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The CEPA Pipeline Watercourse Management Program Recommended Practices are intended to be considered as a whole, and users are cautioned to avoid the use of individual chapters without regard for the entire Practices.
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# 1. Definition of Terms

The following definitions apply in this document.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Alberta Energy Regulator (AER)</strong></td>
<td>Regulator for pipelines within the province of Alberta.</td>
</tr>
<tr>
<td><strong>Asset:</strong></td>
<td>A generic reference to an arbitrary grouping of components, equipment or facilities where groupings are usually defined based on rules specific to each Operating Company.</td>
</tr>
<tr>
<td><strong>Consequence:</strong></td>
<td>Describes the result of an accidental event. The consequence is normally evaluated for human safety, environmental impact and economic loss.</td>
</tr>
<tr>
<td><strong>Depth of Cover (DoC)</strong></td>
<td>The distance from the pipeline to the top of the ground above the pipeline.</td>
</tr>
<tr>
<td><strong>Dent</strong></td>
<td>A depression caused by mechanical means that produces a visible disturbance in the curvature of the wall of the pipe or component without reducing the wall thickness.</td>
</tr>
<tr>
<td><strong>DOT-PHMSA</strong></td>
<td>Department of Transportation, Pipeline and Hazardous Materials Safety Administration; regulator for inter-state pipelines in the United States.</td>
</tr>
<tr>
<td><strong>Diameter</strong></td>
<td>The specified outside diameter (OD) of the pipe, excluding the manufacturing tolerance provided in the applicable pipe specification or standard.</td>
</tr>
<tr>
<td><strong>Engineering Assessment:</strong></td>
<td>A detailed technical analysis, as may be required from time to time, to assess or analyze whether a piece of equipment, or grouping of equipment, is suitable for service in its intended purpose or application.</td>
</tr>
<tr>
<td><strong>Fatigue</strong></td>
<td>The phenomenon leading to fracture of a material under repeated or fluctuating stresses having a maximum value less than the tensile strength of the material.</td>
</tr>
</tbody>
</table>
| **GIS** | Geographic Information System; a system designed to capture, store,
manipulate, analyze, manage, and present all types of geographical data.

Hazard: A condition or practice with the potential to cause an event that could result in harm to people, the environment, the company’s reputation, business or operation / integrity of its facilities.

Hydrotechnical Hazard Management Program: A documented program specific to pipelines that may be affected by hydrotechnical hazards that identifies the practices used by the Operating Company to ensure safe, environmentally responsible, and reliable service.

Inline Inspection (ILI) The inspection of the pipeline from the interior with a powered tool (“smart pig”) that travels with the fluid in the pipeline.

Integrity: Used in the context of managing pipeline systems, a general understanding or definition of integrity has to do with quality; that a component meets or exceeds design specifications for an intended purpose or application.

Integrity Management Program A documented program that specifies the practices used by the Operating Company to ensure the safe, environmentally responsible, and reliable service of a pipeline system.

Mitigation Activities to manage the risk exposure of a particular pipeline system or its individual components. Mitigation activities are broad ranging and are specific to the context (i.e., the type of equipment, its current state, and operating conditions).

National Energy Board (NEB) Regulator for pipelines that cross jurisdictional borders in Canada.

Oil and Gas Commission (OGC) Regulator for pipelines within the province of British Columbia.

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2 CSA Z662 Oil & Gas Pipeline Systems (CSA Z662-11)
**Operating Company:** The individual, partnership, corporation, or other entity that operates the pipeline system or an individual facility.

**Pipeline:** Those items through which oil or gas industry fluids are conveyed, including pipe, components, and any appurtenances attached thereto, up to and including the isolating valves used at stations and other facilities\(^4\).

**Pipeline Integrity Management Program**

A documented program, specific to pipelines, that specifies the practices used by the Operating Company to ensure the safe, environmentally responsible, and reliable service of a pipeline system.\(^5\)

**Pipeline System:** Pipelines, stations, and other facilities required for the measurement, processing, storage, gathering, transportation, and distribution of oil or gas industry fluids.\(^6\)

**Risk:** Strictly defined as the probability of an event or occurrence multiplied by the consequence of that event.

**Risk Assessment:** The detailed study undertaken to establish the risk associated with a specific piece of equipment, facility or pipeline system.

**Right-of-Way (ROW)**

A strip of land containing the buried utilities such as a pipeline or multiple pipelines.

**Service Fluid:** The fluid contained, for the purpose of transportation, in an in-service pipeline system\(^7\).

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\(^4\) CSA Z662 Oil & Gas Pipeline Systems (CSA Z662-11)

\(^5\) CSA Z662 Oil & Gas Pipeline Systems (CSA Z662-11)

\(^6\) CSA Z662 Oil & Gas Pipeline Systems (CSA Z662-11)

\(^7\) CSA Z662 Oil & Gas Pipeline Systems (CSA Z662 latest edition)
2. Introduction

2.1. GOALS AND OBJECTIVES

The purpose of this document is to compile and present the latest Canadian industry practices relating to the management of hydrotechnical hazards at operating pipeline water crossings or encroachments (collectively referred to as watercourses). The recommended practices herein are intended to encourage the safe and consistent management of hydrotechnical hazards along operating pipelines in Canada.

The goal stated above is based on the following objectives:

1. Protecting the safety of the public and pipeline company employees;
2. Protecting the environment, private and company property; and
3. Maintaining the reliable and economical operation of the Canadian pipeline system

2.2. SCOPE

The scope of this document is limited to the management of hydrotechnical hazards that could affect the integrity of onshore pipelines at watercourses. The document provides guidelines and recommendations on the identification, assessment and monitoring methodologies for watercourses. The document does not address other pipeline hazards that may occur in proximity to watercourses.

2.3. REVISIONS TO THIS RECOMMENDED PRACTICE

This Recommended Practice has been developed by CEPA's Pipeline Integrity Working Group (PIWG). It will continue to evolve as new advances and opportunities for improvement are recognized, and from periodic reviews as deemed necessary by CEPA and/or the PIWG.
3. Background Information

3.1. THE CANADIAN ENERGY PIPELINE ASSOCIATION

The Canadian Energy Pipeline Association (CEPA) represents energy transmission pipeline companies that transport over 97% of the oil, petroleum products and natural gas produced in Canada. CEPA’s member companies own and operate more than 110,000 km of pipelines across Canada, transporting natural gas and liquid petroleum products to North American markets providing for the energy needs of millions of consumers.

3.2. CEPA AND PIPELINE WATERCOURSE CROSSINGS

Operating pipelines are exposed to a range of hazards including corrosion, third party impact, mechanical and operational hazards, and geohazards, such as hydrotechnical, geotechnical and seismic hazards. Hydrotechnical hazards associated with watercourse erosion are typically the most common and most active geohazards affecting an operating onshore pipeline.

According to failure incident statistics collected by CEPA, the National Energy Board (NEB), and other Canadian and international organizations hydrotechnical hazards are the cause of only a small portion of pipeline failure incidents. However, as the environmental consequences of pipeline failures at watercourses are often significant, maintaining integrity of the pipelines continues to be a priority of the industry.

In 2004, the Canadian Association of Petroleum Producers (CAPP), CEPA, and Canadian Gas Association (CGA) issued the 3rd edition of the Pipeline Associated Watercourse Crossing. The document is a compilation of modern planning considerations, best practices for pipeline watercourse crossing construction techniques, and available environmental protection methods to meet Provincial and Territorial regulatory requirements and minimize associated fisheries habitat impact. The document was endorsed by the Department of Fisheries and Oceans Canada (DFO) and recognized as a reference document for use both by industry and the DFO.

3.3. APPLICABLE REGULATIONS AND CODES

There are numerous regulations, codes and guiding documents that can provide regulators with a mandate and operators with guidance on acceptable practices for watercourse management. Many of these regulations and guiding documents refer back to the Canadian Standards Association publications.
The following list outlines some of the relevant pipeline codes and guiding documents used in Canada, along with a brief description of their relevance. Further details regarding their application to water crossing management can also be found in Appendix A.

3.3.1. CSA Z662

The Canadian Standards Association (CSA) Document Z662 is intended to establish essential requirements and minimum standards for the design, construction, operation, and maintenance of oil and gas pipeline systems. The Standard is subdivided into categories of design, construction, operation, and maintenance with the addition of several annexes each of which include some facet of watercourse crossings. CSA Z662 is referenced frequently in this guideline.

3.3.2. CSA Alberta Code of Practice for Pipelines and Telecommunication Lines Crossing a Water Body

Under the Alberta Water Act and Water (Ministerial) Regulation, the Alberta Ministry of Environment has produced a Code of Practice specific to crossings of a water body (water course and standing water). This Code of Practice covers all aspects of works related to installation of new pipelines as well as repair and replacement of existing operating pipelines.

3.3.3. The Alberta Pipeline Act

Under Alberta Regulation 91/2005, the Alberta Energy Regulator (AER) of the Alberta Provincial Government administers the Pipeline Act. This Act covers activities associated with both the design of new pipelines as well as the operation of existing pipelines through specifications including materials and design, inspection and maintenance operations, as well as abandonment and removal.

