Final Report for Creative Sentencing

Protecting Worker Safety in Alberta
by Enhancing Field Level Hazard Assessments
and Training for Ground Hazards Associated with
Tailings Facilities, Dams, and Systems

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DEDICATION

May we remember the importance of keeping everyone safe and managing risk in one of the most challenging working environments in Canada. We will never fully be aware of what we don't know, but we can be mindful of our limitations, aware of our surroundings, utilize tools to identify abnormal conditions and ask for help when required.

EXECUTIVE SUMMARY

Efforts related to the safety and performance of oil sands tailings storage and transportation facilities have traditionally focused on preventing catastrophic failures and are well defined by government legislation and industrial best practices. However, a recent death related to ground hazards near oil sands tailings facilities, dykes, and transport systems signals the need for improved worker safety during daily operations near these facilities. Ground hazards are known and understood by geotechnical experts, but a breakdown in communication occurs with respect to informing frontline workers. This final report serves to provide a thorough review of the research completed as part of the creative sentencing project resulting from that fatality. It represents an unprecedented collaboration and initiative between the oil sands industry, regional contractors, the Province of Alberta, and the University of Alberta.

The outcomes of this research project are increasing the discussion of worker safety in tailings by the:

(1) creation of seven tailings specific, so called, Bow Tie Diagrams that graphically provide a means to showcase hazards, threats, consequences and controls,
(2) interviews with 158 frontline workers, leaders and regional contractors to determine the viewpoint of internal stakeholders,
(3) development of a generalized framework for ground hazards in the oil sands tailings operations,
(4) creation of ground hazard photo databases for summer, winter and spring that include descriptions of the ground hazards, potential consequences, precursory conditions and temporal factors,
(5) inaugural Tailings Safety Symposium to promote collaboration between oil sands owner companies and regional contractors, and
(6) presentation of this research to 12 diverse interdisciplinary audiences across Canada.

A holistic approach to operations and worker safety that includes managing the dynamic tailings work environment, job tasks, human factor considerations, and the potential for unknown hazards so that workers are better able to control all hazards in their work environments. Of particular concern are ground hazards in oil sands tailings operations as they not always apparent and pose a threat to workers with no training relevant to ground hazards when working near tailings facilities, dykes, and transport systems.

Over the two-year research project, data were collected from four sources: the Energy Safety Canada tailings hazard inventory; incident databases related to the oil sands tailings operations;

interviews with tailings workers, regional contractors, and leadership; and a ground hazard assessment conducted by the University of Alberta. These four datasets were compared to determine similarities and differences and then provide recommendations for enhancement of the current hazard identification tools and controls for ground hazards.

Process safety management tools such as the Bow Tie Risk Assessment Method were used to cluster the tailings hazard inventory and identify areas for enhanced controls. Energy Safety Canada subject matter experts reviewed the bow tie diagrams to ensure applicability to tailings operations. The final bow tie diagrams showed a heavy reliance on administrative controls (56% of the controls mentioned were administrative) such as training, permits, and hazard assessment to protect worker safety. This value was confirmed by engineers who indicated that engineering controls and elimination and substitution methods are implemented in the design phase, but administrative controls are the primary method to mitigate hazards in the field during daily operations.

Tailings incident databases from multiple companies were analyzed to determine what incidents are actually happening in the tailings operations and what is being reported. The data were categorized by hazard type, with a focus on incidents caused by or that could cause ground hazards. Incidents in the ground hazard category include slips, trips, and falls; stuck or sunk equipment; pipeline leaks; and reported ground hazards (i.e., berm breaches, washouts, and over-poured cells). It was determined that almost a quarter (23%) of the reported incidents related to ground hazards.

Interviews were also completed with 158 frontline tailings workers, safety personnel, engineers, supervisors, leadership, and regional contractors. Interviewees were asked about the hazards they see in the tailings operations, what solutions or changes they would like to see implemented, and what "words of wisdom" they would pass down to new workers. Workers are aware of the unique, dynamic environment in which they work; however, incidents still occur. One of the reasons incidents are occurring is a lack of information or training regarding tailings specific hazards.

