DEVELOPING A PIPELINE RISK ASSESSMENT TOOL FOR THE UPSTREAM OIL AND GAS INDUSTRY

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ABSTRACT

Developing a pipeline risk assessment tool in the upstream oil and gas industry can be a difficult process. Regardless of the intent (integrity management, resource allocation, compliance etc.), challenges in the form of resource limitations and data constraints need to be overcome to develop a functional risk assessment tool.

This paper describes Talisman Energy's experience in developing an in-house pipeline risk assessment process that fits its business model and overcomes specific challenges. Assumptions and simplifications made in developing this process along with benefits and limitations of such a process are also discussed.

The resulting methodology can be described as a semi-quantitative one that uses an un-mitigated risk approach to identify high risk pipelines. Using this methodology Talisman Energy has been able to highlight high risk pipelines in critical areas and implement integrity management activities to mitigate their risk.

Keywords: Pipeline Risk Assessment, Upstream, Consequence, Likelihood, Risk Ranking

INTRODUCTION

The concept of pipeline risk assessment is not new to the upstream oil and gas industry – operators at a field level have always had an intuitive idea of their high risk pipelines without necessarily arriving at the results through a formal process. However, risk assessments in the industry have evolved over time into quite a complex process that allow documenting and categorizing pipeline risk in an organized manner. This has been driven not only by stricter regulatory requirements, but also by a need for strong integrity management programs that ensure safe and reliable operations and allow economic decisions to be made.

The task of conducting a risk assessment is not often straightforward, especially in the upstream oil and gas industry. The main challenges specific to the upstream industry include data availability, data integrity and resource limitations in terms of personnel, time, and money. This paper describes the procedure developed and simplifications made in order to overcome some of these challenges. In essence, a procedure that allowed risk assessing a large number of pipeline segments in a quick and efficient manner was developed.

RISK ASSESSMENT APPROACH

Talisman Energy Inc. (Talisman) like many other upstream companies has faced the challenge associated with determining the scope of a risk model. Should the assessment address operating fields all together in a unified model or is an ad-hoc approach on a field by field basis sufficient? Should the model be a qualitative, quantitative or semi-quantitative one? How detailed does the model need to be in terms of data input versus useful output? Should the output be used prescriptively to drive integrity management programs or should the model be used merely as a screening tool? Should the risk model deal with mitigated or un-mitigated risk? How frequently does the assessment need to be done? What type of risk matrix should be adopted i.e. a 4x4, 5x5 matrix? These were some of the questions that were considered in developing Talisman's pipeline risk model.

Talisman has settled on a unified model specific to its North American assets. It is a semi-quantitative, un-mitigated, 4x4 risk model developed in-house with the objective of identifying its high risk pipelines. The focus was on a simple, re-usable assessment tool that would not predict failure rates or locations per se, but would highlight pipelines requiring risk mitigation. These pipelines would then warrant a closer look in order to manage their associated risk via an appropriate integrity management program; a program that would be established by the Asset Integrity group in conjunction with Field Operations groups. Emphasis was applied on field verification of risk assessment results. By using the same model to measure risk on all its North American pipelines, Talisman was able to evaluate and compare the risk of various assets across North America. A semi-quantitative approach allowed for repeatability while not needing detailed and specific data that is often difficult to obtain and also time consuming. Further, an un-mitigated risk tool avoided the uncertainty or dangers associated with numerically estimating the effects of risk reduction activities. The mitigation aspect was left as part of a subjective post-assessment process which is discussed later in the paper.

In order to make the task of delivering a pipeline risk assessment on a fairly large number of pipelines manageable, a two-phased approach was adopted. Phase 1 consisted of determining only a consequence of failure, whereas Phase 2 included the detailed, more traditional view of risk consisting of both consequence and likelihood of failure.

PHASE 1: CONSEQUENCE BASED APPROACH

Any fluid carrying pipeline in the upstream industry is exposed to various threats. The threats vary in type and extent depending on the type of environment, geographical location and service the pipeline is in. To account for major threats and implement them into a semi-quantitative model that allows for repeatability and reproducibility is quite an involved process that is resource and data intensive. The upstream industry often faces data voids which limit the development of comprehensive models within finite resource and time restrictions. Thus, an alternate first-cut approach is to look at only the resultant consequence of failure from any of the numerous threats. This allows for a quick and relatively simple way to determine important or high profile pipelines. Subsequently, resource spending through integrity management programs can be focused on these high consequence pipelines as a starting point.

Consequence Factors

Talisman's approach involves four consequence of failure factors namely, health and safety, environmental, public concern, and production. Health and safety captures the damage or loss to human health if a particular pipeline fails and is accounted for in the tool via pipeline pressure, sour gas content and also by nature of fluid in the pipeline (i.e. a low vapor pressure (LVP) or high vapor pressure (HVP) fluid). Environmental consequence captures the damage to the environment from release of pipeline fluid due to a failure and is accounted for by gathering information on water ways, land type and wildlife habitat intersects. The public concern piece accounts for direct impact on humans and is captured via road and railway crossings and population densities i.e. proximity to towns and dwellings. Also, included here is a place to capture land owner sensitivity and media coverage which accounts for effects on land owner relationships and company image owing to a failure. The production factor accounts for water and hydrocarbon volumetric flow through the pipeline. Hydrocarbon loss from a failure is directly associated with revenue loss, whereas water is included in order to capture negative impact on water injection and water transfer projects, along with potential negative impacts to the environment.