3.4. APPLICABLE GUIDELINES AND REPORTS

3.4.1. CAPP/CEPA/CGA Pipeline Associated Watercourse Crossings

The working groups of the Canadian Association of Petroleum Producers (CAPP), CEPA, and Canadian Gas Association (CGA) collectively developed a joint guideline on Pipeline Associated Watercourse Crossings. This guideline provides a list of regulatory and information requirements and discussion of:

1. Risk-based watercourse crossing selection processes,
2. Environmental mitigation procedures,
3. Habitat mitigation and compensation, and

This document is publicly available on the CEPA website.

3.4.2. PRCI Report Enhancement of Integrity Assessment Models/Software for Exposed and Unburied Pipeline in River Channels

This report and associated software ‘River-X’ published by Pipeline Research Council International (PRCI) presents a methodology for the advanced assessment of exposed pipelines under hydrodynamic loads, impact loads from floating or moving debris and fatigue due to vortex shedding. This guideline and software supports analytical estimates on the magnitude of damage at exposed pipelines caused by river channels.

This document is available for purchase from PRCI.

3.4.3. DNV Recommended Practice DNV-RP-F105 Free Spanning Pipelines

The document presents a methodology for the advanced assessment of exposed free-spanning pipelines at specific sites subjected to combined wave and current loading. It includes a brief introduction to the basic hydrodynamic phenomena, principles and parameters. The basic principles applied in this document are in agreement with most recognized rules and reflect state-of-the-art industry practice and research.

3.5. DEPTH OF COVER REQUIREMENTS AT WATERCOURSE CROSSINGS

3.5.1. New Pipeline Construction

To determine the required depth of cover for a new pipeline, the designer must consider the physical characteristics of the watershed and crossing including the stability of the bed and banks, maximum scour depths or other features that could cause adverse effects. In Canada, the minimum required depth of cover for a new pipeline water crossing is 1.2m. Reduced cover, but not less than 0.6m\(^8\), may be used if analysis demonstrates that the likelihood for erosion is low.

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\(^8\) The minimum depth of cover for pipelines regulated by the Alberta Energy and AER is 0.8 metres.
3.5.2. Operating Pipelines

The depth of cover for operating pipelines should be at a level to maintain the integrity and safe operation of the pipeline. Pipeline companies should be able to demonstrate that either the pipeline has a low likelihood for exposure or has a low likelihood of damage or failure (vulnerability) if it were to become exposed.

Therefore when considering flow forces, less than 1.2m of cover may be acceptable for water crossings with minimal erosion potential or crossings that have insufficient flow energy to damage an exposed pipeline in the event of an exposure. Conversely, more than 1.2m of cover may be required at crossings with high erosion potential, in order to minimize the likelihood that the scour depth could exceed the depth of cover and expose the pipeline to damage.

In Alberta, the minimum depth of cover (0.8m) must be maintained for all operating and discontinued pipelines constructed after 1977, unless otherwise authorized by the AER.

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9 As defined in the Alberta Pipeline Act, discontinued is the temporary deactivation of a pipeline or part of a pipeline.
10 The minimum depth of cover requirement for pipelines is to maintain the "code at the time of construction". For example in Alberta, this means that pipelines built before 1977 do not have a minimum cover depth requirement, so long as they are not exposed, and the pipeline operator deems the risk to be manageable.
4. Hydrotechnical Hazards

4.1. OVERVIEW OF HAZARD TYPES

Hydrotechnical hazards at pipeline water crossings are related to stream channel changes. Rapid and unexpected changes can occur in streams due to natural disturbances of the fluvial system and/or in response to human activities within the watershed. Natural disturbances such as floods, drought, earthquakes, landslides, forest fire, etc. may result in large changes in sediment load in a stream and changes in the stream channel. Human-induced changes in the drainage basin and the stream channel, such as the installation of bridges, culverts, levees, reservoirs or changes to vegetation cover or land use can have major effects on streamflow, sediment transport and channel geometry and location.

Although channel changes are driven by many factors, those effecting pipeline water crossings are primarily seen to be in response to floods. All natural streams transport water and sediment (i.e. sand and/or gravel) downstream. During floods, the water and sediment quantities are increased dramatically and wood, ice or other debris may also be transported. The way that the water, sediment, wood and ice move downstream determines how the stream channel develops and changes. Over time, it is normal for streams to erode their banks and move laterally, or change the streambed elevation, with either the erosion or deposition of sand and/or gravel. It is these changes to the stream channel, from flooding or otherwise, that can create the hazards of pipe exposure and the potential for pipe damage.

The extent a stream channel changes over time is related to the stability of the stream. Factors that affect stream stability can be classified as geomorphic factors (relating to channel shape and alignment) and hydraulic factors (e.g. flow velocities and flow depths, sediment transport, magnitude and frequency of floods, ice and other floating debris, bed forms and flow constrictions). Geomorphic and hydraulic factors affecting stream stability are well understood and have been documented in numerous textbooks and other reference documents. A detailed description of geomorphic and hydraulic factors is beyond the scope of this discussion. The reader is directed to the available literature, a few examples include Charlton, 2008; Julien, 2002; Robertson et Al, 1998; Sturm, 2009; Robert, 2003 and U.S. Army Corps of Engineers, 2004. As channel conditions vary rapidly from river to river and reach to reach, it is often best to obtain a site specific assessment by qualified personnel.

Hydrotechnical hazards resulting from stream stability issues can be categorized by the type of channel movement. A common categorization method delineates hydrotechnical hazards into three types, which can be further delineated as follows\(^\text{11}\):
Vertical Channel Movement

- Scour
- Degradation
- Aggradation

Horizontal Channel Movement

- Bank erosion
- Encroachment

Channel Relocation

- Avulsion
- Meander Cutoffs

4.2. VERTICAL CHANNEL MOVEMENT

4.2.1. Scour

Scour is the local deepening of the channel commonly caused by obstructions, constrictions, and/or impingements that re-direct and concentrate the flow pattern of the stream. Examples of obstructions, constructions and impingements include piers, large woody debris, stream confluences, riprap revetments, large boulders, etc. A schematic diagram of scour is shown in Figure 1. Example photographs of pipeline scour hazards are provided in Appendix B.

![Figure 1. Schematic of local scour due to obstruction in channel](image)

vertical channel movement and Lateral Stability is the combination of horizontal channel movement and Channel Relocation with the same sub-hazards.
4.2.2. Channel Degradation and/or Aggradation

Degradation is the general and progressive (long-term) lowering of the channel bed due to erosion, over a relatively long channel length. While scour is considered to be an event-based process, channel degradation occurs over a long period of time and along relatively long stream sections. The causes of channel degradation are complex, but can be caused by an increase in water discharge, reduction in sediment supply, lowering in the elevation of downstream base levels, removal of downstream obstructions (e.g. beaver dam). Degradation is a very common fluvial hazard at pipeline watercourse crossings. Figure 2 is a schematic diagram of channel degradation. Example photographs of degradation hazards are provided in Appendix B.

Aggradation is the increase in streambed elevation due to the deposition of sediment. Aggradation of a watercourse decreases the capacity of the channel resulting in more frequent and increased-over-bank flows. Often, the cause of aggradation is an increase in upstream sediment load and/or size of sediment exceeding the transport capacity of the channel. Adverse consequences associated with aggradation include channel avulsion.

![Figure 2. Schematic of channel degradation](image)
4.3. HORIZONTAL CHANNEL MOVEMENT

4.3.1. Bank Erosion

Bank erosion is the lateral migration of the channel banks at those sites where the pipeline runs across the watercourse crossing. This hazard will often be present on the outside of meander bends in erodible soils. Bank erosion is often the most recognizable sub-hazard and is often detectable during aerial patrols. Active bank erosion is characterized by steep banks, with little or no vegetation. In some cases clumps of soil and vegetation falling into the channel may be identifiable.

Bank erosion rates will depend on the bank’s erosion resistance (i.e. soil type, vegetation, riprap, etc.) and the attack from the river’s current (i.e. angle of attack, water velocity against the bank, undermining, logjams redirecting flow, etc.) Erosion can take place slowly over a period of years or suddenly during a single flood event. Bank erosion at a pipeline crossing could result in exposure of the over-bends of the pipeline. Figure 3 is a schematic of bank erosion. Example photographs of pipeline bank erosion hazards are provided in Appendix B.

![Figure 3. Schematic of bank erosion](image)

4.3.2. Encroachment

Encroachment is similar to bank erosion in that they both involve lateral channel migration. However, encroachment occurs where the pipeline runs parallel to the watercourse and does not cross it. Like bank erosion, this hazard is likely to be present at the outside of meander bends. Encroachment characteristics that can be noted by field inspection are similar to bank erosion. Figure 4 is a schematic of encroachment. Example photographs of pipeline encroachment hazards are provided in Appendix B.
Although the mechanism driving the movement of the channel may be the same for encroachment and bank erosion, the hazard to the pipeline is different due to the orientation of the pipeline to the flow of the watercourse. Pipelines subject to encroachment are usually situated parallel to the flow of the watercourse at the encroachment site (e.g. outside bank of meander bend). If a pipeline becomes exposed due to an encroachment, a longer length of pipe may be exposed more quickly as an additional meter of bank erosion may expose several meters of pipe along the encroachment. However, pipelines situated parallel to flow can withstand longer free span lengths and are less susceptible to vortex shedding and impact loads.

