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## FIELD INSPECTION MODULE FOR HYDROTECHNICAL HAZARDS

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### ABSTRACT

Terasen Pipelines (Terasen) owns and operates an 1146 km low vapour pressure petroleum products pipeline between Edmonton, Alberta and Burnaby, British Columbia. Its right-of-way passes through some of the most geotechnically, hydrotechnically, and environmentally challenging terrain in Western Canada. This paper describes the latest advancement of a natural hazards and risk management database application that has supported a 6-year hazard management program to quantitatively assess and prioritize the geotechnical and hydrotechnical risk along the pipeline. This database was first reported at IPC 2002 in a paper entitled "Natural hazard database application – A tool for pipeline decision makers" [1]. This second paper describes the advancements since then, including the addition of the Hydrotechnical Field Inspection Module (FIM), an add-on tool that allows field inspection observations to adjust hazard and vulnerability. This paper discusses the challenges in building a methodology that is practical enough for field maintenance personnel to use yet sufficiently comprehensive to accurately describe improving or worsening hydrotechnical hazard conditions. Functionality to enter hazard inspection data, review inspection results in the office, and authorize changes to the hydrotechnical hazard probabilities are described in the paper and demonstrated in the conference presentation. The relationship between revised hazard, vulnerability, risk, and response thresholds (such as inspection frequency, monitoring, site surveys, or mitigation) are demonstrated using a river crossing with a dynamic hazard history. As in previous years, this paper is targeted to pipeline managers who are seeking a systematic hazard and risk management approach for their natural hazards. (Keywords: database, hazard, vulnerability, risk, pipeline, geotechnical, hydrotechnical, landslide, river, stream).

### INTRODUCTION

Terasen Pipelines Inc. owns and operates over 4000 km of low vapour pressure, petroleum product, transmission pipelines in Western Canada and the mid-west of the United States. The formerly named Trans Mountain pipeline is an NPS 24, 1146 km long system beginning at Terasen's terminal in Edmonton, Alberta and ending at its tank farm in Burnaby, British Columbia. The right-of-way for this pipeline traverses the Rocky Mountains, Jasper National Park, Mount Robson Provincial Park, over 500 watercourse crossings and numerous environmentally sensitive areas. This terrain presents on-going challenges to maintaining reliable pipeline operation while also demanding responsible stewardship. Terasen is able to provide safe, continued operation of its pipeline through its commitment to proactive management of geotechnical and hydrotechnical hazards.

In the last decade, Natural Hazard and Risk Management (NHRM) has become a widespread tool for multinational corporations [2-4]. Proper natural hazard risk management requires that the natural hazards be identified, the frequency and consequences of their occurrence be assessed and then managed in order to reduce impacts on pipelines, the public and the environment. Furthermore, demonstrating risk reduction should be the primary goal of NHRM systems in order to justify mitigation, monitoring, and management expenditures. To facilitate the comparison of risk reduction between natural hazards and other types of operational risk, the quantification of natural hazard risk should follow well established risk principles [5,6].

Hazard activity and its potential to impact on the pipeline facilities are not static. Re-assessment of the hazard, vulnerability, and risk should be ongoing because the hazard causal factors, activity, and site defences may improve or deteriorate with time. Many corporations invest in the

development of a hazard inventory and an initial prioritisation system but, unfortunately may neglect to maintain the inventory and the assessments through on-going inspections, as part of Risk Control [5,6].

This paper revisits the role of database applications in risk management and emphasises their utility during Risk Control Phases of Risk Management, specifically field inspection and remediation and demonstrating risk reduction. Background on this database is provided by Leir and Reed [1] and strategies for designing NHRM systems to accommodate field inspections are discussed by Leir [7].

## HAZARD AND RISK TERMINOLOGY

NHRM includes quantifying risk using probabilities and mathematical equations. A review of some standard terminology and principles is required to understand how the dynamic nature of risk can be assessed in the field. The following is summarised from a collection of key technical publications [5,6, 8-12]

**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 (a.k.a. energy) occurring in a certain location. Hazard may be expressed quantitatively as a relative or absolute probability between 0 (certain not to occur) and 1 (certain to occur) and, by correlating the probability with industry thresholds, can also be expressed qualitatively as low, medium, or high hazard class or hazard likelihood. Large databases of historical hazard events are used to develop frequency-magnitude relationships [13].