Data Classification

Talisman's in-house Geo Spatial Services group was used to import pipeline data into the risk assessment tool. GIS software was used to identify pipelines intersecting with different external features which were in turn categorized and fed into the model. Establishing the granularity and classification of this data was a key component in ensuring meaningful output from the risk model. Typically, it has been a challenge to obtain a reasonable spread on pipeline risk as a model output. It is quite difficult to balance the number and type of data inputs required to ensure appropriate segmentation of pipelines based on their risk to the company. For example, in an operating field where there is a known distribution between high, medium and low risk (or consequence) pipelines, the risk assessment output should reflect this spread. This is especially important when assessing pipelines in different operating fields with the same criteria. To this end, the classes under the consequence factors were further sub-divided into appropriate groups. For example, under environmental, water ways constituted of pipeline intersections with “big permanent” water bodies, “small permanent” water bodies, “temporary” water bodies and no water body intersects. The “big permanent” group was made up of specific GIS data types such as rivers, lakes, swamps etc. Similarly, water attributes were assigned to the other categories. Refer to Table 1 for the data set used in Alberta. A different score was assigned to each intersect type with the highest score for a “big permanent” water body intersect (Table 2). Similarly, sub-categories were set up for land type, wildlife, road or rail crossings and population.

Model Mechanics and Features

Algorithm

All the consequence factors previously mentioned contribute in varying degrees to a mathematical algorithm to generate a final consequence score between zero (lowest consequence) and four (highest consequence). The algorithm combines the environmental and public concern scores to form a base value onto which the health and safety score is applied. Finally, the production score is factored in to yield the overall consequence score. A graphical representation of this is shown in Figure 1. The health and safety and production scores are used essentially, as positive multipliers that only increase the consequence score. Overall, this algorithm yielded results that were consistent with real pipeline failure consequences. Some examples are provided in the Examples section.

Simplifications

In order to reduce some of the data requirements and deliver results quicker, a few simplifications were made on the production and health and safety factors. This applied to only Phase 1 and was not done on the detailed Phase 2 assessment. Instead of using actual production numbers, actual operating pressure and actual sour gas content, licenced outside diameter (OD), licenced maximum operating pressure (MOP) and licenced H_2S content were used. For example, an OD score that increases with increasing pipeline diameter was assigned to different pipeline OD ranges. This was customized to suit Talisman’s pipeline size distribution. By eliminating actual production volumes, pipeline connectivity and flow connections were not required.

The drawback with making these simplifications is quite apparent. For example, a smaller diameter pipe may actually be transporting higher volumes than a larger one at any given time. However, these exceptions would be highlighted during a field verification process of the results. In fact, the option to enter production volumes was built into the model to accommodate for cases where such data was easily accessible and thus, enable the user to avoid the simplification.

Qualitative Field Input

While the attempt was to achieve reproducibility and repeatability of results via a set algorithm there was an allowance built into the model to capture some of the unique field characteristics. For example, even though the land owner sensitivity and media coverage scores were default generated by the logic in the algorithm, the true intent was to use these two parameters as qualitative field inputs. This would capture any past history or relationships with specific land owners that could affect the consequence of having a failure on that particular property. In a similar vein, an option was built in to override some of the GIS driven data in the model with a flagging tool to identify the change. For example, a road crossing may be deemed un-important owing to the fact that it is a secondary paved road. However, in reality the road may in fact be an important one owing to its function and traffic density exposure. Thus, the override feature would allow elevating the consequence of a pipeline failure on this particular road crossing which would have been missed otherwise. A provision was made to add comments to capture the reasoning behind these exceptions.

PHASE 2: DETAILED CONSEQUENCE AND LIKELIHOOD APPROACH

Phase 2 consisted of the conventional method of calculating pipeline risk by determining both consequence and likelihood of a failure. Similar to Phase 1, a semi-quantitative approach was used to determine the likelihood of failure. However, the aim was to determine only an un-mitigated likelihood of failure i.e. establish how likely is a pipeline failure if none of the pipeline threats are controlled or managed. Although Phase 2 was significantly more involved than Phase 1, specific methodologies were adopted in order to simplify the process and at the same time yield meaningful results. The priority was to conduct the full risk assessment on high consequence pipelines determined in Phase 1 first and then apply the methodology to other lower consequence pipelines. In order to determine the likelihood of failure it was essential to establish the main factors or threats that contribute to pipeline failures and how they interact with each other. Also, actual operating conditions were a requirement and thus, simplifications made in Phase 1 (OD, MOP, licenced H_2S) were removed in order to determine the consequence of failure in Phase 2.

Likelihood Factors

To establish the likelihood factors, it was necessary to consider historical events and gather information on the main failure mechanisms pertinent to Talisman's pipelines. The aim was to adopt a broad enough approach that would cover most of the failure mechanisms while maintaining a manageable level of detail. The likelihood factors selected were internal corrosion, external corrosion, historical (previous failures, pipeline age etc.), third party damage and geotechnical.