Figure 4. Schematic of channel encroachment

4.3.3. Channel Relocation

4.3.3.1. AVULSION

Avulsion refers to the sudden establishment or re-establishment of a new channel. Depending upon the watercourse, the original channel may become abandoned. The new avulsion channel can be temporary or permanent, and can be particularly hazardous to a pipeline when it is located in an area not designed for a watercourse crossing. Avulsion is predominantly a concern on flood plains and alluvial fans that carry high sediment loads, or on channel that become obstructed (e.g. logjams, ice jams, or debris flows.). Figure 5 shows a schematic of channel avulsion. Example photographs are avulsion hazards are provided in Appendix B.
4.3.3.2. MEANDER CUTOFFS
A meander cutoff occurs when the two closest parts of a meander bend are 1) breached by a cutoff channel or 2) migrate together. The process can occur suddenly during a large flood or gradually as a result of horizontal bank erosion. The abandoned section of the channel may form an oxbow lake. The meander cutoff causes a significant shortening and local steepening of the watercourse channel. Overtime the bed elevations in the cutoff channel decrease with upstream bed degradation and downstream bed aggradation. This over-steepened channel reach is also prone to high rates of bank erosion since the erosion effectively lengthens the channel and thus reduces the channel slope.

A threat to a pipeline could occur if:

1. The pipeline crossing is located upstream of the meander cutoff and is exposed as the bed degrades.
2. The pipeline crossed at the meander bend and is now exposed in the cut-off channel.
3. The meander cutoff increases bank erosion creates a horizontal channel movement problem as described in Section 4.3.1, or the new (poor) alignment of the river through the crossing increases bank erosion.
4.4. HYDROTECHNICAL DAMAGE MECHANISMS

Exposure or suspension of a pipeline at a watercourse crossing could potentially impact the integrity of the pipeline from hydrodynamic loads, impact loads and fatigue caused by vortex shedding. Although pipeline exposures are not desirable and are attempted to be prevented, it is important to recognize that the flow in some smaller creeks and channels may not be sufficient to damage an exposed pipeline.

4.4.1. Hydrodynamic Loads

Hydrodynamic loads can be amplified by debris pile-ups around the pipeline, particularly trees with root bulbs, which effectively increase the cross-sectional area of the pipeline that is subjected to the flow. If the length of the exposure and the magnitude and velocity of water flow is sufficient the combined loading may result in unacceptable plastic strain levels to develop in the pipeline.

4.4.2. Impact Loads

Floating debris (i.e. wood, ice) or rocks transported by the flow of the water could impact an exposed pipeline damaging the coating, denting the pipe, or causing a puncture. Floating debris could be present in watercourses and may be comprised of woody debris such as trees and tree branches. Woody debris is often mobilized during flood events when water levels are sufficiently high to float fallen trees in the floodplain, or undermine trees on channel banks causing them to fall into the river. Hydraulically transported rocks or floating debris could potentially cause damage to an exposed pipeline if the transported objects are large enough and are moving quickly enough so that an impact with an exposed pipeline would cause a load greater than the
pipeline can withstand. Falling riprap may be a concern where existing armouring is undermined.

4.4.3. Fatigue

A free-spanning pipeline may be susceptible to fatigue damage from vortex induced vibration (VIV) caused by vortex shedding. Vortex shedding is an unsteady flow phenomenon that occurs at special flow velocities governed by the length and shape of the exposed pipeline. Each time a vortex is shed from the object it alters the local pressure distribution around the pipeline and the pipeline experiences an induced stress. The main component of the induced stress is perpendicular and vertical to the flow direction. In addition a smaller fluctuating component of the stress with a frequency twice that of the vortex shedding is also present.

Depending upon the length of the free-spanning pipe and the watercourse flow velocity, interactions may arise between the vortex shedding mechanism and the pipeline deflection. Under certain conditions, the pipeline may oscillate at a frequency at or near its natural frequency, potentially resulting in large and destructive stresses. If the critical free-span length and required flow velocity is reached, VIV may cause immediate failure of the pipeline. Figure 7 depicts the relationship of free span length and velocity for a set of specific pipe properties.

![Figure 7: Example of Allowable free span length vs. water velocity](image)
5. Program Overview

The Program for managing watercourse crossings presented here is developed from the guidelines in Annex B and Annex N of CSA Z662.

As illustrated in Figure 9, an idealized hydrotechnical hazard management program should consist of the following activities. In accordance with CSA Z662-11 Annex N, the idealized framework could be expanded to include the option of implementing hazard controls instead of risk estimation and analysis.

(Figure 8: Hydrotechnical Hazard Management Program)
5.1. PROGRAM SCOPE

The first step to creating a Pipeline Watercourse Management Program (the Program), is to clearly define which should define the following:

1. Define what watercourses constitute a potential hydrotechnical hazard. A pipeline watercourse site includes locations where a watercourse may interact with a pipeline that is either crossing or is located adjacent to the watercourse.

   Hydrotechnical hazards may be defined as:
   a. a watercourse of a certain width, length and/or watershed area;
   b. an ephemeral, intermittent or seasonal gully, stream or river;
   c. a channel where appreciable channelized water flow is occurring;
   d. a lake, reservoir, beaver pond with potential for flow or discharge

   A precise and robust definition of a pipeline watercourse site is essential to keep the Program within a practical scope. The definition may be revised as the Program and industry practices evolve.

2. Define operational thresholds for assessing and evaluating hydrotechnical hazards. The assessment would evaluate the probability that a specific hydrotechnical hazard would meet the defined threshold(s), and would compare this probability against the pipeline operator’s acceptance criteria. Operational thresholds may include:

   a. a depth of cover (DoC) less than the anticipated erosional or scour depth at a given flow condition, return period or flood intensity;
   b. an exposed pipe (DoC = 0 m);
   c. an unacceptable span length (hydrodynamic loads or vortex shedding);
   d. an unacceptable probability of damage from impact;
   e. an unacceptable probability of failure; and
   f. movement of a watercourse channel to a point deemed too close to an operational pipeline.

   Some operational thresholds may be less complex and easier to implement due to more inherent conservatism. Programs shall consider potential effects of interacting features including, but not limited to corrosion, cracking, weld flaws, and mechanical damage that may change the potential pipeline damage in the event a pipeline becomes exposed.
5.2. PROGRAM IMPLEMENTATION

The following items could be considered for the successful implementation of a Pipeline Watercourse Management Program:

1. Define the scale of the Program (Leir 2004). A Program may start with a screening level assessments and conceptual level recommendations. Screening level assessments would then result in more detailed studies at fewer hydrotechnical hazard sites, potentially resulting in basic engineering level designs and recommendations. In parallel with screening and basic engineering initiatives, more extensive risk assessments could be reserved for select high priority pipeline watercourse sites requiring detailed engineering recommendations. Understanding and applying these scales to the Program will help better allocate resources effectively.

2. Consider implementing the Program in a phased approach beginning with higher risk pipeline systems. Identify what pipeline systems or sections the Program will be implemented on first. Selection may be based on a variety of criteria such as, but not limited to: pipeline diameter, operating pressures, product, historical observations, environmental sensitivity, or geographic regions. The Program should evolve and expand to all pipeline systems.
6. Hazard Identification

The purpose of hydrotechnical hazard identification is to gain an understanding of the number, location, and characteristics of the watercourses near operating pipelines. Hazard identification is discussed in Section B.5.2.3 of Annex B in CSA Z662. The first step is an office inventory of all the known sites where potential hydrotechnical hazards could affect operating pipelines (pipeline watercourse sites). Each pipeline watercourse site should be visually inspected in the field to, at least, confirm their existence. Baseline inspections at each pipeline watercourse site with potential for hydrotechnical hazards and to characterize their current and potential impact on the pipeline. Risk assessment at each site may then follow.

6.1. PRELIMINARY WATERCOURSE INVENTORY

6.1.1. Office Based

A preliminary pipeline watercourse site inventory is typically prepared in the office to identify watercourses that are currently crossing or encroaching on the pipeline. This task can be accomplished by overlaying the pipeline over a hydrology network and by reviewing existing operational records to determine where hydrotechnical hazards have occurred or been mitigated in the past and by reviewing the data sources described below:

- Pipe alignment sheets,
- Route maps,
- Design drawings or as-built drawings,
- GIS images and base data,
- Existing environmental inventories,
- Existing survey data,
- Existing ILI data,
- Aerial photos and ortho imagery,
- TRIM or NTS topographic maps,
- Surficial geology and bedrock maps,
- Aerial/ground observation reports,
- Historical Engineering or remediation reports, and
- Original design notes.