Given the lack of training on tailings specific hazards, a framework was developed to discuss ground hazards in the oil sands tailings operations. This framework includes definitions of the four main ground hazards identified by the University of Alberta during their site visits: soft ground, surface erosion, subsurface erosion, and slope instability. To accompany this framework, three ground hazard photo databases have also been created. The photos were taken in three seasons (summer, winter, and spring) of representative tailings facilities, dykes, and transport systems. The hazards in tailings operations are seasonal, indicating the importance for multiple site visits and differentiation between times of the year. How these ground hazards manifest, potential consequences, precursory conditions, and temporal factors are discussed in the figures.

Another deliverable of this project was the dissemination of information. The results of this research were presented numerous times to the Energy Safety Canada Tailings Safety Task Force at their office in Fort McMurray. This task force has representation from all of the major oil sands operators and regional contractors. Participation from members was invaluable in terms of providing expert information for the project. Information provided at these meetings was shared with the respective organizations represented by these participants. This type of collaboration regarding tailings related safety in the oil sands is unprecedented, and is set up to continue after the conclusion of this project.

On November 29, 2018, the results of this research were also presented to the most important stakeholders—the tailings workers, contractors, and leadership—at an inaugural Tailings Safety Symposium. The 105 people in attendance represented 15 organizations. The findings from the project were presented to the group and feedback on next steps was solicited through group brainstorming methods.

In addition to the local oil sands community, this research has also been presented 12 times to diverse audiences at academic and industrial conferences and workshops, including the Canadian Institute of Mining Convention 2018, Petroleum Safety Conference 2018, Canadian Chemical Engineering Conference 2017 and 2018, GeoEdmonton 2018, and 2018 Geohazards 7. The attendees at these presentations provided valuable feedback on the project at every stage of the research process. The full list of academic presentations can be found in Appendix G along with the accepted abstracts. This research will continue to be disseminated after submission of this report as the work has been accepted for presentation at two conferences in 2019: the Society for Risk Analysis and the Center for Risk, Integrity and Safety Engineering Symposium.

Based on the analysis of the collected data and discussions with subject matter experts at Energy Safety Canada eight recommendations were developed. The recommendations are:

(1) increased communication within industry,

(2) increased communication within companies,

(3) enhancements to hazard identification tools,

(4) critically evaluate current operations, like the operation of spill boxes,

(5) increase resources,

(6) tailings-specific training,

(7) regional standardization, and

(8) enhancements to incident databases.

Energy Safety Canada has already begun the process of implementing these recommendations with the oil sands tailings industry by taking the following actions: setting up continued meetings of the tailings safety task force, creating smaller working groups to address regional training, alignment of standards on all sites, pipeline leak best practices, spill box operation best practices, working on water and ice best practices, and engaging with emergency response teams to ensure competency for successful emergency response plans. They have also proposed a monthly call for companies (owners and contractors) to discuss lessons learned and share incidents. This type of collaboration regarding safety is unprecedented in industry, and the continued partnership will significantly improve personal safety in the tailings. Hopefully, other industries will see this project as a case study to begin their own collaborations.

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Imperial Oil Limited

Ketek

Ledcor

Owl Moon Environmental Inc.

Primoris Canada

Rough Rider International Limited

Suncor Energy

Syncrude Canada Limited

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LIST OF ABBREVIATIONS

AER	Alberta Energy Regulator
AICHE	American Institute of Chemical Engineers
APEGA	Association of Professional Engineers and Geoscientists of Alberta
BT	Bow Tie Analysis Method
COSIA	Canada's Oil Sands Innovation Alliance
CIM	Canadian Institute of Mining
DyPASI	Dynamic Procedure for Atypical Scenarios Identification
ESC	Energy Safety Canada
FLHA	Field Level Hazard Assessment
FLRA	Field Level Risk Assessment
HEO	Heavy Equipment Operator
IAS	Industry Accepted Standards
IRP	Industry Recommended Practices
JSA	Job Safety Analysis
LPSA	Loss Prevention Self Assessment
MOC	Management of Change
NORMs	Naturally Occurring Radioactive Materials
OHS	Occupational Health and Safety
PFD	Personal Flotation Device
PPE	Personal Protective Equipment
PSC	Petroleum Safety Conference
REB	Research Ethics Board
SIFp	Serious Injury and Fatality Prevention
TDA	Tailings Discharge Area
TSS	Tailings Safety Symposium
U of A	University of Alberta
WCB	Workers Compensation Board

TECHNICAL GLOSSARY

Administrative Control Failure: when an administrative control fails to work, resulting in a near miss or incident.

Basic / Root Causes: the reason why substandard acts and conditions exist.