Internal Corrosion Likelihood

Quantifying the internal corrosion likelihood was probably the most difficult task and also, the topic that generated the most debate. Internal corrosion in the upstream oil and gas industry can be quite a complex phenomenon to predict, especially when it comes to localized corrosion. Apart from numerous corrosion mechanisms such as CO_2 corrosion, sour pitting and bacterial attack, there are various operational and historical factors such as shut-in production, chemical pump failures and pigging inefficiencies that affect the true internal corrosion rate. While numerous advancements have been made in corrosion modeling, Talisman's focus was to develop a tool that would draw out pipelines more likely to fail from internal corrosion relative to other pipelines and not necessarily determine an absolute corrosion rate or failure rate. Thus, emphasis was placed on accounting for the different possible mechanisms of attack in a particular pipeline and judging their importance. This approach also enabled Talisman to obtain results without requiring extensive input data which would not only be time consuming to obtain and implement, but would also be resource intensive.

The basic parameters considered for internal corrosion were flow regime, corrosion rate to wall thickness ratio (CR/WT) and water chlorides content. For flow regime, the internal corrosion factor used a model for horizontal pipelines simple enough to be programmed in a spreadsheet. The corrosion rate accounted for temperature and CO_2 partial pressure of the fluid. CR/WT was used instead of just a corrosion rate in order to account for adverse impacts on thinner walled pipe relative to thicker walled pipe when dealing with the same corrosion rate. Water chlorides input captured the potential of higher chlorides content to increase the likelihood of internal corrosion via increased water conductivity, disruption of protective scales, and promotion of localized corrosion in sour environments. However, it is important to mention that this approach would not capture top of the line corrosion which could occur at low chloride concentrations.

To account for the influence of different corrosion mechanisms, several factors were included namely, sour corrosion, microbiologically influenced corrosion (MIC), under deposit corrosion i.e. solids, elemental sulfur corrosion, oxygen corrosion and also, methanol associated corrosion. If any of the mentioned factors were believed to be present in the pipeline, a positive multiplier was applied to increase the base corrosion score. Each multiplier was assigned a different weighting that modified the corrosion likelihood score accordingly. The weighting was based on Talisman's past experiences and its view on severity of attack.

External Corrosion Likelihood

The risk of external corrosion was calculated using a more subjective approach. The calculation assumes that a pipeline coating in good condition along with a well designed and well maintained cathodic protection (CP) system is enough to mitigate external corrosion. Therefore, the user is required to input the condition of the pipeline coating and confirm the presence of cathodic protection along with its associated rectifier readings. If the cathodic protection system has issues like shorts or interference (from nearby pipelines), the calculation increases the risk of external corrosion. Due to the subjective nature of the external corrosion factor it is crucial that the inputs are verified by field operations groups.

Typically, external corrosion factors include actual CP pipe to soil (P/S) readings, P/S distance, P/S age and the type of soil that pipelines go through among other things. For example, highly conductive soils like wetlands and swamps pose a higher risk of external corrosion than dry sandy soil. However, in Talisman's case some of this data was either not easily accessible or was difficult to implement into the risk assessment tool. Thus, it was left as potential work for future versions of the tool.

Historical Likelihood

The historical likelihood factor was found to be the best way to account for previous events or operating conditions that may have been detrimental to pipeline integrity. As mentioned before, the internal corrosion factor accounts for current operating conditions and provides a ranking based on the perceived corrosiveness of the environment. However, previous pipeline events like extended shut-in periods as well as changes in acid gas composition, liquid holdup, pressure and temperature would promote pipeline wall loss. Knowing the difficulty of quantifying previous operational events, it was decided to consider a combination of variables that would highlight old pipelines, damaged pipelines or pipelines with a history of no flow. The historical factor requires information like pipeline construction date, failure history and shut-in time throughout the life of the asset. Failure history accounted for not only the number of previous failures but also “near failure” situations i.e. cases where measured wall loss was determined to be above 80% (via an ILI tool or other means). Only relevant failures were considered. For example, a reported failure due to a leaking gasket would not be considered as a relevant failure. In cases where no shut-in history was available a default of three weeks per year was applied. This accounted for planned shut-in and turn around time.

Third Party Damage Likelihood

Although pipeline damage or failures caused by third parties may be seen as random events, their likelihood could be subjectively estimated. Talisman’s approach consisted of three base parameters namely, right of way (ROW) activity, pipeline materials and pipeline depth of cover. A ROW score was calculated based on GIS road and railway crossing information and also based on field input. Two pipeline material classes were defined namely, metallic and non- metallic. Non-metallic pipelines were considered to be more prone to third party damage than metallic pipelines due to lower material strength. Depth of cover was captured subjectively by assigning a value for four cases i.e. good cover (>1m), unknown, insufficient cover and known exposed pipeline.

Due to the highly subjective nature of assessing third party likelihood the impact of this score on the overall likelihood score was minimized. However, when third party issues were known to be present in an area based on field input (due to increased human activity or vandalism), the option of a field input override was provided. In only these cases, the weighting of the third party damage factor was increased relative to the other likelihood factors.