Resolution of aerial photographs and ortho imagery can be a limitation in characterizing pipeline watercourse sites. Runoffs from small depressions can usually be recognizable as some form of drainage path in aerial photographs. However, these drainage paths often cannot be identified in the field because flow runs along an almost flat surface and is not channelized. These minor channels do not normally represent a threat to the pipeline and are generally not included in hazard inventories.
6.1.2. Aerial Inspection

Aerial inspection is an effective means of rapidly reviewing a pipeline right-of-way to verify if the sites identified in the preliminary inventory actually exist. Aerial inspections can be effective at confirming or identifying obvious hydrotechnical hazards, often at larger water crossings. Characterization of a pipeline watercourse site from air is not as effective as assessing it from the ground and most sites will require a ground based inspection. However, the results from an aerial inspection could be used to prioritize the baseline ground inspection of hazard sites.

6.2. BASELINE GROUND INSPECTION

A baseline ground inspection is a thorough approach for hazard characterization which involves a brief site investigation to confirm and evaluate the hazard. Access can either be by foot, all-terrain vehicle, automobile, or helicopter.

The goal of the Baseline Ground Inspection is to collect enough information in the field to allow effective risk assessment (see Section 7.0). Natural or anthropogenic changes in the controls that affect stream channel stability such as stream flow, sediment supply and/or the presence or absence of vegetation, should be assessed as they may be indicators of an elevated hydrotechnical hazard or activity.

Collection of the following information should be considered during a Baseline Ground Inspection.

- Site GPS coordinates,
- Characterization of hydrotechnical hazards currently or potentially impacting the pipeline such as scour, channel degradation, bank erosion, encroachment, and avulsion,
- Description of geomorphological, hydrotechnical or geotechnical properties that may influence the susceptibility or severity of the hydrotechnical hazard types (listing of example properties listed in Section 7.1.1),
- Minimum depth of cover over the pipeline within the active channel and within the broader floodplain (if present),
- Horizontal distance from the pipeline sag bends to the channel banks,
- Site photographs, and
- Any additional information pertinent to the crossing.

The scope of the program and details of the risk assessment process will define what information is required from an inspection.
7. Risk Assessment

Risk assessment includes risk estimation and risk evaluation.

Risk estimation is the process of estimating the risk to the pipeline caused by the hydrotechnical hazards at each site. Risk Estimation is part of Risk Analysis as per CSA Z662 Annex B. Risk evaluation is the follow-up process of evaluating the significance of the risk that has been estimated at each site.

The Program should identify the type of risk assessment technique (see Table 1) recognizing that each technique has a range of technical and economic advantages, disadvantages and accuracies. The complexity of the assessments typically increases from qualitative, to semi-quantitative to quantitative analysis. However, due to the complexity of hydrotechnical hazard processes, each method will typically involve a blend of quantitative engineering assessments and qualitative expert judgments.

<table>
<thead>
<tr>
<th>Analysis Method</th>
<th>Description of Risk Analysis Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qualitative</td>
<td>Qualitative risk analysis typically adopts words or a descriptive scale to describe the relative risk of the hydrotechnical hazard at each site. Results can be used to compare individual sites against a predetermined risk threshold, but only to sites assessed with the same methodology.</td>
</tr>
<tr>
<td>Semi-Quantitative</td>
<td>Semi-quantitative risk analysis is assessed on numeric scales to describe the relative risk of the hydrotechnical hazards at each site. As with the qualitative analysis these values are used to compare individual sites to a predetermined threshold. Numerical results are commonly normalized to a useful scale (i.e. 1 to 100) or grouped into predetermined classifications.</td>
</tr>
<tr>
<td>Quantitative</td>
<td>Quantitative analysis seeks to provide an absolute estimate of the probability of pipeline failure. Quantitative methods are typically based on historical frequencies of pipeline failures or adopt the use of event trees. The pipeline failure rate is usually extracted from industry performance databases and is a required starting point for the historical failure rate methodology.</td>
</tr>
</tbody>
</table>

7.1. RISK ESTIMATION

Probability and consequence can be subdivided into more descriptive terms or components. This subdivision helps practitioners identify and understand the sub-components that contribute to the estimated risk (MOF 2004).
7.1.1. Frequency Analysis

Frequency analysis is used to estimate the likelihood or probability the identified hydrotechnical hazard may pose a threat to the integrity of the pipeline. To estimate this likelihood, it can be useful to estimate the probability the hazard will expose the pipeline (probability of exposure) and the probability the pipeline will be damaged once it is exposed (vulnerability).

The probability of exposure analysis should include consideration of the different types of hydrotechnical hazards that may act to expose a pipeline at a water crossing. Empirical equations and relationships are available to estimate the depth of vertical erosion or the susceptibility of horizontal bank erosion. Estimated vertical erosion (e.g. scour) depths can then be compared to the pipeline depth of cover to estimate the probability of exposure. Similarly, the susceptibility of a bank to horizontal erosion can be compared to the horizontal distance from the bank to the pipeline overbend or sag bend. Table 2 provides a list of example factors that may be considered to evaluate the likelihood a hydrotechnical hazard may lead to an exposure of the pipeline.

Table 2: Example of Factors Assessed in a Probability of Exposure Analysis

<table>
<thead>
<tr>
<th>Hazard Type</th>
<th>Probability of Exposure Factors¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avulsion</td>
<td>Upstream Channel Confinement</td>
</tr>
<tr>
<td></td>
<td>Upstream Channel Gradient</td>
</tr>
<tr>
<td></td>
<td>Aggradation/Overbank Deposits</td>
</tr>
<tr>
<td>Bank Erosion</td>
<td>Angle of Attack</td>
</tr>
<tr>
<td></td>
<td>Bank material/protection</td>
</tr>
<tr>
<td></td>
<td>Length of Bank Erosion</td>
</tr>
<tr>
<td>Channel Degradation</td>
<td>Channel bed material</td>
</tr>
<tr>
<td></td>
<td>Site Features</td>
</tr>
<tr>
<td></td>
<td>Height of Control Structure</td>
</tr>
<tr>
<td>Encroachment</td>
<td>Angle of Attack</td>
</tr>
<tr>
<td></td>
<td>Site Features</td>
</tr>
<tr>
<td></td>
<td>Perpendicular distance to pipeline</td>
</tr>
<tr>
<td>Scour</td>
<td>Bank height</td>
</tr>
<tr>
<td></td>
<td>Scour hole depth</td>
</tr>
<tr>
<td></td>
<td>Angle of Attack</td>
</tr>
</tbody>
</table>

¹The depth of cover of the pipeline should be considered for all hydrotechnical hazard sites. For bank erosion and avulsion, the depth of cover at the new bank or channel location should be considered.

The vulnerability analysis assesses the likelihood or probability that an exposed pipeline will be damaged by the hydrotechnical hazard. The analysis should include consideration of damage from hydrodynamic loading, impact.
loads and fatigue due to vortex shedding. Secondary features such as corrosion, cracking, or welds that may decrease the strength of the pipeline in the watercourse should also be considered. Additional guidance is available in DNV Recommended Practice on Free Spanning Pipelines DNV-RP-F105, the Pipeline Research Council Institute (PRCI) report Enhancement of Integrity Assessment Models/Software for Exposed and Unburied Pipelines in River Channels.

Table 3 provides an example list of factors to be considered that can affect the vulnerability of the pipeline in a watercourse crossing.

Table 3: Example of Factors Assessed in a Vulnerability Analysis

<table>
<thead>
<tr>
<th>Damage Mechanism</th>
<th>Vulnerability Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrodynamic Loading</td>
<td>Stream discharge and flow velocity&lt;br&gt;Length and attributes of exposure&lt;br&gt;Geological and geotechnical parameters&lt;br&gt;Potential for debris build-up (dimensions, type, etc.)</td>
</tr>
<tr>
<td>Impact loads</td>
<td>Stream discharge and flow velocity&lt;br&gt;Type and size of impacting objects (e.g. rock, tree, ice)&lt;br&gt;Length and attributes of exposure</td>
</tr>
<tr>
<td>Vortex Shedding</td>
<td>Stream discharge and flow velocity&lt;br&gt;Length and attributes of exposure</td>
</tr>
</tbody>
</table>

Information regarding the pipeline properties and loads are required for the vulnerability analysis of hydrotechnical damage mechanisms. Required pipeline properties include diameter, wall thickness and material properties such as yield stress, modulus of elasticity, Poisson’s ratio, etc. Table 4 provides a listing of loads that may be considered during a vulnerability analysis.

Table 4: Example of Loads Considered in Vulnerability Analysis

<table>
<thead>
<tr>
<th>Load Classification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operational Loads</td>
<td>Loads arising from the intended use of the pipeline including internal operating pressure, external hydrostatic pressure, weight of the pipeline, residual stresses from installation, etc.</td>
</tr>
<tr>
<td>Load Classification</td>
<td>Description</td>
</tr>
<tr>
<td>-------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Construction Loads</td>
<td>Loads from the construction of the pipeline system such as loads resulting from the handling, storage and transportation, installation, and pressure testing.</td>
</tr>
<tr>
<td>Accidental Loads</td>
<td>Loads imposed on a pipeline during unplanned but plausible circumstances. Examples include loads from sudden decompression, third party damage.</td>
</tr>
</tbody>
</table>

### 7.1.2. Consequence Analysis

Consequence analysis is used to quantify the potential loss to the environment, public, and infrastructure if there is a failure. Watercourses are recognized as being environmentally sensitive, predominantly due to increased product dispersion rates. Any release of product into such locations would be considered a high consequence and correspondingly unacceptable.

