Kashechewan First Nation

Assessment of Dam Safety Risks and Dam Safety Management Requirements for the Kashechewant Ring Dyke

For

Assessment of Risks and Dam Safety Management

H348671-000-200-230-0001
Rev. 0
February 19, 2015

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Report

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Executive Summary

Dam safety is a fundamental concern of responsible dam owners and regulators alike. In Canada, the Canadian Dam Association (CDA) have developed a comprehensive set of dam safety guidelines that outline principles and approaches for the evaluation and safety management of dams and associated structures. The application of these guidelines is voluntary, but they are widely recognized and used as the standard of practice by virtually all provinces across Canada.

The Kashechewan Ring Dyke, constructed in 1995 is in a deteriorating condition. The current state of dam safety management practiced at the Kashechewan Ring Dyke was reviewed and compared with recommended practices for dam safety management in Canada (as defined by the CDA Dam Safety Guidelines, 2013), Ontario (as defined by the Ontario Dam Safety Guidelines, 2011) and internationally as described in various technical bulletins published by the International Committee on Large Dams (ICOLD). On the basis of this review it was concluded that the current state of practice for dam safety for the Kashechewan Ring Dyke is not in line with accepted practice. Based on an assessment of the available information, the Dam Safety Management and Operations and Maintenance practices currently employed at the Kashechewan Ring Dyke were found to be compliant with only four of the eighteen Canadian Dam Association Guiding Principles for Dam Safety, have low to moderate compliance with 6 of these Principles and are non-compliant with eight.

An assessment of the Ring Dyke, in its present condition, with the current state of Dam Safety Management being exercised, the limited assessments that have been performed and the limited data available indicates that the Dyke presents an **INTOLERABLE** risk (as defined by the CDA) to the community in terms of overtopping, slope stability and piping risks.

It is considered that implementation of a robust Dam Safety Management System and the performance of appropriate remedial repairs to correct dam safety deficiencies will rectify this situation. However, for any Dam Safety Management Program to be effective, adequate funding will be needed for the initial work required to reach standards and ongoing amounts must be made available for maintaining and complying with the standards, as well as to ensure appropriate staffing and staff training.

1. Introduction

Dams are structures that differ from most other infrastructure as a result of the exceptional length of their economic life. The expected useful life of a properly engineered and maintained dam or dyke can easily exceed 100 years. In fact, properly maintained, the actual life span can be much longer. For example, there are dams in Iran, the Bahman and Mizan Dams, built in the 1st and 4th century A.D. respectively, (Figure 1-1 and Figure 1-1 respectively).

Figure 1-1: Bahman Dam

Figure 1-2: Mizan Dam

As illustrated in Figure 1-3, dams with a life span in excess of 100 years is relatively common.

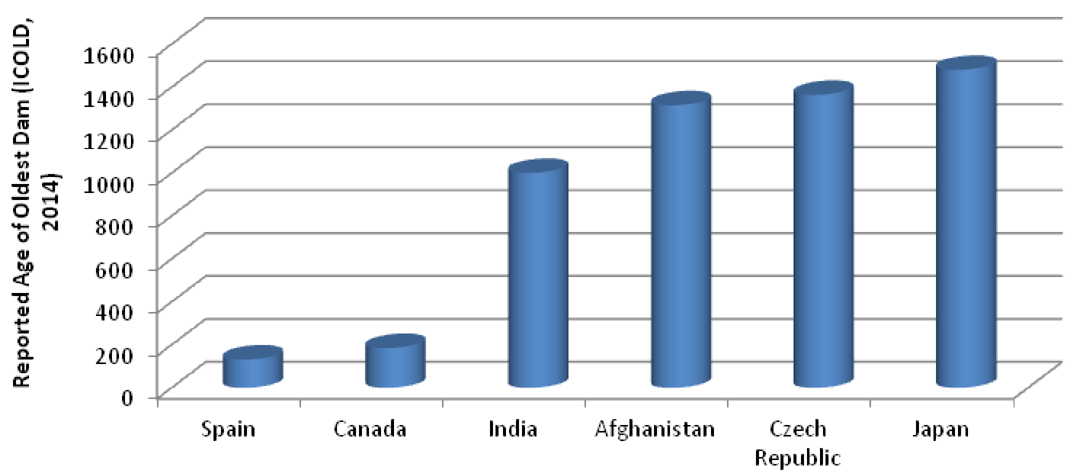

Figure 1-3: Reported Age of Oldest Dam by Country

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However, incidents of dam failure can and do occur. For example, in the spring of 1889, the largest dam failure incident in North American history occurred. Following a period of heavy rains, the 22-m high South Fork dam, located just upstream of Johnstown, Pennsylvania broke releasing over 20 million tons of water and debris into a narrow valley, killing more than 2200 people. Over a century later, also following a period of unprecedented rainfall, Canada's most significant dam safety event took place during the devastating Saguenay floods of 1996. In this case, eight dams were overtopped. While there was no loss of life directly associated with this incident, thousands were displaced making this event one of the largest natural disasters in Canadian history (Table 1-1).

Table 1-1: Summary of Canadian Natural Disasters

Date	Event	Economic Impacts
2001 to 2002	Drought (Canada wide)	roughly $5 billion
1998	Ice storm (Ontario and Quebec)	$4.2 billion
1979 to 1980	Drought (Prairies)	$2.5 billion
1988	Drought (Prairies)	$1.8 billion
1996	Flood (Saguenay)	$1 billion
1984	Drought (Prairies)	$1 billion

In the United States, an overall average probability of dam failure in the order of 1 x 10^{-4} failures per dam year has been determined since records were kept starting in 1994. Figure 1-4 provides an indication of how a well-structured dam safety management program can reduce the risks of dam safety incidents. Following the enactment of dam safety legislation in the US, the occurrence of dam safety incidents reduced dropping from an average of about 39 failures per year between 1995 and 2000 to about nine dam failure incidents per year after the dam safety programs began to take effect.

Systems to ensure the safety of dams must be designed to be effective over the entire life cycle of the structure. This life cycle consists of six phases commencing with the initial concept, through design, construction, commissioning to operation and maintenance and, ultimately, to decommissioning. It is the operation and maintenance phase that is, by far, the longest, often extending for generations. For this reason, the dam industry has long recognized that the organization responsible for the dam or dyke must have an effective process in place designed in such a manner that it will remain effective over long periods of time and has the ability to proactively identify, track and address all potential and actual problems that can impact the safety of the structure.

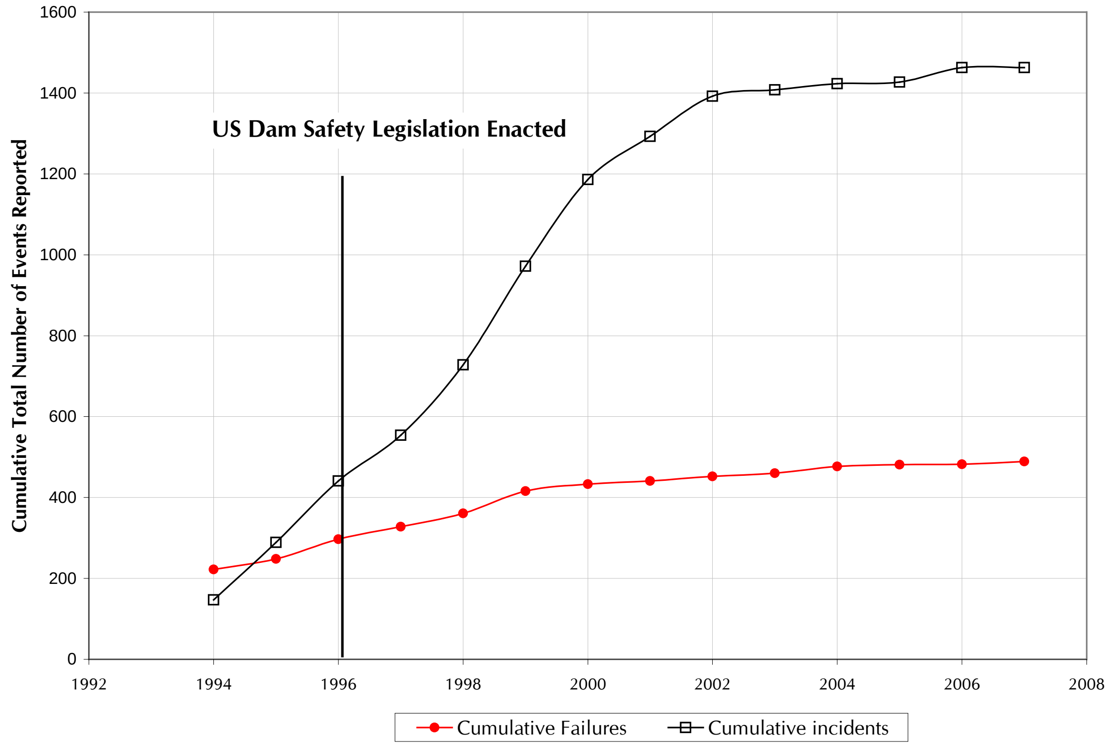

Figure 1-4: Occurrence of Dam Failures and Dam Incidents in the United States (data taken from National Performance of Dams data base)

In all industries, including the dam industry, the method of ensuring that operation and maintenance activities are being effectively carried out is through a management system. In a general sense, dam safety management involves the proactive management of the risks that can impact people, property and the environment as a result of either dam failure or mis-operation. Many organizations around the world have identified the requirement for such a systematic approach to dam safety management. For example, The Australian National Committee on Large Dams (ANCOLD) published guidelines on Dam Safety Management that state that the objective of dam safety management is to protect life, property and the environment from the failure of any dam and that this objective can be achieved by establishment on a dam safety program as conceptually detailed in Figure 1-5.

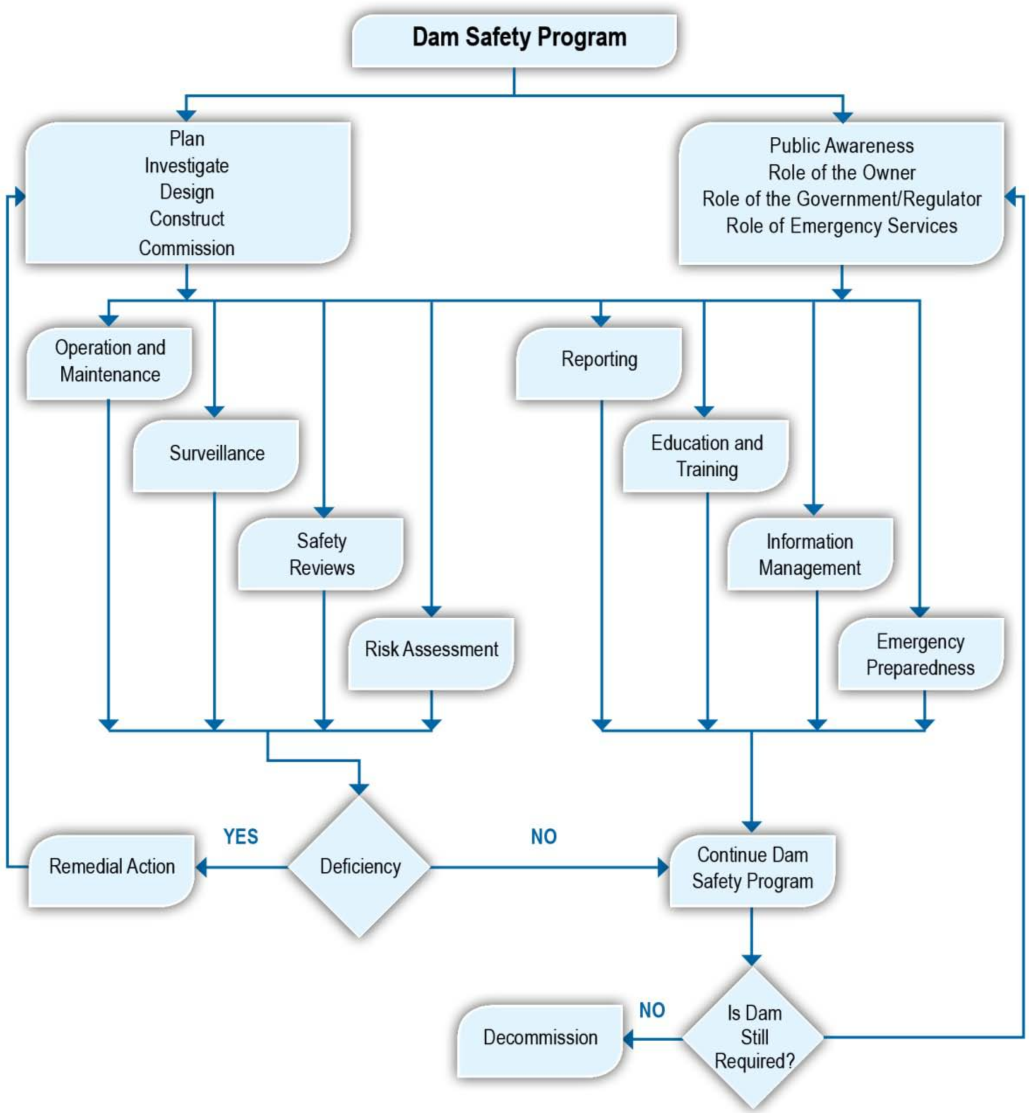

Figure 1-5: Elements of a Dam Safety Management Plan

The recently (2013) revised Dam Safety Guidelines of the Canadian Dam Association go one step further by explicitly stating that the extent of the protection for the public and the environment should be such that the identified risks are kept as low as reasonably practicable and this should be undertaken through the implementation of a Dam Safety Management System that specifically addresses the guiding principles of the CDA Dam Safety Guidelines. Similarly, the Ontario Dam Safety Guidelines published in 2011 recognises the need for a comprehensive Dam Safety Management Plan.

The Kashechewan Council has identified a number of dam safety remedial works issues that are currently not being attended to in a manner consistent with the dam industry's Dam Safety Management Practices. It is in this context that Hatch was requested to

- provide a description of the state of practice that exists in the dam industry for the management of the safety of water retaining structures
- undertake an assessment of the risks that the Kashechewan Ring Dyke poses to the community using a newly developed Dam Safety Risk Screening Tool and compare this risk with tolerability guidelines outlined in the CDA Dam Safety Guidelines.

In Section 2 the background to the Kashechewan Ring Dyke is presented. Section 3 describes what a properly designed dam safety management plan should entail. Section 4 lists some of the identified dam safety remedial work tasks that are required to maintain the Kashechewan Ring Dyke. Section 5 provides details of a dam safety risk assessment that was performed for the Dyke. Section 6 provides some general conclusions as to the adequacy of dam safety management practices and the risks that the Kashechewan Ring Dyke presents to the community.

2. Background

2.1 Geological Setting

2.1.1 Regional Physiography

The region in which the project is located is physiographically known as the Hudson Bay Lowlands. This is a relatively flat area bordering on Hudson Bay. It ranges in elevation from sea level to 20 m and gently slopes towards Hudson Bay. The Kashechewan Community is generally situated between e. 7 and 9 m. The Albany River is the regional drainage channel and flows east-north-east into Hudson Bay.

The river has eroded its channel in the overburden which mantles the entire region. Riverbanks are up to 10-m high and can be significantly eroded. The lower-most reach of the river is characterized by many small islands which have resulted from bed load deposition. The largest island, Albany Island, near the Kashechewan site, was formed by the river diverging into north and south channels.

The area surrounding the Albany River is characterized by bogs and marshes, peat deposits and small streams. The groundwater table is high.

2.1.2 Geological History in Brief

The region has been glaciated several times, the last one being the Wisconsinan glaciation which occurred during the Pleistocene Epoch (Ministry of Northern Development Mines, 1987). The main effects of the glaciation were to depress the underlying bedrock, to level the relatively soft bedrock and to deposit a layer of till overtop of the bedrock.

As the glacier receded approximately 8000 years ago, glacial lakes formed along the periphery and fine-grained marine silts and clays were deposited. The biggest lake was Lake Agassiz which developed mainly to the west of the project region. It is not known if this lake actually covered the site area but deposits similar to those seen in areas where Lake Agassiz is known to have existed are seen at the Kashechewan site.

As the sea receded, and as isostatic rebound occurred, the lake deposits became coarser (sandier) accounting for the variability seen in the upper portions of the overburden deposit at the Kashechewan site.

2.1.3 Bedrock Geology

Bedrock in the site area comprises flat-lying sedimentary rock of the Kenogami River Formation which was deposited in the Silurian Period, i.e., more than 395 million years ago (Ontario Geological Survey, 1996, and Ontario Department of Mines and Northern Affairs, 1970).

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The beds strike northwest and dip very gently southwest. They comprise mainly limestone and dolostone, but may also include siltstone and evaporites. No bedrock outcrops exist at the site with a depth to bedrock appearing to exceed 14 m.

Upstream of the site, bedrock of the Stooping River Formation of Devonian age unconformably overlies the Kenogami River Formation. This formation comprises similar rock types.

2.1.4 Site Overburden Conditions

Several geotechnical investigative studies have been carried out in the past in Kashechewan and its neighbouring communities. The most recent was a comprehensive geotechnical investigation carried out by Hatch in 2007. In this program, 28 boreholes were completed and 17 piezometers were installed. Based on the results of the 2007 geotechnical investigation program the overburden materials at the Kashechewan site consist of the following deposits:

Organics

A layer of organic material (peat) was observed in several locations at the foundation of the dyke and at surface. Borehole results indicated a maximum thickness of approximately 200 to 300 mm for the organic layer.

Sand with Silt

A layer of silt and fine sand, trace clay content material was encountered below a layer of peat material on the north and west side of the dyke. This was inferred as a native silt and sand layer. In addition, a layer of silt with medium to coarse sand material was encountered on the south side of the dyke.

Silt with Clay

A layer of silt with clay material of marine origin is situated below the silt and sand layer mentioned previously. This layer of material was encountered generally from a depth of 4.5 to 5 m below the crest of the dyke to approximately a 12-m depth with the consistency of the material varying from stiff to very soft with depth. Two deep boreholes drilled at the toe of the dyke showed that the overburden material was predominantly composed of silt and clay, with some random sand layers in the top 3.0 m with a maximum thickness of 20-cm . These sandy inclusions could form areas of concentrated seepage, enhancing the potential for piping. Dense till was encountered at a depth of about 12 m.

2.2 The Kashechewan Ring Dyke

The Kashechewan ring dike was constructed between 1995 and 1997 to protect residents from flooding that occurs as a result of ice jams during spring break-up. The need for the dike is clear. Since 1976, the Kashechewan First Nation Community has been evacuated on a number of occasions (Table 2-1) with the most severe occurrence the spring of 2006

(Figure 2-1). All of this points to the fact that this dike does not appear to meet the original design intent of providing long-term protection for the community.

Table 2-1: Summary of Evacuation Events

Date	Description
1976	Major Flooding, April 26th, up to 1 m of water on the mainland, evacuation of Fort Albany and Kashechewan communities.
1985	Major Flooding on April 26th. Evacuation of both the Fort Albany and Kashechewan communities occurred.
1989	Minor Flooding on April 25th, evacuation of Fort Albany and Kashechewan communities.
1992	No Flooding, on May 10th, evacuation of Fort Albany and Kashechewan communities.
1994	No Flooding, on May 12th, evacuation of Fort Albany and Kashechewan communities.
1996	No Flooding occurred but Fort Albany and Kashechewan communities were evacuated, May 14, for precautionary reasons.
1997	Minor Flooding occurred on May 20th on Sinclair Island. Fort Albany and Kashechewan communities were evacuated for precautionary reasons.
2005	No flooding occurred but the communities were evacuated. Date of peak flow of 7282 m^3/s, April 18th at 5:00 am. The following day (the next reading) flows reduced tp3757 m^3/s.
2006	Flooding occurred and the communities were evacuated. On April 22nd, the water level rose at Kashechewan as high as about el. 10 m, roughly 0.6 m below the top of the perimeter dyke (South End). Without the dyke, the community would have been flooded with 1 to 3 m of water.
2008	The Fort Albany FN dyke system was overtopped during the spring break-up due to historically high flow rates on the Albany River. 886 Kashechewan residents were evacuated for approximately ten days as a precautionary life-safety measure. However flood waters did not reach the base of the dyke.
2012 - 2013	Partial evacuations of the most vulnerable (i.e. chronic illness, babies, etc) carried out as a precautionary measure due to time needed for medical transfers by air.
2013	Evacuation of 30 households due to sewage back up in basements.
2014	On May 10, 2014 Kashechewan First Nation declared a State of Emergency due to flooding from the Albany River. The 2014 flood event caused extensive damage and resulted in the emergency evacuation of the entire Community. As at the preparation of this report many residents remain unable to return to the Community due to the flood damage to their homes and are presently housed in accommodations in Kapuskasing.

Figure 2-1: River and Ice Conditions during the 2006 Ice Jam Flood

Prior to the construction of the dike, geotechnical investigations performed by a number of groups indicated that the foundation of the dike was generally impervious; being composed of a clayey silt with the exception of a local portion of the southwest corner of the dike where sand to a depth of 2.7 m was encountered. In addition, it was reported that the clayey silt deposit contained sand seams and layers that could allow seepage through the soil mass in the upper 2 to 3 m. It was further reported that the consultant responsible for the final design and construction supervision of the dike did not have access to all of these data meaning that the design of the seepage defenses would not have accounted for this seepage path.

During the design of the structure, seepage analyses were not apparently performed to establish the depth of cut-off into the foundation and there appears to have been no filters installed behind the core to guard against the potential for piping erosion. The design factor of safety for the specified dike section was reported to be around 1.3 which is below modern accepted requirements for levels of safety, particularly, for a structure where failure could result in the potential for loss of life.

Further complicating the situation is the fact that it appears construction was not performed in accordance with the drawings and specifications. It was reported that portions of the dike were constructed in the winter period and that the fill materials had inclusions of ice which is not in accordance with industry good practice. In addition, the degree of compaction performed, and the exact details of the materials used in the construction of the dam, are not known, but there are reports that indicate the methods used were potentially inadequate.

There are as-built drawings that suggest that a core trench was installed to a depth of 2 to 3 m for the entire length of the dike as was specified and as would be good practice given the existence of sand seams in the upper portion of the foundation. However, drilling investigations performed by Klohn Crippen Consultants (KCC) could not confirm the existence of a core trench. The more extensive drilling performed by Hatch in 2007 confirmed that indeed there is no core trench and, in fact, that there is no core at all. Rather, the dam is a homogeneous structure composed, primarily, of sands and gravels. This results in increased seepage through the structure when the river stages up. While this is not desirable, it does not directly constitute a dam safety problem. However, given the potential for increased seepage, what is needed is the design and installation of appropriate filters and drainage schemes to safely collect and dispose of the seepage waters.

Inspection reports by the designer prepared during the construction of the dyke indicate that approval was given to allow some or the entire dyke to be founded on peat. The results of the 2007 investigation program confirmed that this was indeed the case. In fact, the results indicate that it is likely that the entire structure was founded on peat. What appears to have been done is that, in the “core” trench area, the peat was excavated to a set depth of about 1 m. The dam was then constructed on the remaining peat deposit. This would have resulted in uneven settlement of the dyke, as is apparent today. This again would not be in accordance with standard industry practice as impervious portions of a dike built on a soft material that can consolidate can result in differential settlements that can cause the impervious fill to crack increasing the risk of piping. In this case, where downstream filters were not apparently used, and where compaction of the materials appears to have been less than adequate, differential settle can be at least a possibility and possibly an expected consequence. For this reason, over the long-term, cracking might occur in areas of the dyke where cohesive soils were used resulting in localized concentrated seepage paths that can widen and erode under the effects of a hydraulic gradient. This settlement also produced local depressions in the crest of the dam. Although the more significant depressions were corrected as part of previous remedial works overseen by Hatch, settlement and rutting of the crest of the dyke continues and ongoing maintenance is essential to reduce the risks associated with overtopping and breaching at settled areas of the dyke.

It is also clear that the dike was, at least locally, not constructed in accordance with the specifications. For example, a substantial section of the dike was constructed entirely of clayey silt materials, likely due to the fact that the planned borrow deposit was exhausted. This had led to a situation where severe rutting is occurring as a result of vehicular traffic (a matter that will progressively worsen with time) and longitudinal cracking of the crest is evident (possibly as a result of differential settlement during to the gradual and uneven consolidation of the organic materials beneath the dike). While the designer was apparently aware of this change to the dike section, it is not clear if a stability analysis was ever performed for this revised section of the dike or indeed for the actual as-built section of the remainder of the dike which is also thought to be significantly different from what had been specified.

In 2008, river bank erosion was identified as a significant concern and, at the location of the Bell tower, the available berm between the stable portion of the river back and the toe of the dike had eroded to a point where it was only a meter in width. (Figure 2-2)

Figure 2-2: Example of ongoing erosion in 2008

The original design criteria specified a minimum of 8 m to maintain the stability of the river bank/dike system. Therefore, the ongoing erosion issues represented a significant dam safety problem. This issue was rectified through the construction of a stabilizing berm (Figure 2-3) that was designed to ensure the stability of the dyke/riverbank system met and exceeded current CDA and Ontario Dam Safety Standards.

Figure 2-3: Stabilizing Berm in 2009 (uncompleted "gap" between the lower slope and berm)

As indicated in Figure 2-3, a number of planned erosion protection measures were never completed and the berm has not been maintained. As a result, local, uncontrolled surface runoff is producing deep ruts and is causing local erosion beneath the erosion protection blocks. In addition, a number of these erosion protection blocks are missing, ether due to the effects of ice plucking or vandalism or both. This lack of maintenance and failure to complete the designed erosion protection measures is causing the berm to deteriorate (Figure 2-4) which, if unchecked could reach a point where the stability of the riverbank/Dyke system may fall below currently accepted standards for safety.

Figure 2-4: Examples of damage to the Stabilization Berm

Another area of concern is the existence of various conduits through the dike and its foundation. In any structure where such conduits are needed, special care is required to avoid the potential for piping failure as the often poorly compacted materials surrounding the dike gradually erode under the effects of a hydraulic gradient. These conduits are similarly not being monitored or maintained such that, currently, at least one is not functional. This will permit rising waters during the spring breakup period to flow into the community. An engineered assessment and repair of these critical structures (including an assessment of any potential for piping) is needed.

Finally, drainage within the community is inadequate. This has obvious health and safety issues but also can cause degradation of the downstream toe of the dyke and mask potential issues associated with piping and concentrated seepage.