Geotechnical Likelihood

In Talisman’s experience, the frequency of pipeline failures due to a geotechnical event has been low. Also, quantifying geotechnical likelihood can be a difficult task. Keeping in mind these factors, a subjective approach similar to third party likelihood was taken. Two parameters were considered namely, pipeline material and pipeline terrain.

Non-metallic pipelines were considered to be more prone to damage from stresses associated with ground movement. Hilly terrain was considered to present more of a threat than flat terrain. Similar to third party damage, the impact of these parameters on the overall likelihood score was minimized. However, in cases where geotechnical threats were known to be present based on past experience or specific data, the weighting of geotechnical likelihood was increased relative to the other likelihood factors.

Likelihood Algorithm

The next logical step after calculating all the likelihood factors was to create an algorithm that combined these factors to produce the overall likelihood score. A scale between zero (lowest likelihood) and four (highest likelihood) was used. It was established that the resulting algorithm should be able to highlight the main pipeline integrity threats and take advantage of the allowable data spread in order to differentiate pipelines with low, medium and high likelihood of failure. To this end, several methods were tested in developing the likelihood algorithm.

Initially, the likelihood factors were given a percentage weight based on actual failure statistics for Talisman. The main disadvantage of this approach was that the heavier weighted likelihood factors would dominate the overall likelihood score. As a result, the lower weighted factors would never make any significant impact on the overall score.

Subsequently, the likelihood factors were also averaged as an alternative approach. This method fared worse than weighting factors because it assumes all factors have the same weight. Averaging promoted the high likelihood factors to be diluted by the low likelihood factors and thereby, reduced the overall score. This in turn, failed to capture the true likelihood of a pipeline failure.

After testing combinations of both weighting factors and averages, the process eventually evolved into a cascading approach. Using this approach the likelihood factors were introduced from the highest level of importance to the lowest. Figure 2 shows a graphical representation of the algorithm. The calculation first evaluates the likelihood of internal and external corrosion and provides a base score. Then the algorithm uses a cascading approach to apply the historical, third party damage and geotechnical likelihood factors to yield the overall likelihood score. This allows any of the threats to impact the overall likelihood score as necessary without diluting the base score. An overview of the entire pipeline risk assessment process is shown in Figure 3. Some examples showing results from this process are also provided in the Examples section.

RISK ASSESSMENT CHALLENGES

Almost every aspect of creating the risk assessment tool posed its unique challenges. Some of the main issues are summarized below.

- Time and Resources - In the upstream industry, having a dedicated team of people to generate a risk assessment process is often a challenge. In Talisman's case, the entire process was developed in-house primarily by three asset integrity engineers along with a computer specialist and a GIS specialist. Development was carried out amidst other responsibilities and thus, time constraints were a challenge.

- Data constraints - The intention of the development team was to create a risk assessment tool applicable to all North American Operations. Access and integrity of data required to calculate the various failure likelihoods were restrictive. Also, data type varied between jurisdictional areas. For example, in certain provinces or states in North America, pipeline licencing is not mandatory. Thus, unique licence-line numbers are not necessarily available everywhere leading to segmentation difficulties in the risk assessment process.

- Pipeline connectivity – Creating pipeline networks for complex gathering systems is generally not an easy task. To overcome this challenge in Phase 2, Talisman decided to generate connected networks for primarily high consequence pipelines as determined in Phase 1. Group and sales lines typically were part of this. Production volumes were fed in directly from production accounting databases. However, where feasible certain gathering systems were fully flow connected using a commercial flow modeling software already owned by Talisman.

IMPLEMENTATION OF RISK ASSESSMENT RESULTS

Risk assessed pipelines were placed in a 4x4 matrix color coded green, yellow and red according to Talisman's perception of risk. The implementation of the final risk assessment allowed Talisman to focus resources on pipelines that showed high consequence and high likelihood of failure.

High risk pipelines were then reviewed to confirm whether risk mitigation measures were in place and if not, initiatives were put in place to mitigate the risk. Some of the risk mitigation activities implemented were corrosion inhibition via chemical programs, corrosion monitoring, pipeline inspections, pigging, ground movement monitoring, signage, and ROW inspections. Proposed changes were presented during regular asset integrity meetings and captured through Management of Change (MOC) documents.

FUTURE WORK AND IMPROVEMENTS

This was Talisman's first attempt at evaluating all its North American pipelines with the same risk assessment tool. Throughout the development and use of the tool various ideas to improve the tool emerged. Some of those ideas were implemented in the current version but others have been left for future versions. One key change planned is to include financial impact directly as a consequence of failure instead of capturing it indirectly through production. This would include financial loss through lost production, shut-in production, repair costs, environmental clean up costs, and other miscellaneous costs associated with a failure. Future work is also planned to include all risk mitigation initiatives in a single placeholder such as a database that contains pipeline integrity management program data. This would allow for point forward risk assessments to be made with historical information captured in this database. Another improvement involving GIS data would be to consider proximity to water bodies using a pre-defined buffer instead of just using intersects. This would account for cases where a nearby spill has the potential to flow into a river or a lake. The ideal scenario would include an integrated visual and data system which would allow all the outputs to be seen on one interface. For example, results could be viewed on a GIS system with pipeline risk, spatial, feature, historical and integrity related data attributes all on this GIS interface.