Due to their dynamic nature, characterizing the potential consequences at a watercourse can be difficult because the consequences can vary with seasonal flow conditions, weather and other factors. Recognizing that a pipeline failure at any watercourse is a high consequence, many pipeline operators focus resources into minimizing the probability of a pipeline release at every watercourse site (e.g. focus on the frequency analysis described in Section 7.1.1). That is, recognizing that a pipeline failure consequence at every watercourse is high, the first phase or stage of the risk assessment may be to assign a consequence of 1 to all watercourses. This level of assessment focuses on minimizing the probability of failure at hydrotechnical hazards; and is often utilized during the initial development of a Program or the assignment of control measures such as inspection or monitoring. Nevertheless, consequence analysis can be effectively used to refine risk estimates, prioritize resources and assign control measures.

Consequence analysis may be effectively integrated into the risk estimation explicitly or incorporated into the Program through stages or phases. Table 5 provides a listing of factors that may be considered during a consequence analysis. Depending on the risk assessment stage or phase, the consequences may be assessed subjectively at many sites, assessed in more detail using office based information at fewer higher priority sites, or more quantitatively at a relatively small number of sites utilizing an appropriate consequence analysis model. Examples of consequence modeling for hydrotechnical hazards are described in A GIS-Based System to Assess the Environmental Consequence of a Liquid Pipeline Rupture at Watercourse Crossing IPC2012-90473 (Ripley et al, 2012) and An Overland –Hydrographical Spill Model and its Application to Pipeline Consequence Modeling IPC2008-64389 (Zuczek et Al, 2008).
### Table 5: Example of Factors Considered in Consequence Analysis

<table>
<thead>
<tr>
<th>Factor</th>
<th>Description of Consequence Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product Type</td>
<td>Consequences of a potential failure and selection of receptors depends on the product transported in the pipeline.</td>
</tr>
<tr>
<td>Volume</td>
<td>If a pipeline was to leak or rupture then the consequences of the failure would depend on the volume of product released.</td>
</tr>
<tr>
<td>Response Time</td>
<td>Depends on detectability of the failure, site accessibility, weather, time of day, time of year.</td>
</tr>
<tr>
<td>Receptors</td>
<td>The number and type of receptors is required to understand the consequence of a failure. Examples of receptors include, people, sensitive environmental features, (e.g. river, lakes, wetlands) and infrastructure such as bridges and facilities, buildings. Topography and hydrology at and around the failure location may impact the magnitude of the consequences. Dense populations and sensitive environmental features in close proximity to the pipeline failure location usually result in higher consequences.</td>
</tr>
</tbody>
</table>

### 7.2. Risk Evaluation

Risk Evaluation is where the estimated risk at each pipeline watercourse site is compared to an individual, corporate or industry threshold. This threshold may be called the risk threshold to differentiate it from other thresholds required in a Program. Sites higher than the threshold move to Risk Control (Section 8.0), while sites lower than the threshold may require no further action. Recognizing and defining the threshold is an essential step in risk management of watercourse crossings. Defining a threshold may be a challenging process because the perception of risk varies widely across individuals, corporations, industries and the public. Objective data extracted from industry databases can often help with defining a risk threshold.

Techniques for Risk Evaluation should correspond to the estimation method adopted in the Program. An example technique for Risk Evaluation involves the communication of risk using words and evaluated using a risk matrix, an example of such is shown in Figure B.2 of CSA Z662. For each hydrotechnical hazard site, the estimated frequency of the event and the associated consequence are crossed in the table to arrive at a risk of the site.

When absolute risks have been estimated then the concept of tolerable risks and acceptable risks can be utilized to provide guidance on the results of the frequency and consequence analysis. Datasets on the historical pipeline leaks and ruptures are maintained by regulatory agencies such as the NEB, OGC, AER, and DoT-PHMSA and is a required starting point for estimating historical failure rates from hydrotechnical hazards.
8. Risk Management Activities

Risk Control is the process of decision making for implementing or enforcing risk mitigation measures and treatment options such as more/less frequent inspections, obtaining more details, or conducting mitigation activities. Risk Control includes re-evaluation of the risk control factors, typically through re-inspections.

8.1. TYPES OF RISK CONTROL ACTIVITIES

The following is a selection of risk control activities for reducing, managing and re-assessing the risk of hydrotechnical hazards at watercourses. These activities should be conducted at a frequency commensurate with an operator’s risk threshold. Guidance on assignment and scheduling of risk control activities including re-inspection intervals is provided in the following sections.

8.1.1. Inspections

Regular office, aerial, or ground inspections should be conducted at a frequency commensurate with an operator’s or industry risk threshold (Section 7.0). Types of inspections may include:

1. Office - An office-based task such as the brief review of as-built designs or documents or surveys to help build a more complete assessment of risk at the site.

2. Aerial - Visual assessments from the air to subjectively assess the hydrotechnical hazard and provide new or revised conceptual level recommendations. The effectiveness of the protection around the pipeline cannot be assessed unless the helicopter lands at the site and a pipe locator is used to determine the position and depth of cover at the location. Aerial patrols conducted by personnel trained in hydrotechnical hazard identification with the mandate to land and collect depth of cover information can be an effective form of risk control.

3. Ground - Site visits on foot may be used to conduct a visual assessment and subjectively assess the hydrotechnical hazard activity, the effectiveness of the protection around the pipeline, and to provide new or revised conceptual recommendations.

The goal of an inspection is to increase the understanding of the hydrotechnical hazard and the pipeline condition/protection to allow for accurate risk estimation, thereby enabling risk mitigation to be implemented when and if required. Inspections at a site do not necessarily result in detailed
investigations or mitigation – repeat inspections are the most common type of activity for managing the risk of a site.

8.1.2. Detailed Investigations

A Detailed Investigation is a site-specific surface or subsurface investigation to gather additional and/or more comprehensive information at specific watercourses than would be obtained from a visual inspection. The goal of a detailed investigation is to increase the understanding of the hydrotechnical hazard and pipeline condition/protection towards reducing the risk of failure at the site.

Detailed Investigations should be conducted by a qualified engineer or geoprofessional. Specialist trades such as professional surveyors or geotechnical drillers may be employed to support the investigation. The types of information gathered during a detailed investigation include:

- Pipe depth/location through the entire length of the crossing;
- Site topography;
- Watercourse bed bathymetry;
- Watercourse flow rate history/capacity;
- Historical behavior of the site through time series airphoto review;
- Review of as-built drawings;
- Watercourse characterization/scour analysis; and
- Factors that could lead to damage of the pipe at the crossing caused by hydrodynamic loads, impact loads and fatigue caused by vortex shedding.

Significantly more resources are required for a Detailed Investigation than a visual inspection. Therefore, detailed investigations are performed on a subset of the site inventory in order to clarify either the current state of the site or to make more accurate predictions about future performance. Predictions may be done in consideration of a review of historical air photographs and a detailed determination of the morphology and predicted performance during flood events. Detailed Investigations at a site do not necessarily result in mitigation – repeated detailed investigations can be an effective method of managing the risk at a site.

8.1.3. Engineering Assessments

An engineering assessment is an assessment of the effect of relevant variables upon the fitness for service of a pipeline using engineering principles. This assessment should be conducted by, or under the direct supervision of, a competent person with demonstrated understanding and experience in the application of the engineering and risk management principles related to the
issue being addressed\textsuperscript{12}. Engineering assessments are commonly used to refine preliminary assessments to determine if mitigative actions are required.

8.1.4. Site Monitoring

Site monitoring includes reading and analysis of instrumentation to quantify the progression of a hydrotechnical hazard and/or its impact on the pipeline. Examples include repeat bathymetric surveys of the crossing, installation of instruments in the bed and banks of the river to monitor watercourse movement and installation of survey markers on the banks of the river to measure erosion. Monitoring may require one to several hours per site to complete. While monitoring alone does not result in mitigation, monitoring can be an effective method of managing the risk of a site.

8.1.5. Maintenance

Maintenance includes field actions typically not requiring an engineering design or significant input from the operator’s engineering department. Maintenance activities can be carried out independently by pipeline operations field staff but may require supervision by a technical specialist. Examples of maintenance include cleaning culverts, minor ditch or berm construction, replacement of swamp weights or pipeline markers, culvert installation, and access road maintenance.

8.1.6. Mitigation

Mitigation includes actions typically requiring an engineering design or significant input from a registered professional engineer. Construction is usually preceded by a detailed investigation (topographic and bathymetric survey), engineering assessment, engineered design, regulatory permitting (e.g. environmental), and landowner consultations. Site mitigations may require one week to several months to prepare for and complete. The mitigation employed at a particular site will be dependent on the nature of the hydrotechnical hazard, the river morphology and the root causes of the hydrotechnical hazard changes, but the main goal of the mitigation is to reduce the risk of pipeline damage or failure while minimizing the impact on the environment. Some examples of mitigation include:

- Installation of erosion protection for the bank or bed of the watercourse,
- Lowering the pipeline,
- Moving the location of the sag bend to further from the watercourse,
- Building a new crossing by directional drilling or constructing an aerial crossing, and
- Rerouting a pipeline section to avoid the watercourse.