3. Assessment of the Practice of Dam Safety at the Kashechewan Ring Dyke

3.1 Dam Safety Management Systems

The overall objective of any Dam Safety Management Plan (DSMP) is to ensure that an existing dam or dyke is suitably constructed, operated and maintained in order to provide for the protection of persons and property who might be adversely affected in the event of a dam breach or dam mis-management. This objective is achieved where it can be demonstrated that sufficient measures have been taken to sufficiently manage the risks to persons and property associated with an existing dam.

The DSMP provides the dam owner with an understanding of the current condition of the dam and the safety measures that must be maintained, or enhanced, in order to adequately manage risks to persons and property; as well as a specific timeframe for their implementation. The safety measures included with a DSMP will typically include a range of engineering, monitoring and maintenance activities designed to address the specific hazards associated with a given dam within a given time frame in a logical and efficient manner. To achieve this goal all DSMPs must include a timeframe for reviewing the conclusions made within the DSMP in order to determine the degree to which they remain valid. Under a modern DSMP an owner is required to demonstrate, at all times, that the measures identified within a DSMP as being necessary to comply with the dam safety criteria are in place or planned to be in place.

A Description of Ontario's approach to Dam Safety Management is provided in Appendix B.

The CDA's Guiding Principles for Dam Safety focus on Dam Safety Management

PRINCIPLE 1d of the most recent edition of the Canadian Dam Association Dam Safety Guidelines states;

"A dam safety management system, incorporating policies, responsibilities, plans and procedures, documentation, training, and review and correction of deficiencies and non-conformances, shall be in place".

To accomplish this goal the CDA recommends that a dam safety management system designed to provide a framework for safety activities, decisions, and supporting processes as depicted in Figure 3-1 be in place. As a minimum the CDA states that the dam owner's policies and practices should clearly demonstrate commitment to safety management throughout the complete life cycle of the dam. The policy should cover the following:

- Level of safety that is to be provided—Applicable regulations that need to be satisfied with due regard for industry practice and standard due diligence.

- Ultimate accountability and authority in the organization for ensuring that the policy is implemented—Responsibilities and authorities need to be delegated within the organization for all dam safety activities.
- Decision-making process within the organization for decisions related to dam safety—Critical safety decisions with significant societal or financial implications must be made or approved at the highest level.

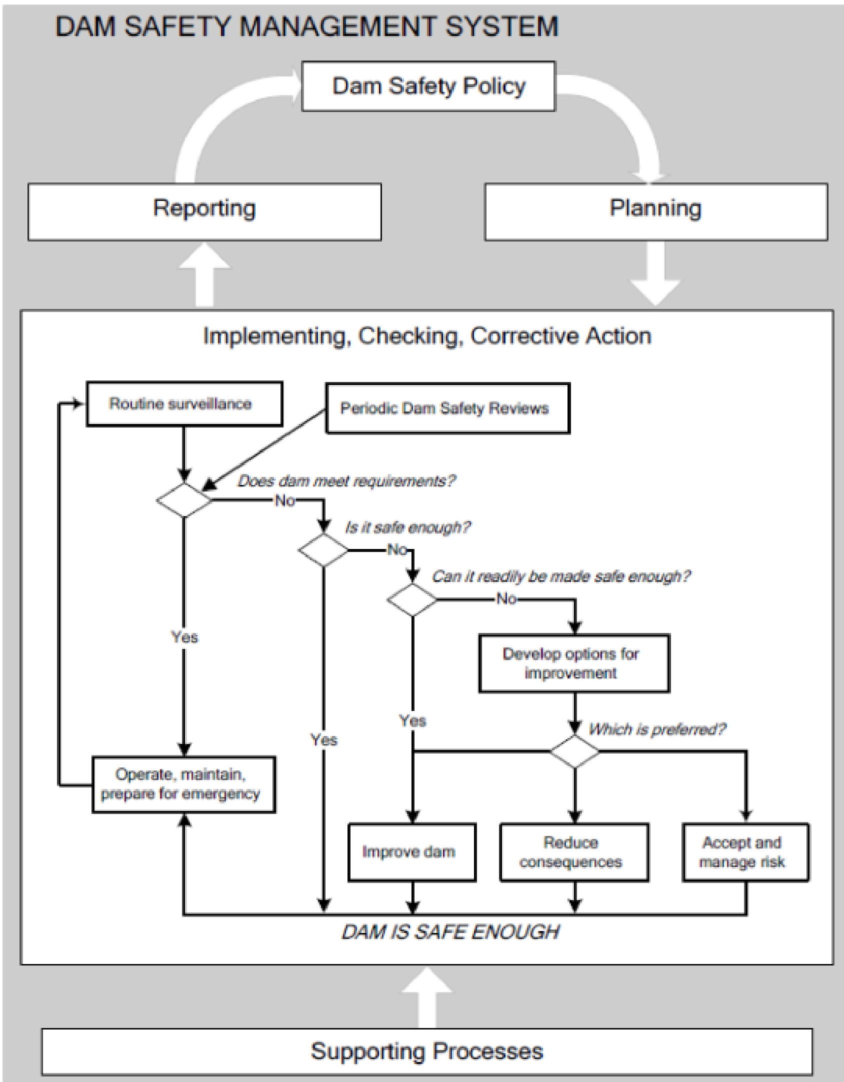

Figure 3-1: Overview of a Dam Safety Management System (after CDA, 2007)

The practice of Dam Safety Management recommended by the CDA is outlined in detail in ICOLD's Bulletin 154 - Dam Safety Management: Operational Phase of the Dam Life Cycle (in Press). This document builds on principles established in previous Bulletins 59 and 130 and reinforces the fact that the Dam Owner is ultimately responsible for assuring the safety of the public, property and environment around and downstream of dams and dykes. Specifically, in the case of the Kashechewan Ring Dyke, this includes a government institution or agency that is responsible for the safety of the dam and the public, either directly or through oversight over the safety management activities of the bodies that operate the dam.

In the Bulletin it is specifically stated that the safety of the dam or dyke must conform to the requirements and expectations of government and the prevailing laws, regardless of how they are established and implemented. This implies that the owner's dam safety management program and systems must be in compliance with overarching legislative and regulatory requirements which, in the case of the Kashechewan Ring Dyke, would imply compliance with the Ontario and CDA dam safety guidelines. Under the CDA guidelines the owner is responsible for

- establishing and maintaining the necessary resources
- providing adequate training and information
- establishing procedures and arrangements to maintain safety under all conditions
- verifying the adequate quality of facilities and activities and of their associated equipment
- ensuring the safe control of all inflows, outflows and stored volumes
- ensuring the safe control of all sediments and deleterious materials that arise as a result of the dam.

Dam safety management is intended to cover the full spectrum of hazardous conditions that can arise from the activities associated with retaining and discharging water. Since dam the need for dam safety management can span generations, any plan must consider the requirements for both present and future operations. In this respect it is the responsibility of the owner within the dam safety management system to make appropriate allowances for the continuity of responsibilities and the fulfillment of funding requirements in the long term.

In most of the industrial operations, a "management system" such as a Dam safety Management System is the method by which operational activities are carried out and the goals of the program are assured. In general, the management system establishes a systematic and consistent way of implementing the owner's responsibilities as illustrated in Figure 3-2.

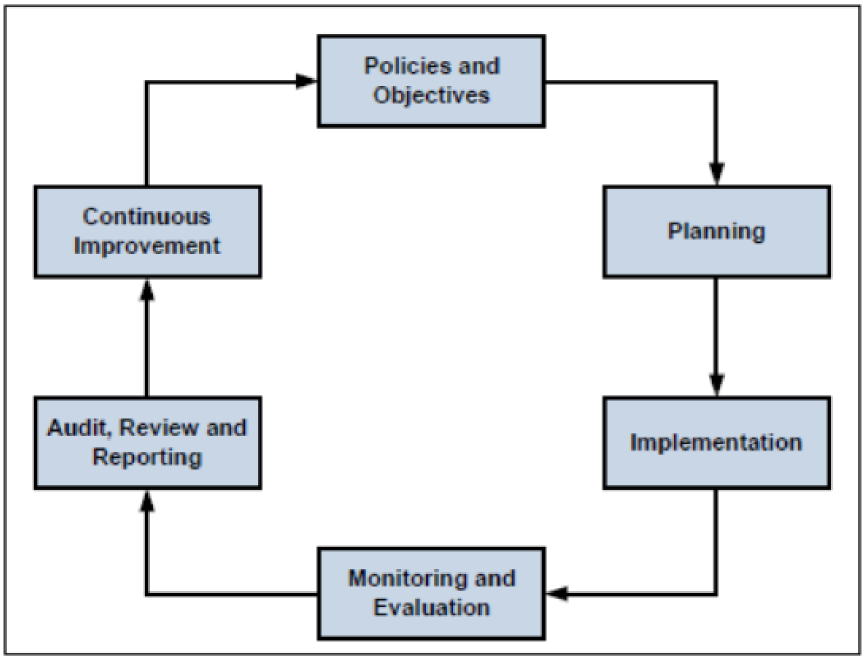

Figure 3-2: Elements of a Management System

Policies and Objectives provide a clear direction to follow to achieve all of the Dam Safety goals.

Planning sets the objectives and targets to be achieved, develops plans for implementation, and defines performance standards. Comprehensive assessment of risks and uncertainties that could adversely impact the operation and achievement of the objectives, and the development of contingency plans, would normally precede the implementation of the plan. This step also includes determination of resources required to achieve the objectives.

Implementation activities put in place an effective management structure and system of procedures that ensure that the objectives are achieved.

Monitoring and Evaluation of performance provides information on the effectiveness of the activity and whether the management system is maintaining operation within its defined objectives. Performance is measured against the standards established in the Planning step.

Audit, Review and Reporting provides a systematic review of performance, based on information collected by Monitoring and Evaluation, with additional data provided by independent audits. Performance can be assessed not only against the standards set in the Planning step, but it can also be compared with external practice.

Continual Improvement uses the results of Performance Monitoring and Evaluation along with results from Audit, Review and Reporting, to make adjustments and improvements in the policies and processes.

3.2 Life-Cycle Management

The efforts to achieve compliance with safety objectives usually vary within the life-cycle of a given dam in proportion to increasing or decreasing dam safety risks. Life-cycle management is the most important component of a Dam Safety Management System providing the means to reduce risk over the entire life cycle of the dam by

- optimizing operation and maintenance activities
- ensuring that the desired levels of performance and safety are met.

In the past, life-cycle management of dams has often been dealt with on an ad hoc basis by adjusting the management approach as the dam moves through its life-cycle phases and issues emerge (as is generally the case for the Kashechewan Ring Dyke). Such *ad hoc* decisions, aimed at reducing costs without understanding of long term impacts, can lead to a situation where risks are significantly increased and the overall costs over the life of the dam far exceed the savings any realized within a particular phase of its lifecycle . Therefore, it is very important that all safety-related decisions and considerations at any phase of the dam life-cycle address all implications for the subsequent life-cycle phases.

The overarching principle enshrined in the CDA and ICOLD's guidelines is that, in order to ensure the sustainability of dams and dykes, all reasonably practicable efforts should be made to prevent and mitigate failures and accidents. The dam owner is responsible to ensure that all relevant factors that might affect present and future safety of the dam are identified, recorded and analyzed to establish solutions to mitigate risks to the extent that is reasonably practicable. The CDA and International practice require that remedial actions be implemented in a timely and rational manner to avoid a situation where degradation of the structure does not lead to unacceptable risks to the public.

3.3 Integrated Management Systems

Although it has been long recognized that the most effective approach in organizational management is an integrated approach, the reality generally differs from this ideal model. Quite often different systems (for environment, health, and safety, for example) are used as stand-alone control and documenting mechanisms, with independent management in the organization. The benefits of integration are enhancement of safety, reduction of duplication and costs, increased efficiency, and more effective and efficient collection and use of information, which generally improves overall business performance. A well designed integrated management system can provide a dam owner with a single framework for all arrangements necessary to achieve the overarching goal of safety to the public. Integration of management systems can provide a consistent and coherent approach to planning strategies to meet all corporate goals and objectives.

3.4 Maintenance and Repairs

A well designed Dam Safety Management System must include suitable and sufficient processes to ensure that all components important to safety remain in compliance with the relevant dam safety guidelines. The process should ensure that a systematic approach is taken to identify which maintenance activities are to be performed and at what intervals. The process should establish how maintenance activities are initiated, managed, assessed, prioritized, planned and scheduled. The identification, selection and frequency of maintenance activities should take into account

- magnitude of risks involved
- guidelines and requirements of applicable codes and standards
- design and operation conditions
- operating experience
- vendor recommendations
- ageing management requirements.

The maintenance program should include all activities aimed at avoiding, detecting and repairing any deficiencies endangering structural integrity of dam components. These maintenance activities can be divided into two groups that have different objectives, namely

- preventive maintenance whose primary role is to avoid and detect failures
- corrective maintenance which encompasses all activities aimed at repairing components which are already in the failed state.

Preventive maintenance includes predictive, periodic and planned activities. Preventive maintenance also requires the development of a formal process to detect access and manage deterioration of dam components as a result of ageing effects.

Corrective maintenance requires the development of a process for designing and performing temporary repairs. The process requires an efficient approval process, an assessment of the adequacy of the temporary repairs and time period allowable for performance of permanent repairs.

All maintenance activities should be performed in accordance with written approved procedures should be designed in accordance with applicable codes and standards should be adequately supervised by experienced personnel and the DSMS should ensure that all maintenance activities are carried out in an adequate and timely manner.

3.5 Performance Monitoring and Evaluation

A modern Dam Safety Management System requires that monitoring systems be in place to ensure that the safety targets are being satisfied and to provide early warnings of inadequate performance. In general, the monitoring and evaluation process should have the capability to determine whether the overall safety performance is constant, deteriorating or improving. The outcomes of the process should be sufficient to identify the underlying causes of unsatisfactory performance and to provide the basis for identification of corrective measures. At the Kashechewan site, this would require routine walk over inspections, annual formal inspections by trained dam safety personnel, periodic dam safety reviews by independent dam safety personnel, monitoring and assessment of the instrumentation and documentation of any incidents such as deformation, settlement or seepage.

3.6 Audit, Review and Reporting

The effectiveness of the Plan should be evaluated to confirm its ability to achieve the dam safety objectives and to identify opportunities for improvement as illustrated in Figure 3-3.

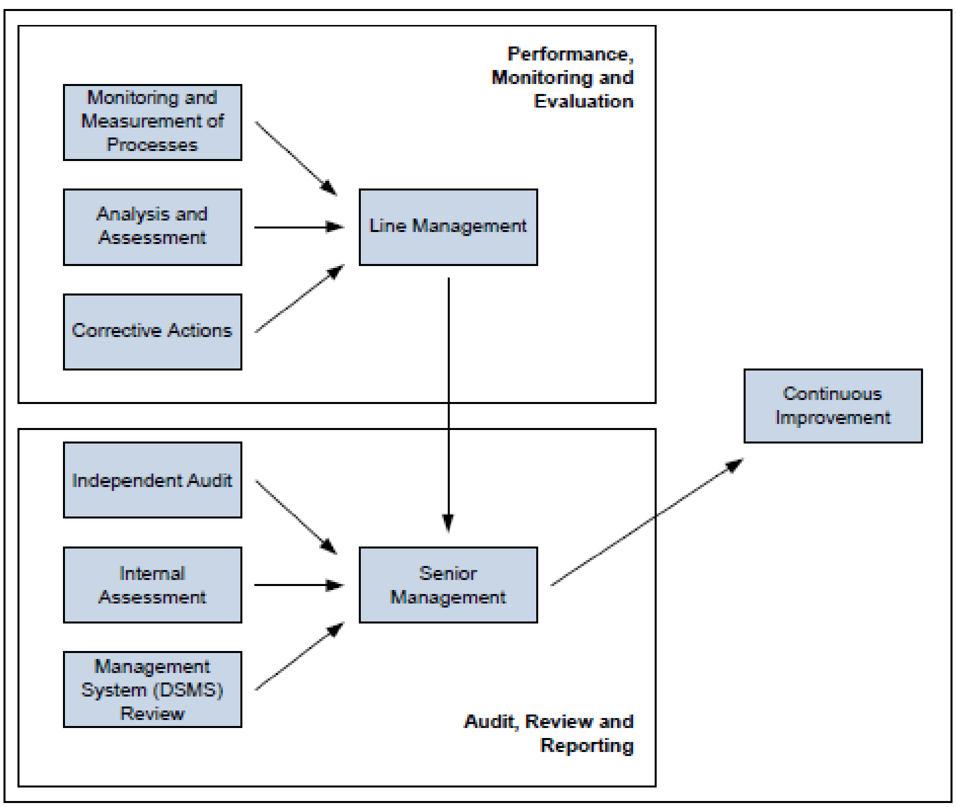

Figure 3-3: Relationships within the Dam Safety Management System

3.7 CDA Recommendations for Operation, Maintenance, and Surveillance

PRINCIPLE 2a of the Canadian Dam Association Dam Safety Guidelines states that;

Requirements for the safe operation, maintenance, and surveillance of the dam shall be developed and documented with sufficient information in accordance with their impacts of operation and the consequences of dam failure.

A critical part of the dam safety management system is the development, implementation, and control of procedures for the operation, maintenance, and surveillance of the facility, taking into account public safety and security.

The CDA states that Operation, maintenance, and surveillance procedures should be documented in an Operation, Maintenance, and Surveillance Manual (OMS Manual) and reviewed regularly to ensure that the information is up to date.. Ongoing log books, records, or reports should be maintained to show that the specified activities and observations have been carried out and that the dam safety requirements are being met.

At Kashechewan, an OM&S manual has been prepared in accordance with the CDA guidelines but it has not been finalized or implemented with the requisite training and resources.

PRINCIPLE 2b of the Canadian Dam Association Dam Safety Guidelines states that;

Documented operating procedures for the dam and flow control equipment under normal, unusual, and emergency conditions shall be followed.

Proper operation of discharge facilities (in this case the drainage culverts) is critical to safety and performance and mitigating potential impacts to the public. The CDA state that these operating procedures should take into account the complexity of the site and the consequences of mis-operation.

As discussed under Principle 2a, an OM&S manual does exist that would satisfy this requirement but has not been finalized or implemented.

PRINCIPLE 2c of the Canadian Dam Association Dam Safety Guidelines states that;

Documented maintenance procedures shall be followed to ensure that the dam remains in a safe and operational condition.

In the case of the Kashechewan Ring Dyke, maintenance of drainage culverts and associated systems is required to ensure operational availability, safe operations, and integrity of the dam and the mechanical and electrical systems where failure can be sudden. The particular maintenance needs of critical components or subsystems, such as power supply, backup power, mechanical components, public safety and security measures need to be prioritized, carried out in a timely manner and documented with due consideration of safety implications. Regular maintenance of the dyke itself to correct things such as settlement, slope instabilities and the stabilizing berm would be expected to be performed annually as issues become apparent. Inside the dyke, maintenance of the drainage and discharge systems would be expected.

PRINCIPLE 2d of the Canadian Dam Association Dam Safety Guidelines states that;

Documented surveillance procedures shall be followed to provide early identification and to allow for timely mitigation of conditions that might affect dam safety.

Surveillance, including visual inspections and instrument monitoring, is a method for checking whether or not the dyke is performing satisfactorily. Effective dam surveillance is based on an understanding of how the dyke might fail (failure modes), what early signs of failure to look for and what inspection or monitoring measures are available (such as piezometers, settlement monuments and weirs) to detect a developing failure. The surveillance program should include

- comparison of the actual and design performance to identify deviations
- detection of changes in performance or the development of hazardous conditions
- confirmation that the entire dyke system (ring dyke, stabilizing berm, drainage and discharge facilities are in compliance with dam safety requirements
- confirmation that adequate maintenance is being carried out on a timely basis by trained personnel.

The CDA recommends that the frequency of inspection and monitoring activities reflect the consequences of failure, the dam condition and past performance, the potential rapidity of the development of potential failure modes, access constraints due to weather or the season, regulatory requirements, security needs, and other factors. In addition to scheduled and documented inspections, surveillance is recommended to take place each time staff visits a site for other routine activities. Special inspections should be undertaken following unusual events, such as earthquakes, floods, or rapid drawdown.

A summary of monitoring and surveillance recommendations by various entities is provided in Table 3-2.

Table 3-1: Summary of Recommended Inspection Frequency in Various Jurisdictions

Jurisdiction	Recommended Frequency (varies depending on dam classification)		
	Routine Inspections	Engineering Inspections	Periodic Dam Safety Review
CDA Guidelines (2013)	Weekly to Monthly	Semi-annually to Annually	5 to 10 years
Quebec Regulations (2002)	Monthly to Annually	Four per year to Annually	10 years
BC Regulations (2000)	Weekly to Quarterly	Semi-annually to Annually	7 to 10 years
Ontario Guidelines (2011)	Monthly to Annually	Annually to every 5 years	10 years

Jurisdiction	Recommended Frequency (varies depending on dam classification)		
	Routine Inspections	**Engineering Inspections**	**Periodic Dam Safety Review**
US Federal Emergency Management Agency	As determined by responsible engineer.	Annually to as determined by responsible engineer.	At intervals not exceeding 5 years
New Zealand Society for Large Dams (2000)	Weekly to every 4 months	Annually to every 2 years	5 to 10 years
Sweden RIDAS (2002)	Weekly	Semi-annually to Annually	15 to 30 years

Training should be provided so that inspectors understand the importance of their role, the value of good documentation, and the means to carry out their responsibilities effectively. Instrumentation may be useful or necessary, depending on the consequences of dam failure and on the need to understand performance parameters that should be measured quantitatively.

Instrumentation needs are recommended to be designed accounting for the hazard the dyke or dam presents and the regular monitoring program should document

- how often instruments are read and by whom
- where instrument readings will be stored, how they will be processed, and how they will be analyzed
- what threshold values or limits are acceptable for triggering follow-up actions
- what the follow-up actions should be; and what instrument maintenance and calibration are necessary.

Follow-up actions might range from continued or enhanced inspection and monitoring, to remedial repairs, to appropriate follow-up of surveillance findings. In some situations, immediate action, such as reservoir lowering or emergency repairs, may be necessary to manage the risks.

At the Kashechewan Ring Dyke formal Inspections are not performed, a formal dam safety assessment has not been undertaken and the instrumentation installed in 2007 is not being monitored.

PRINCIPLE 2e of the Canadian Dam Association Dam Safety Guidelines states that;

Flow control equipment shall be tested and be capable of operating as required.

The CDA recommends that testing of flow control equipment be carried out to demonstrate that it will reliably handle the expected operating loads and site conditions, retaining or releasing water upon demand. The operational capability of equipment should be assessed with consideration of both normal and unusual conditions and the consequences of equipment failure. Test procedures should take into consideration upstream and downstream effects, including impacts on public safety and environmental concerns. Normal and standby power sources, as well as local and remote controls, should be tested. The test results should be documented.

At the Kashechewan site the “flow control equipment” consists of the discharge culverts. Maintenance is not performed and repairs are not undertaken n a timely basis. A redundant power sources in the form of a diesel generator is available but it is not known if it is operable.

3.8 Assessment of Compliance with the Canadian Dam Association Guiding Principles

An assessment of the compliance of Dam Safety Management for the Kashechewan Ring Dyke is provided in Table 3-2.

Table 3-2: Assessment of Compliance with CDA Guiding Dam Safety Principles

Principle	Description	Compliance
1	**Dam Safety Management**	**Overall – Non-compliant**
1a	The public and the environment shall be protected from the effects of dam failure, as well as release of any or all of the retained fluids behind a dam, such that the risks are kept as low as reasonably practicable.	**Non-compliant.** The risk of overtopping and piping has not been defined.
1b	The standard of care to be exercised in the management of dam safety shall be commensurate with the consequences of dam failure.	**Non-compliant.** The standard of care is inadequate for an EXTREME Hazard dam.
1c	Due diligence shall be exercised at all stages of a dam’s life cycle.	**Non-compliant**
2	**Operation, Maintenance, and Surveillance**	**Overall – Low to Moderate**
1d	A dam safety management system, incorporating policies, responsibilities, plans and procedures, documentation, training, and review and correction of deficiencies and non-conformances, shall be in place.	**Non-compliant**
2a	Requirements for the safe operation, maintenance, and surveillance of the dam shall be developed and documented with sufficient information in accordance with the impacts of operation and the consequences of dam failure.	**Moderate.** An O&M manual has been prepared but is incomplete and no training has been performed.
2b	Documented operating procedures for the dam and flow control equipment under normal, unusual, and emergency conditions shall be followed.	**Moderate.** An O&M manual has been prepared but is incomplete and no training has been performed.
2c	Documented maintenance procedures shall be followed to ensure that the dam remains in a safe and operational condition.	**Moderate.** An O&M manual has been prepared but is incomplete and no training has been performed.
2d	Documented surveillance procedures shall be followed to provide early identification and to allow for timely mitigation of conditions that might affect dam safety.	**Non Compliant**. No surveillance is being performed.
3	**Emergency Preparedness**	**Overall – Moderate to Compliant**
3a	An effective emergency management process shall be in place for the dam.	**Compliant.**
3b	The emergency management process shall include emergency response procedures to guide the dam	**Compliant.**

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Principle	Description	Compliance
	operator and site staff through the process of responding to an emergency at a dam.	
3c	The emergency management process shall ensure that effective emergency preparedness procedures are in place for use by external response agencies with responsibilities for public safety within the floodplain.	**Compliant.**
3d	The emergency management process shall ensure that adequate staff training, plan testing, and plan updating are carried out.	**Moderate.** The Flood Forecast tool is no longer being used and local staff have not yet been trained in the use of the tool.
4	**Dam Safety Review**	**Overall – Non-compliant.**
4a	A safety review of the dam ("Dam Safety Review") shall be carried out periodically.	**Non Compliant**. A formal DSR has never been performed.
4b	A qualified registered professional engineer shall be responsible for the technical content, findings, and recommendations of the Dam Safety Review and report.	**Non Compliant**. A formal DSR has never been performed.
5	**Analysis and Assessment**	**Overall – Non-compliant to Compliant.**
5a	The dam system and components under analysis shall be defined.	**Compliant.**
5b	Hazards external and internal to the dam shall be defined.	**Low.** The risk of overtopping and piping has not been defined.
5c	Failure modes, sequences, and combinations shall be identified for the dam.	**Low.** The risk of overtopping and piping has not been defined.
5d	The dam shall safely retain the reservoir and any stored solids, and it shall pass flows as required for all applicable loading conditions.	**Non-compliant.** The risk of overtopping and piping has not been defined.