**Spatial Impact, P(S:H)** – The probability of the hazard impacting the element. Spatial impact depends on the location of the hazard relative to the element as well as the potential travel distance, and velocity of the hazard.

**Temporal Impact, P(T:S)** - The probability of the element being “present” when the impact occurs. 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) or the number of lives affected by the hazard.

**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.

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

$$R = P \times C \quad (1)$$

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

$$R = P(H) \times P(S:H) \times P(T:H) \times V \times E \quad (2)$$

The goal of risk analysis is to define, within the limits of the project scope and resources, the above terms in Eq. (2) as accurately as possible. Risk reduction can be achieved by focusing on reducing the contribution from each term. For example, measures that reduce the likelihood of hazard occurring P(H), reaching the pipeline P(S:H), or the amount of damage V, will reduce the risk R. Conversely, evidence that a hazard is increasing in size or frequency P(H) should also translate into a higher risk.

To start, Terasen is restricting their program to assessing the risk of pipeline exposure. Consequences of pipeline exposure are also not included at this time, so some simplifications to Eq. (2) can be made.

Firstly, since the pipeline does not move, the probability of temporal impact P(T:S) is set to 1, meaning temporal impact is certain. Secondly, to avoid the complexities of hazard/pipe interactions we assume that if the hazard impacts the pipeline then exposure is certain, therefore, V = 1. Investigation into these interactions can be conducted during more detailed (Stage 3 [7]) site specific studies. Finally, at this time Terasen has elected not to include the financial cost of pipeline exposure, so E is dropped from the equation. Hence risk, R is now defined as a specific risk, Rs, and is quantified as the annual probability or likelihood of pipeline exposure.

With these simplifications, the risk equation is now:

$$R_s = P(H) \times P(S:H) \times \cancel{P(T:S)} \times \cancel{V} \times \cancel{E}$$

$$R_s = P(H) \times P(S:H) \quad (3)$$

## PURPOSE OF THE DATABASE

Proper risk management requires documented, repeatable and quantifiable methodologies. Documented for legal due diligence, repeatable from one assessor to another to minimize personal bias, and quantifiable in order to maximize objectivity. These requirements alone justify a database application. Furthermore, these requirements also indirectly encourage the assembly of corporate historical databases that are intended to serve many generations of employees. Key personnel may leave a company with a considerable amount of corporate history in their heads. Often very little of this experience has been well documented or can be efficiently passed on to the replacement personnel. Replacement personnel are often forced to rebuild their own corporate history. Terasen recognized that a database application would meet the requirements of risk management and could form the nucleus of information that would grow with Terasen’s risk management

programs. Terasen also recognized that a digital database could be efficiently shared amongst different interested departments in BC, Alberta, and Washington State.

When employing quantitative risk assessment methodologies project managers naturally gravitate to spreadsheets for their data management needs. However, as data collection evolves to include photos, reports, plans, maps and video, plus the number of users requiring access to this data increase, the spreadsheet often becomes too cumbersome to manage. Spreadsheets are strong tools for performing calculations but are poor tools for multi-user data management. More importantly, as a hazard management program moves forward into multi-year site inspections, structured information management is required to ensure that hazard sites are prioritized correctly or not missed entirely and the status of their inspection is tracked. These are all strong arguments for a database application.

### **ADVANCEMENTS TO THE NHRM DATABASE**

Since 2002 four significant advancements have been made to the database:

1. Transition from index based approach to a quantitative risk assessment (QRA) framework.
2. Development of the Hydrotechnical Field Inspection Module (FIM).
3. Addition of Creek Book; a tool to automatically generate lists of sites requiring inspection.
4. Addition of an Inspection Reviewer; functionality to review and authorise incoming inspections.

The FIM, Creek Book, and the Inspection Reviewer are new tools to help assign risk and manage the inventory of hazards and accompany previously constructed tools for managing hazard photos and accessing supporting reports and documents [1]. In short, the FIM is a risk based field form and algorithm that helps assess and prioritise the risk of exposure from hydrotechnical hazards. The Inspection Reviewer helps office managers check the results of the new inspections and ensure all of the key information from the field is sound. The Creek Book is a tool to help office personnel to quickly generate new lists of inspections with accompanying due dates and supporting documentation such as past inspections and photos. All together, these tools support the iterative process of deciding where and when to inspect, what to look for in the field, what to do at each site, and recalculation and reprioritisation of risk. More details of the new tools are provided below.