Refer to the \textit{Pipeline Associated Watercourse Crossings, 4th Edition} for additional guidance and regulatory requirements working within watercourses.

\textsuperscript{12} CSA Z662 Oil & Gas Pipeline Systems (CSA Z662-11)
8.2. ASSIGNMENT OF RISK CONTROL ACTIVITY

Determination of the appropriate risk control measure is a complex assessment involving many factors and considerations. Figure 9 provides an idealized framework that may be employed by the qualified engineer or integrity professional when evaluating the risk significance and assigning the appropriate risk control measures.

![Figure 9. Assignment of risk control activities](image-url)
### 8.3. SCHEDULING RISK CONTROL ACTIVITY

Risk control activities should be scheduled commensurate with an operator’s or industry risk threshold in order to manage the threat of the hydrotechnical hazard.

#### 8.3.1. Inspection Intervals

Hydrotechnical hazard sites are unique due to site specific hazards, construction practices and site history. As a result, the inspection intervals may vary for each site with active hydrotechnical hazards depending up on the estimated risk of the site. A general guideline for setting inspection intervals is provided in Table 6.

**Table 6: Maximum Recommended Inspection Intervals**

<table>
<thead>
<tr>
<th>Risk Rating</th>
<th>Inspection Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>5 – 10 years</td>
</tr>
<tr>
<td>Medium</td>
<td>1 – 5 years</td>
</tr>
<tr>
<td>High</td>
<td>Every year</td>
</tr>
</tbody>
</table>

The defined inspection interval for a site may be decreased based on several factors such as, but not necessarily limited to, those listed below. Refer to Section 9.0 for additional guidance.

- Severe flooding or other extreme hydraulic conditions
- New observations from aerial or field patrols
- Results from monitoring instrumentation or programs
- Pipeline operation and maintenance (O&M) activities
- New learning’s, such as results from incident investigations

Refer to Section 9.0 for additional guidance.

#### 8.3.2. Scheduling Mitigation and Maintenance

The primary consideration for scheduling mitigation and maintenance activities is to control risk at the pipeline watercourse site to below the defined threshold. Other considerations for the scheduling of hydrotechnical mitigations may typically include environmental and fisheries restrictions and the seasonal flow conditions. Ideally, mitigation would be completed during low flow conditions (usually late summer or early fall).
However, regulatory requirements may require the work to be completed during a specific time period to minimize the impact to fisheries or other environmental elements. To facilitate the mitigation, it may be possible to isolate the work area outside the restricted timeframe and return to construct the mitigation during lower flow conditions.

Obtaining regulatory permits to work in or near watercourses may take four to six months or longer in some cases. This lead time requirement should be considered when scheduling maintenance or mitigation activities.

Refer to the *Pipeline Associated Watercourse Crossings* for additional guidance and regulatory requirements working within watercourses.
9. Flood Management

Periodically, pipeline systems will be impacted by low frequency–high magnitude storms and floods (triggers) that, at a subset of sites, will require action(s) that are in addition to, or outside of the regularly scheduled inspections and other monitoring activities. The concepts and corresponding risk management steps outlined in this document are still applicable; however, the rate at which an operator moves from hazard assessment to risk control may be compressed in time.

**Steps required to manage the risk associated with flood activity along a pipeline system**

**the same general management framework of hazard identification, risk assessment**

**with the additional customization of the individual components (see Figure 10).**

### 9.1. Flood Monitoring and Identification

The goal of the flood monitoring is to identify flooding activity that could negatively affect a pipeline near a watercourse.

There are several options for flood identification. The accuracy and corresponding resource requirements increase down the below list:

- Weather alerts for storms, high rainfall, and stream flow advisories are issued by provincial or federal environmental agencies such as Environment Canada’s Meteorological Service (MSC). These can help anticipate which section of a pipeline system could be or is being affected by a storm/flood. Operators can sign up for these alerts or commission consultants to monitor and synthesize these alerts.
- In the spring, a higher than normal snow pack may lead to high flow rates or flood conditions. In the case of a high snow pack, operators may increase the frequency of monitoring on melt-water streams in the area.
- Many large rivers and streams are equipped with gauge stations that report the flow rate and/or water height. The gauges could be monitored relative to established flood frequency curves to quantify flooding events.

Customized flood reporting systems can be developed that focus on specific areas of the pipeline system while integrating risk thresholds and response protocols. The systems
are typically based on hydraulic models that apply flow rates or water heights from gauged stations to ungauged water crossing.

Figure 10. Flood Management Framework

9.2. FLOOD RISK ASSESSMENT

A risk assessment methodology specific to evaluate flooding events should be established using the concepts discussed in this recommend practice. Prior to the onset of flood activity, pipeline operators may wish to conduct assessments to establish which sites require flood monitoring. Sites where the pipeline would not become exposed or
be damaged during the largest of flood events do not need to be monitored for flood activity. Conversely, at sites that could be at risk during flood events, pipeline operators may wish to establish site-specific thresholds and associated actions (e.g. post-flood inspection) to accelerate the risk assessment and decision making process due to the quick onset of flooding.

9.3. FLOOD RISK CONTROL

Risk control for flooding events varies from the general framework as pipeline operators must consider the requirement for immediate risk reduction actions during extreme flooding events. Prior to establishing risk reduction activities during flooding events activities such as monitoring gauges or additional field inspection may be required. Additional information can then be used to complete an engineering assessment to determine if immediate actions are required.

If immediate actions during a flooding event are required actions may range from:

- Additional ground or aerial inspections to monitor the flooding event when safe to do so
- Installation of monitoring instrumentation or equipment
- Reduction of pipeline operating pressure or purge the pipeline

If required, post-flood inspections can be scheduled in advance of the previously scheduled site inspection. For severe flooding, post-flood inspections should be conducted as soon as practicable following the flood event.

It should be noted that the measured depth of cover following a flood event may not represent the cover during the flood event. During the peak of a flood event the flow of the water may scour the pipeline reducing the depth of cover or potentially exposing the pipeline. However, as the flood diminishes and flows decrease, transported sediments and debris may re-deposit reestablishing some or all of the original depth of cover.

Ideally, depth of cover measurements would be taken during the peak of a flooding event to determine the depth of cover remaining on a pipeline. However, due to the high flows this is often not possible due to safety concerns and other factors. Pipeline operators are currently researching advanced monitoring methods and instrumentation to improve monitoring capabilities during large flood events.
10. **ROW Surveillance and Monitoring**

Pipeline companies regularly monitor the condition of their ROW’s and level of activity on or in proximity to their ROW’s utilizing a variety of surveillance methods and programs. The surveillance methods and programs should be leveraged and incorporated to increase the effectiveness of a pipeline company’s Watercourse Management Program.

10.1. **AERIAL OR ROW PATROLS**

Aerial or ROW pipeline patrols should be regularly conducted by pipeline operators to identify abnormal surface conditions or other factors that may affect the safe operation of pipelines. Aerial patrols have been effective in detecting exposed pipelines, bank erosion, soil settlement, flooding or ROW’s, vegetation loss, and encroachment hazards (see Figure 11).

Specific higher-risk water crossings may be more closely inspected during aerial patrols. Pipeline companies may consider developing an aerial patrol watch-list that lists specific sites that should be photographed during the regularly scheduled patrols. The lists should include a brief description of the hazard and the preferred point of view and location for the photograph(s).

![Figure 11. Pipeline exposure identified by aerial patrol](image)

10.2. **MONITORING RESULTS**

Specific sites may have a designated monitoring plan established to monitor for the rate of change of a hazard. Site monitoring can range from low-tech marker posts to high-tech instrumentation and communication systems. An effective, low-tech, cost-effective method for monitoring bank erosion is to install a series of equally spaced high visibility...
marker posts that step back from the eroding bank. The rate of bank movement can be easily identified and calculated by counting the posts and measuring the distance from the bank to the posts (Figure 12).

![Figure 12. Marker posts to easily monitor bank erosion.](image)

Regardless of the type of monitoring strategy, pipeline companies should have an established method or management system to allow for the incorporating the monitoring results into the Watercourse Management Program. Wherever practical, it is advantageous to define required actions based on pre-set limits or thresholds.

10.3. OTHER OPERATION AND MAINTENANCE (O&M) ACTIVITIES

Pipeline companies conduct a range of other operation and maintenance (O&M) activities along their pipeline ROW's such as in-line inspections, cathodic protection surveys, depth of cover surveys, leak surveys, excavations, brushing, weed control that may offer the opportunity to identify pipeline exposures or other significant hydrotechnical issues. Where O&M activities identify potential hydrotechnical issues they should be included into the Program.
11. Program Administration

11.1. QUALIFICATIONS AND TRAINING

Recommended minimum qualifications for individuals participating in a Program are described below.