EXAMPLES

Phase 1 – Consequence Output Examples

Figure 4 shows an example of four different pipeline outputs from the consequence model.

- Line 1 is a 6 inch sales oil line with a MOP of 7,860 kPa. It has a highway crossing, a railway crossing, a major river crossing and is also close to a town. This is considered to be a high consequence pipeline and a score of 3.4 reflects this.
- Line 2 is a 2 inch produced water line with a MOP of 4,830 kPa. It crosses small temporary water bodies and goes through farmland. Thus, owing to its small size, and low environmental and public concern consequence, the pipeline is considered to be a low consequence pipeline (score of 0.9).
- Line 3 is a 6 inch oil effluent line with a licenced H_2S content and MOP of 0.5% and 4,830 kPa, respectively. It crosses small permanent water bodies, has a secondary paved or gravel road crossing and goes through farmland. This is a mid sized pipeline (based on Talisman's North American pipeline size distribution) that has some environmental and public concern consequence and thus, gets a score of 2.5.
- Line 4 is a 4 inch natural gas line with a MOP of 690 kPa. It has a secondary paved or gravel road crossing, a small temporary water body crossing and goes through farmland. This pipeline gets a score of 1.6 which is driven by its size and environmental consequence.

Phase 2 – Risk Output Examples

Figure 5 illustrates the risk assessment scores obtained for three Talisman pipelines from an oil effluent system. These pipelines connect wells to facilities like batteries, satellites or other pipelines. The results of the unmitigated pipeline risk analysis showed moderate to high likelihood of failure with minor consequences. Some of the parameters that generated low consequence scores were low production, low pressure and lack of intersects that could cause environmental damage or public concern. The moderate to high likelihood scores resulted from a combination of pipeline integrity threats such as pipeline age (up to 28 years from construction date), previous relevant failures (line 3), high water chloride content and presence of H_2S and significant CO_2 content in the gas phase.

Figure 6 presents the likelihood and consequence scores for four Talisman pipelines from a gas gathering system. The high consequence score seen on line 4 resulted from significant H_2S content in the gas, high production throughput and pipeline intersects with populated and environmentally sensitive areas. Notice that lines 3 and 4 showed a high unmitigated likelihood. This was due to pipeline age (43 years from construction) and known poor coating condition. Lines 1 and 2 resulted in low likelihood and consequence scores. Line 1 is fiberglass pipeline that carries natural gas from a well to a pipeline junction and thus, has no internal or external corrosion likelihood. This pipeline does not intersect any areas of public or environmental concern. Line 2 carries natural gas from a well to a pipeline junction under similar operating conditions to Line 1, but its likelihood increases due to the fact that the pipeline material is steel (internal and external corrosion threats). In this line, the likelihood increases due to flow regime (stratified flow) and a history of shut-in periods. The consequence score of Line 2 is also higher than the calculated score for Line 1 because the pipeline is in proximity to a community and its right of way intersects an environmentally sensitive area.

CONCLUSIONS

A consequence of failure approach based on GIS data can be applied in order to get an idea about a company's critical or high profile pipelines in a quick and efficient manner. Upon establishing the importance of a pipeline from a consequence viewpoint, the likelihood of failure can be determined through a semi-quantitative process to further refine a company's pipeline risk data set. In Talisman's case, this type of step based risk assessment allowed the use of available resources to categorize pipelines according to their risk level and implement integrity management activities in required areas.

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TABLES & FIGURES

TABLE 1:

GIS DATA SET USED TO DEFINE DIFFERRENT WATER BODY CLASSES IN ALBERTA

HYDROGRAPHY POLYGONS	**GIS Data Type**	**Assigned Water Body**
GA08850000	Major canal	Big Permanent
GA61850000	Major river	Big Permanent
GA80100000	Wetland	Big Permanent
GB21400000	Dugout	Small Permanent
GB37500000	Commercial lagoon	Big Permanent
GB37800000	Recurring (intermittent) lake	Big Permanent
GB37800200	Recurring (intermittent) lake	Big Permanent
GB37950000	Perennial lake	Big Permanent
GB37950200	Perennial lake	Big Permanent
GB49800000	Recurring (intermittent) oxbow	Temporary
GB49850000	Perennial oxbow	Big Permanent
GB56300000	Quarry	Big Permanent
GB60300000	Reservoir	Big Permanent
GD34700000	Icefield	Small Permanent
SINGLE LINE NETWORK	**GIS Data Type**	**Assigned Water Body**
GA01350000	Aqueduct	NA
GA08800000	Canal	Small Permanent
GA08800200	Canal	Small Permanent
GA20700000	Ditch	Small Permanent
GA20700200	Ditch	Small Permanent
GA28362230	Major canal primary flow representation	Big Permanent
GA28362350	Icefield primary flow representation	NA
GA28362400	Lake primary flow representation	Big Permanent
GA28362530	Major river primary flow representation	Big Permanent
GA28363230	Major canal secondary flow representation	Big Permanent
GA28363530	Major river secondary flow representation	Big Permanent
GA61700000	Indefinite stream	Small Permanent
GA61700200	Indefinite stream	Small Permanent
GA61750000	Recurring (intermittent) stream	Temporary
GA61750200	Recurring (intermittent) stream	Temporary
GA61900000	Perennial stream	Small Permanent
GA61900020	Perennial stream	Small Permanent
GA68650000	Spillway	NA
GB49800000	Recurring (intermittent) oxbow	Temporary
GB49850000	Perennial oxbow	Big Permanent
GE15870100	Manual arbitrary flow representation	NA
GE15870150	DEM arbitrary flow representation	NA