### **Transition to Quantitative Risk Assessment (QRA)**

The transition from index based to quantitative risk assessment is a significant advancement in Terasen's hydrotechnical risk assessment program. Three advantages of this transition are discussed below.

Firstly, adopting a QRA approach helps define where risk reduction can be achieved. 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. Understanding where risk reduction can be demonstrated then helps in designing an effective field inspection program.

Secondly, separating risk assessment into components of hazard occurrence, spatial and temporal impact, and vulnerability facilitates a more objective assessment because a logical and defensible assessment methodology can be used and each component can be assessed independently.

Finally, QRA allows Terasen to compare risk from natural hazards with other types of risk to pipeline facilities such as third party impact or corrosion. Direct comparison helps pipeline companies allocate resources to manage all types of risk. Index-based risk assessment methods usually do not present risk as an absolute probability making direct comparison difficult.

The transition included systematically converting subjective assessments and hazard rating scores into separate assessments of hazard and vulnerability. Risk matrices were used to cross hazard and vulnerability to produce an initial baseline risk. A quantitative field inspection tool was constructed to adjust the risk up or down depending on what the inspectors observed on site during each hydrotechnical inspection.

### **Hydrotechnical Field Inspection Module (FIM)**

The purpose of the FIM is to allow Terasen field personnel to easily collect key objective observations about hydrotechnical hazards and report those observations back to Terasen managers. Changes in observations between consecutive inspections may result in adjustment of the hazard and vulnerability classes up or down, and depending on the thresholds the new classes exceed, a corresponding revision to the inspection frequency and action priority. New hazard classes would not be authorised until Terasen managers have reviewed all of the incoming field observations.

For example, the results of field observations from a recent inspection indicate that the crossing continues to deteriorate. Accordingly, the FIM proposes to raise the hazard class from "medium" to "high" and the vulnerability class from "low" to "medium". Using the matrix in Table 1, the risk is increased from low to high and the FIM also increases the inspection frequency from 1 inspection every 3 years to 1 inspection every year. Additionally, recommended actions such as further inspections, detailed studies, or mitigation that were proposed by inspectors are also reassigned a priority from "due within 3 years" to "due within the year". If the Terasen manager is confident that the observations made in the field are reasonably accurate then the manager can authorise the inspection observations and the FIM changes the classes, inspection frequency, and action priority. Due to the deteriorating conditions, the crossing would now receive more attention in the form of more frequent inspections and a timelier deadline for action.

Flexibility is also built into the FIM to allow the reviewer to choose an appropriate recommended action based on their understanding of the risk at the crossings under consideration. These actions can range from aerial inspection to mitigation.

### **Creek Book**

In any inspection/monitoring program it is necessary to establish what needs to be inspected and at what priority the

inspections should occur. Between 1998 and 2003 Terasen inventoried the hydrotechnical hazards along 1049 km of its pipeline between Edmonton, Alberta and Popkum, B.C. The current inventory stands at 588 watercourse crossings. During the inventory process baseline risk assessments at each of the watercourse crossings were prepared. The inventory and the baseline assessments form the basis for prioritizing and undertaking future inspection work. Organization of this work will be done through Creek Books.

**Table 1 Risk matrix with proposed inspection frequencies.**

Hazard Class		Inspection Frequency		
		Medium	High	High
↑	High	Medium <i>1 in 2 years</i>	High <i>1 in 1 years</i>	High <i>1 in 6 months</i>
	Medium	Low <i>1 in 3 years</i>	Medium <i>1 in 2 years</i>	High <i>1 in 1 years</i>
	Low	Low <i>1 in 5 years</i>	Low <i>1 in 3 years</i>	Medium <i>1 in 2 years</i>
		Low	Medium	High

**Vulnerability Class**

The Creek Book lists the watercourse crossings within a pipeline maintenance group’s geographic operating area. The book can be automatically generated by users of Terasen’s Natural Hazard Management database and contains the most current inspection status of each crossing. Initially, the book will list the crossings scheduled for re-inspection as recommended by the baseline risk assessment and inspection “due date”. Based on results from continued re-inspections these actions and intervals will automatically be adjusted depending on whether individual site conditions improve, deteriorate or remain the same.