11.1.1. Program Managers

Personnel responsible for implementing the requirements of this guideline should have a good working knowledge of pipelines, risk management and hydrotechnical issues and the processes and procedures to assess and mitigate them. These individuals should maintain and/or improve their knowledge by attending industry sponsored conferences, workshops etc., and through meetings and hands-on training.

11.1.2. Technical Contributors

Personnel involved in hazard identification, characterization and visual inspection should have experience in river engineering and/or river geomorphology. The qualifications required for the detailed assessments, monitoring, and mitigation design should have experience in hydrotechnical engineering and/or geoscience with experience in the pipeline industry. Personnel should be familiar with risk management concepts.

11.1.3. Inspectors

Inspections shall be conducted by personnel with qualifications congruent with the risk level of the site. For lower risk sites, inspections can be performed by pipeline operations or maintenance personnel familiar with the different types of hydrotechnical hazards and trained on the use of pipeline locator equipment. Higher risk sites may require inspection by a qualified engineer or geo-professional with an appropriate level of experience in the analysis and evaluation of the applicable hazard in addition to supplementary inspections by other personnel.

11.1.4. Aerial Patrol Personnel

Personnel performing aerial patrols should be able to recognize and identify the different types of hydrotechnical hazards affecting the pipeline system. Formal or in-house training of personnel is recommended.

11.2. RECORDS MANAGEMENT

A Program must include the development and maintenance of documented records for each pipeline watercourse site that contains the information used to characterize the
hazard and justify the risk management activities. The records should always be accessible.

Types of information in the audit trail for each pipeline watercourse site include:

- the site name, and location
- active or potentially active hydrotechnical hazards that exist at the site
- a characterization and status of the hazard(s) currently or potentially affecting the pipeline,
- details and supporting documents/photos of past risk reduction management activities,
- risk estimation and evaluation results
- recommendation or next course of action, and
- when the action is due.

11.3. FEEDBACK AND REVIEW

Following a management system approach to a Pipeline Watercourse Management Program requires that the Program be regularly evaluated and re-assessed. A commitment should be considered for annual review of the Program to ensure it is meeting Integrity Management Program objectives and includes industry best practices.
12. References


Canadian Association of Petroleum Producers (CAPP), Canadian Energy Pipeline Association (CEPA), and Canadian Gas Association (CGA), 2005. Pipeline Associated Watercourse Crossings (3rd Edition)


A. Extracts from Relevant Pipeline Regulations, Codes, and Guidelines

A1. CSA Z662-11

The Canadian Standards Association (CSA) Document Z662 (2011 ed.) is intended to establish essential requirements and minimum standards for the design, construction, operation, and maintenance of oil and gas industry pipeline systems. The Standard is broken down into many of the same categories of design, construction, operation, and maintenance with the addition of numerous appendices; and each of which include some facet of watercourse crossings.

**Design (Section 4)**

§ 4.3.1.2 Designers shall provide adequate protection to prevent unacceptable damage to the piping from unusual or special external conditions.

§ 4.11.1 The cover requirements for buried pipelines shall be as given in Table 4.9, except that where underground structures or adverse conditions prevent installation with such cover, buried pipelines may be installed with less cover, provided that they are appropriately protected against anticipated external loads.

<table>
<thead>
<tr>
<th>Location</th>
<th>Type of pipeline</th>
<th>Class location</th>
<th>Normal excavation</th>
<th>Rock excavation requiring blasting or removal by comparable means</th>
</tr>
</thead>
<tbody>
<tr>
<td>General (other than as indicated below)</td>
<td>LVP or gas</td>
<td>Any</td>
<td>0.60</td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td>HVP or CO₂</td>
<td>1</td>
<td>0.90</td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td>HVP or CO₂</td>
<td>2, 3, or 4</td>
<td>1.20</td>
<td>0.60</td>
</tr>
<tr>
<td>Right-of-way (road or railway)</td>
<td>Any</td>
<td>Any</td>
<td>0.75</td>
<td>0.75</td>
</tr>
<tr>
<td>Below travelled surface (road)*</td>
<td>Any</td>
<td>Any</td>
<td>1.20</td>
<td>1.20</td>
</tr>
<tr>
<td>Below base of rail (railway)†</td>
<td>Any</td>
<td>Any</td>
<td>1.20</td>
<td>1.20</td>
</tr>
<tr>
<td>— Cased</td>
<td>Any</td>
<td>Any</td>
<td>2.00</td>
<td>2.00</td>
</tr>
<tr>
<td>— Uncased</td>
<td>Any</td>
<td>Any</td>
<td>1.20†</td>
<td>0.60</td>
</tr>
<tr>
<td>Water crossing</td>
<td>Any</td>
<td>Any</td>
<td>0.75</td>
<td>0.60</td>
</tr>
<tr>
<td>Drainage or irrigation ditch invert</td>
<td>Any</td>
<td>Any</td>
<td>1.20†</td>
<td>0.60</td>
</tr>
</tbody>
</table>

†Reduced cover, but not less than 0.6 m, may be used if analysis demonstrates that the potential for erosion is minimal.

§ 4.3.1.2 Designers shall provide adequate protection to prevent unacceptable damage to the piping from unusual or special external conditions.
Note: Examples of such protection include increasing the pipe wall thickness, using additional cover, constructing revetments or other suitable mechanical protective devices, providing erosion protection, installing anchors, replacing potentially unstable soil with stable soil, using insulating materials, using refrigeration or heat tracing, using special construction procedures to reduce surface disturbance, and using right-of-way revegetation. Grade and above-grade installations are additional alternatives.

§ 4.12.4.1 The wall thickness of pipe shall be determined as specified in Clauses 4.2, 4.3, and 4.6 to 4.10. Special attention shall be given to the physical characteristics of crossings, such as composition and stability of the bed and banks, waves, currents, scouring, flooding, type and density of water-borne traffic, and other features that can cause adverse effects. Weight-coatings, river weights, screw anchors, or other means shall be used to maintain the position of pipelines under anticipated conditions of buoyancy and water motion.

The above sections from Section 4 of CSA Z662 pertain to the design and subsequent installation of new pipelines. The cover for buried pipelines in CSA Table 4.9, as outlined in § 4.11.1, provides the minimum acceptable as part of installation of a new pipeline and is not intended to represent the minimum acceptable for ongoing operations, as is covered in Section 10 of CSA Z662.

Operating, Maintenance, and Upgrading (Section 10)

§ 10.3.1 Where the operating company becomes aware of conditions that can lead to failures in its pipeline systems, it shall conduct an engineering assessment to determine which portions can be susceptible to failures and whether such portions are suitable for continued service.

§ 10.6.1.1 Operating companies shall periodically patrol their pipelines in order to observe conditions and activities on and adjacent to their rights-of-way that can affect the safety and operation of the pipelines. Particular attention shall be given to the following:

(a) Construction activity;
(b) Dredging operations;
(c) Erosion;
(d) Ice effects;
(e) Scour;
(f) Seismic activity;
(g) Soil slides;
(h) Subsidence;
(i) Loss of cover; and
(j) Evidence of leaks.

§ 10.6.4.2 Underwater crossings shall be inspected periodically for adequacy of cover, accumulation of debris, and other conditions that can affect the safety or integrity of the crossing.

Guidelines for Pipeline System Integrity Management Programs (Annex N)

§ N.10.4 The options that may be used to reduce the frequency of failure and damage incidents associated with natural hazards include the following, as applicable:
(a) Alternative design, materials, and location;
(b) Inspection and evaluation of areas subject to washout erosion, freeze-thaw, settlement due to construction or undermining, earthquake, or slope movement;
(c) Increase frequency of right-of-way inspections and patrols;
(d) Programs to monitor the pipeline system or soil movement (e.g., inspections using in-line geometry tools, survey techniques and slope inclinometers);
(e) Excavation and reburial to relieve loads;
(f) Relocation; and
(g) Installation of structures or materials to protect the system from external loads.

§ N.13.3 When inspection and patrols indicate soil settlement, slope movement, or washout that could cause excessive longitudinal stress or deflection of the pipe (see Clause 4.6), operating companies shall consider implementing a monitoring and evaluation program that includes criteria for corrective action to prevent failure incidents. The use of increased line patrols, in-line geometry tools, and slope inclinometers, as appropriate for the type of pipeline systems, should be considered for such programs.

A2. Alberta Government Code of Practice for Pipelines and Telecommunication Lines Crossing a Water Body

Under the Alberta Water Act and Water (Ministerial) Regulation, the Alberta Ministry of Environment, has produced a Code of Practice specific to crossings of a water body. This Code of Practice covers all aspects of works related to installation of new pipelines as well as repair and replacement of existing pipelines.