As depicted in Figure 3-4, other than emergency preparedness, the dam safety practices followed at the Kashechewan Ring Dyke Dam were found to be moderately compliant to non-compliant with the CDA Guiding Principles for Dam Safety Management with 8 of the 18 being non-compliant.

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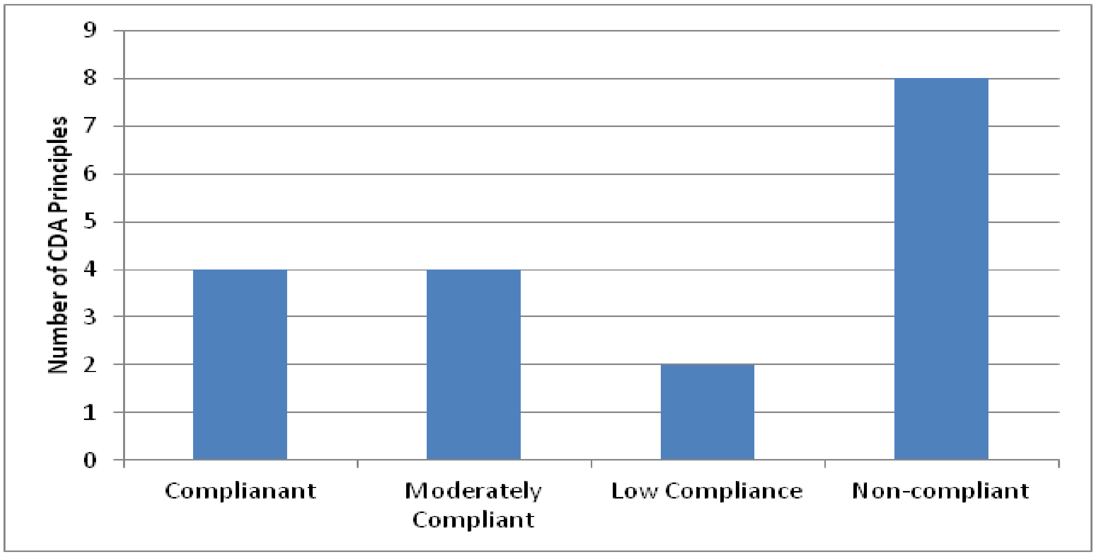

Figure 3-4: Summary of Compliance with CDA Dam Safety Principles

3.9 Estimate of the Annual Costs of a Well Designed Dam Safety Management Program

To obtain a rough estimate of what might be required to implement a dam safety management program in compliance with the CDA guidelines, a report entitled, "The Cost of Rehabilitating Our Nation's Dams, A Methodology, Estimate & Proposed Funding Mechanisms" prepared by a Task Committee of the Association of States Dam Safety Officials (October 2003) was consulted. In this report, an inventory of US dams was divided into dam height categories and actual costs associated with maintaining the dams and dykes tabulated. In this way, dam height was used to as an indication of costs for engineering review, repairs and upgrades required within a structured Dam Safety Management Program.

To obtain an estimate of the order of magnitude of the annual costs of maintaining the Kashechewan Ring Dyke in accordance with modern Dam Safety Management practices, the average annual costs for small dams established in the 2003 study, escalated to 2014 dollars were tabulated. To these amounts, a "northern factor" was applied to account for the increased costs associated with a remote site in Canada's far north.

The results of the assessment, as summarized in Table 3-2 indicate an annual Dam Safety Management Program Cost, excluding personnel costs, outstanding training, periodic dam safety review costs and engineering and construction costs for major remedial works project, in the order of $370,000.

Table 3-3: Order of Magnitude Estimate of the Annual Costs of a Dam safety Management Program for the Kashechewan Ring Dyke

Category	Height (m)	No. of Dams	2014 $CDN						
			Deferred Maintenance ($)		Engineering Assessment ($)		Routine Remedial Action ($)		Total Cost ($)
			Per Dam	Total	Per Dam	Total	Per Dam	Total	
A[1]	<4.5	36			24,000	864,000			720,000
		36	12,000	432,000	24,000	864,000			1,080,000
		12			24,000	288,000	140,000	1,680,000	1,740,000
		12	12,000	144,000	24,000	288,000	140,000	1,680,000	1,860,000
		12			24,000	288,000	280,000	3,360,000	3,240,000
		12	12,000	144,000	24,000	288,000	280,000	3,360,000	3,360,000
Total A		**120**		**720,000**		**2,880,000**		**10,080,000**	**12,000,000**
Cost per dam				**12,000**		**24,000**		**210,000**	**246,000**
Northern allowance (50%)				**6,000**		**12,000**		**105,000**	**123,000**
Total Annual DSMS Costs[2]				**18,000**		**36,000**		**315,000**	**369,000**

[1] Classification as per 2003 study.
[2] Dam Safety Management Program Costs do not include personnel costs, outstanding training, periodic dam safety review costs or engineering and construction costs for major remedial works projects.

4. Identified Dam Safety Remedial Work Tasks

Since 2007, Hatch has been providing engineering services on generally an ad-hoc basis to assist in identifying dam safety risks and undertake the designs and supervision of reactive dam safety repairs. Asks have included

- geotechnical investigations in 2007 and 2010
- design and supervision of emergency priority dam safety remedial works in 2008
- design and supervision of emergency repairs to the drainage culverts in 2008
- assistance with the Flood Watch program in 2011 to 2013
- design and supervision of the construction of a stabilizing berm in 2009
- design and implementation of some localized repairs to the stabilizing berm in 2010.

A listing of some of the identified issues that remain to be addressed are listed in Table 4-1.

Table 4-1: Identified Remedial Work requirements – Kashechewan Ring Dyke

Alternative	Description	Comments
Raise the dam to provide adequate freeboard.	Based on the 2006 event it is clear that there is insufficient freeboard.	Issues to consider include cost, the level of protection needed, methods to achieve the required level of protection, stability of the dyke, etc.
Reduce the impact of ice jamming.	This may involve the construction of a “far field” structure upstream.	If deemed to be useful, ice modeling would be performed for promising alternative scenario’s.
Deal with dam safety seepage and piping issues.	Alternative - Install an upstream membrane around the entire dyke.	This could involve a geomembrane, a “bentomat” covering or a natural impervious fill blanket. Analyses and cost considerations are needed to select the most appropriate alternative. For example, the durability of geomembranes subjected to northern climatic conditions needs to be reviewed.
	Alternative - Allow the dyke to leak.	Given the uncertain nature of the internal workings of the Ring Dyke, any attempt to eliminate seepage through the structure carries with it certain risks (and high costs). Another alternative would be to design the dam to remain stable during leakage events by installing downstream filters, weighting berms and drainage measures. For example, the boiling seen during the 2006 event may be a result of pressure that quickly built up in the sandy layers within the clayey

Alternative	Description	Comments
		silt. If so, a simple trench, [properly drained and backfilled with filter materials] could serve as an effective “pressure relief” system. The extent of the trench could be established on the basis of seepage analyses techniques to determine where hydraulic gradients are such that boiling could occur.
	Alternative - Install a total cutoff.	Leakage could be mitigated and issues with piping of the fine grained impervious soils dealt with by means of a cement bentonite wall extending through the dam into the underlying impervious clayey silts or even to bedrock.The depth of the wall would be such that it could be excavated by backhoe. This solution has the advantage that it is relatively weather insensitive. However, the solution may be cost prohibitive.
	Alternative - Construct a partial cut-off.	Analyses could show that either gradients or the consequences of failure are such that a cut-off is not needed for the entire dyke reducing costs and enhancing schedule. Issues such as end-run seepage and other risks would be needed to assess this possibility.
River Bank Erosion	Maintain the stabilization berm	Deterioration of the berm includes loss of armour protection and ongoing erosion issues due the lack of maintenance and failure to complete this work during the intial program
Gate Reliability	Perform reliability tests and assess means of simplifying or enhancing operations.	A detailed assessment of the operation and reliability of the slide ad flap gates is necessary. On the basis of this review, it may be possible to recommend certain enhancements that may improve reliability and simplify operations.
Drainage Culvert Deterioration	Routine maintenance and inspection of the drainage culverts	This would include assessment of any potential for piping
Dam Safety Inspections	Routine and formal inspections	A formal inspection program complete with standard documentation, training and assessment of the results of inspections is required at a frequency in accordance with CDA recommendations for an EXTREME Consequence Dam
Dam Safety Assessment	Periodic Dam Safety Assessment	Periodic dam safety inspections at a frequency in accordance with CDA

Alternative	Description	Comments
		recommendations for an EXTREME Consequence Dam by an third party dam safety professional is required. This would include seepage, stability analyses, assessment of the potential for piping, review of the emergency preparedness plans, PM&S manual, adequacy of reporting and staff training.
Emergency Preparedness Plan	Training and use of the flood forecast tool	Full integration of the flood forecasting tool into the Emergency Preparedness Planning activities is required. Although training occurred, there has not yet been a successful transition and funding to local use requiring ongoing support by Hatch. This, in recent years has led to the discontinuance of the use of the tool. This could result in less warning time shortening the time available to properly evacuate the community, particularly in the event of adverse weather conditions. In addition, more robust monitoring stations on river and/or local weather station are needed to fully exploit the flood forecasting capabilities of the tool.
Operations, Maintenance and Safety Manual	Finalize and Implement the manual	This includes finalization of the manual itself, implementation of the procedures and training of personnel and adequate funding for the OM&S program
Repair of the Drainage Culverts	At least one of the drainage culverts is not functioning and requires immediate attention	The functioning of the culverts has become an ongoing issue. An engineering assessment of all of the issues and the implementation of a repair that deals with all known and potential problems is necessary. Assessments should also be performed to establish a more robust and maintainable solution with due attention to issues such as redundancy, automation and vandalism.
Community Drainage	Drainage systems are inadequate.	Upgrading of the entire drainage system within the community with due attention to issues such as filtering to reduce the risk of piping is necessary. In addition, If water inside the dyke cannot get a quick rise in water levels due to seepage during a flood event could result in life safety risks to individuals living in low lying areas of

Alternative	Description	Comments
		the community. (The Ontario Guidelines suggest a safety risk occurs with water levels as low as 2 feet under certain conditions).

5. Dam Safety Risks Associated with the Kashechewan Ring Dyke

5.1 Dam Safety Classification

Table 5-1 shows the dam safety classification and dam safety parameters that would be required for the Kashechewan Ring Dyke on the basis of the CDA recommendations for selection of dam safety parameters as detailed in Appendix A.

Table 5-1: Design Basis Flood and Design Basis Earthquake

Dam Classification[1]	Persons Affected	Estimated persons at Risk	Design Parameter	Selected Parameter
EXTREME	2000	20 to 100	Inflow Design Flood	Probable Maximum Flood or Probable Maximum Ice Jam Flood (whichever is greater).
HIGH	2000	<10	Design Basis Earthquake	1:2500-yr return period earthquake event.

[1] CDA 2013 Dam Classification
[2] Low probability of an ice jam flood and earthquake occurring at the same time. Persons at risk estimated on the basis that a local failure could bury a house of individuals

5.2 Dam Safety Risk Assessment

Risk-informed decision making has been gaining increased attention as a tool for understanding the level of safety associated with an existing dam and determining what level of deviation from the normal performance condition can be considered tolerable (CDA, 2007). This risk-informed approach has been formally adopted as a regulatory tool within the Australian states of New South Wales (NSW, 2010), and Victoria (DEPI, 2014) and has been used as an asset management tool by large dam owns in the United States such as the Army Corps of Engineers (USACE, 2011).

In Ontario, the Ontario Ministry of Natural Resources and Forestry (MNRF), working in partnership with Ontario Power Generation (OPG), the Grand River Conservation Authority (GRCA) and Hatch Ltd. has developed a conceptual framework for regulating the use of risk-informed decision making. As part of this initiative Hatch developed a unique risk assessment tool that has been tested by the Ministry and Ontario Power generation and found to provide realistic, repeatable results for assessing the probability of occurrence of Key Dam Safety failure modes.

The methodology for completing the risk assessment consisted of the following:

Step 1: Selection of the Failure Modes

Step 2: Determination of Failure Probabilities

Step 3: Estimate of Consequences

Step 4: Risk Evaluation

A more complete description of the Dam Safety Risk Assessment Tool is provided in Appendix B.

5.2.1 *Step 1: Selection of Project Components and Associated Failure Modes*

The reasons for a dam to fail have been studied by numerous authors. In 1975 a study performed by ASCE/USCOLD showed that there were four general causes of dam failure as depicted in Figure 5-1.

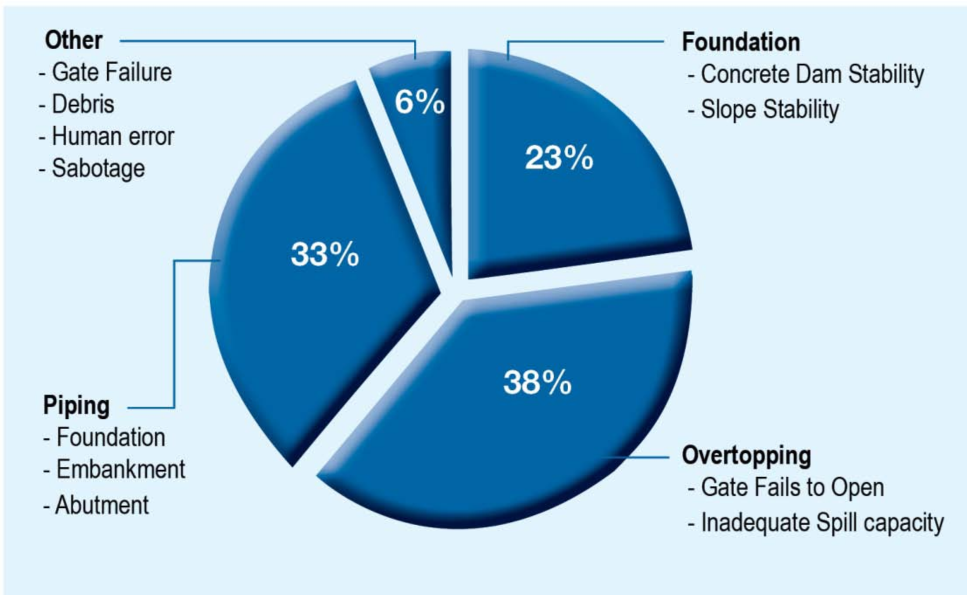

Figure 5-1: Causes of Dam Failure (Source: ASCE/USCOLD, 1975)

As described in Table 5-2, the risk assessment tool evaluates the probability of failure for these key failure modes using a variety of proven methodologies.

Table 5-2: Basis of the Probability Estimates

Module	Description	Basis of Estimate	Remarks
1	Failure of Gate to Open	Expert Judgment	38% of Failures
	Potential for Overtopping	Standard hydrotechnical Statistical Analysis	
	PMF Analysis	Statistical Assessments	
2	Embankment Dam Piping	*Empirical Analysis*	33% of Failures
3	Embankment Dam Slope Stability	*Empirical Analysis*	Part of 23% of Failures
4	Concrete Dam Sliding	Mathematical analysis using the Capacity-Demand methodology	
5	Gate Failure	Mathematical analysis using	Part of 8% of all

Module	Description	Basis of Estimate	Remarks
6	Penstock Failure	the Capacity-Demand methodology	Failures

The key failure modes that need to be considered for the Kashechewan Ring Dyke are

- overtopping of the dyke as a result of an Ice Jam flood
- internal erosion (piping)
- slope instability (when subjected to the design water level or as a result of an earthquake).

5.2.2 Step 2: Determination of Failure Probabilities

5.2.2.1 Probability of Overtopping

The history of flooding at Kashechewan is dominated by ice jam floods. These floods occur when higher than average temperatures melt the snowpack while river ice is still thick. The melting snow, often reinforced by rainfall, results in large floods in the Albany River that lift the ice cover on the river and carry it downstream. On the North Channel of the Albany River this results in the formation of ice jams, particularly at Fafard Island downstream from Kashechewan Community. The backwater effects from these ice jams cause the flood levels at the Ring Dyke to rise much higher than the levels resulting from the floods of the same magnitude during the open water season.

Abdelnour (2013) has identified peak water levels and flows associated with historical ice jam floods using the flow record from the Water Survey of Canada stream flow station at Hat Island on the Albany River (1965-2013). Figure 5-1 and Figure 5-2 show historical flood levels at Kashechewan Community and flood flows at Hat Island.

Figure 5-2: Maximum Ice Jam Levels at Kashechewan Dyke (Source: Abdelnour (2013))

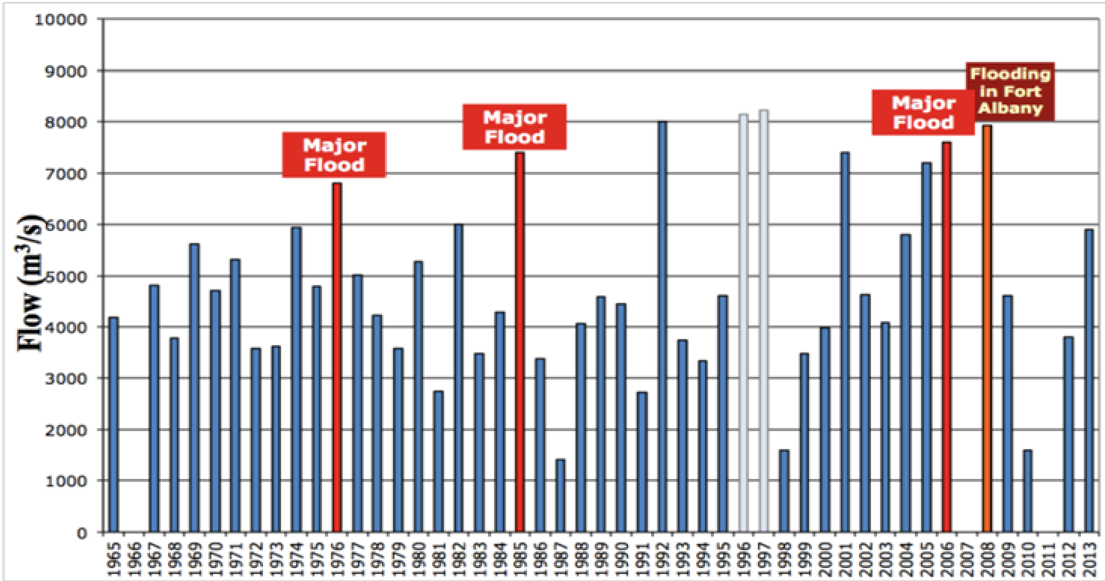

Figure 5-3: Maximum Floods in the Albany River at Hat Island (Source: Abdelnour (2013))

Hatch (2013) developed an early warning model to alert the Kashechewan Community of the potential for severe ice jam floods. The model includes an early warning criterion, represented by Moosonee daily rainfall and daily water equivalent of snowpack depletion accumulated from the end-of winter (March 1st), and late warning criteria comprising

- the 3-day rate of increase in flow rate of 700 m^3/s/day
- a threshold flow rate of 4750 m^3/s
- a calendar date of April 28^{th}.

Figure 5-3 and Figure 5-4 show the model application results for 2006 (retroactively) and for 2013. The application to 2006 hydrometeorological conditions shows that the early warning criterion and the late warning criteria were greatly exceeded by the 2006 ice jam flood. In contrast snowmelt and rainfall in the spring of 2013 was low and did not peak till well after April 28^{th}, historically the latest date for major ice jam flood occurrence.

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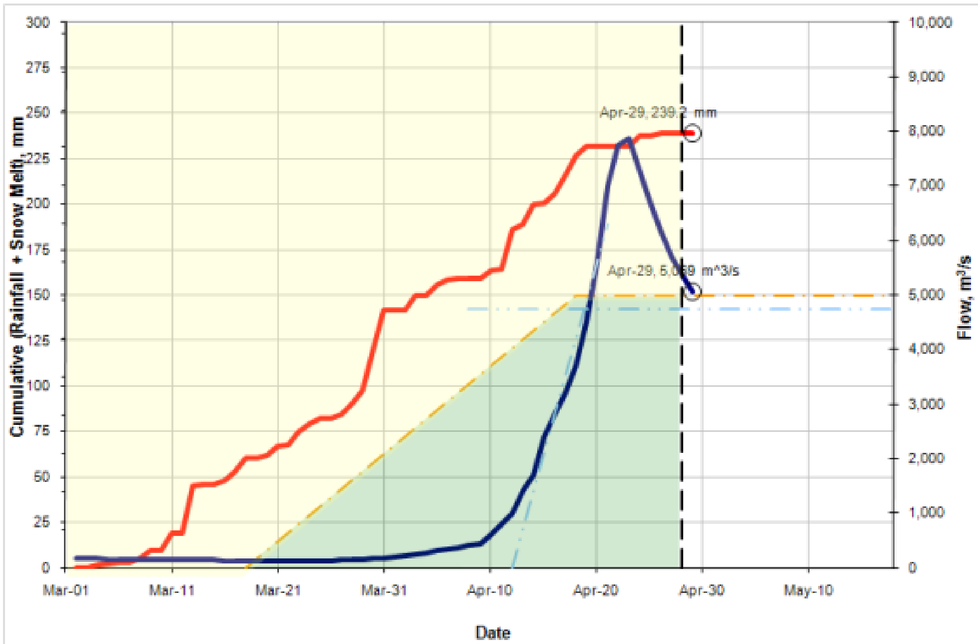

Figure 5-4: Model Output (2006) (Source Hatch)

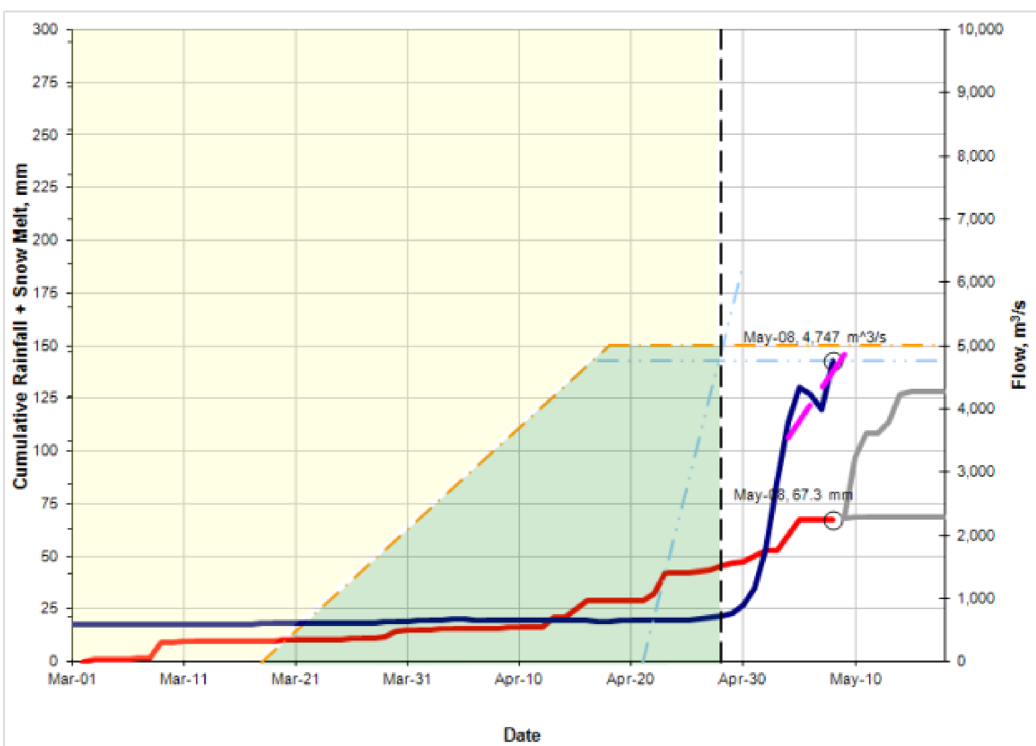

Figure 5-5: Model Output (2013) (Source Hatch (2013)

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Observations made by Abdelnour (2013) cover the years 1965-2013, when flows for the Albany River at Hat Island are available. To extend this dataset and improve the frequency analysis of potential ice jam flood levels at the Kashechewan Ring Dyke, the early warning component of the Hatch model was applied to Moosonee temperature and precipitation data for the years 1933-1964. This increased the time base for the frequency analysis to 81 years.

Table 5-3 shows the estimated and observed ice jam flood levels at the Ring Dyke during this period The results indicate that suggests that a significant ice jam flood at the Kashechewan Ring Dyke can be expected once every ten years on average.

Table 5-3: Estimated Ice Jam Flood Levels at the Kashechewan Ring Dyke (1933-2013)

Year	Ice Jam Flood Level (m)
1942	7.38
1951	9.21
1952	7.82
1955	7.48
1976	7.80
1985	7.60
2005	8.00
2006	10.00

Figure 5-5 shows the 3-parameter Log Normal distribution fitted to the values in Table 5-2, taking into account the 81 years of record from which the values were derived. These results indicate that the probability of overtopping (and failing) the Ring Dyke at elevation 10.7 m is 3.64E-03 or an annual probability of occurrence of about1:280 years. Assuming the probability of not evacuating persons following the current practices is in the order of 1:10, the probability of occurrence of an ice jam flood with persons in the community is in the order of 1:2,800.

As discussed previously, for an EXTREME consequence dam or dyke the CDA, Ontario and virtually all dam safety authorities would specify an annual flood frequency of not more than 1:10,000 years and potentially in excess of 1:100,000 years. Clearly the risks associated with overtopping are unacceptable leading to the need for the frequent evacuations that have occurred since 1976.