Benches: earthen structures used to stabilize the steep working faces of the mine or tailings discharge area and prevent ground from sloughing onto workers or equipment below.

Berms: sloped dividing walls between cells in the tailings discharge area, made by bulldozers pushing produced tailings into walls at approximately a 3:1 ratio.

Biological Hazard: poses a threat due to exposure to something in the environment, e.g., dust, wildlife, NORMs, etc.

Cells: the non-compacted tailings discharge containment area.

Chemical Hazard: poses a threat that is toxic, corrosive, flammable, explosive, reactive, or creates an oxygen-deficient atmosphere.

Controls: a measure (engineered, administrative, or personal protective equipment) that brings the risk of a hazard to a level that is as low as reasonably practicable.

Creative Sentence: an often unorthodox or innovative sentence as an alternative to imprisonment, especially with the aim of linking the punishment to the crime (Oxford Dictionary, 2018).

Cuts: when process water and tailings are discharged into the tailings discharge area at a high velocity, the product can erode the sand and tailings below and create an erosion feature.

Consequence: the possible impact of an unwanted event.

Differential Settlement: when the ground settles at different rates due to the varied compositions of soil, tailings, silt, and clay.

Electrical Hazard: poses a threat that could cause electrocution due to exposure to live circuits or stored energy in systems.

End of Line Device: an end-of-pipe device to help dissipate the kinetic energy from the tailings discharge pipeline and avoid the creation of cuts and other erosion features in the cell; also called a spoon.

Ergonomic Hazard: poses a threat to a moving body part or the moving body.

Erosion: being gradually worn by natural mechanisms, typically by tailings, process, or ground water in this case.

Erosion Gully: removal of ground along drainage lines.

Fine Tailings: smaller fraction (clay, silt, fine sand particles) of the by-product of the bitumen extraction process for oilsands operations. It consists of a mixture that includes water, silt, clay, residual bitumen and lighter hydrocarbons.

Ground Hazard: naturally occurring hazard, such as surface and subsurface erosion, soft ground, or slope instability, that could have an adverse effect on people, the environment, assets, or production in oil sands tailings operations

Group 1 Risk: an intolerable risk requiring immediate corrective action.

Group 2 and Group 3 Risks: medium risks requiring reduction measures.

Group 4 Risk: a risk that is currently being appropriately managed but must be monitored for continuous improvement.

Hazard: an agent that can cause harm to people, the environment, assets, or production.

Incident: an unplanned and undesired event.

Likelihood: the probability of an unwanted event occurring.

Line of Fire Hazard: direct contact between a person and a force their body cannot endure. Includes contact with stored energy, striking hazards, and crushing hazards (ESC, 2018a)

Lagging Indicators: major injuries, minor injuries, and property damage incidents; includes fatalities, serious injuries, equipment damage, or loss of containment with a consequence to people or the environment.

Leading Indicators: substandard acts and conditions observed on the site; includes unsafe acts/ conditions, auditing of structured rounds, or the culture in the workplace.

Loss of Containment: an unplanned or uncontrolled release of material from primary containment, including non-toxic and non-flammable materials (CCPS, 2018b).

Mature Fine Tailings (MFT): tailings consisting mostly of clay and water.

Mitigation Controls: after an unwanted event occurs, these measures prevent a consequence from occurring, typically via administrative or personal protective equipment.

Near Miss: an incident that could have but did not result in a loss to people, the environment, assets, or production.

Potential Gravitational Hazard: poses a threat due to a fall to the same or a lower level.

Precursory Events: indicators that could help workers to proactively identify changes in the ground prior to an incident occurring.

Sink Holes: a cavity in the ground caused by a collapse in the surface layers into an underlying void.

Soft Ground: ground that may have problems supporting the weight of a person or a piece of equipment due to saturated conditions.

Structured Rounds: daily tasks that workers in the tailings operations complete to ensure the process is operating effectively and safely.

Substandard Acts: violation of an accepted procedure that could permit the occurrence of an incident.

Subsurface Erosion: erosion of soil materials underneath the exposed, visible ground surface or snow/ice cover; typically caused by water with the potential to generate large voids or caverns.

Substandard Conditions: hazardous physical conditions or circumstances that could directly permit the occurrence of an incident.

Slope Instability: a slope on the verge of failure; the substandard condition that could lead to a failed slope when sediment, tailings, rock, ice, or snow moves downhill in response to gravity.

Sloughing: sand or soil falling off slopes in sheets in slumps due to loss of cohesion.