TABLE 2:

SCORES ASSIGNED FOR PIPELINES CROSSING DIFFERENT WATER BODIES

	Water Ways Score
Big Permanent	4
Small Permanent	3
Temporary	2
No Crossings	0

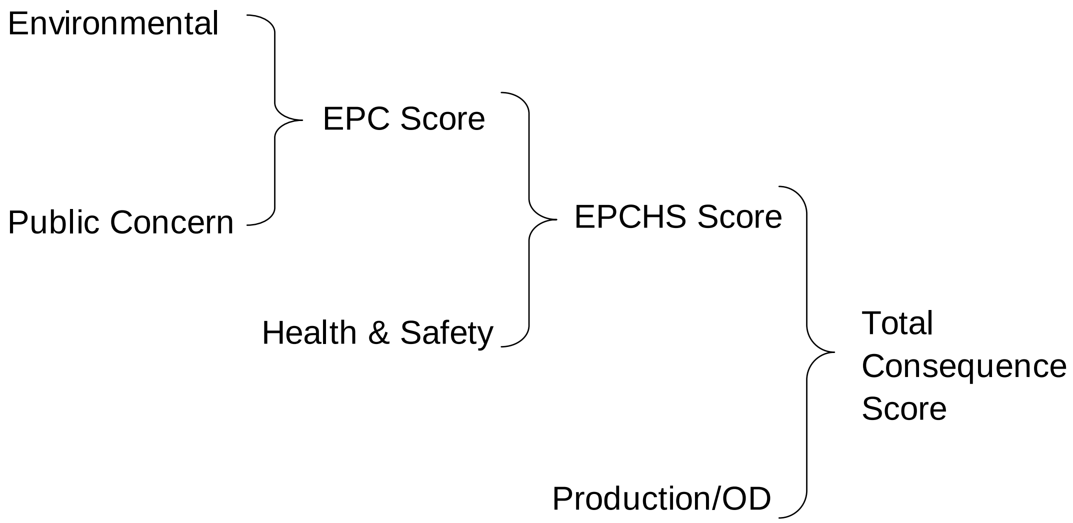

FIGURE 1 - Consequence Calculation Algorithm