Plans

§ 6.1 At least 14 days before work is carried out, an owner must prepare a plan for the works that contains or incorporates the following:

(c) In addition to any monitoring measures contained in the written specifications and recommendations of a professional engineer, owner or qualified aquatic environment specialist,

1. Specifications of the monitoring measures that will, during the anticipated life of the pipeline crossing or telecommunication line crossing, meet the requirement of this Code of Practice

Schedule 2 - Plans

§ 1 (c) All pipes for pipeline crossings must be installed at an elevation that is below the one in fifty year bed scour depth of the water body except for pipes under clause (d);

§ 1 (d) All pipes for pipeline crossings that will carry a substance that causes or may cause adverse effect on the aquatic environment, including fish habitat, must be installed at an elevation that is below the one in one hundred year bed scour depth of the water body;

A3. AER Pipeline Act
Under Alberta Regulation 91/2005, the Alberta Energy Regulator (AER) of the Alberta Provincial Government administers the Pipeline Act. This Act covers activities associated with both the design of new pipelines as well as the operation of existing ones through specifications including materials and design, inspection and maintenance operations, as well as abandonment and removal.

Minimum Earth Cover

§ 20 (1) Unless otherwise authorized by the AER, and subject to subsection (3), the minimum earth cover for any pipeline must at all times be the greater of the minimum earth cover specified in CSA Z662 and, as the case may be,

(a) 1.4 meters within the right of way of a highway,
(b) 1.1 meters within the right of way of a road, and
(c) 0.8 meters in any other place.

(2) Unless otherwise authorized by the AER, the minimum earth cover set out in subsection (1) must be maintained for all operating and discontinued pipelines.

(3) Unless otherwise specified by the AER, for a pipeline existing at the time that this Regulation comes into force, if lesser earth cover was permitted by the construction standards and regulatory requirements in place at the time of construction, that less cover is acceptable.
B. Photographs of Hydrotechnical Hazard Subtypes

B1. CHANNEL DEGRADATION

Photo B-1: An incised channel from progressive channel degradation through flat terrain.
Photo B-2: Channel degradation through highly erodible agricultural soil.
Photo B-3: Channel degradation due to an intense precipitation event in 2011. Inset photo of same stream, looking upstream, in 2009.
B2. SCOUR

Photo B-4: Aerial view of the river and scour hole in the previous photograph. The arrow shows the direction of river flow and points to the upstream edge of the scour hole.
Photo B-5: Large scour hole created by constriction in a braided river channel.
Photo B-6: Profile survey drawing of the above photographed scour hole.

Photo B-7: Plan survey drawing of the above photographed scour hole. Brown line is the 2010 ground profile and the black line is 2012 ground profile. The red line is pipeline.
B3. BANK EROSION

Photo B-8: Right bank erosion to the right of the rip-rap in 2009.

Photo B-9: Active bank erosion, as noted by the vertical banks.
Photo B-10:  Active bank erosion at the outside of a meander bend. Shallow instabilities are evident in the bank. Note how some vegetation is re-establishing on the bank face.
B4. ENCROACHMENT

Photo B-11: Encroachment occurring at an unprotected bank at the outside of a meander bend. The red dashed line is the approximate pipeline centerline.
Photo B-12: Encroachment at an unprotected bank at an outside meander bend. The red dashed line is approximate pipeline centerline.
Photo B-13: Encroachment that has been mitigated with extensive boulder rip-rap.
B5. AVULSION

Photo B-14: Aerial view of an avulsion channel. As a result of high flows, the creek avulsed out of the confined, armored channel and formed a new channel.
Photo B-15: A close-up photo of the avulsion channel in the previous photograph.
Photo B-16: Avulsion channel (foreground, flowing right to left) occurring in the flood plain of a large river (background).
Photo B-17: Avulsion in mountainous terrain.
C. Example Hydrotechnical Hazard Using Management Framework

**Note:** Example case study provided in Appendix C is fictitious and is included only to demonstrate the application of the management framework.

C1. Example Case Study

A NPS 20 pipeline crosses a braided stream named Example Creek. A baseline ground inspection completed in Year 1 showed that the predominant hydrotechnical hazard at the crossing is scour, which is caused by the constrictions of the braided channel. Utilizing the company's risk assessment process, the site was assessed to be a medium risk and scheduled for re-inspection in four years (i.e. next inspection to be conducted in Year 5).

However, in Year 2 flood monitoring along the pipeline identified a flood event occurring at Example Creek. Utilizing available site information for Example Creek the following case study illustrates how the methodologies presented within this document could be applied to maintain the integrity of the pipeline.

**Information Available for Example Creek**

The following information for Example Creek is available from pipeline records and the baseline ground inspection, and follow-up re-inspections.

Pipeline Records
- Pipeline properties such as diameter, wall thickness, grade, operating pressure, in-line inspection records, coating type, etc.
- Bankfull width at crossing equals 7 metres
- Pipeline crossing construction method was open-cut

Baseline Ground Inspection
- Hydrotechnical hazard is scour caused by constrictions of the braided channel
- Channel bed material is assessed to be marginal due to a combination of soft and granular materials (e.g. bed can be readily mobilized during a flood event)
- The minimum depth of cover recorded in the channel was 1.7 metres

**Flood Management (9.0)**

Flood Management Framework presented in
Figure 10 is used to manage the flood event.

**Flood Identification (9.1)**

Monitoring of nearby river gauges indicate that the stream is experiencing a significant flood event.

**Risk Assessment (9.2)**

Flooding often occurs rapidly and unexpectedly which affords limited time for a pipeline operator to conduct a detailed risk assessment. Therefore, many pipeline operators have established risk assessment processes or flood thresholds to quickly assess the threat level to the pipeline during flooding.

Assume that the pipeline operator developed a vulnerability assessment procedure based on the maximum free-span length. For this pipeline the operator determined that the maximum span length of an exposed section of the pipeline would be limited by fatigue damage caused by vortex shedding.

A conservative estimate for the maximum length of an exposure is to assume that the pipeline is fully exposed across the bankfull width. For most water crossings this assumption is quite conservative, but it can be used as a screening level value to determine if a pipeline crossing is at risk due to flooding.

Assuming Figure 7 is the vortex shedding curve for this pipeline. Based on the flow rates from the nearby gauges and the channel geometry at Example Creek, the velocity of the water is estimated to be approximately 3 m/s. From Figure 7, the allowable free span length is approximately 27 m. As the bankfull width of Example Creek is 7 m, it is extremely unlikely that an exposure of the pipeline at Example Creek would result in damage or failure to the pipeline. Therefore, the pipeline concluded that the current flooding does not pose an immediate risk to the pipeline.

**Risk Control (9.3)**

**Question:** Is further Information Required?

**Answer:** No additional information was required

- Flood data was from nearby gauges and deemed to be representative of Example Creek
- Information from Baseline Ground Inspection was deemed to be accurate and reliable as it was only one year old

**Question:** Immediate Action Required

**Answer:** No immediate action is required

- Maximum potential exposure of the pipeline (7m) is much less than the length of exposure required for failure based on vortex shedding curve
- Operator concluded that the flooding does not pose an immediate threat to the pipeline so no immediate actions are required.

**Question:** Post-Flood Inspection Required

**Answer:** Pipeline operator determined that a post-flood inspection is required
Flooding was deemed severe enough that it may have changed the condition of the crossing from the baseline inspection. Operator will re-inspect the site and re-assess the risk of the site.

Next step will be to conduct inspection and enter Figure 6 within Section 5.0.

**Hydrotechnical Hazard Management Framework (5.0)**

Pipeline Operator conducts a ground inspection of Example Creek following the flood event. Assume Figure B-5 is a photograph from the ground inspection. The inspector observes a large scour hole in the middle of the braided channel. Unfortunately, the scour hole is too deep and the inspector cannot safely obtain a depth of cover measurement within the scour hole. The inspector collects the remaining available information to support the risk assessment of the site.

**Risk Assessment (7.0)**

Based on the observations from the ground inspection the predominant hazard is still concluded to be scour caused by the constriction of the braided channel. However, without a depth of cover measurement within the scour hole the companies risk assessment determines that risk of the site is unacceptable and actions are required to reduce the risk or refine the risk assessment.

**Risk Control (8.0)**

Pipeline Operator determines that a detailed investigation should be conducted at the site to gather additional information, specifically the depth of cover within the scour hole. Professional surveyors are contracted to conduct pipeline depth of cover survey, topographic and bathymetric surveys.

Assume Figures B-6 and B-7 is the survey results from the detailed investigation. The minimum depth of cover in the scour hole is determined to be 0.62m. With the additional information the pipeline operator re-assesses the risk of the site.

**Risk Assessment (7.0)**

The flood event reduced the depth of cover from 1.7m to 0.62m, which represents a reduction of 1.08 metres. Based on the new depth of cover and the other additional information collected during the detailed investigation, the companies risk assessment process determines the risk of the site to be high, but still acceptable.

**Risk Control (8.0)**

Based on the new risk level of the site, the pipeline operator determined that a ground inspection should be conducted within one year (Year 3) to monitor the depth of cover within the scour hole. The depth of cover may naturally increase as bed material is re-deposited within the scour hole. The ground inspections would be scheduled to coincide with low-flow conditions such that an inspector could safely obtain the depth of cover measurement without the support of professional surveyors.

The site would be re-assessed following the ground inspection and appropriate risk control actions would be assigned and scheduled based on the new observations and risk assessment of the site.
D. Example Form for Assessment of Hydrotechnical Hazards