**Inspection Reviewer**

The inspection reviewer is a database tool for reviewing and authorising incoming inspections. Authorised Terasen personnel review the field observations to ensure they are reasonable and the proposed changes to the hazard and vulnerability classes are suitable. Recommendations from inspectors can be reviewed and edited if required. Authorised inspections are date stamped and coded with the inspectors initials making the proposed changes to the hazard, vulnerability, risk, inspection frequency, and recommendation due date effective. A log of the previous inspections is retained in the database.

**IMPLEMENTATION OF THE FIM**

Implementation of the FIM at Terasen began in 2004 and will to be completed in 2005. Initially, it will be rolled out to three pipeline maintenance groups (PLM) who will then use the system for a year during which time any bugs in the system will be “ironed” out. In the ensuing period the FIM will be implemented at the remaining field groups.

The FIM forms an integral part of Terasen’s overall Natural Hazard Management System and will use the following process model:

1. Prepare and issue Creek Books – Head Office
2. Undertake watercourse inspection – PLM groups
3. Enter inspection data – PLM groups
4. Review inspection data – Regional Offices
5. Provide additional data (if required) – PLM groups
6. Authorize inspection data – Regional Offices
7. Provide recommendations for follow-up work – Regional and Head Office
8. Undertake follow-up activities – Regional and Head Office
9. Re-issue Creek Books – Head Office

Once the Creek Books have been issued it will be the responsibility of the PLM groups to undertake the inspections within the time frames provided. Initially, collection of this information will use a paper-based system requiring the field personnel to return to their office to do data entry. It is expected that this will be modified to electronic data collection in 2005.

Working from the prioritizations in the Creek Books, field personnel will re-inspect and collect standardized observations at each crossing. Past inspection information, including photos will be available from the database. Personnel making observations will compare present day conditions to those noted during previous inspections and photos and note the differences on inspection forms for each of the crossings. This information will then be entered into the FIM system but, at this point, will not alter any of the previous assessments.

Once the re-inspection data has been entered into the database it will be the responsibility of Regional Engineering personnel to review it for completeness, obtain/enter any missing information and, based on improvement or deterioration at the crossing, recommend follow-up activities. These activities may range from continued aerial or ground inspection to undertaking mitigation efforts. Upon completion of the Regional Engineering review the crossing re-inspection will have been authorized which will allow the new data to be accepted into the database.

Acceptance of new information in the database may result in changes to the hazard and vulnerability classes for some or all of the newly inspected crossings. This in turn could revise the inspection frequency and recommendation due date (as shown in Table 1). It will be the responsibility of the Terasen’s Head Office Engineering & Technical Services Department to monitor these changes and, working with Regional personnel, to ensure that follow-up activities are undertaken in a timely fashion. It will also be the responsibility of this Head Office group to periodically re-issue the Creek Books after inspections and actions are performed. The system will not preclude the requirement to inspect the system after a major (100 year) flood event.

**Challenges**

The development and implementation of Terasen’s Natural Hazard Management Program continues to present a number of challenges that are worth discussing:

Time. Depending on the size of the pipeline system and

resources available it can take a considerable amount of time to develop the detailed inventories and prepare the baseline assessments necessary to implement this approach. Terasen conducted 1049 km of baseline risk assessments over a five year period.

Momentum. Due to the time frame it can be a challenge to maintain the momentum necessary to see the development and implementation through to its successful conclusion.

Overlapping Programs. Development of NHRM programs will usually be done to replace less systematic approaches to natural hazard management. Depending on the pace of implementation, a transition period will be required where management decisions will be based on the older system until the new system is implemented.

Training. As outlined in this paper and by Leir and Reed [1], implementation of this program requires field personnel to receive general training concerning natural hazards as well as specific training on how the new system works. This must be planned and budgeted for in advance as there can be many seasonal constraints to training schedules.

## Benefits

Despite the challenges Terasen believes that the benefits to this approach will result in improved pipeline reliability and integrity. Among the major benefits are:

Risk Reduction. Standardized observations on set intervals, storage of legacy information and heightened awareness of developing situations will decrease the potential for disruption of pipeline operations by natural hazard events.

Information Availability. Through the Natural Hazard database and FIM diverse groups of Terasen staff will now have easier access to a common source of information on the condition of watercourse crossings.

Resources. Re-inspection of crossings will now be scheduled based on risk, making the best use of precious field resources.

Early Hazard Identification. Re-inspection will help to proactively identify hazards earlier in their development, increase the available time to respond, and improve the overall integrity of Terasen's pipeline system.

