can you afford to reassess the factor in future inspections?
- Causal factors can be assessed or refined through a range of Stages.
- Causal factors are not static and reflect the dynamic nature of the hazard and vulnerability.

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