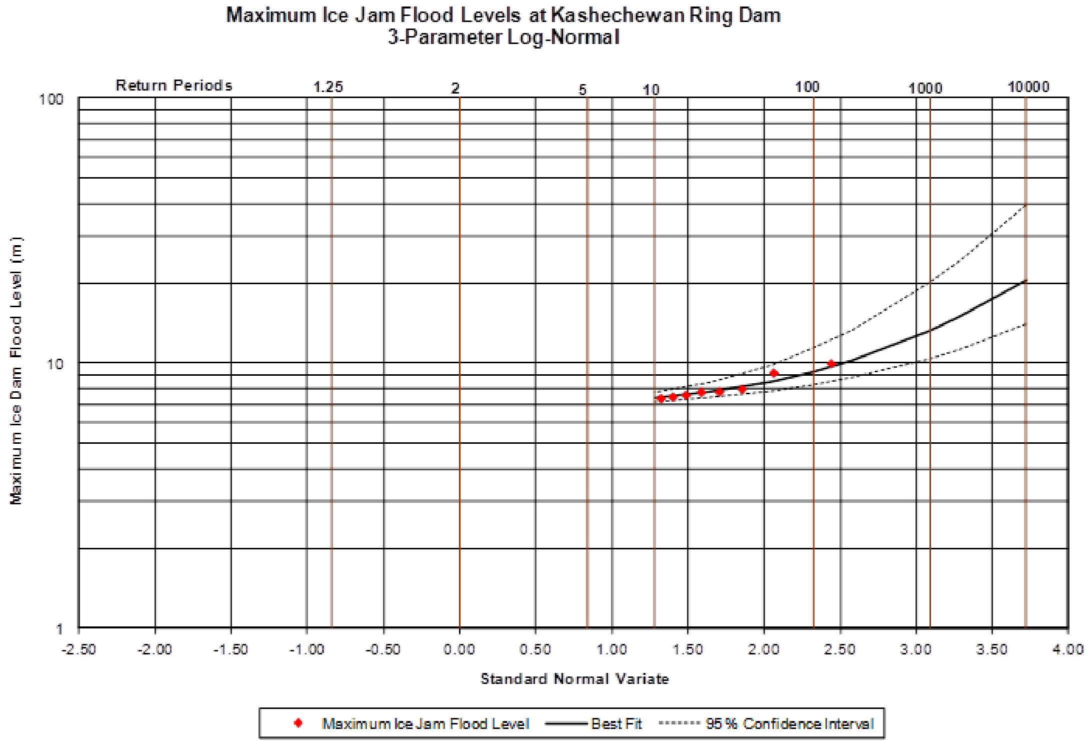

Figure 5-6: Frequency Analysis of Critical Ice Jam Flood Levels at the Ring Dyke

5.2.2.2 Probability of Embankment Failure due to Piping

The risk tool makes use of an empirical methodology developed by the University of New South Wales (UNSW) that is based on analysis of historic failures and accidents in embankment dams. Three piping failure modes are examined as summarized in Table 5-4.

Table 5-4: Piping Failure Modes

Mode	Probability of Failure
Within the Embankment	P_E
Within the Foundation	P_F
Between the Embankment and the Foundation	P_{EF}

The method accounts for the average historic frequency of failure embankment dams by mode of failure. These historical averages are then modified based the characteristics of the dam including factors such as dam zoning, filters, age of the dam, core soil types, compaction, foundation geology, performance, monitoring and surveillance.

The Kashechewan Ring Dyke has a calendar age of 18 years. However, it has experienced high water level events rarely and only for short periods of time (2 to 3 weeks per event) during this time period. Therefore, for the purposes of this assessment the effective age of the dyke is less than 5 years old in terms of actual Service Life. This is an important distinction when determining the risk of piping failure as it is the experience of the engineering community that dams with less than 5 years of service history are more than ten times to fail in this manner than older dams.

The Ring Dyke was constructed as a Homogeneous earth fill embankment without filters which is inherently more prone to piping than other embankment types. The dyke was found to have generally been constructed using well graded sand and gravels. The results of the geotechnical investigations indicates that the embankment was generally well compacted. However, there is a lack of construction records and it is known that the level construction control and supervision was modest at best. In addition the embankment has a number of drainage conduits that pass through it. These conduits constitute a known risk for piping failure. Given the lack of drawings and construction records, it is prudent to assume that these conduits were not installed to highest design standards without such risk mitigation measures as seepage collars.

It is known that the dyke was constructed on the native soil without a cut-off trench or preparation of the subgrade as evidenced by the peat that was encountered beneath the embankment in the borings. This lack of proper site preparation also increases the likelihood of a piping failure occurring as the water pressure may move the foundation material under the embankment over time.

This dyke has been reported to have seepage and some sand boils that occur during high water events which may be an indication of future piping failure in these areas. There is no documented formal inspection program nor any functioning monitoring devices or routine maintenance program for this embankment. Therefore, there is no mechanism to identify signs of distress and undertake remedial action before a critical condition is reached.

The combination of an inherently vulnerable embankment constructed on an unprepared and weak foundation, without a monitoring and response system, combine to make this site vulnerable to a piping with a probability of occurrence of 4.5 x 10-2 or an annual frequency of about 1:22 years. The probability of the river level reaching elevation 9.6 m, (i.e., the design elevation of one meter below crest level that would result in inundation of the community in the event of a piping or slope failure) was estimated to be 8.4 x 10-3 equivalent to an annual probability of occurrence of 1:120 years.

The overall probability of piping failure when the river has staged to the design level as a result of an ice jam is estimated to be 3.8 x 10-5 or about an annual probability of occurrence of 1:2,600 years.

5.2.2.3 Probability of Embankment Slope Failure During an Ice Jam Flood

Research in 2008 (T.W Lambe et al) provided a method to correlate failure probability to the calculated factor of safety modified by factors that account for the quality of the embankment slope. This quality is based on three main factors

- the quality of the design, including the amount of investigations, testing and analysis performed
- the quality of the construction of the structure
- the level of monitoring performed.

Each factor is assessed on a number of characteristics and assigned a weighting factor that is used to adjust average failure probabilities for embankment dams in order to estimate a failure probability specific to the Kashechewan Dyke.

The Kashechewan Ring Dyke has a number of high risk factors including poor records of the design and a lack of investigation data and analyses used to support the design, poor quality control during the construction and a lack of maintenance and operational reaction to the deteriorating condition of the dyke. The investigations that were performed reduces the risk as does the post-construction analysis that was performed using this data. However, there is some doubt that the computed Factors of Safety is fully representative of the whole site due to the variability in the construction, the existence of zones of silty clays and the lack of quality documentation. On the basis of these observations the probability of slope failure was determined to be1.2 x 10-2 or about 1:80 years.

Given the previously stated probability of occurrence of river levels staging to el. 9.6m where inundation would occur in the event of a slope failure of, the probability overall probability of a slope failure during a period in which water levels have risen to el. 9.6 was determined to be roughly 1 x 10-4 equivalent to an annual probability of occurrence of about 1:10,000 years.

5.2.2.4 Probability of Embankment Slope Failure during an Earthquake Event

The probability of slope failure is the same for slope failure under earthquake loading as as described above. In this instance, failure is assumed to initiate when the design earthquake (in this case 1:2500) is exceeded. Therefore, the overall probability of failure due to an earthquake is estimated to be negligible at 5 x 10-6 equivalent to an annual probability of occurrence of 1:200,000 years. In this case, inundation of the community would not occur. However, it is possible that a dwelling near the dyke could be buried.

5.2.2.5 Overall Probability of Failure of the Kashechewan Ring Dyke

The probabilities of failure due to piping or slope failure modes, combined with the probability of reaching elevation 9.6 m are shown in Table 5-5 along with the probability of failure due the overtopping and the probability of slope failure due to earthquake loadings.

Table 5-5: Estimated Probabilities of Ring Dyke Failure due to Ice Jam Floods

Failure Mode	Overtopping	Piping	Seismic	Stability	Total
Probability of initiating event.	3.64E-03	8.40E-03	4.00E-04	8.40E-03	
Probability of failure under the initiating event.	3.64E-03	4.49E-02	1.24E-02	1.24E-02	
Probability of not evacuating.	1/10	1	1	1	
Probability of Failure	3.64E-04	3.77E-04	4.94E-06	1.04E-04	8.49E-04
Annual probability of occurrence.	2,747	2,654	202,500	9,643	1,177

On this basis, the overall combined probability of failure for the Ring Dyke is estimated to be in the order of 5 x 10-4 or about 1:2,000 years.

5.2.3 Step 3: Consequence Analysis

The primary consequences of a dam failure are life safety risks within the population at risk (PAR) and economic losses. In this case it is clear that the population at risk is the primary consideration. Therefore, the risk assessment focused on this issue. The Kashechewan First Nation Community has a population approaching 2000. If the ring dyke were to fail without evacuating the community the life safety risks are estimated on the basis of the '2 x 2' rule (any combination of water depth in feet multiplied by flood velocity in feet/sec that equals 4) as mandated under Ontario's Lakes and Rivers Improvement Act. Within the Kashechewan community the population at risk varies depending on the failure mode considered.

For the overtopping mode of failure the inundation level would exceed el. 10.6 m flooding the entire community by 1.6 to 3.6 m of water. The Ontario Provincial Dam Safety Guidelines would indicate under such conditions the entire community of 2000 persons would be affected. If it is assumed that there would be some foreknowledge of the possibility of the overtopping event occurring it is considered reasonable to assume that there could be a life safety risk to as many as 20 persons (1% of the population) if evacuation was not undertaken in time.

For the piping mode of failure and the embankment slope failure during the design flood level, water levels have been assumed to be at el 9.6 m meaning that failure would result in inundation of the community by 2.6 to 0.6 m with limited warning time. In this case, also assuming a 70% occupancy and the unexpected nature of the failure mode but assuming that a that portion of the community would be at reduced risk due to the limited depth of flooding, a life safety risk to as many as 100 persons (5% of the community) has been assumed. For the embankment slope failure mode under the effects of an earthquake, it was assumed that an individual dwelling could be buried with little or no warning time. In this case, it was assumed four persons could be buried.

5.2.4 *Step 4: Risk Evaluation*

With probabilities of failure calculated for each of the components of the dam for various potential failure modes and the consequences of those failures determined (as described in Step 3), the overall risk of the Kashechewan Ring Dyke was evaluated. The results are summarized in Table 5-6.

Table 5-6: Summary of Results of Risk Assessment

Failure Mode	Overtopping	Piping	Seismic	Stability	Total
Probability of Failure	3.64E-04	3.77E-04	4.96E-06	1.04E-04	8.50E-04
Consequence (Life Safety Risk)	20	100	4	100	

A comparison of the currently estimated risk profile for the Kashechewan Dyke in comparison with tolerability limits as defined by in the CDA Dam Safety Guidelines is shown in Figure 5-7.

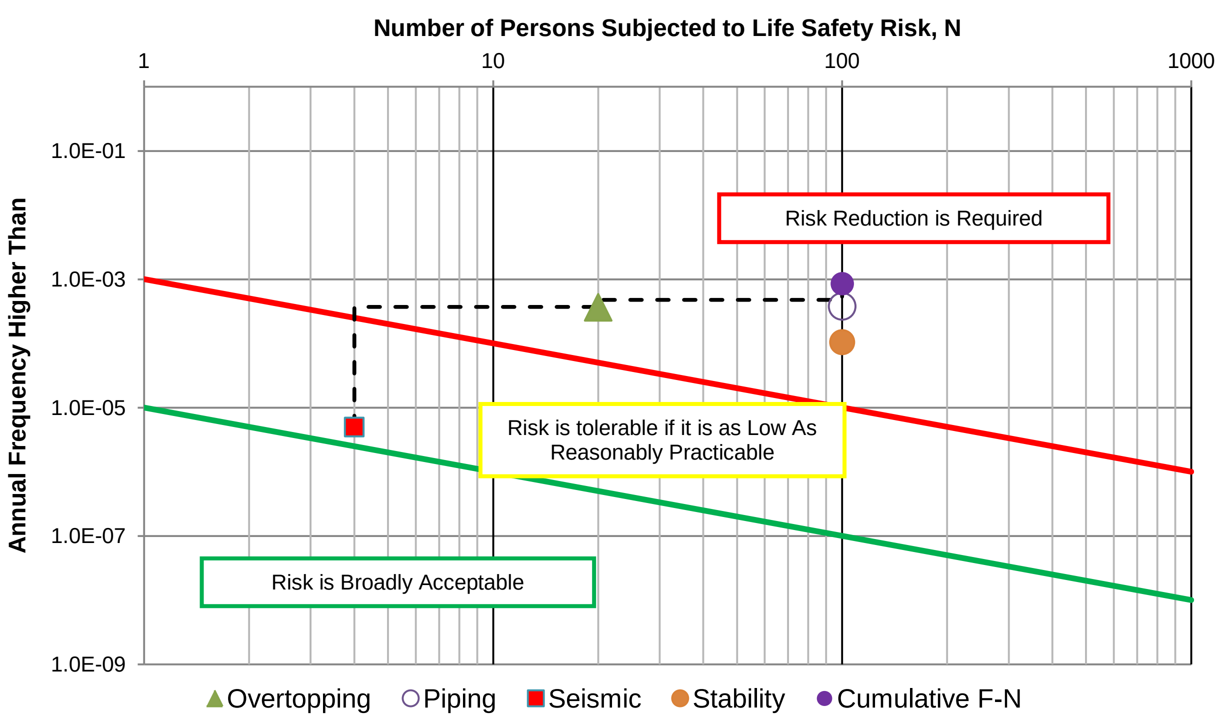

Figure 5-7: Life Safety Risks Presented by the Kashechewan Ring Dyke Compared with CDA Dam Life Safety Risk Tolerability Criteria

The results clearly indicate that the risk control measures currently in place at the Kashechewan Ring Dyke are do not meet modern standards for dam safety.

5.3 Risk Reduction for the Kashechewan Ring Dyke

An evaluation was performed to determine what risks the Ring Dyke would present if modern concepts for dam safety were implemented and the identified remedial works programs were carried out. This would be effective in reducing all risks with the exception of overtopping.

To reduce the risk of overtopping, a rough estimate of the amount the dyke would need to be raised to reduce the probability of occurrence of overtopping to about 1:10,000 was determined to be in the order of 5 to 10m. This would not represent a practical solution for the community for a variety of reasons.

As an alternative, if the probability of not evacuating the community could be reduced to about 1:1,000, as detailed in Table 5.7 and as summarized in Figure 5.8 risks could be reduced to within the CDA's tolerable zone. This points to the need for highly effective flood forecasting making use of the available decision support systems and upgraded tools to permit accurate data collection along the Albany River to ensure at least two weeks warning is available with a high degree of assurance.

Table 5-7: Summary of Risks Associated with the Kashechewan Ring Dyke After Remediation, Implementation of a Dam Safety Management Program and Implementation of Measures to Ensure Evacuation is Achieved

Failure Mode	Hydrologic	Piping	Seismic	Stability	Total
Probability of initiating event	3.6E-03	8.4E-03	4.0E-04	8.4E-03	
Probability of failure under the initiating event	1	6.2E-04	8.8E-05	8.8E-05	
Probability of not evacuating	1.0E-03	1	1	1	
Probability of failure	3.6E-06	5.2E-06	3.5E-08	7.4E-07	9.6E-06
Consequence (Life Safety Risk)	20	100	4	100	

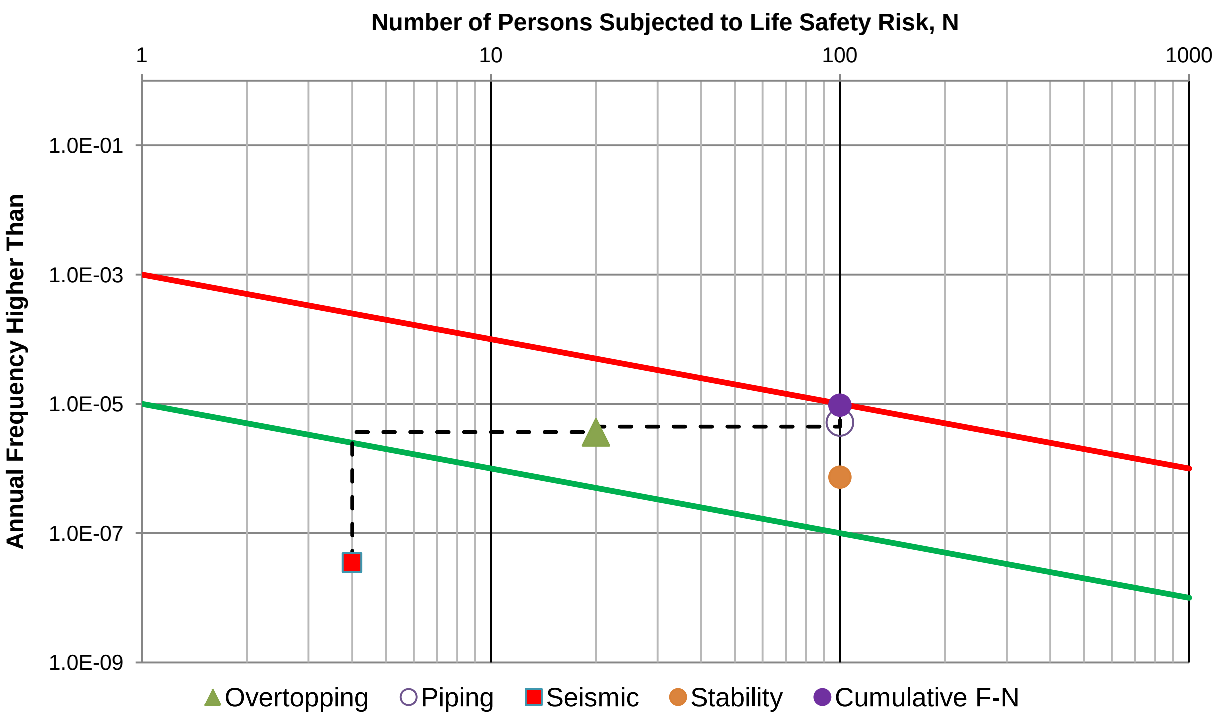

Figure 5-8: Life Safety Risks Presented by the Kashechewan Ring Dyke Compared with CDA Dam Life Safety Risk Tolerability Criteria after recommended Risk Mitigation Measures are Implemented

6. Conclusions

The Kashechewan Ring Dyke is in a deteriorating condition. The practices used to maintain the dyke are not in compliance with the Canadian Dam Association (CDA) or the Province of Ontario Dam Safety Guidelines and recommended best practices. Based on an assessment of the available information, the Dam Safety Management and Operations and Maintenance practices currently employed at the Kashechewan Ring Dyke were found to be compliant with only four of the eighteen Canadian Dam Association Guiding Principles for Dam Safety, have low to moderate compliance with 6 of the Principles and are non-compliant with 8.

An assessment of the Ring Dyke, in its present condition, with the current state of Dam Safety Management exercised, the limited assessments that have been performed for the dyke and the limited data available indicates that the Dyke presents an **INTOLERABLE** risk (as defined by the CDA) to the community in terms of overtopping, slope stability and piping risks.

While such an analysis is beyond the scope of this study, it is anticipated that the identified dam safety risks could be reduced to tolerable levels through the introduction of a modern Dam Safety Management System, upgrading of data collection for use in flood forecasting and the performance of identified remedial works program in order to comply with the CDA Guiding Principles.

Appendix A
CDA Dam Safety Classification

Dam Class	Population at Risk [Note 1]	Incremental Losses		
		Loss of Life [Note 2]	**Environmental and Cultural Values**	**Infrastructure and Economics**
Low	None	0	Minimal short-term loss No long-term loss	Low economic losses; area contains limited infrastructure or services.
Significant	Temporary Only	Unspecified	No significant loss or deterioration of fish or wildlife habitat. Loss of marginal habitat only. Restoration or compensation in kind highly possible.	Losses to recreational facilities, seasonal workplaces and infrequently used transportation routes.
High	Permanent	10 or fewer	Significant loss or deterioration of important fish or wildlife habitat. Restoration or compensation in kind highly possible.	High economic losses affecting infrastructure, public transpiration and commercial facilities.
Very High	Permanent	100 or fewer	Significant loss or deterioration of critical fish or wildlife habitat. Restoration or compensation in kind possible but impractical.	Very high economic losses affecting important infrastructure or services (e.g. highway, industrial facility, storage facilities for dangerous substances).
Extreme	Permanent	More than 100	Major loss of critical fish or wildlife habitat. Restoration or compensation in kind impossible.	Extreme losses affecting critical infrastructure or services (e.g. hospital, major industrial complex, major storage facilities for dangerous substances).

[1] Definitions for population at risk:
None – There is no identifiable population at risk, so there is no possibility of loss of life other than through unforeseeable misadventure.
Temporary – People are only temporarily in the dam-breach inundation zone (e.g. seasonal cottage use, passing through on transportation routes, participating in recreational activities).
Permanent – The population at risk is ordinarily located in the dam-breach inundation zone (e.g. as permanent residents); three consequence classes (high, very high, extreme) are proposed to allow for more detailed estimates of potential loss of life (to assist in decision-making if the appropriate analysis is carried out).
[2] Implications for Loss of life:
Unspecified – The appropriate level of safety required at a dam where people are temporarily at risk depends on the number of people, the exposure time, the nature of their activity, and other conditions. A higher class could be appropriate, depending on the requirements. However, the design flood requirement, for example, might not be higher if the temporary population is not likely to be present during the flood season.

Appendix B
Technical Papers

CDA 2013 Annual Conference
Congrès annuel 2013 de l'ACB
Montréal, Québec
October 5-10, 2013
Du 5 au 10 octobre 2013

A DESCRIPTION OF THE DEVELOPMENT AND APPLICATION OF A NEW QUANTITATIVE DAM SAFETY RISK ASSESSMENT TOOL

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Rebecca Crosthwait[ix], P.Eng, Hatch, Ontario, Canada

ABSTRACT:

In a traditional risk analysis, failure probability for a given component and the interdependencies across component boundaries are established on the basis of a subjective and qualitative analysis relying heavily on the experience and judgment of the investigators. This results in the quality of the analysis being subject to factors which can neither be measured nor quantified. In order to reduce the reliance of this method and the often-speculative selection of input parameters, a unique quantitative risk assessment tool has been developed that makes use of peer reviewed, scientific and transparent methods for estimating the probability of occurrence of the various events that can lead to a dam failure.

This paper focuses on a description of this new dam safety tool and an example application of the methodology for a dam located in Northern Ontario. The results of the assessment show the effectiveness of risk informed approaches in minimizing dam safety risks.

RÉSUMÉ:

Dans une analyse de risque traditionnelle, la probabilité de défaillance d'un composant donné et les interdépendances à travers les frontières des composants sont établies sur la base d'une analyse subjective et qualitative, en s'appuyant fortement sur l'expérience et le jugement des enquêteurs. La qualité de l'analyse dépend par conséquent de facteurs qui ne peuvent être mesurés ou quantifiés. Afin de réduire la subjectivité de cette méthode et la sélection souvent spéculative des paramètres d'entrée, un outil unique d'évaluation quantitative des risques a été développé sur la base de méthodes scientifiques et transparentes validées, permettant d'estimer la probabilité d'occurrence des différents événements qui peuvent conduire à une rupture de barrage.

Cet article décrit ce nouvel outil de sécurité des barrages et offre un exemple d'application de la méthodologie pour le cas d'un barrage situé dans le nord de l'Ontario. Les résultats de l'évaluation démontrent l'efficacité de l'approche basée sur l'évaluation des risques en minimisant les risques de sécurité des barrages.

1 INTRODUCTION

The most widely applied approach to dam safety management is the Standards Based Approach that is in fact a *de facto* management of risk throughout the life cycle of a water retaining system. This is achieved by defining and applying a deterministic set of principles, rules and requirements for the design and operation of the system that are intended to ensure a relatively high, but essentially unknown, level of safety. The expectation is that, if the prescribed requirements are satisfied, risk to the public will remain acceptably low. For this reason, conservatism in defining the safety requirements is necessary in order to attempt to account uncertainties that cannot be quantified explicitly. The drawback to this approach is that the assessments are potentially overly conservative, are confined to a select list of hazards that do not include all of the potential failure modes, and generally do not account for the possibility of coincident occurrence of hazards.

To enhance the safety of water retaining structures, formal risk assessment involving risk identification, risk analysis and risk evaluation is gaining favour. Its purpose is to provide evidence-based information and analysis in order to allow informed decisions to be made on how to treat particular risks and how to select between options (adopted from IEC/ISO 31010). Some of the major benefits of performing risk assessment include:

- a better understanding of the risk and its potential impact is obtained
- additional information is provided to decision-making process
- the selection of remedial treatment options, tailored to risk reduction, is better facilitated
- priorities are better understood.

The results of a risk assessment can, therefore, contribute to effective dam safety management by quantifying:

- the factors contributing the greatest risk at a given site
- the facilities with the greatest risk
- what additional analyses and/or data collection are needed to better understand critical uncertainties
- the anticipated risk reduction effectiveness (including interim measures) of alternative courses of action
- allocation of resources that will contribute the greatest overall risk reduction.

The overall objective of using risk assessment as a tool for dam safety evaluation is to better identify the measures needed to eliminate intolerable risks *as soon as reasonably practicable* (adapted from NSW DSC, 2010). In engineering applications risk is usually defined as being a combination of the probability of an event occurring and the adverse consequences of that event. If this combination is expressed as the product of probability and consequences, it represents the probabilistic expectation of the consequences. The difficulty associated with the performance of quantitative risk assessment lies in the fact that there is no universally accepted comprehensive, scientific and transparent method for estimating the probability of occurrence of various events that can lead to a dam failure. It is also difficult to estimate the incremental consequences associated with potential failure modes.

In this paper, a methodology for establishing the probability of occurrence of key dam safety failure modes is presented and examples of its use described.

2 DEFINING RISK CRITERIA FOR DAM SAFETY RISK ASSESSMENTS

The first step in developing a quantitative risk assessment process is to establish the criteria under which the assessments are to be performed.

2.1 Equity and Efficiency

Risk criteria are derived on the basis of two fundamental principles as described in ICOLD (2005):

- Equity: The right of individuals and society to be protected such that the interests of all are treated with fairness with the goal of placing all members of society on an essentially equal footing in terms of levels of the risk that they face. This requires that risks to both individuals and groups of individuals (societal risk) be below certain maximum tolerable thresholds.
- Efficiency: The need for society to distribute and use available resources so as to achieve the greatest benefit. This requires defining a level of risk where the marginal benefits equal or exceed the marginal cost.

In the application of these principles there are, therefore, conflicting priorities due to the fact that equity requires that a tolerable risk limit be met even if efficiency does not support the costs of achieving this goal. In a quantitative risk assessment there is, therefore, a need to define an appropriate balance between equity and efficiency in the development of tolerable risk thresholds.