Objectivity. Standardized risk-based data collection during the re-inspection process will improve the objectivity of the assessment and will allow "apples to apples" comparison of hydrotechnical hazards at different points along Terasen's pipeline system. This will allow for more objective resource allocation decisions with regards to mitigation efforts should they become necessary.

Corporate Knowledge. Incorporation of field inspection information in the database will improve the retention and availability of historical information previously lost when personnel retire or leave the company.

Communications. The inspection system encourages better and more frequent communication between field offices and head office. This is important as demands field resources increase.

## FUTURE WORK

Future development of this system and database may include:

- calibration of the current risk assessments to historical incidents of exposure,

- refinements to the estimation of hazard occurrence, probability of impact, and the probability of exposure,
- include the monetary costs of exposure in the calculation of risk,
- development of Pocket PC functionality to minimise paper-based field data collection and data re-entry, and/or,
- development and implement of a Geotechnical FIM to inspect geotechnical hazards along the pipeline.

## CONCLUSIONS AND RECOMMENDATIONS

Over the last five years Terasen and BGC have learned that the development of NHRM systems requires technical vision and commitment from management to ensure that the objectives remain clear and are sustainable. Focusing on NHRM systems that adopt a quantitative risk assessment framework, accommodate re-inspections, and demonstrate risk reduction, from the outset, should be key technical goals. NHRM is not a static or one-time event. Refinements to risk estimation procedures and algorithms will be ongoing as resources are refocused on high risk sites within smaller study areas. The database and inspection tools that Terasen has developed provide a solid technical foundation to conduct inspections and manage their natural hazard risk in a defensible manner.

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## REFERENCES

1. Leir, M., and Reed, M., 2002, "Natural Hazard Database Application – A Tool for Pipeline Decision Makers," *Proc., IPC 2002, 4th International Pipeline Conference*, AMSE, New York.
2. Porter, M., and Savigny, K.W., 2002, "Natural Hazard and Risk Management for South American Pipelines," *Proc., IPC 2002, 4th International Pipeline Conference*, ASME, New York.
3. Savigny, K.W., Porter, M., Chen, J., Yaremko, E., Reed, M., and Urquhart, G., 2002, "Natural Hazard and Risk Management for Pipelines," *Proc., IPC 2002, 4th International Pipeline Conference*, AMSE, New York.
4. Esford, F., Porter, M., Muhlbauer, K., Dunlop, C., 2004, "A risk assessment model for pipelines exposed to natural hazards," *Proc., IPC 2004, 5th International Pipeline Conference*, ASME, New York.
5. Canadian Standards Association, 1997, CAN/CSA-Q850-97, Risk Management: Guidelines for Decision-Makers.

6. Australian Geomechanics Society, Subcommittee on Landslide Risk Management, 2000, "Landslide Risk Management Concepts and Guidelines", Australian Geomechanics, p 49-92.
7. Leir, M. 2004, "Bridging the Gap Between Field Operations and Risk Management", *Proc., Terrain and Geohazard Challenges Facing Onshore Pipelines*, Thomas Telford, London
8. Fell, R. 1994, "Landslide Risk Assessment and Acceptable Risk," *Canadian Geotechnical Journal*, **31**, pp. 261-272.
9. Cruden, D.M. and Varnes, D.J. 1996, "Landslide Types and Processes," *Landslides, Investigation and Mitigation*, Turner, A.K. and Schuster, R.L., eds., Transportation Research Board Special Report 247, National Academy of Sciences, Washington, D.C., pp. 36-75.
10. Cruden, D. and Fell, R., 1997, "Quantitative Risk Assessment for Slopes and Landslides – The State of the Art," *Landslide Risk Assessment*, Cruden, D. and Fell, R. eds., Balkema, Rotterdam, pp. 3-12.
11. Fell, R., and Hartford, D., 1997, "Landslide Risk Management," *Landslide Risk Assessment*, Cruden, D. and Fell, R., eds., Balkema, Rotterdam, pp. 51-110.
12. Hungr, O., 1997, "Some Methods of Landslide Intensity Mapping," *Landslide Risk Assessment*, Cruden, D. and Fell, R., eds., Balkema, Rotterdam, pp. 215-226.
13. Hungr, O., Evans, S.G., and Hazzard, J., 1999, "Magnitude and Frequency of Rock Falls and Rock Slides Along the Main Transportation Corridors of South-western British Columbia," *Canadian Geotechnical Journal*, **36**, (2), pp. 224-238.