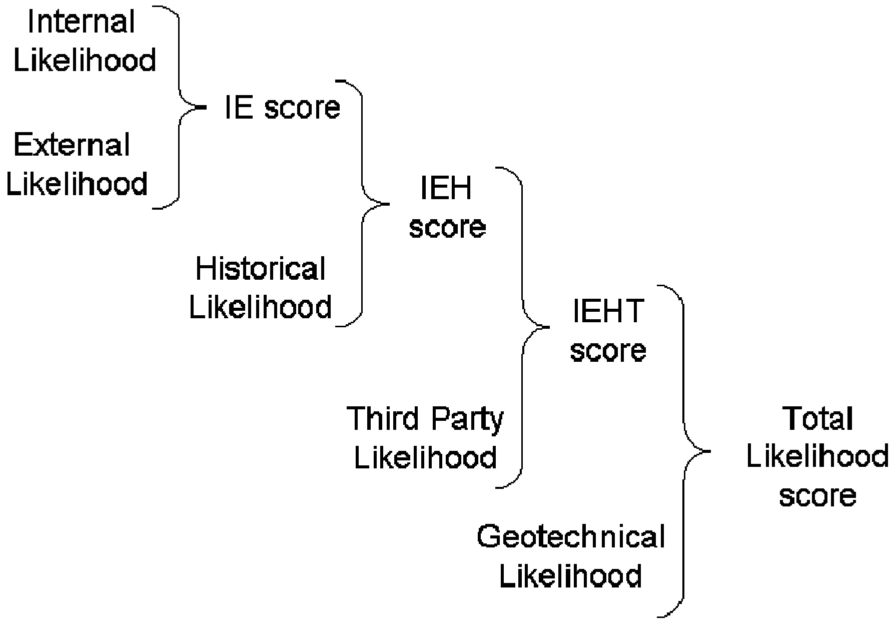

FIGURE 2 - Likelihood Calculation - Cascading Approach Algorithm

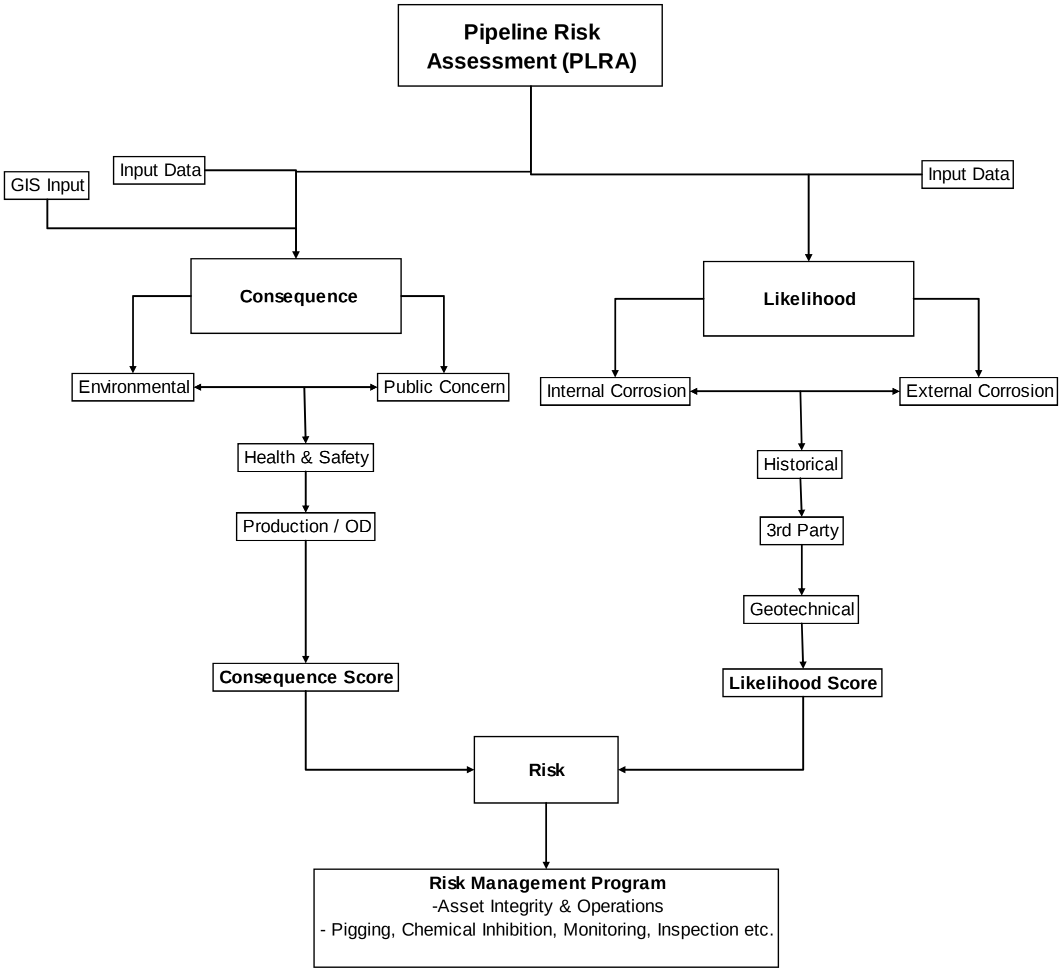

FIGURE 3 - Pipeline Risk Assessment Flowchart

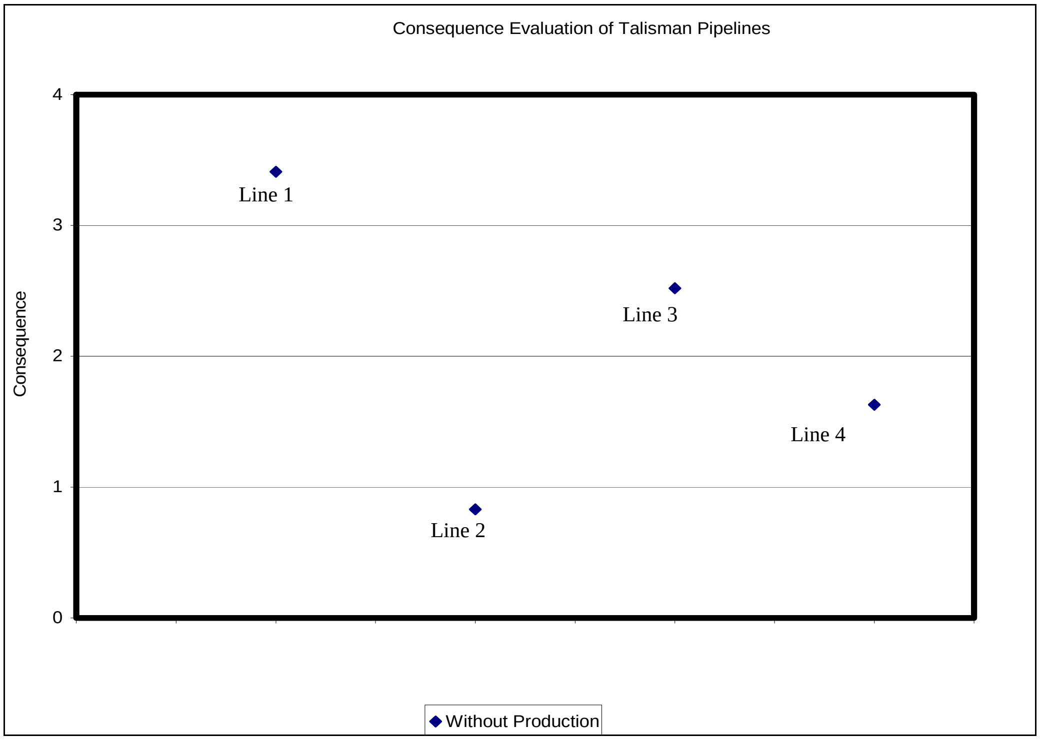