2.2 Risk Tolerability

In general, society is more averse to risks if multiple fatalities occur as a result of a single event. This impacts society as a whole creating a socio-political response. In contrast, society tends to be less averse to risks that result from many individual small loss accidents involving only one or two fatalities, even if the total loss from the sum of all of the small loss accidents is larger than that from the single large loss accident. This leads to the notion that tolerable risk should consider both societal and individual risks as an integral part of the framework for managing risks (Munger et al, 2009).

The matter of tolerability of risk to individuals and society has received attention by regulators in the United Kingdom and the Netherlands with respect to water retaining structures. It has also been of interest to dam safety regulators in Australia and to the US Bureau of Reclamation and US Army Corps of Engineers. The tolerability of risk is fundamentally a matter of political choices, preferences, and policies. The emerging, although not universally accepted, view is that risk and uncertainty are fundamental factors that have to be considered when making dam safety decisions.

Individual life safety risk criteria

The individual life safety risk is represented by the probability of incremental loss of life (ILOL) for a person defined by a location that is most at risk (Munger et al, 2009). This is combined over all modes of failure with due regard for non-mutually exclusive failure modes. The tolerability thresholds embedded in the tool are detailed in Figure 1.

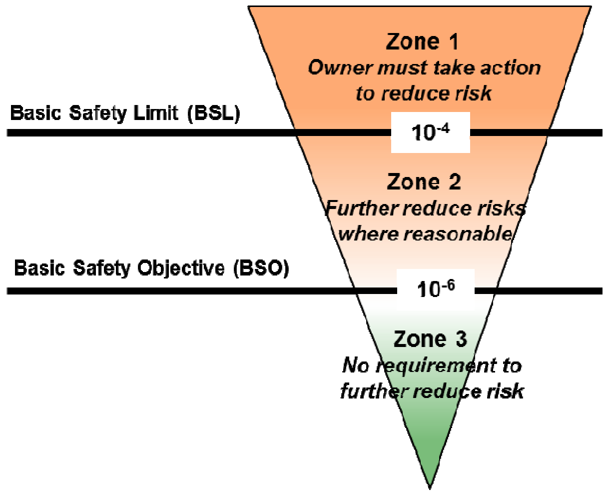

Figure 1: Individual Risk Tolerability Criteria

Societal life safety risk tolerability

Societal life safety risk is expressed in two different ways – a probability distribution of potential incremental loss of life (ILOL) and annualized incremental life loss. The societal tolerance for risk varies depending on the numbers of persons exposed as detailed in Figure 2.

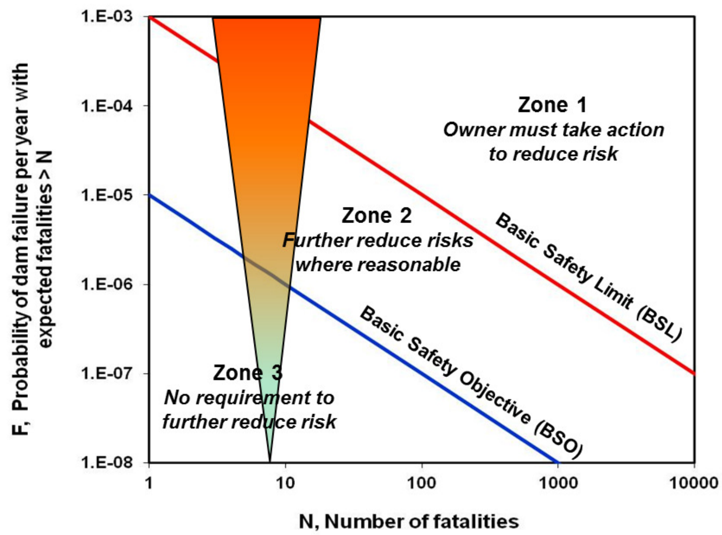

Figure 2: Societal Risk Criteria

Economic Risk Tolerability

The economic risk thresholds embedded in the tool are outlined in Figure 3, which shows the cumulative annualized probability of dam failure against direct third party incremental economic losses. The costs are in 2007 dollars with assessments performed by de-escalating the actual estimated costs to this baseline.

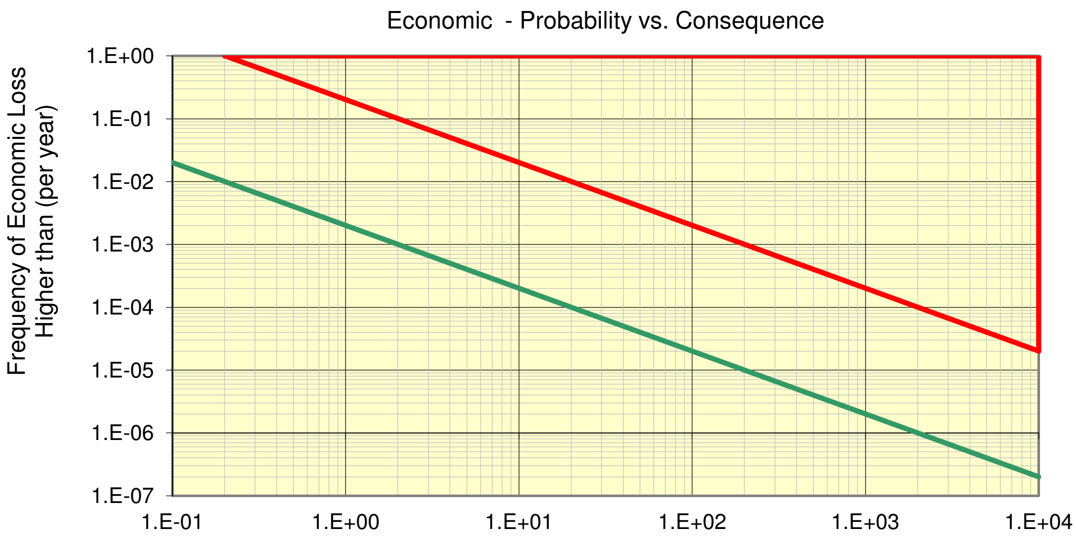

Figure 3: Economic Risk Diagram

2.3 Environmental and Other Non-Monetary Risk Tolerance

A dam failure can have direct and indirect consequences that cannot be measured in monetary terms. These stem the both the dam failure impacts and the loss of the dam's reservoir on environmental, cultural, and historic resources. At this time the tool does not include risk assessment criteria for demonstrating that these interests have been adequately protected in the selection of risk reduction measures.

2.4 "As-Low-As-Reasonably-Practicable"

The concept of "as-low-as-reasonably-practicable" (ALARP) is based on legal principles originally developed in the United Kingdom that aim at controlling the level of risk associated with a hazardous activity. it is an explicit consideration under ANCOLD (2003) and NSW DSC (2010) tolerable risk guidelines.

The principles provide a way to address the efficiency aspects in both individual and societal tolerable risk evaluations. It only has meaning in evaluating risk reduction measures: The concept for the use of ALARP considerations is that risks between the Basic Safety Limit and Basic Safety Objective are tolerable only if further risk reduction is impracticable or if the cost is grossly disproportionate to the risk reduction. The concept of gross disproportion as applied in ALARP considerations implies that a simple cost benefit analysis is insufficient and the analysis should be progressively weighted to favour carrying out the safety improvement as the risk increases from almost negligible to virtually intolerable.

Application of the ALARP principle requires:

- Comparison of benefits (avoided loss of life) and costs related to considered risk reduction measure (upgrade option);Consideration of any relevant and recognized good practice
- Consideration of relevant societal concerns.

2.5 Definition of the Cost of Risk Reduction

Within the risk tool the annualized value (C_A) of the capital cost (C) of risk reduction option is calculated using the following formula:

$$C_A = (C \times r) \times (1 + r)^n / [(1 + r)^n - 1]$$

n=number of years over which the cost is annualized
r = discount rate
C = capital cost of the upgrade in $M 2007
The total annualized cost is the sum of C_A and the annual operating cost of the risk reduction option.

2.6 Definition of the Benefits of Risk Reduction

The benefits realized from implementation of considered upgrade option are calculated as expected annual avoided incremental loss of life using the following formula:

$$B = [(N_b \times P_b) - (N_a \times P_a)] \times VPF$$

N_b = number of potential fatalities before the upgrade
N_a = number of potential fatalities after the upgrade
P_b = cumulative failure probability before the upgrade
P_a = cumulative failure probability after the upgrade
VPF = Value of Preventing Fatality

Discount Rate

The discount rate is used to reduce the capital cost of the remedial measure to an annual cost that can be compared with the annual reduction in risk.

The term discount rate refers to the time value of the costs and benefits from the viewpoint of society. It is similar to the concept of the private opportunity cost of capital used to discount a stream of net cash flows of an investment project, but the implications can be more complex.

Choosing a discount rate can be a contentious aspect of the cost-benefit analysis that involves the interpretation of regulatory policies (TBCS, 2007). The Treasury Board of Canada Secretariat (TBCS) has developed guidelines for the selection of discount rates for use in performing cost-benefit analysis to support regulatory decisions (TBCS, 2007). Based on the results of Canadian-specific research, TBCS recommends that a “real rate” of 8% be used as the discount rate for the evaluation of regulatory interventions in Canada. However, where cost-benefit analysis includes consider of factors other than the economic opportunity cost of funds, some federal departments, governments and international organizations have chosen to apply a “social discount rate” which are lower than the 8% recommended by TBCS. In these circumstances, the literature compiled by TBCS suggests using a social discount rate of 3%, recognizing there is still controversy in the literature on the use of these social discount rates and further guidance will be needed in the future.

Within the risk tool a social discount rate of 3% is used when assessing the benefits of adopting further risk control measures to reduce risk of ILOL. Where there is no risk of ILOL, a discount rate of 8% is used.

Whatever rate is used, the costs and benefits should be discounted to the same year using the same desecration factors.

Value of Preventing Fatalities

Reports developed by the HSE (2001) note that this useful concept is often misrepresented. It is often misunderstood as to mean that a value is being placed on a life. It is actually another way of expressing what people are prepared to pay to secure a certain averaged risk reduction. For example, a VPF of $1,000,000 corresponds to a reduction in risk of 1 in 100,000 as being worth about $10 to an average individual. It should not to be confused with the value society might put on the life of a real person or the compensation appropriate for the loss of an individual life. The intention of defining the value of preventing fatality (VPF) is to provide a means of reflecting the marginal change in risk level for a large number of individuals but not for specific, identified individuals.

For the risk tool a VPF of C$6.7 million (in 2007 dollars) was selected based on recommendations in other jurisdictions in Canada (TC, 1994), (TBCS, 2007), (PRI, 2009) and (HC, 2010).

Disproportionality and Costs/Benefit Assessment

The original HSE guidance recommended that the disproportionality factor (D) range from 10 at the BSL target to 3 at the BSO target. In the risk tool the disproportionality factor at the BSL target was selected as 10, However, the BSO target was set equal to 1. The rational for this reduction was to be consistent with the understanding that further reduction of risks which are at or below the BSO target are justifiable on the basis of strict cost-benefit analysis.

Between these two target lines the disproportionality factor is calculated in accordance with the following formula to weight the benefits based on the number of expected fatalities and the probability of failure implementation of any dam safety risk reduction measures.

$$D = 1 + [(N_b \text{ x } P_b)\ 10^{-5}] / (1.1 \text{ x } 10^{-4})$$

Where; Nb = the number of potential persons subjected to a life safety risk
Pb = the probability of failure before implementation of a risk reduction measure

Comparison of the costs and the benefits (weighted by the disproportionality factor) is performed by calculating the following ratio, R:

$$R = (D \text{ x } B)/C_A$$

If the ratio is greater than 1 then the option should be implemented. If the ratio is less than one and no other options are available the risk is considered to be ALARP. In all cases, when comparing costs and benefits the value of costs and benefits must be evaluated on the same basis. In the Risk Assessment tool all benefits and the costs of implementing risk reduction measures are in ear 2007 dollars making usage of Stats Canada cost indices.

3 RISK ASSESSMENT METHODOLOGY

The methodology for completing a risk assessment comprises the following five (5) steps:
Step 1: Selection of Project Components and Associated Failure Modes
Step 2: Assessment of Failure Probabilities
Step 3: Consequence Analysis
Step 4: Risk Evaluation
Step 5: Evaluation of Remedial Measures

3.1 Step 1: Selection of Project Components and Associated Failure Modes

Depending on the nature of the facility being assessed, the probability of failure of following components and failure modes can be assessed within the tool:

- Overtopping of dam
  - Failure of flow control equipment to operate
  - Failure caused by insufficient discharge capacity to pass flood event
- Embankment dam
  - Internal erosion (piping)
  - Slope instability

- Concrete dam section
    - Sliding
- Structural failure of a spillway gate or stoplogs
- Penstock failure.

3.2 Step 2: Assessment of Failure Probability

The reasons for a dam to fail have been studied by numerous authors. In 1975 a study performed by ASCE/USCOLD showed that there were four general causes of dam failure as depicted in Figure 3-1.

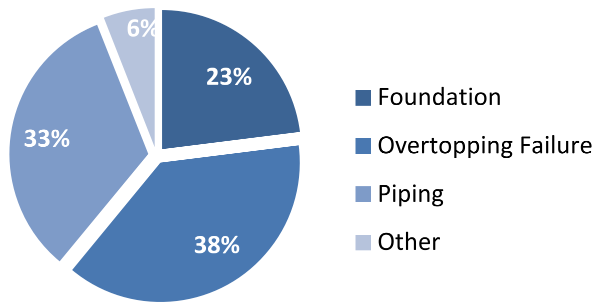

Figure 4: Causes of Dam Failure (Source: ASCE/USCOLD, 1975

As described in Table 1, the risk assessment tool evaluates the probability of failure for these key failure modes using a variety of proven methodologies.

Table 1: Basis of the Probability Estimates

Module	Description	Basis of Estimate	Remarks
1	Failure of Gate to Open	Expert Judgement	38% of Failures
	Potential for Overtopping	Standard Hydrotechnical Statistical Analysis	
	PMF Analysis	Statistical Assessments	
2	Embankment Dam Piping	*Empirical Analysis*	33% of Failures
3	Embankment Dam Slope Stability	*Empirical Analysis*	Part of 23% of Failures
4	Concrete Dam Sliding	Mathematical analysis using the Capacity-Demand methodology	
5	Gate Failure	Mathematical analysis using the Capacity-Demand methodology	Part of 8% of all Failures
6	Penstock Failure		

Probability of Overtopping Failure

The tool allows for the assessment of weirs, gates and stoplogs accounting for the variability of each of these components in passing flood events. For example, weirs can only be in one state (free overflow), gates could be open or fail to operate while the capacity of a stoplog structure depends on the number of logs that can be reliability removed.

Flood frequency analyses are performed to determine the required discharge capacities for various flood recurrence intervals with conditions during spring flood and non-spring flood events assessed separately. The maximum amount of overtopping that can be tolerated without causing the dam to fail depends on the configuration of the structure and the ability of individual components to withstand the overtopping. The water level associated with the maximum tolerable amount is defined as the Failure Threshold Water Level (FTWL). The concept of the FTWL for a typical composite dam as defined within the tool is shown in Figure 5.

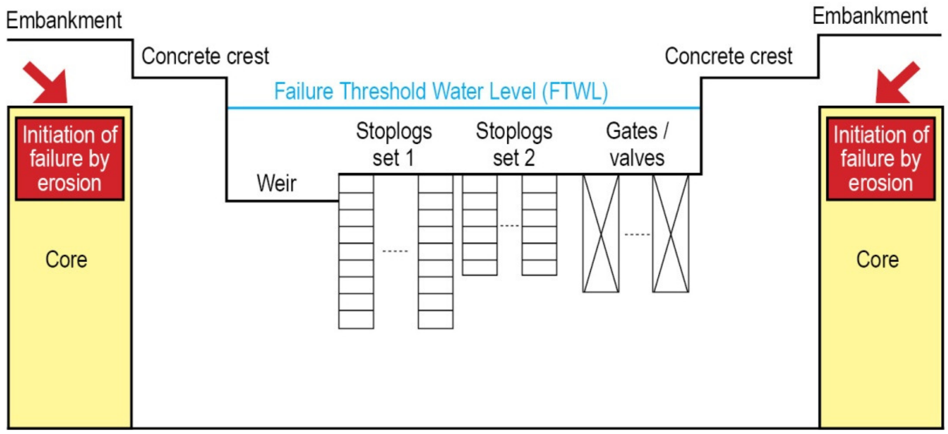

Figure 5: FTWL for a Composite Dam with Impervious Core < Dam Height

The approach taken to determine the conditional probabilities of overtopping failures involves the availability of one or all gates and one or all stoplog sluices and their state (open or closed) at the FTWL, taking into account the following aspects:

- Weir flow calculations are usually based on the maximum water level for the dam. If the FTWL is higher than the crest of the concrete dam, the flow over the dam up to the FTWL is included
- Spillway gate facilities must take into account discharge capacities over the top of the gates for conditions at the FTWL with all gates closed, as well as at the top of the gate and at the FTWL with all gates open
- Stoplog sluice discharges are handled in a similar manner as spillway gate facilities, but with the additional consideration of partly available openings due to prior winter or summer settings
- For each combination of the season, the type of discharge structure and the probability of availability the following calculations are then conducted:
    - available discharge capacity at the FTWL
    - return period of this capacity
    - probability of exceeding the FTWL.

The aggregate probability due to overtopping of all combinations of season and discharge structure availability is then determined.

Failure of Flow Control Equipment to Operate
Within the tool the probability of failure of flow control equipment to operate is assessed accounting for factors as:

- the number, type, age, condition and maintenance of the flow control equipment
- the type, age, condition and maintenance of the hoist
- a qualitative assessment of debris accumulated against the gate

- any recent testing information
- adequacy of power controls: redundancy, automation, etc
- adequacy of icing control
- structural adequacy (design checks for hoists and gate support).

The probability of a gate failing to opertate is then used to calculate the overall probability of overtopping failure.

Probability of Embankment Failure due to Piping
The tool makes use of an empirical methodology developed by the University of New South Wales (UNSW) that is based on analysis of historic failures and accidents in embankment dams. Three piping failure modes are examined as summarised in Table 2.

Table 2: Piping Failure Modes

Mode	Probability of Failure
Within the Embankment	P_E
Within the Foundation	P_F
Between the Embankment and the Foundation	P_{EF}

The method accounts for the average historic frequency of failure embankment dams by mode of failure. These historical averages are then modified based the characteristics of the dam including factors such as dam zoning, filters, age of the dam, core soil types, compaction, foundation geology, performance, monitoring and surveillance.

Probability of Embankment Slope Failure
Research in 2008 (T.W Lambe et al) provided a method to correlate failure probability to the calculated factor of safety modified by factors that account for the quality of the embankment slope. This quality is based on three main factors:

- the quality of the design, including the amount of investigations, testing and analysis performed
- The quality of the construction of the structure
- The level of monitoring performed.

Each factor is assessed on a number of characteristics and assigned a weighting factor that is used to adjust average failure probabilities for embankment dams in order to estimate a failure probability specific to the structure under evaluation.

Probability of Concrete Gravity Dam Sliding Failure
The calculation of the probability of sliding failure is calculated using the Capacity-Demand analysis method in which probability of failure is defined when the resistance (C) is less than the demand (D) (Morgenroth et. al. 1998). The principle can be expressed as a Warner Diagram as shown in Figure 6.

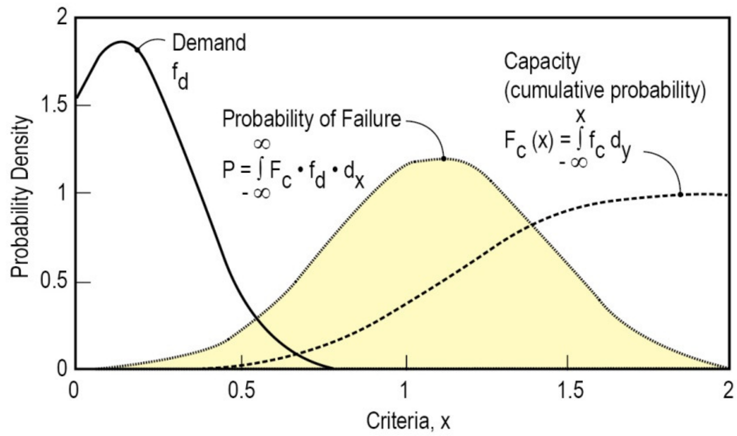

Figure 6: Warner Diagram

For any demand loading the probability of occurrence can be defined by a "probability density function" (pdf) of D; stated as di. For that loading level the probability that the resisting capacity is less than or equal to that demand loading (i.e., an unstable condition) is defined by the "cumulative probability function" (cpf) of C; stated as Ci. The probability of failure is given by the product of these two values integrated over the entire range of feasible loads. Mathematically, this is represented as:

POF = Σ di x Ci

The probability distributions of D and C are determined using the second moment method, which uses the Taylor series expansion to determine the mean and standard deviation of the random variables, which include head and tailwater levels, shear resistance, ice loadings, peak ground acceleration, uplift and the density of the concrete.

In general, all of these variables can be obtained from dam safety reports or selected on the basis of engineering judgement. Based on the mean and standard deviation of these variables, probability distributions can be determined and the overall probability of failure can be established.

Gate Structural failure and Penstock failure

The probability of occurrence of these types of failures is also assessed using the Capacity-Demand methodology as described previously.

The methodology accounts for uncertainty in such factors as the thickness of the skinplate, the spacing of stiffeners and headwater levels to establish a probability-density function. Similar to what was described for sliding failure of a concrete gravity dam, this probability density function is integrated with the cumulative probability function of capacity to yield the likelihood of failure.

3.3 Step 3: Consequence Analysis

The primary consequences of a dam failure are incremental loss of life (ILOL) within the population at risk (PAR), and third party economic losses. These two types of consequences are assessed quantitatively and separately with the results of this assessment inout into the tool to allow for the determination of risk.

3.4 Step 4: Risk Evaluation

With probabilities of failure calculated for each of the components of the dam for various potential failure modes and the consequences of those failures determined (as described in Step 3), the overall risk of the dam can be evaluated.

The first step in the risk evaluation is to prepare a risk table that combines the following aspects of the risk process for selected dam component structures:

- Component failure modes
- Probabilities of failure for each mode
- Failure consequences
  - Incremental loss of life
  - Incremental economic losses.

A typical example of the table is shown in Table 3. In this example, seven independent failure mechanisms associated with three dam component structures are shown. The tool generates the results of analysis that include failure modes, failure probabilities, incremental loss of life and incremental economic damages.

4 EXAMPLE APPLICATION

The new risk assessment tool was applied to six different existing dams owned by a representative sample of Ontario's dam owners in order to test the applicability of the tool and the principles embedded in the tool. The dams assessed included:

- three provincial dams owned by the OMNR
- one conservation authority dam owned by the Grand River Conservation Authority
- one dam used for industrial purpose owned by Vale and
- one dam owned by Brookfield Power, the province's largest Independent Power Producer.

Independently, Ontario's Provincial Utility, Ontario Power Generation, applied the tool to a number of their own facilities. An overview of one of the applications has been provided below.

Table 3: Typical Dam Failure Risk Table

Part 1: Failure Modes

Component			Seismic	Hydrologic	Piping	Slope		Mechanical	
Number	Name	Type				Sliding		Gate	Penstock
1	Main Dam	Concrete - Spillway Structure	Yes	Yes	No	Yes	No	No	No
2	Left Embankment	Embankment - Homogeneous Earthfil - Sheetpile face	Yes	Yes	Yes	No	Yes	No	No
3	Right Embankment	Embankment Homogeneous Earthfil Sheetpile face	Yes	Yes	Yes	No	Yes	No	No

Note: Manually enter names for the station components

Part 2: Probability of Failure

Component			Seismic	Hydrologic	Piping	Slope		Mechanical			
Number	Name	Type				Sliding	Embankment	Gate	Penstock		
1	Main Dam	Concrete - Spillway Structure	1.42E-05	1.10E-07		7.64E-04				7.78E-04	
2	Left Embankment	Embankment - Homogeneous Earthfil - Sheetpile face	2.80E-08	6.09E-05	5.00E-04		8.60E-06			5.70E-04	Total
3	Right Embankment	Embankment - Homogeneous Earthfil - Sheetpile face	2.80E-08	6.09E-05	5.00E-04		8.60E-06			5.70E-04	1.92E-03

Note: Manually transfer the probabilities to this table from workbooks completed for each component

Part 3: Consequence of Failure

Component			Flood			Normal		
Number	Name	Type	ILOL	Economic (Million $)	Environmental	ILOL	Economic (Million $)	Environmental
1	Main Dam	Concrete - Spillway Structure	0.32	0.6		6.6	12	
2	Left Embankment	Embankment - Homogeneous Earthfil - Sheetpile face	0.32	0.6		6.6	12	
3	Right Embankment	Embankment - Homogeneous Earthfil - Sheetpile face	0.32	0.6		6.6	12	

Note: Manually enter the consequences in this table

Part 4: Loss of Life Risk

Component			Seismic	Hydrologic	Piping	Stability		Mechanical			
Number	Name	Type				Sliding	Slope	Gate	Penstock		
1	Main Dam	Concrete - Spillway Structure	9.35E-05	3.52E-08		5.04E-03				5.14E-03	
2	Left Embankment	Embankment - Homogeneous Earthfil - Sheetpile face	1.85E-07	1.95E-05	3.30E-03		5.68E-05			3.38E-03	Total
3	Right Embankment	Embankment - Homogeneous Earthfil - Sheetpile face	1.85E-07	1.95E-05	3.30E-03		5.68E-05			3.38E-03	1.19E-02

Note: These cells are calculated by multiplying the probability of failure by the appropriate consequence. 'Flood' consequences apply to 'Hydrologic' failures only.

Part 5: Economic Risk

Component			Seismic	Hydrologic	Piping	Stability		Mechanical			
Number	Name	Type				Sliding	Slope	Gate	Penstock		
1	Main Dam	Concrete - Spillway Structure	1.70E-04	6.60E-08		9.17E-03				9.34E-03	
2	Left Embankment	Embankment Homogeneous Earthfil Sheetpile face	3.36E 07	3.65E 05	6.00E 03		1.03E 04			6.14E-03	Total
3	Right Embankment	Embankment - Homogeneous Earthfil - Sheetpile face	3.36E-07	3.65E-05	6.00E-03		1.03E-04			6.14E-03	3.35E-02

4.1 Study Dam

One example of the use of the tool was the MNR's Ivanhoe Lake Dam. This dam is located at the northeast outlet of Ivanhoe Lake on the Ivanhoe River watershed, Township of Ivanhoe, in the OMNR Chapleau District. The study dam was originally constructed as a original timber crib dam was constructed in 1918 with a new concrete gravity dam being constructed in 1962. after a flood breached part of an esker causing significant damages in the community of Foleyet. Following other dam breach events a new concrete gravity dam was constructed in 1962. This dam consists of seven spillway bays with earth embankments on either side. The structure is essentially unchanged since its original construction with no major upgrades performed since 1962.

The dam consists of a seven bay spillway approximately 10 m high and 42 m long flanked on either side by conventional embankments that abut onto a breached esker that formed as a result of glaciations during the Pleistocene Period and, more particularly, by the most recent ice recession about 11 000 years ago. Investigations carried out in 1961 showed that the foundation beneath the spillway and embankments consists of a highly permeable granular deposit composed of variable sands to coarse gravels with occasional cobbles and boulders that extends to depths of about 37m. The underlying bedrock is a low permeability Pre-Cambrian granitic formation with few fractures.

The embankments are zoned fill structures with a central impervious core zone consisting of a 1:1 mixture of clay silt or silt with fine sand supported by upstream and downstream shells composed of coarse sand and gravel. Foundation seepage control measures involved a hanging cutoff wall consisting of interlocked steel sheet piling.

A dam safety assessment performed in 2004 following a standards based approach identified the following dam safety deficiencies:

- Under Flood conditions, the spillway section was determined to be stable but did not meet standards with a Factor of Safety of 1.3 against sliding. The recommended solution was to provide additional resistance in the form of soil anchors
- The capacity of the spillway did not satisfy deterministic standards (the PMF)
- While the potential for piping was known, there were no outward signs of any piping related issues and no deterministic standards to satisfy. Therefore, no specific recommendations with respect to this potential hazard were made.

To assess the risks associated with the study dam the structure can be divided into three separate components, the Main Concrete Dam, and the Left/Right embankments. Failure modes consist of the following:

Embankment sections

- Slope Stability
- Piping
- Overtopping (including gate fails to operate)

Main Dam (Sluiceway)

- Sliding stability
- Overtopping (including gate fails to operate)
- Gate failure.

As a first step, the economic risks associated with the various failure modes that existed at the study dam were assessed. As is detailed in Figure 7, the results of this assessment placed the dam risks in the tolerable zone.

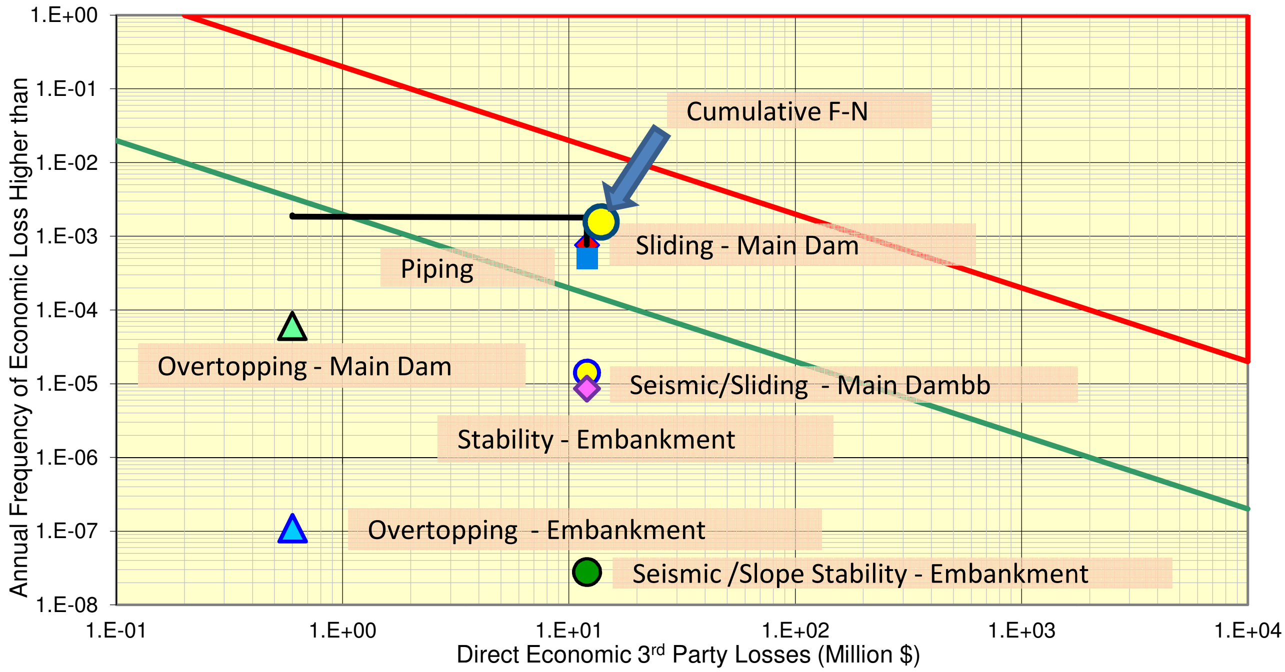

Figure 7: Results of the Economic Risk Assessment

In this example, as is evident from Figure 8, life safety risks placed the structure in the intolerable risk zone.

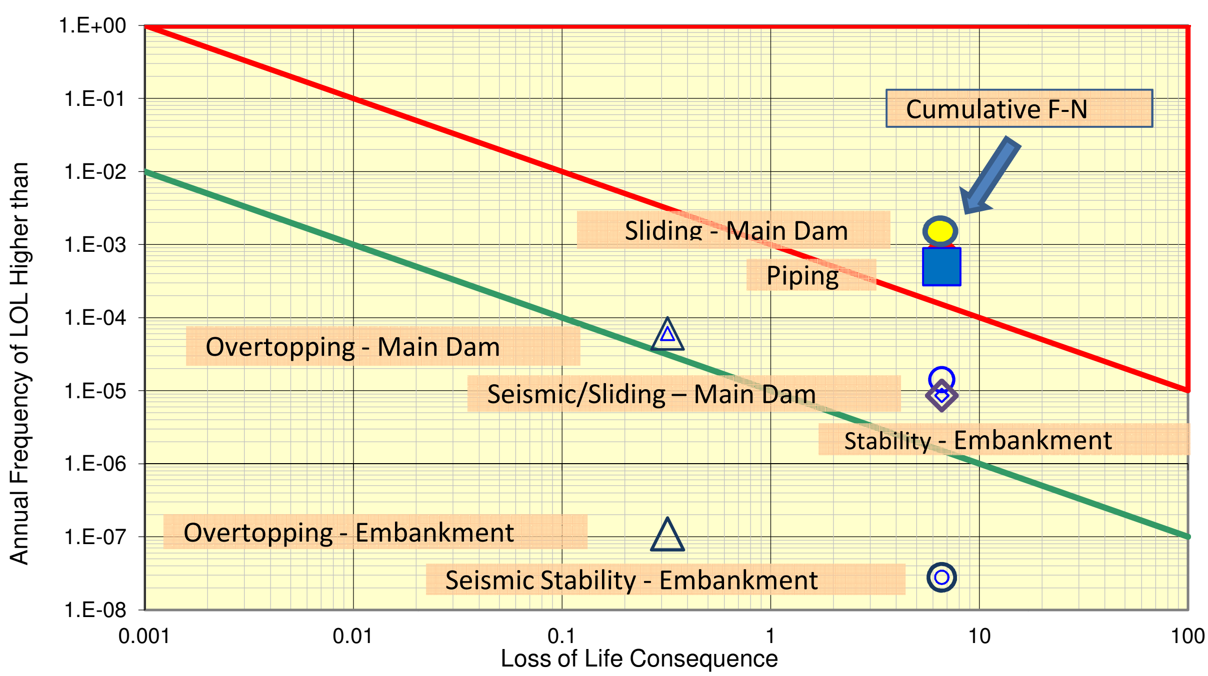

Figure 8: Results of Dam Life Safety Risk Assessment

If the risks indentified during the Standards Based Assessment are treated by means of soil anchors to enhance the stability of the concrete dam and additional flow capacity (gates) to allow the passage of the PMF risks are not reduced below the tolerable threshold (Figure 9). In this example it is clear that there are two risks that govern the safety of this dam, the potential for sliding instability (as evidenced by both the risk assessment and the low factor of safety) and the potential for piping. The potential for overtopping does present a risk, but even without any remediation the risk lies within the tolerable zone.

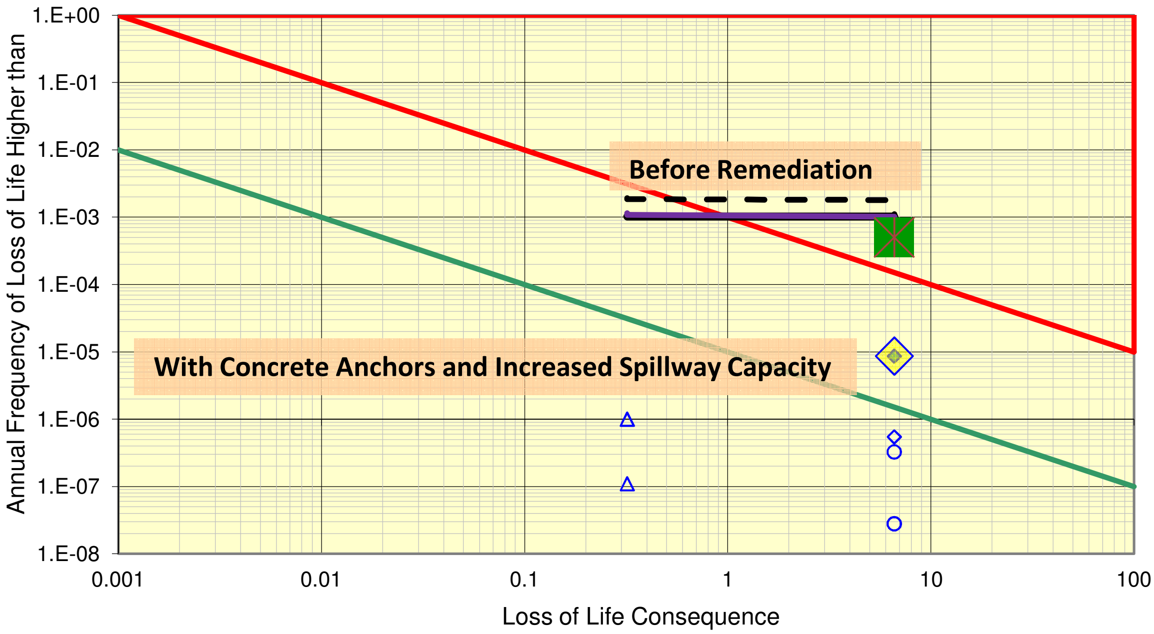

Figure 9: Results of Implementation of Measures to Reduce Overtopping and Stability Risks

It is clear, therefore, that implementation of remedial measures that reduce the overtopping risk without addressing the piping potential have no real impact on the overall risk that the dam presents to the public due to the fact that the piping risk remains. The tool was also used to assess the value of adding additional soil anchors to increase the factor of safety above 1.5 and thereby lower the risk for this failure mode. It was encouraging to note that this additional stability enhancement above commonly accepted standards for dam stability failed the ALARP test providing additional confidence that the tool is providing realistic estimates.

The tool was then used to test the effectiveness of dealing with the two primary failure modes, sliding and piping failure. Remedial measures consisted of the installation of soil anchors and the implementation of additional instrumentation and an enhanced dam safety monitoring program to better identify any signs that piping was occurring.

The results, as shown in Figure 10, the results clearly showed that dealing with the major failure modes provides a cost effective means of dealing with the key risks associated with this dam.

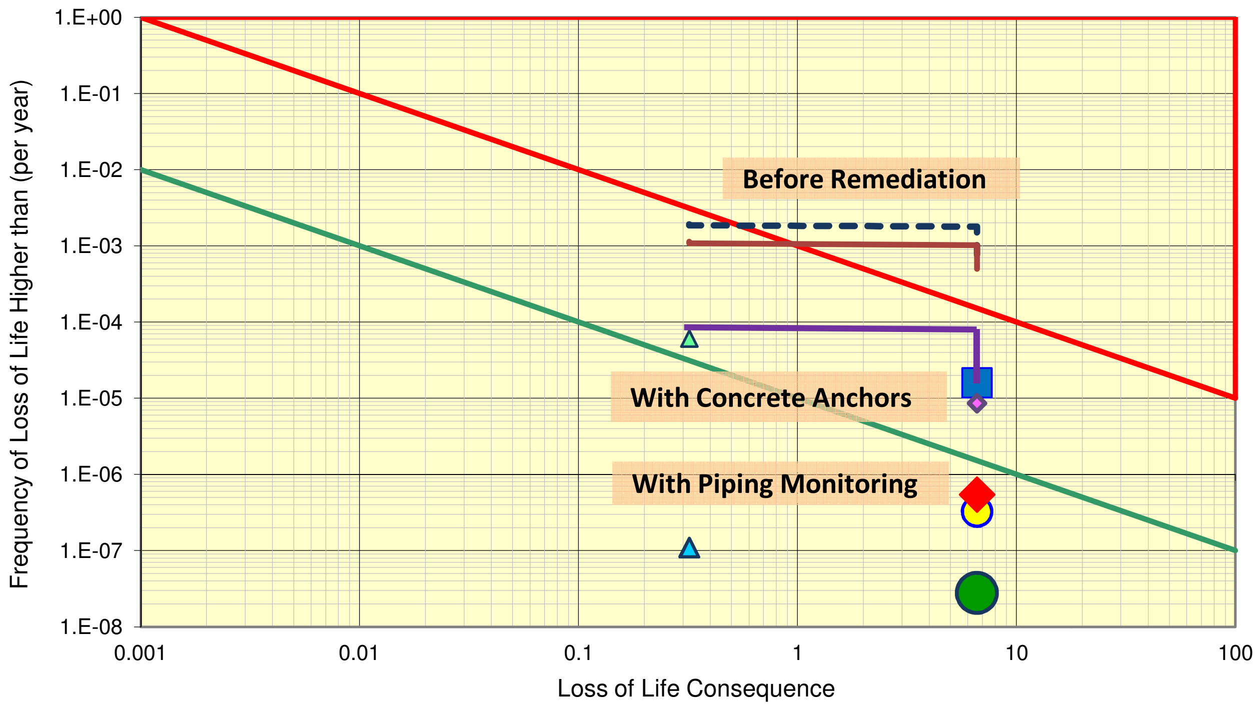

Figure 10: Results of Implementation of Measures to Reduce Piping and Stability Risks

Attempting to further reduce the risks by reducing the overtopping risks failed the ALARP test. Therefore, for this example, it would only be necessary to eliminate the risks associated with the key failure modes that were identified.

In Table 4 the effectiveness of the risk assessment approach is clearly demonstrated. The results show that rectifying the deficiencies identified as a result of the Standards Based review would cost five times more that what would be necessary to and the risk would remain intolerable.

Table 4: Comparison of the Effectiveness of the Standards Based and Risk Assessment Approaches

Methodology	Cost	Residual Risk	Description
Risk Assessment	< 1 million	2×10^{-5}	Tolerable
Standards Based Review	> 5 million	4×10^{-4}	Intolerable

5 CONCLUSIONS

The results showed that the Risk Assessment Tool provided a consistent and rational definition of the risks associated with the various dams studied and was capable of defining cost effective methods for reducing risk to tolerable levels in accordance with ALARP principles. In the example discussed herein it demonstrated that exceeding the normal standards for stability was not justified and that simply dealing with the failure modes identified as part of the Standards Based assessment would not be effective in reducing the real dam safety risks to tolerable levels and would require five times the investment

Overall, these results provide confidence that the use of this risk-informed methodology will enhance the safety of water retaining structures.

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DAM SAFETY MANAGEMENT PLANS: A CONCEPTUAL FRAMEWORK FOR RISK-INFORMED DECISION MAKING IN ONTARIO

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ABSTRACT:

The Ontario Ministry of Natural Resources and Forestry (MNRF), working in partnership with Ontario Power Generation (OPG), the Grand River Conservation Authority (GRCA) and Hatch Ltd. has developed a framework to integrate risk-informed decision making into the regulation of dam safety in Ontario. Under the conceptual framework dam owners electing to demonstrate the safety of an existing dam through the application of a risk assessment would be required to prepare, and remain in compliance with, a Dam Safety Management Plan (DSMP). The DSMP describes the measures to be taken by the dam owner to ensure that the risks associated with dam under study are identified, and managed in a manner that meets the minimum safety criteria established by the Ministry.

Previous papers such as *A Description of the Development and Application of a New Quantitative Dam Safety Risk Assessment Tool* (Donnelly, et al; 2013 CDA Annual Conference) have presented elements of the approach. Currently the MNRF, OPG, GRCA and Hatch Ltd. are working through sample cases studies to demonstrate practical applications.

The proposed risk-informed approach is aligns with the tolerability criteria presented in Section 6 of the CDA Dam Safety Guidelines and if adopted, would represent the first demonstration of these principles by a Canadian regulator.

RÉSUMÉ

TBC

1 INTRODUCTION

Risk-informed decision making has been gaining increased attention as a tool for understanding the level of safety associated with an existing dam and determining what level of deviation from the normal performance condition can be considered tolerable (CDA, 2007). While the risk-informed approach has been formally adopted as a regulatory tool within the Australian states of New South Wales (NSW, 2010), and Victoria (DEPI, 2014) and has been used as an asset management tool by large dam owns in the United States such as the Army Corps of Engineers (USACE, 2011) and the United States Bureau of Reclamation (USBR, 2011), it has yet to be formally integrated into the management and regulation of dams in Canada.

The Ontario Ministry of Natural Resources and Forestry (MNRF), working in partnership with Ontario Power Generation (OPG), the Grand River Conservation Authority (GRCA) and Hatch Ltd. has developed a conceptual framework for regulating the use of risk-informed decision making in Ontario. Under the conceptual framework dam owners electing to demonstrate the safety of an existing dam through the application of a risk assessment would be required to prepare, and remain in compliance with, a Dam Safety Management Plan (DSMP). The DSMP would be required to describe the measures to be taken by the dam owner to ensure that the risks associated with dam under study are identified, and managed in a manner that meets the minimum safety criteria established by the MNRF. The minimum safety criteria being considered for use in Ontario by the MNRF aligns with the principles of risk-informed decision making and risk tolerability criteria presented in Section 6 of the CDA Dam Safety Guidelines (CDA, 2007) and if adopted, would represent the first demonstration of these principles by a Canadian regulator.

This paper outlines the process and criteria for preparing a DSMP currently being considered for adoption by the MNRF in order to generate the opportunity for discussion within the dam industry. At this time it does not represent Ministry approved policy or any formal commitment for integrating risk-informed decision making into existing regulatory requirements in Ontario. Prior to making a decision on whether or not to pursue the risk informed approach the Ministry will need to complete the demonstration case histories being prepared by OPG, the GRCA and Hatch Ltd., as well as have a formal review of the process by experts in the field and through public consultation. Until that time the applicable requirements for the construction of a new dam, or the alteration, improvement or repair of an existing dam in Ontario are outlined within the Ministry's series of *Technical Bulletins* which can be obtained from the MNRF website at www.ontario.ca/dams.

2 REGULATION OF DAM SAFETY IN ONTARIO

The *Lakes and Rivers Improvement Act* (LRIA) provides the MNRF with the legislative authority to regulate the location, design, construction, operation and maintenance of dams in Ontario (LRIA, 1990). An important consideration when making regulatory decisions under the authority of the LRIA is whether or not dams are suitably constructed, operated, and maintained in order to provide for the protection of persons and property.

Currently, the only way for a dam owner to demonstrate that an existing dam is suitably constructed, operated and maintained in order to provide for the protection of persons and property is to demonstrate compliance with deterministic standards set out within MNRF's series of *Technical Bulletins.* As an alternative to this approach, MNRF is considering providing dam owners with the option of demonstrating the safety of an existing dam by either complying with Ministry approved deterministic standards, or, through the completion of a comprehensive risk assessment.

Where an owner elects to demonstrate the safety of an existing dam through completion of a comprehensive risk assessment, they would be required to prepare, file, and remain in compliance with a Dam Safety Management Plan (DSMP) prepared in accordance with the process and criteria established by the MNRF.

3 DAM SAFETY MANAGEMENT PLANS

The objective of a DSMP is to ensure that an existing dam is suitably constructed, operated and maintained in order to provide for the protection of persons and property. This objective is achieved where it can be demonstrated that sufficient measures have been taken to sufficiently manage the risks to persons and property associated with an existing dam.

Once complete, the DSMP would provide the dam owner, and the MNR, with an understanding of the current condition of the dam and the safety measures that must be maintained, or enhanced, in order to adequately manage risks to persons and property; as well as a specific timeframe for their implementation. The safety measures included with a DSMP will typically include a range of engineering, operating and maintenance activities designed to address the specific hazards associated with a given dam.

The conclusions made within a DSMP would be intended to provide a "snapshot in time" of the measures required in order to ensure that the existing dam is suitably constructed, operated and maintained in order to provide for the protection of persons and property. All DSMPs would be required to specify a timeframe for reviewing the conclusions made within the DSMP in order to determine the degree to which they remain valid. In most cases, the DSMP would need to be reviewed, and updated as appropriate, following the completion of the owner's next scheduled dam safety review. Any additional considerations which may warrant an earlier review of the DSMP would need to be noted within the plan.

Once complete, an owner would be required to demonstrate at all times that the measures identified within a DSMP as being necessary in order to comply with the dam safety criteria for existing dams established by the Ministry were in place, were being followed, and were in full compliance with the requirements set out within the DSMP.

3.1 When Would a Dam Owner Be Required to Prepare a Dam Safety Management Plan?

Where an owner determines that an existing dam, or specific components of a dam, subject to Ministry requirements, fails to comply with the deterministic standards outlined within a Ministry approved *Technical Bulletin,* the dam owner would be required to either:

1. Design and implement measures to achieve compliance with the applicable Ministry approved deterministic standard(s); or
2. Prepare a DSMP outlining the measures to be taken by the dam owner to bring the dam into compliance with the minimum safety criteria for existing dams established by the Ministry.

The preparation of a DSMP, supported by the completion of a comprehensive risk assessment, would be used to provide MNRF with assurance that sufficient rationale has been developed, documented, assessed and reviewed in order to justify site-specific deviations from Ministry approved deterministic standards.

The decision to demonstrate that the existing dam suitably provides for the protection of persons and property through compliance with Ministry approved deterministic standards or through the development of a DSMP would be left solely to the discretion of the dam owner.

3.2 How Would Dam Safety Management Plans Inform Subsequent LRIA Approval Decisions?

Preparation of a DSMP would not limit or negate legislative requirements under the LRIA for obtaining prior Ministry approval of proposed alterations, improvements or repairs (herein alterations) which may affect the dam's safety or structural integrity, the waters or natural resources. Where a DSMP identifies that alterations to an existing dam are required in order to implement the DSMP, dam owners would still be required, as applicable, to obtain Ministry approval for these alterations.

Where a DSMP has been prepared, proposed alterations to that dam must be shown to bring the dam into compliance with the final DSMP prepared by the dam owner and filed with the Ministry. Applications for approval of proposed alterations to an existing dam subject to a DSMP would be reviewed by MNRF to ensure that the alterations being proposed comply with the requirements established within the DSMP. Preparation of the DSMP would determine the steps that must be taken by the owner in order to provide for the protection of persons and property and the subsequent plans and specifications approval would ensure that the those steps have been taken.

The completion of a DSMP would not constitute an approval under the LRIA nor would it relieve the dam owner from compliance with the provisions of any other applicable federal, provincial, or municipal statutes, regulations or by-laws, or confer upon the proponent any right to occupy or flood lands owned by others including the Crown. Proponents would remain responsible for obtaining any necessary legal authority required to implement the measures specified within a DSMP. Demonstrating compliance with the requirements established within a DSMP within an application for approval under the LRIA would not limit or preclude the MNRF from imposing as terms and conditions of the approval any other requirements considered necessary in order to further any other purpose of the LRIA or to protect the Aboriginal and treaty rights and interests of Aboriginal communities.

4 ROLES AND RESPONSIBILITIES FOR PREPARING A DAM SAFETY MANAGEMENT PLAN

Development of a Dam Safety Management Plan (DSMP) would involve the participation of a diverse range of expertise provided by a number of individuals and groups. Conceptual roles and responsibilities in developing a DSMP have been outlined below.

4.1 Dam Owners

Dam owners are responsible for the safe management of dams and ensuring that an appropriate standard of care has been exercised in the management of dam safety (CDA, 2007).

Dam owners electing to demonstrate the safety of an existing dam through the development of a DSMP would be required to have effective dam safety management programs in place which meet or exceed MNRF Best Management Practices (BMPs), and where no MNRF BMPs exists, the practices of the Canadian Dam Association (CDA) Dam Safety Guidelines (2007).

Owners would also be responsible for employing staff with the necessary qualifications, knowledge and expertise required to develop a DSMP and for ensuring that the owner’s conclusions and supporting risk assessment were valid and have been verified through an internal quality assurance process and an external independent review.

Compliance with the safety criteria and associated requirements for preparing a DSMP established by the Ministry would not provide dam owners with any exemption from any other legal obligations or responsibilities for protecting persons and property from the hazards associated with an existing dam. Dam owners would remain responsible for determining when achievement of safety levels above and beyond those required for demonstrating compliance with Ministry approved safety criteria are required in order to meet the extent of legal responsibilities owed by an owner at law to other persons.

The final DSMP would need to be approved by the applicable Officer of the dam owning organization in accordance with the information requirements outlined in Section 5 of this paper prior to filing the final DSMP with the Ministry.

4.2 Lead Engineer

The dam owner would be required to assign a Lead Engineer with the overall responsibility for developing and reviewing the DSMP on behalf of the dam owner.

The Lead Engineer would be required to have broad experience in all facets of dam engineering and would be accountable for:

- Determining the composition of the Analysis Team;
- Completing an overall review of the DSMP;
- Quality assurance;
- Verifying that all comments from the Independent Peer Reviewer(s) have been addressed or appropriately dispositioned;
- Verifying that all comments from the MNRF's Dam Safety Committee have been addressed or appropriately dispositioned; and
- Verifying that, once implemented, the DSMP will bring the existing dam into compliance with MNRF's dam safety criteria for existing dams.