FIGURE 4 – Phase 1 Consequence Output of Four Talisman Pipelines

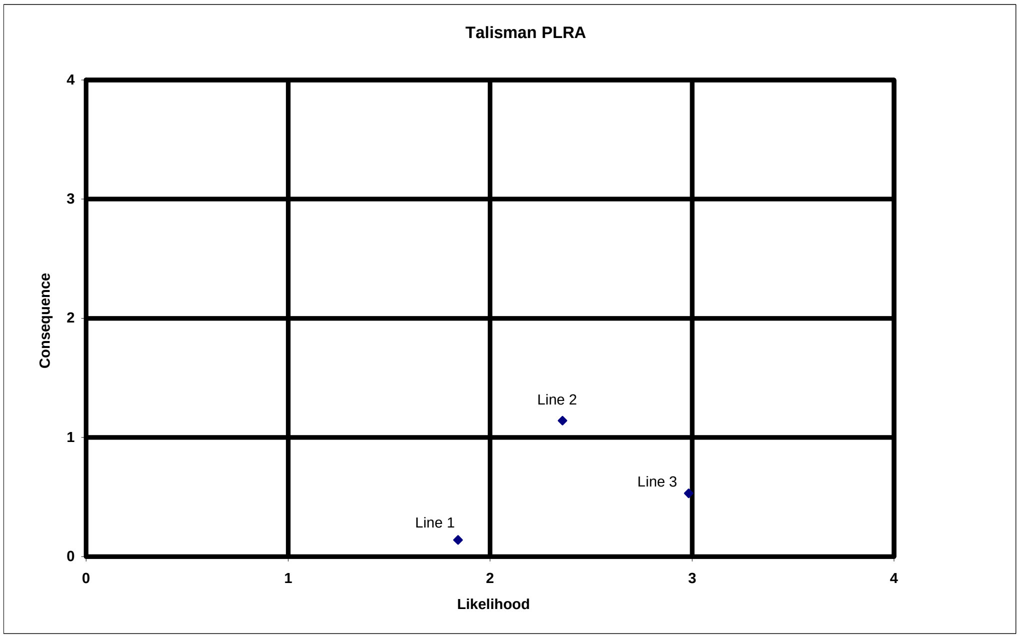

FIGURE 5 – Phase 2 Risk Output of Three Talisman Oil Effluent Pipelines

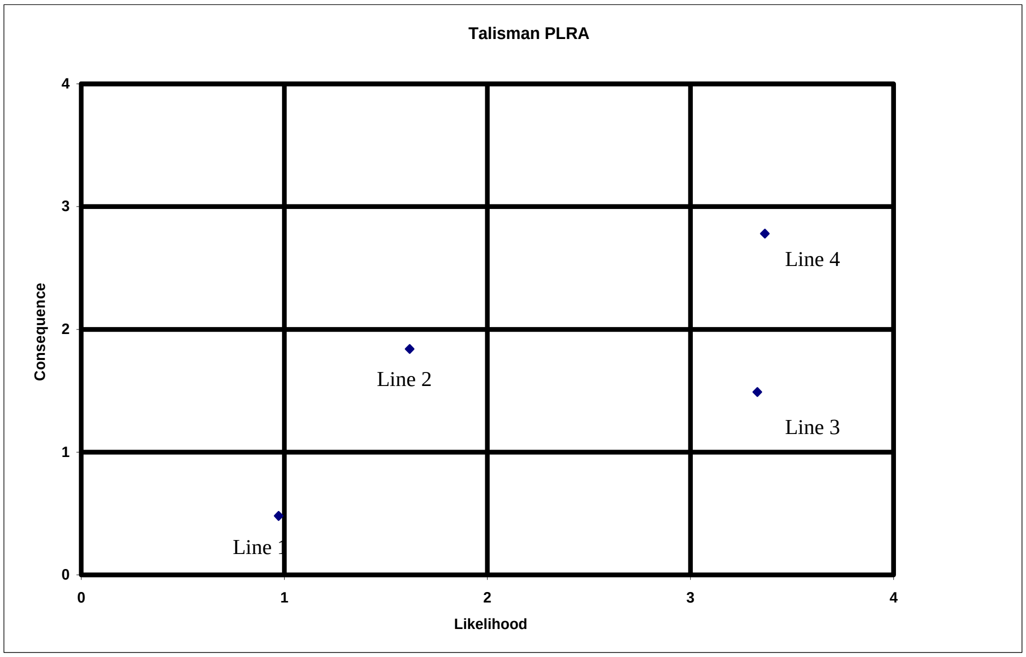

FIGURE 6 - Phase 2 Risk Output of Four Talisman Gas Pipelines