The final DSMP would need to be signed, sealed and dated by the Lead Engineer in accordance with the information requirements outlined in Section 5 of this paper.

4.3 Analysis Team

The DSMP would need to be prepared by a team of competent persons with the necessary qualifications, knowledge and experience required to prepare the DSMP and supporting risk assessment.

The Analysis Team would need to include at least one person experienced in risk assessment – preferably being experienced in dam engineering, who is by virtue of their training and application of professional practice:

- Familiar with the state-of-the-art and practice of risk assessment, including the requirements established by the MNRF;
- Understands the principles and mathematics of probability; and the nature of uncertainty; and
- Can apply the knowledge of probability and uncertainty to complete a risk assessment of engineering systems.

The Analysis Team would also be required to include persons knowledgeable in consequence assessment as well as persons who have a specific knowledge of the dam under study, including the operations, maintenance and surveillance procedures as well as the emergency preparedness and response plans and public safety measures plans in place.

Additional specialists would need to be brought in to participate in the analysis where deemed necessary by the Lead Engineer and may include, but not be limited to, hydrotechnical, geological, geotechnical, mechanical, electoral, hydraulic and structural Engineers, as well as Engineers specializing in flow control equipment. In some instances, the scope and complexity of the analysis being completed may warrant considering obtaining additional technical advice from meteorologists (for extreme precipitation estimates), seismologists (for earthquake hazard analysis), hydrologists (for magnitude and annual exceedance probability of floods), geologists (for understanding of foundations and natural materials), and economists (for advanced analysis of economic losses). The Lead Engineer would be responsible for determining where the scope and complexity of the analysis being completed warranted the inclusion of additional specialists.

The MNRF and/or the MNRF's Dam Safety Committee would retain the authority to challenge an owner to show that suitable persons have been selected to participate on the Analysis Team.

4.4 Quality Assurance

The results of the DSMP and supporting safety case would need to be reviewed through a formal quality assurance process which meets or exceeds applicable national and ISO standards. Quality assurance could be completed internally or by an external consultant. The external consultant completing the quality assurance review could be the same consultant who prepared the DSMP.

The formal quality assurance processes would be intended to ensure that:

- the analysis process is logically correct;
- the analysis is based so far as possible on accepted scientific principles;
- judged values and assumptions made, are reviewed and tested;
- the methodology captures the logic and rationale of the process; and
- calculations are free from error

The Lead Engineer would be required to retain overall responsibility for the quality assurance process.

4.5 Independent Peer Reviewers

All DSMPs and supporting risk assessments would be required to undergo an independent peer review in order to challenge the assumptions, analysis and resulting conclusions made by the Analysis Team.

Independent peer review would typically need to be completed by one to three persons depending on the complexity of the DSMP. A panel of three reviewers would be recommended in order to ensure that sufficient challenge and debate occurs and to allow for a broader mix of skills, knowledge and experience. Independent Peer Reviewers would need to be contracted by the dam owner at the beginning of the project and would need to be involved at key milestones throughout the analysis process while avoiding being drawn into the Analysis Team. It would be unacceptable for Independent Peer Reviewers to only be engaged at the end of the analysis process.

The primary role of the Independent Peer Reviewer(s) would be to provide the dam owner and MNRF with assurance that the conclusions of the Analysis Team as to whether or not implementation of the DSMP will bring the dam into compliance with Ministry approved safety criteria for existing dams are valid. In fulfilling this role, the Independent Peer Reviewers would be expected to:

- Confirm that the analysis process applied by the Analysis Team is logically constructed;
- Confirm that the analysis undertaken by the Analysis Team is based so far as possible on accepted scientific principles;
- Review the judged values, assumptions and conclusions made by the Analysis Team in the course of developing the DSMP;
- Verify that any interim measures recommended by the Analysis Team adequately address risks until further measures can be completed where required; and
- Ensure that the DSMP was prepared in accordance with requirements established by the MNRF.

The role of the Independent Peer Reviewer(s) would not include verifying the correctness of calculations completed by the Analysis Team and reviewed by the owner’s quality assurance process.

The Independent Peer Reviewer(s) may be selected by the dam owner preparing the DSMP but would need to be proposed to the MNRF for acceptance prior to their engagement. The MNRF would retain the authority to challenge the owner to demonstrate the suitability of the Independent Peer Reviewer(s). Independent Peer Reviewers proposed by the dam owner would be required to meet the following conditions:

- Not be an employee of the dam owner or the entity which prepared the DSMP or supporting safety case;
- Have knowledge and experience with the particular dam safety issues being assessed;
- Be experienced in dam engineering and risk assessment; and
- Not have undertaken part of, or all, of the risk assessment.

The Independent Peer Reviewer(s) would be required to provide the dam owner with a separate report outlining the findings of their review with the owner responsible for providing a copy of the report to the MNRF. In addition to the final report, the owner would be required to provide a statement giving an account of the owner’s response to the report of the Independent Peer Reviewer(s). If the owner disagrees with comments or recommendations from the Independent Peer Reviewer(s), the owner would be responsible for resolving the matter prior to completion of the DSMP.

4.6 MNRF's Dam Safety Committee

For the purpose of supporting the integration of risk-informed decision making into provincial requirements for the management of dams, the MNRF is considering establishing a Dam Safety Committee, comprised of experts in select areas, to support the development and review of owner's DSMPs. The role of the Dam Safety Committee would include providing advice to MNRF and dam owners on the:

- Suitability of the proponent's Analysis Team to prepare the DSMP;
- Suitability of the proposed Independent Peer Reviewer(s) prior to their engagement;
- Degree to which any relevant aspects of the risk assessment have not received any, or adequate, consideration;
- Need to undertake additional studies or reviews to complete the risk assessment;
- Soundness of the owner's conclusions on whether or not the DSMP, once implemented, will bring the dam into compliance with the safety criteria for existing dams established by the Ministry.

Dam owners preparing a DSMP would be required to present the results of their assessment to the Dam Safety Committee at various project milestones as deemed necessary by the MNRF. Separate presentations would typically be given following the selection of project components and associated failure modes analysis, assignment of failure probabilities, the consequence analysis, risk evaluation and evaluation of remedial measures.

4.7 MNRF Staff

The role of MNRF staff would be to participate in the development of the DSMP as appropriate and to confirm that subsequent applications for approval of proposed alterations, improvements or repairs to a dam subject to a DSMP comply with the requirements specified within the Plan.

MNRF staff would participate in the development of the DSMP in order to obtain a better understanding of the analyses that went into the preparation of the DSMP and to challenge the assumptions and/or conclusions made by the Analysis Team and Independent Peer Reviewers during the development and review of the DSMP. MNRF staff may also participate in the development of the DSMP in order to inform specific questions and/or areas of review to bring to the attention of the MNRF's Dam Safety Committee. The level of participation of MNRF staff in the development of the DSMP would be left to the discretion of the Ministry. Dam owners would be required to confirm the level of involvement MNRF staff wish to have in the development of a DSMP prior to commencing with its development.

The participation of MNRF staff in the development of a DSMP would not constitute MNRF's approval of the proposed DSMP or limit the responsibility of a dam owner, through its analysts and Independent Peer Reviewers, to ensure that the DSMP complies with the safety criteria for existing dams established by the MNRF. The MNRF's participation throughout the development of the DSMP would not limit the role of MNRF staff in reviewing subsequent applications for approval of proposed alterations subject to Ministry approval.

5 CONCEPTUAL SAFETY CRITERIA FOR EXISTING DAMS

As stated above, the objective of a DSMP is to ensure that an existing dam is suitably constructed, operated and maintained in order to provide for the protection of persons and property. This objective would be achieved where it can be demonstrated that implementation of the DSMP will bring the existing dam into compliance with minimum dam safety criteria for existing dams established by the Ministry. The criteria currently being considered for use by the MNRF has been outlined below and is consistent with risk tolerability guidelines outlined by the CDA in the 2013 revision of the CDA Dam Safety Guidelines (CDA, 2007).

5.1 Life Safety Criteria

Dam owners would be required to demonstrate compliance with two types of life safety criteria - individual safety, and societal safety. The individual and societal life safety criteria currently being considered for use by the MNRF has been outlined below.

5.1.1 Individual Life Safety Criteria

Individual life safety criteria is represented by the probability of incremental loss of life (ILOL) for the identifiable person or group, defined by a location that is most at risk (Munger et al, 2009). This would be combined over all modes of failure with due regard for non-mutually exclusive failure modes. The incremental loss of life would be understood as the life loss that is caused by dam failure less the loss that would have occurred without the failure.

Individual safety would need to be checked downstream of the main dam and each auxiliary dam to verify that the person or group that is most at risk is provided a level of protection that satisfies the individual incremental safety criteria.

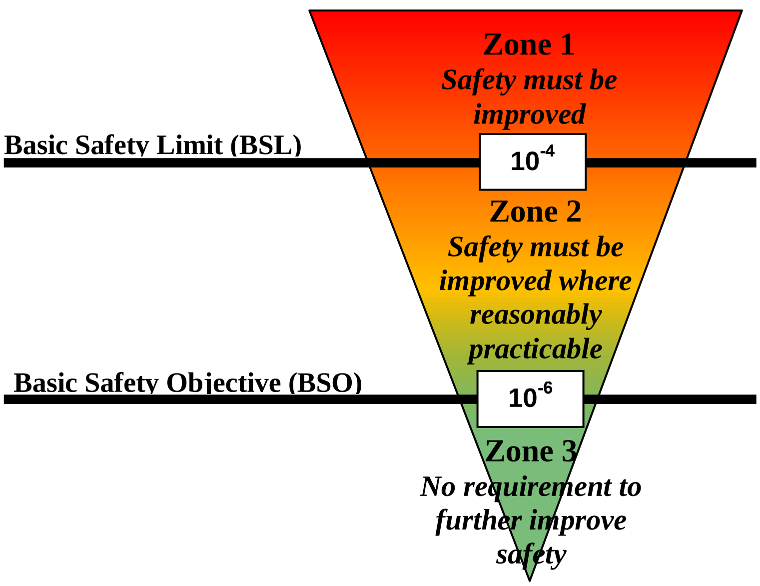

Figure 1 – Individual Life Safety Criteria

For Individual Life Safety Criteria, the upper limit of tolerable individual risk (Zone 2) would be 1E-04. Therefore, if the cumulative probability of fatality of the most exposed individual is greater than 1E-04 (Zone 1) the risk would be considered intolerable and additional safety measures would be required to lower the risk below this threshold level regardless of the cost of the remedial measures.

Risks less than 1E-04 but greater than 1E-06 would need to be shown to satisfy the ALARP test as outlined below.

Risks less than 1E-06 (Zone 3) would be deemed as being adequately controlled and as such negligible. MNRF would not require any further action to reduce risks within Zone 3. Where the best estimate of risk is within Zone 3, the decision to adopt additional measures designed to further improve safety would be left to the discretion of the dam owner.

Where the analysis shows that the ILOL is less than 1, professional engineering judgement would be used to evaluate the need for further remedial measures.

5.1.2 Societal Life Safety Criteria

Societal Life Safety Criteria is expressed in two different ways – a probability distribution of potential incremental loss of life (ILOL) and annualized incremental life loss.

The societal safety profile for a dam related to loss of life is displayed on a chart that relates the annual probability of failure (F) and the ILOL (N); referred to as the F-N chart shown in Figure 2 below.

This F-N chart plots the cumulative annual probability of dam failure (on the vertical axis) against estimated ILOL (on the horizontal axis), on a log-log scale. In this case the cumulative annual probability represents the aggregate of all hazards considered.

Zone 2 would be bounded by diagonal lines descending from left to right with a slope of one log cycle of probability vs. one log cycle of ILOL. These lines represent BSO and BSL for societal risk.

- The upper boundary (BSL) would pass though probability 1E-03 and 1 ILOL.
- The lower boundary (BSO) would pass though probability 1E-05 and 1 ILOL.

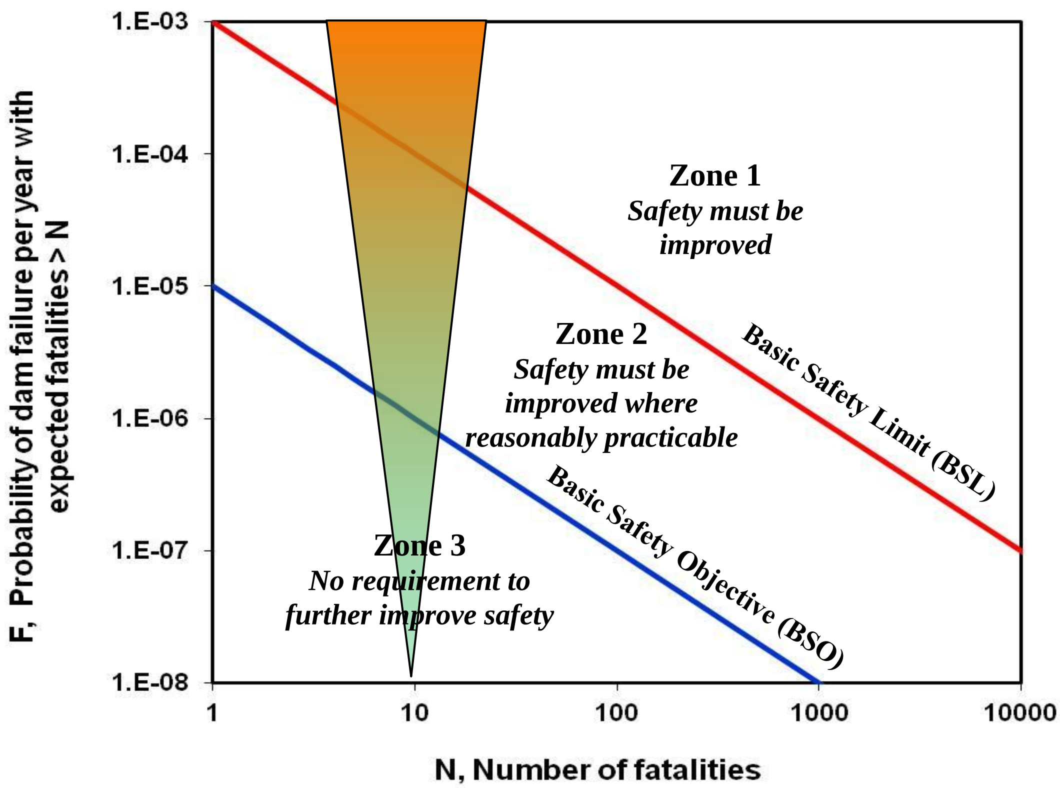

Figure 2 – Societal Life Safety Criteria

5.2 Economic Safety Criteria

Economic losses associated with a dam are displayed on an F-E chart (Figure 3). This chart plots the cumulative probability of dam failure (per year) against incremental economic loss on a log-log scale. Zone 2 would be bounded by diagonal lines descending from left to right with a slope of one log cycle of probability vs. one log cycle of economic loss. The boundaries are defined as follows:

- The Basic Safety Limit (BSL) line passes though probability 1E-03 and $2E08 ($200 million) incremental economic loss
- The Basic Safety Objective (BSO) line passes though probability 1E-05 and $2E08 ($200 million).

In the context of the MNRF *Technical Bulletin*s economic losses refers to 3rd party direct losses; though from an owner's perspective they may include their own (first party) losses into decision making.

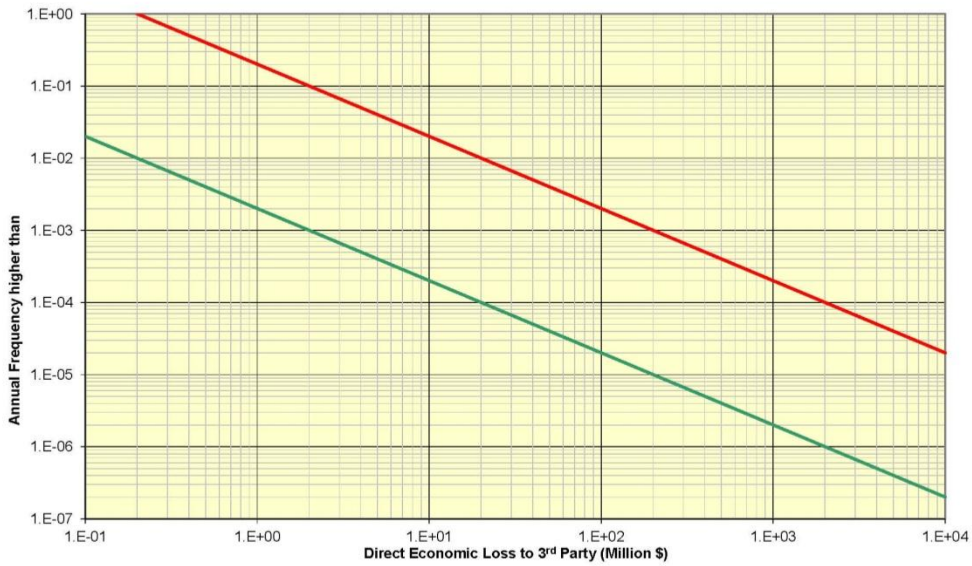

Figure 3 – Economic Criteria Diagram

5.3 Environmental and Other Non-Monetary Consequences

A dam failure has both direct and indirect consequences that cannot be measured in monetary terms. These stem from the impacts of the dam failure flood and loss of the dam's reservoir on environmental, cultural, and historic resources. In most cases, the assessment of the impacts of dam failure will be based on considerations such as the area and type of habitat impacted, habitat of threatened and endangered species impacted, and number and type of built-cultural heritage sites impacted.

The MNRF would not establish minimum safety criteria for demonstrating that these interests have been adequately protected in the selection of safety measures. Where the consequences of dam failure are limited to, or driven by, these considerations, proponents would be required to demonstrate compliance with MNRF's deterministic standards (e.g. Inflow Design Flood standards as determined necessary by the dam's Hazard Potential Classification).

5.4 Criteria for Demonstrating the ALARP Principle

The concept of ALARP would play a significant role in demonstrating that an existing dam is reasonably safe. The notion of reasonably practicable embedded within the ALARP principle requires comparing the benefits obtained from implementing further risk reductions with the cost of the measures necessary to reduce that risk. If it is found that there is a gross disproportion between the cost of additional safety measures and the magnitude of improvement in the overall safety of the dam, then the existing risk would be deemed to be ALARP.

As a result, application of the ALARP principle requires:

- Calculating the costs associated with the adoption of additional safety measures
- Calculating the benefits realized from implementation of additional safety measures
- Comparison of the costs and benefits to determine disproportionality

5.4.1 Calculating Costs

The annualized value C_A of the capital cost C of additional safety measures would be calculated using the following formula:

$$C_A = (C \times r) \times (1 + r)^n / [(1 + r)^n - 1]$$

n = number of years over which the cost is annualized
r = discount rate
C = capital cost of the safety measure (e.g. upgrade) in $M

The above formula takes the following form if the annualization process is extended to perpetuity:

$$C_A = C \times r$$

Total annualized cost is the sum of C_A and the annual operating cost of the safety measure being considered.

5.4.2 Discount Rates

A discount rate is required to reduce the capital cost of the risk reduction option to an annual cost that can be compared with the annual reduction in risk.

Choosing a discount rate has been one of the most contentious and controversial aspects of the cost-benefit analysis of regulatory policies (TBCS, 2007). The term discount rate refers to the time value of the costs and benefits from the viewpoint of society. It is similar to the concept of the private opportunity cost of capital used to discount a stream of net cash flows of an investment project, but the implications can be more complex.

The Treasury Board of Canada Secretariat (TBCS) has developed guidelines for the selection of discount rates for use in performing cost-benefit analysis to support regulatory decisions (TBCS, 2007). Based on the results of Canadian-specific research, TBCS recommends that a “real rate” of 8% be used as the discount rate for the evaluation of regulatory interventions in Canada. However, where cost-benefit analysis includes consider of factors other than the economic opportunity cost of funds, some federal departments, governments and international organizations have chosen to apply a “social discount rate” which are lower than the 8%recommended by TBCS. In these circumstances, the literature compiled by TBCS suggests using a social discount rate of 3%, recognizing there is still controversy in the literature on the use of these social discount rates and further guidance will be needed in the future.

For the purpose of completing a risk assessment in support of preparing a DSMP, the MNRF a social discount rate of 3% would be used when assessing the benefits of adopting further risk control measures to reduce risk of ILOL. Where there is no risk of ILOL, the MNRF would permit use of a discount rate of 8% to assess the benefits of adopting further risk control measures to reduce the risk of 3rd party economic losses.

Whatever rate is used, the costs and benefits would need to be discounted using the same rate.

5.4.3 Calculating Benefits

The benefits realized from implementation of considered safety measures would be calculated as expected annual avoided losses of life using the following formula:

$$B = [(N_b \times P_b) - (N_a \times P_a)] \times VPF$$

N_b = number of potential fatalities before the upgrade
N_a = number of potential fatalities after the upgrade
P_b = cumulative failure probability before the upgrade
P_a = cumulative failure probability after the upgrade
VPF = Value of Preventing Fatality

5.4.4 *Value of Preventing Fatality*

Reports developed by the HSE (2001) have pointed out that this useful concept is often misrepresented and it is often misunderstood as to mean that a value is being placed on a life. It is actually another way of expressing what people are prepared to pay to secure a certain averaged risk reduction. A VPF of $1,000,000 corresponds to a reduction in risk of 1 in 100,000 as being worth about $10 to an average individual. For this reason, the VPF should not to be confused with the value society might put on the life of a real person or the compensation appropriate for the loss of an individual life. The general idea is that when a risk reduction option (potentially producing benefit of "saving lives" or preventing fatalities) is available a monetary value on achieving a reduction in the risk of death needs to be assigned. The intention of defining the value of preventing fatality (VPF) is to provide a means of reflecting the marginal change in risk level for a large number of individuals but not for specific, identified individuals.

For the purpose of completing a risk assessment in order to prepare a DSMP, the MNRF would require dam owner to use a VPF of C$6.7 million (in 2007 dollars), based on recommendations in other jurisdictions in Canada (TC, 1994), (TBCS, 2007), (PRI, 2009), (HC, 2010).

5.4.5 *Disproportionality and Comparison of Costs and Benefits*

Original HSE guidance recommended that the disproportionality factor between the cost of lowering risk and the benefits resulting from the improvement of risk should range from 10 at the BSL target to 3 at the BSO target. The MNRF is considering defining disproportionality factor at the BSO target as equal to 1. Such definition is consistent with the understanding that further reduction of risks which are at or below the BSO target can be justifiable on the basis of strict cost-benefit analysis. Between these two target lines the disproportionality factor that should be used to weight the benefits can be estimated from the number of expected fatalities, Nb, and the probability of failure before the remedial measure, P_b , using the following equation:

$$D = 1 + [(N_b \text{ x } P_b)\ 10^{-5}] / (1.1 \text{ x } 10^{-4})$$

For example, for a dam with the probability of failure = $5.1 \text{ x } 10^{-5}$ resulting in loss of life of 7, D= 4.15

Comparison of the costs and the benefits (weighted by the disproportionality factor) can be now performed by calculating the following ratio, R:

$$R = (D \text{ x } B)/C_A$$

If the ratio is greater than 1 then the option should be implemented. If the ratio is less than one and no other options are available the risk is considered to be ALARP.

In all cases, when comparing costs and benefits the value of costs and benefits would need to be evaluated on the same basis using Statistics Canada or other approved cost indices.

5. SUPPORTING DOCUMENTATION

The MNRF would require dam owners to prepare and submit the following documentation to the Ministry in order for the DSMP to be considered complete:

1. a final copy of the Dam Safety Management Plan approved by an officer of the Corporation;
2. the results of the Risk Assessment Study completed in support of preparing the DSMP;
3. the report of the Independent Peer Reviewer(s);

4. a statement giving an account of the owner's response to the report of the Independent Peer Reviewers;
5. a statement giving an account of the owner's response to comments received from MNRF's Dam Safety Committee;
6. an assurance statement issued under the authority of the dam owner providing their assurance that:
    i. The dam owner has in place policies, approved by Officers of the Corporation that require dams owned by the owner to be managed under a dam safety management program; and
    ii. The dam owner's dam safety management program is managed by a Professional Engineer and retains qualified staff to effectively execute the requirements of the program; and
    iii. The elements of the dam owner's dam safety management program are compliant with the current requirements of the MNRF Technical Bulletins and Best Management Practices, as well as those of the Canadian Dam Association Dam Safety Guidelines and Guidelines for Public Safety Around Dams where additional guidance is needed; and
    iv. The dam owner's dam safety management program constitutes a managed system which seeks to embed continuous improvement in the process and include elements for regular inspections, dam surveillance, instrument monitoring, and flow control equipment testing together with a managed maintenance program, documented operating practices and plans for emergency preparedness and response, and public safety measures; and
    v. The dam owner's dam safety management program ensures that dams owned by the dam owner are subject to regular assessments and reviews including independently conducted audits by external consultants, to insure compliance with the managed system, policies, standards and procedures; and
    vi. The dam owner's dam safety management program requires annual reporting to the Officers of the Corporation on the status of activities; and
    vii. Once implemented, the safety measures outlined within the DSMP, will bring the dam(s) subject to this plan into compliance with all MNRF safety criteria for existing dams; and
    viii. The dam owner, through its analysts, internal quality assurance program and Independent Peer Reviewers, is able to defend the validity of the DSMP and supporting risk assessment in providing for the protection of persons and property.
7. an assurance statement signed by the Lead Engineer providing their assurance that:
    i. The DSMP, once implemented, will bring the dam(s) subject to this plan into compliance with the safety criteria for existing dams established by the MNRF; and
    ii. The DSMP, and supporting safety case, has been prepared in accordance with, and meets all the requirements established by the MNRF; and
    iii. The DSMP, and supporting risk assessment, provides an accurate assessment, so far as is reasonably practicable, of the current condition of the dam and the safety measures that the owner must implement in order to bring the dam into compliance with the safety criteria for existing dams established by the Ministry, as well as a timeframe for their implementation; and
    iv. The DSMP, and supporting risk assessment, provides an accurate assessment, so far as reasonably practicable, of the likelihood and consequences associated with all relevant failure modes associated with the dam(s) under study; and
    v. The DSMP specifies a timeframe for reviewing the conclusions made within the plan in order to determine the degree to which they remain valid as well as any additional considerations which may warrant an earlier review of the plan; and

vi. The DSMP and supporting risk assessment, was prepared by an Analysis Team with sufficient qualifications, knowledge, and experience to prepare the plan as specified by the MNRF; and

vii. The risks associated with the dam(s) subject to the DSMP were analysed using a methodology pre-approved by the MNRF; and

viii. The rationale underpinning risk values, including assigned probabilities, have been clearly documented; and

ix. Where life safety risks or economic risks were located within Zone 1, all remedial measures were applied to the highest identified risk factor(s) successively until those risks were reduced, as a minimum, to fall within Zone 2; and

x. All residual risks associated with the dam(s) under study have been deemed to fall within Zone 3, or where located within Zone 2, have been shown to be as low as reasonably practicable; and

xi. Adequate arrangements have been made for emergency preparedness and response in the case of the failure of the dam(s) subject to the DSMP; and

xii. The DSMP, and supporting risk assessment, were reviewed through a formal quality assurance process in compliance with applicable national and ISO standards; and

xiii. The DSMP, and supporting risk assessment, underwent an independent review in accordance with requirements established by the MNRF and all comments provided by the Independent Reviewers have been addressed or appropriately dispositioned; and

xiv. The DSMP, and supporting risk assessment, was reviewed by the members of the Dam Safety Committee established by the MNRF and all comments provided by Committee members have been addressed or appropriately dispositioned;

8. a summary of the dam owner's Dam Safety Management Program

9. an inventory of dams within the owner's portfolio identifying basic information on the dam (e.g. type, purpose, height, storage and discharge capacity, year of construction etc.) and identifying whether the dam has in place a(n):

   i. Emergency Preparedness and Response Plan, and date of last review/ update;

   ii. Operations, Maintenance and Surveillance Manual, and date of last review/ update; and

   iii. Public Safety Measures Plan and date of last review/ update;

   iv. Dam Safety Review and the date of last review/ update.

6 CONCLUSION

The conceptual framework outlined within this paper is intended to provide readers with an initial sense of breadth and depth of requirements being considered by the MNRF in order to support greater integration of risk-informed decision making into regulatory requirements for the management of dams in Ontario. Completion of a risk assessment alone would not be considered sufficient demonstration that sufficient measures are being taken to ensure that an existing dam provides for the protection of persons and property. The risk assessment completed by the dam owner must also pass through a robust process with sufficient checks and balances built into it to ensure that the dam owner and regulator have confidence in its results. The process and criteria for completing a risk assessment and preparing a Dam Safety Management Plan outlined above has been based in large part on the regulatory framework recommended by the Australian National Committee on Large Dams (ANCOLD, 2003) and the requirements established by the Dam Safety Committee (DSC) in New South Wales Australia.

It is the hope of those who have contributed to the development of the conceptual regulatory framework outlined above will provide the ground work for formally integrating risk-informed decision making into provincial requirements for the management of dams in Ontario.

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Appendix C
Kasheshewan Ring Dyke Failure due to Piping

C.1 Assessment of Piping Risk under Existing Conditions

Notes: 1) This assessment considers the season usage of the dyke which has only seen a few events with a total wetted time well below the 5 year threshold.

2) The total risk of piping failure using this evaluation needs to consider the low frequency of high water events which has a mitigating effect on the annual risk.

3) The primary reference is the Hatch 2010 Geotechnical Site Investigation Report (Rev A), 15 April 2015. Unless otherwise noted.

Summation of Piping Risk:

	Return Period	
4.49E-02	22.3	Reciprocal of Risk

Table C 1: Embankment Weighting Factors

Factor	Factor Description	Score	Commentary
Embankment Filters	No Filter	2	Poor records available.
Core Geological Origin	Marine	1	Section 3.2
Core Soil W_E	Well graded sand & gravel.	1	Lab test results.
Compaction W_E	Rolled, modest effort.	1.2	It is dense but no records (Not "good control").
Conduits	Conduits with some poor details.	2	Not to USBR Standards
Foundation Treatments	No Abutments	1	Neutral
Observations of Seepage	Seepage on slopes observed.	2	
Monitoring & Surveillance	Inspection Annually	2	Poor records; no formal inspections.
	W_E =	19.200	Embankment Weighting Factor
	P_E =	2.08E-03	Homogeneous Earthfill; < 5 yrs Old
	Embankment Risk =	3.99E-02	(Considers the Seasonal Aspect)

Table C 2: Foundation Weighting Factors, W_F

Factor	Factor Description	Score	Commentary
Filters	No Filters	1	
Foundation (Below Cut-off)	Soil Foundation	5	Soil Foundation, no cut off.
Cut-off (Soil Foundation)	Shallow or no cut-off trench.	1.2	
Cut-off Rock Foundation	Not Applicable	1	Neutral value.
Soil Geology below Cut-Off	Marine	1	Section 3.2
Observations of Seepage	Sand Boils	2	During high water events.
Observations of Pore Pressures	Low pore pressures in the foundation.	0.8	Based on season usage and low permeability foundations.
Monitoring & Surveillance	Inspection Annually	2	Poor records; no formal inspections.
	W_F =	19.200	Foundation Weighting Factor
	P_F =	2.55E-04	Homogeneous Earthfill; < 5 yrs Old
	Foundation Risk =	4.90E-03	(Considers the Seasonal Aspect)

Table C 3: Embankment Piping into the Foundation Weighting Factors

Factor	Factor Description	Score	Commentary
Filters	Independent of Filters	1	
Foundation Cut-off Trench	Shallow or no Cut-off Trench	0.8	
Foundation	On Soil	0.5	
Erosion Control Measures for the Core	No System	1.2	Variable materials may not always be compatible
Grouting of the foundation.	Soil Foundation Only (NA)	1	Soil Foundation (NA)
Soil Geology Types	Glacial below Marine	0.5	Marine appears to be wide spread and thick. Take the credit.
Rock Geology Types	Not Applicable	1	Neutral
Core Geologic Origin	Marine	1	Section 3.2
Core Soil Type	Well graded sand & gravel.	1	Lab test results.
Core Compaction	Independent of Compaction	1	For this mode of failure.
Foundation Treatments	Not Applicable	1	Neutral
Observations of Seepage	Sand Boils	2	During high water events.
Monitoring & Surveillance	Inspection Annually	2	Poor records; no formal

Factor	Factor Description	Score	Commentary
			inspections.
	W_{EF} =	0.960	Embankment Weighting Factor
	P_{EF} =	1.90E-05	Homogeneous Earthfill; < 5 yrs Old
	Embankment into Foundation Risk =	1.82E-05	(Considers the Seasonal Aspect)

C.2 Assessment of Piping Risk After Remediation

Notes: 1) This assessment considers the season usage of the dyke which has only seen a few events with a total wetted time well below the 5 year threshold.

2) The total risk of piping failure using this evaluation needs to consider the low frequency of high water events which has a mitigating effect on the annual risk.

3) The primary reference is the Hatch 2010 Geotechnical Site Investigation Report (Rev A), 15 April 2015. Unless otherwise noted.

Summation of Piping Risk:

	Return Period	
6.17E-04	1621.9	Reciprocal of Risk

Table C 4: Embankment Weighting Factors

Factor	Factor Description	Score	Commentary
Embankment Filters	Well designed and constructed filter good quality.	0.02	Install filter on downstream side.
Core Geological Origin	Marine	1	Section 3.2
Core Soil W_E	Well graded sand & gravel.	1	Lab test results.
Compaction W_E	Rolled, modest effort.	1.2	It is dense but no records (Not "good control").
Conduits	USBR Standard	1	Upgrade to USBR standards.
Foundation Treatments	No Abutments	1	Neutral
Observations of Seepage	Upgrade to "Steady & Clear"	1	Install reverse filter on seepage points.
Monitoring & Surveillance	Daily Monitoring & Reporting	0.5	Train local staff; monitor during High Water.
	W_E =	0.012	Embankment Weighting Factor
	P_E =	1.90E-04	Homogeneous Earthfill; < 5 yrs Old
	Embankment Risk =	2.28E-06	(Considers the Seasonal Aspect)

Table C 5: Foundation Weighting Factors, WF

Factor	Factor Description	Score	Commentary
Filters	No Filters	1	
Foundation (Below Cut-off)	Soil Foundation	5	Soil Foundation, no cut-off.
Cut-off (Soil Foundation)	Shallow or no cut-off trench.	1.2	
Cut-off Rock Foundation	Not Applicable	1	Neutral Value
Soil Geology (Below Cut-off)	Marine	1	Section 3.2
Observations of Seepage	Upgrade to "Steady & Clear"	1	Install reverse filter on seepage points.
Observations of Pore Pressures	Low pore pressures in the foundation.	0.8	Based on season usage and low permeability foundations.
Monitoring & Surveillance	Daily Monitoring & Reporting	0.5	Train local staff; monitor during High Water.
	W_F =	2.400	Foundation Weighting Factor
	P_F =	2.55E-04	Homogeneous Earthfill; < 5 yrs Old
	Foundation Risk =	6.12E-04	(Considers the Seasonal Aspect)

Table C 6: Embankment Piping into the Foundation Weighting Factors

Factor	Factor Description	Score	Commentary
Filters	Independent of Filters	1	
Foundation Cut-off Trench	Shallow or no cut-off trench.	0.8	
Foundation	On Soil	0.5	
Erosion Control Measures for the Core	No System	1.2	Variable materials may not always be compatible.
Grouting of the foundation.	Soil Foundation only (NA)	1	Soil Foundation (NA)
Soil Geology Types	Glacial below Marine	0.5	Marine appears to be wide spread and thick. Take the credit.
Rock Geology Types	Not Applicable	1	Neutral
Core Geologic Origin	Marine	1	Section 3.2
Core Soil Type	Well graded sand & gravel.	1	Lab test results.
Core Compaction	Independent of compaction.	1	for this mode of failure.
Foundation Treatments	Not Applicable	1	Neutral
Observations of Seepage	Upgrade to "Steady & Clear"	1	Install reverse filter on seepage points.
Monitoring & Surveillance	Daily Monitoring & Reporting	0.5	Train local staff; monitor during High Water
	W_{EF} =	0.120	Embankment Weighting Factor
	P_{EF} =	1.90E-05	Homogeneous Earthfill; < 5 yrs Old
	Embankment into Foundation Risk =	2.28E-06	(Considers the Seasonal Aspect)

C.3 Calculation of the Annual Probability of Slope Failure based on Lambe Method (2008) - Existing Conditions

Level of Engineering	Rating	Site Safety Factor	1.25	Dam Age (years)	20			Construction	Select	Operation and Monitoring	Select
		DESIGN									
		Investigation	Select	Testing	Select	Analysis and Documentation	Select				
Best Facilities with high failure consequences	0.2	* Evaluate design performance of nearby structures	No	* Run lab tests on undisturbed specimens at field conditions	Yes	* Determine FS using effective stress parameters based on measured data (geometry, strength, pore pressure) for site	Yes	*Full time supervision by qualified engineer	No	* Complete performance program including comparison between	No
		* Analyze historic aerial photographs	Yes	* Run strength test along field effective and total stress paths	Yes	* Consider field stress path in stability determination	No	* Construction control tests by qualified engineers and technicians	No	Predicted and measured performance (e.g. pore pressure, strength, deformations)	No
		* Locate all nonuniformation (soft, wet, loose, high, or low permeability zones)	Yes	* Run index field tests (e.g. field vane, cone penetrometer) to detect all soft , wet, loose, high, or low permeability zones	Yes	* Prepare flow net for instrumented sections	No	* Construction report clearly documents construction	No	* No malfunctions (slides, cracks, artesian heads	No
		* Determine site geologic history	Yes	* Calibrate equipment and sensors prior to testing program	Yes	*Predict pore pressure and other relevant performance parameters (e.g. stress, deformation, flow rates) for design	No	* No errors or omissions documents construction activities	No	* Continuous maintenance by trained crews	No
		* Determine subsoil profile using continuous sampling	No			* Have design report clearly document parameters and analysis used for design	No				
		* Obtain undisturbed samples for lab testing of foundation soils	Yes			* No errors or omissions	No				
		* Determine field pore pressure	Yes			* Peer review	No				
		Calculated Rating	0.26	Calculated Rating	0.20	Calculated Rating	0.37	Calculated Rating	0.00	Calculated Rating	0.00
Above Average Ordinary Facilities	0.4	* Evaluate design performance of nearby structures	No	* Run standard tests on undisturbed specimens	Yes	* Determine FS using effective stress parameters and pore pressures	Yes	* Part-time supervision by qualified engineer	No	* Periodic inspection by qualified engineer	No
		* Exploration program tailored to project conditions by qualified engineer	Yes	* Measure pore pressure in strength tests laboratory test conditions and	Yes	* Adjust for significant differences between field stress paths and stress path implied in analysis that could affect design	No	* No errors or omissions	No	* No uncorrected malfunctions	No
				* Evaluate difference between field conditions	Yes					* Selected field measurements	No
										* Routine maintenance	No
		Calculated Rating	0.50	Calculated Rating	0.00	Calculated Rating	0.50	Calculated Rating	0.00	Calculated Rating	0.00
Average Unimportant or temporary facilities with low failure consequences	0.6	* Evaluate performance of nearby structures	No	* Index tests on samples from site	Yes	* Rational analysis using parameters inferred from index tests	Yes	* Informal construction supervision	Yes	* Annual inspection by qualified engineer	No
		* Estimate subsoil profile from existing data and borings	Yes							* No field measurements	No
										* Maintenance limited to emergency repairs	No
		Calculated Rating	0.00	Calculated Rating	0.00	Calculated Rating	0.00	Calculated Rating	0.60	Calculated Rating	0.00
Poor	0.8	* No field investigation	No	* No laboratory tests on samples obtained at the site	No	* Approximate analysis using assumed parameters	No	* No construction supervision by qualified engineer	No	* Occasional inspection by non-qualified person	Yes
										* No field measurements	Yes
		Calculated Rating	0.00	Calculated Rating	0.00	Calculated Rating	0.00	Calculated Rating	0.00	Calculated Rating	0.80
		SELECTED RATING	0.50	SELECTED RATING	0.20	SELECTED RATING	0.50	SELECTED RATING	0.60	SELECTED RATING	0.80

C.3.1 *RESULTS Annual Probability of Slope Failure based on Lambe Method (2008) Existing Conditions*

The probability of Slope Failure is a function of Factor of Safety which is calculated for a site.

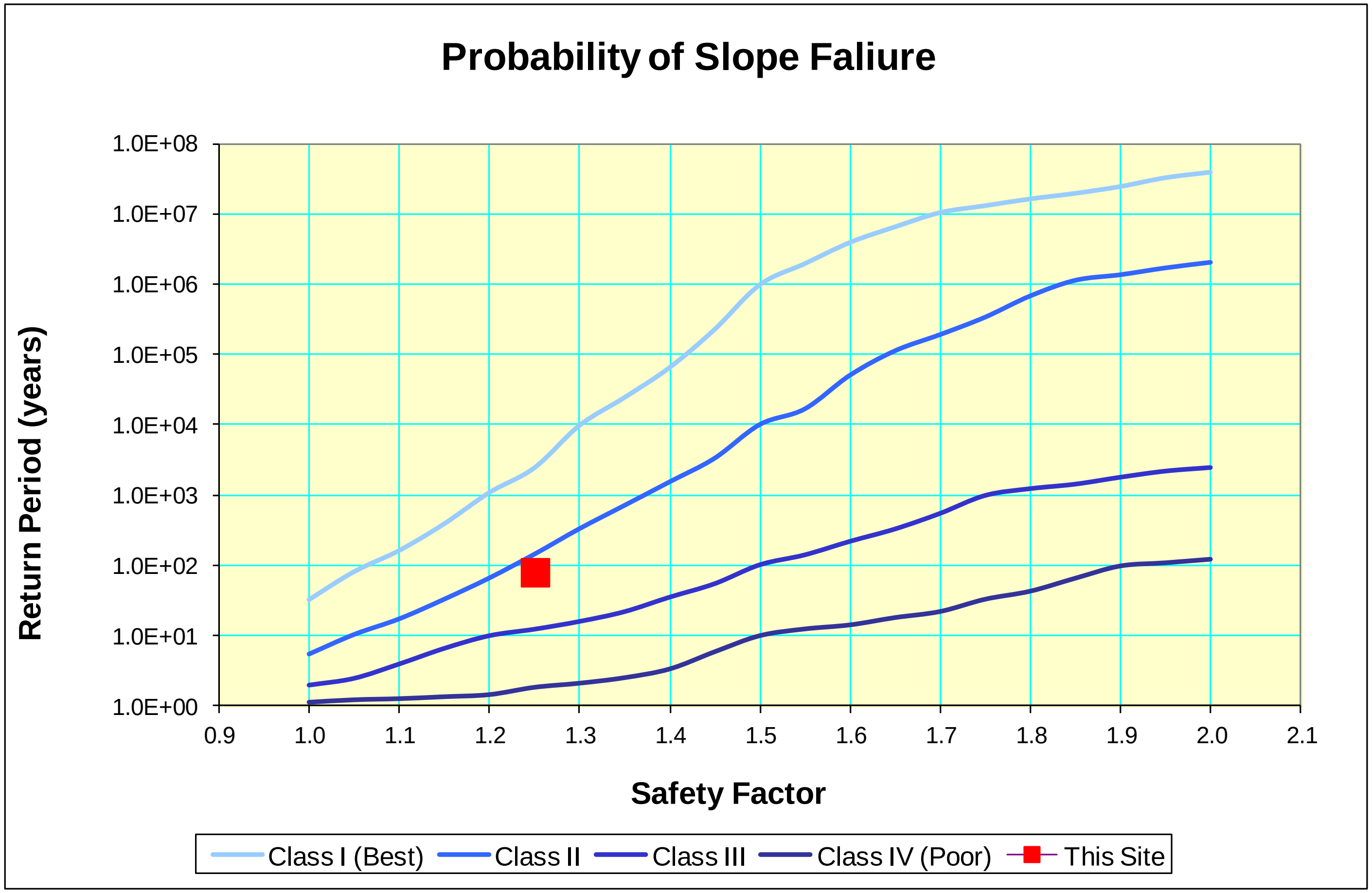
Earth Structures can be classified into 4 Classes based on; Investigation, Testing, Analysis & Documentation, Construction, and Operation & Monitoring.

Safety Factor	1.25

Class	Score	Return Period
I	1	4149
II	2	182
III	3	13
IV	4	2

Site Score				
Design			Construction	Operation and Monitoring
Investigations	Testing	Analysis & Documentation		
0.50	0.20	0.50	0.60	0.80

Overall Score	2.60	
Failure Return Period	81 years	1.2E-02
Expected Life of Typical Dam	100 years	


Probability of Slope Faliure
Return Period (years)
1.0E+08
1.0E+07
1.0E+06
1.0E+05
1.0E+04
1.0E+03
1.0E+02
1.0E+01
1.0E+00
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
Safety Factor
Class I (Best)
Class II
Class III
Class IV (Poor)
This Site

C.4 Calculation of Annual Probability of Slope Failure based on Lambe Method (2008) After Remediation

Level of Engineering	Rating	Site Safety Factor	1.3	Dam Age (years)	5						
		DESIGN									
		Investigation	Select	Testing	Select	Analysis and Documentation	Select	Construction	Select	Operation and Monitoring	Select
Best Facilities with high failure consequences	0.2	* Evaluate design performance of nearby structures.	No	* Run lab tests on undisturbed specimens at field conditions.	Yes	* Determine FS using effective stress parameters based on measured data (geometry, strength, pore pressure) for site.	Yes	*Full time supervision by qualified engineer.	No	* Complete performance program including comparison between.	Yes
		* Analyze historic aerial photographs.	Yes	* Run strength test along field effective and total stress paths.	Yes	* Consider field stress path in stability determination.	No	* Construction control tests by qualified engineers and technicians	No	Predicted and measured performance (e.g. pore pressure, strength, deformations).	Yes
		* Locate all nonuniformation (soft, wet, loose, high, or low permeability zones).	Yes	* Run index field tests (e.g. field vane, cone penetrometer) to detect all soft, wet, loose, high, or low permeability zones.	Yes	* Prepare flow net for instrumented sections.	No	* Construction report clearly documents construction.	No	* No malfunctions (slides, cracks, artesian heads.	Yes
		* Determine site geologic history.	Yes	* Calibrate equipment and sensors prior to testing program.	Yes	*Predict pore pressure and other relevant performance parameters (e.g. stress, deformation, flow rates) for design.	No	* No errors or omissions documents construction activities.	No	* Continuous maintenance by trained crews.	Yes
		* Determine subsoil profile using continuous sampling.	No			* Have design report clearly document parameters and analysis used for design.	No				
		* Obtain undisturbed samples for lab testing of foundation soils.	Yes			* No errors or omissions.	No				
		* Determine field pore pressure.	Yes			* Peer review.	No				
		Calculated Rating	0.26	Calculated Rating	0.20	Calculated Rating	0.37	Calculated Rating	0.00	Calculated Rating	0.20
Above Average Ordinary Facilities	0.4	* Evaluate design performance of nearby structures.	No	* Run standard tests on undisturbed specimens.	Yes	* Determine FS using effective stress parameters and pore pressures.	Yes	* Part-time supervision by qualified engineer.	No	* Periodic inspection by qualified engineer.	No
		* Exploration program tailored to project conditions by qualified engineer.	Yes	* Measure pore pressure in strength tests laboratory test conditions.	Yes	* Adjust for significant differences between field stress paths and stress path implied in analysis that could affect design.	No	* No errors or omissions.	No	* No uncorrected malfunctions.	No
				* Evaluate difference between field conditions.	Yes					* Selected field measurements	No
										* Routine maintenance	No
		Calculated Rating	0.50	Calculated Rating	0.00	Calculated Rating	0.50	Calculated Rating	0.00	Calculated Rating	0.00
Average Unimportant or temporary facilities with low failure consequences	0.6	* Evaluate performance of nearby structures.	No	* Index tests on samples from site.	Yes	* Rational analysis using parameters inferred from index tests.	Yes	* Informal construction supervision.	Yes	* Annual inspection by qualified engineer.	No
		* Estimate subsoil profile from existing data and borings.	Yes							* No field measurements.	No
										* Maintenance limited to emergency repairs.	No
		Calculated Rating	0.00	Calculated Rating	0.00	Calculated Rating	0.00	Calculated Rating	0.60	Calculated Rating	0.00
Poor	0.8	* No field investigation.	No	* No laboratory tests on samples obtained at the site.	No	* Approximate analysis using assumed parameters.	No	* No construction supervision by qualified engineer.	No	* Occasional inspection by non-qualified person.	Yes
										* No field measurements.	Yes
		Calculated Rating	0.00	Calculated Rating	0.00	Calculated Rating	0.00	Calculated Rating	0.00	Calculated Rating	0.00
		SELECTED RATING	0.50	SELECTED RATING	0.20	SELECTED RATING	0.50	SELECTED RATING	0.60	SELECTED RATING	0.20

C.4.1 RESULTS - Annual Probability of Slope Failure based on Lambe Method (2008) - After Remediation

The probability of Slope Failure is a function of Factor of Safety which is calculated for a site.

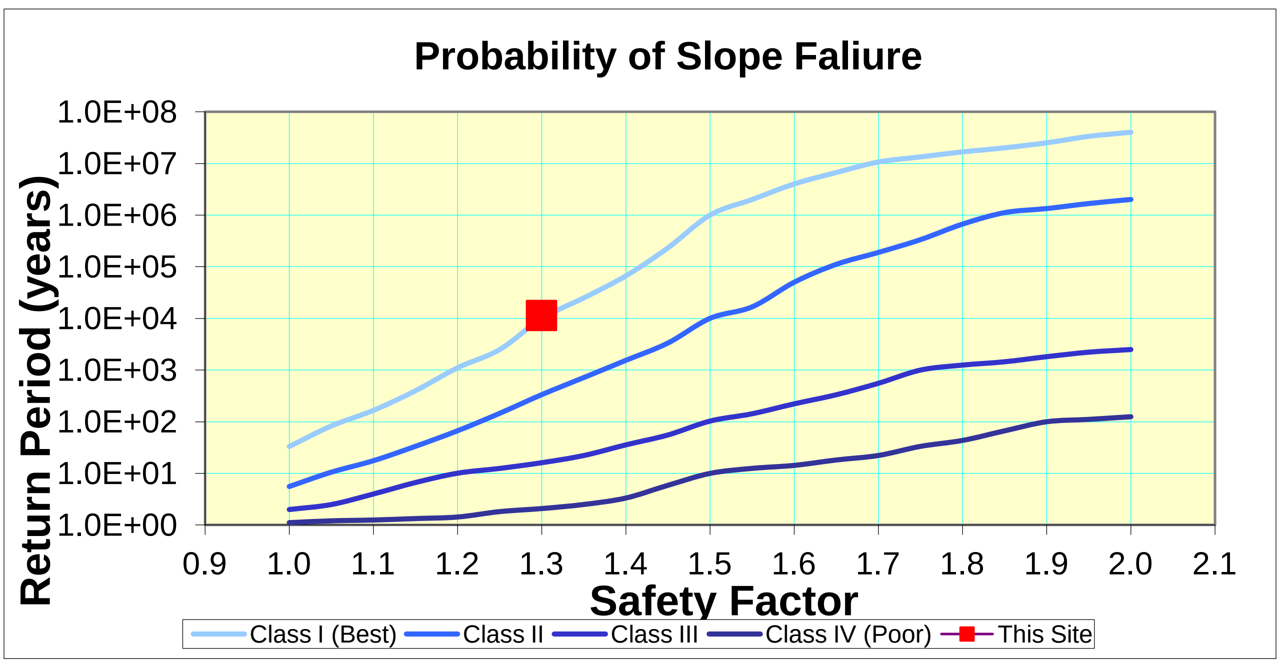
Earth Structures can be classified into 4 Classes based on; Investigation, Testing, Analysis & Documentation, Construction, and Operation & Monitoring.

Safety Factor	1.3

Class	Score	Return Period
I	1	11380
II	2	382
III	3	19
IV	4	2

Site Score				
Design			Construction	Operation and Monitoring
Investigations	Testing	Analysis & Documentation		
0.50	0.20	0.50	0.60	0.20

Overall Score	2.00 (to)	
Failure return period	11380 years	8.8E-05
Expected life of typical dam	100 years	



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