Surface Erosion: sand and soil on the surface being gradually worn by natural mechanisms, typically by tailings, process, or ground water in this case.

Tailings: by-product of extracting bitumen from oil sands, typically consisting of sand, silt, clay, and residual bitumen (AER, 2018).

Tailings Discharge: the waste stream from the extraction process containing silica sand, process water, residual bitumen, and other chemicals.

Tailings Discharge Area: where tailings of larger particle diameter are stored.

Tailings Pond: where mature fine tailings and process water are stored.

Temporal Factors: conditions that can influence the manifestation of ground hazards in a particular area, typically relating to season, temperature, visibility, and climate.

Thermal Hazard: poses a threat due to exposure to a hot or cold substance or enclosed environment.

Threat: activities that could lead to an unwanted event.

Threat Control: measures such as engineered and administrative controls that prevent an unwanted event from occurring.

Uneven Ground: ground with changes in grade and/or elevation due to differential settlement, freeze-thaw cycles, earth work, etc.

Unwanted Event: a potential incident that could happen on the work site.

Washout: the result of a loss of containment event, in which the sand or soil is washed away to create an erosion feature.

Worker Error / Negligence: when worker error or negligence is one of the causes of an incident.

1 Introduction

Ground hazards such as soft ground and slope instability can manifest in industrial settings such as oil sands, construction, or railway. Ground hazards are common and, as such, contribute to the large number of lost time incidents that occur each year in Alberta. In the five-year period from 2011 to 2015, seven fatalities occurred in the Alberta oil sands operations sub-sector, one of which was directly related to a ground hazard (Government of Alberta, 2017). Despite efforts directed towards tailings management, recent incidents have emphasized shortcomings in the identification and control of associated hazards. The Vancouver Sun reported 49 'dangerous occurrences' associated with tailings facilities occurred between 2000 and 2014 in British Columbia (Hoekstra, 2014). This article emphasized that most of these incidents were contained within the mine sites and posed no risk to the public, but worker safety was not mentioned. By enhancing the tools used to identify and control hazards, the number of incidents, fatalities, and lost time could be decreased.

The current ground hazard risk mitigation strategies for the oil sands sector focus on the performance of structures and operations for tailings storage and transport facilities. Occupational Health and Safety (OH&S) legislation is used to protect workers from job-specific hazards. A more holistic approach would incorporate multiple safety management systems and legislation to enhance the current hazard identification and controls and better inform workers about the ground hazards to which they are exposed.

The communication of ground hazard risks to frontline workers has been identified as a gap in both the literature and in practice at oil sands mines. This report aims to address this gap by providing a list of potential hazards, precursory conditions, and controls that can be integrated into training and developing hazard identification tools and training through the examination of four data sources:

1. Energy Safety Canada hazard inventories;
2. Incident databases;
3. Interviews with frontline workers, regional contractors, and leadership; and
4. A ground hazard assessment associated with tailings transport and storage facilities, conducted during field visits by the research team to oil sands operations.

The field visits had the secondary benefit of familiarizing the research team with site operations. Existing industry experience is synthesized through analysis of the inventories, interviews, and incident databases.

1.1 Scope of the Document

As per the accepted proposal for creative sentencing, Protecting Worker Safety in Alberta by Enhancing Field Level Hazard Assessments and Training for Ground Hazards Associated with Tailings Facilities, Dams and Systems (Forbes et al., 2017), a final report is required within two years of the date of the court order. This report will contain the methodologies and tools developed over the duration of the project. The submission of this document serves to communicate the findings and methodologies developed by the University of Alberta (U of A) research group to

Alberta Occupational Health and Safety and Alberta Justice regarding the creative sentencing project.

2 Background

2.1 Description of Fatality

A worker drowned in an underground cavern, created by a pin-hole sized leak of hot tailings from a pipeline on January 19, 2014 around 6:00 am (OHS, 2017). Protocols to ensure the safety of workers were followed, including the use of pipeline leak detection and mitigation, administrative controls such as call-in procedures, and the use of personal protective equipment (OHS, 2017). Despite these hazard identifications and controls, none of the frontline tailings team knew that a tailings leak could create an underground cavern. Steam is typically used as an indicator of a leak in winter because of the temperature differential between the hot tailings and the ambient environment. As the tailings were draining elsewhere from the cavern, no steam was emitted at the leak site, and there was no warning of the pipeline leak. This hazard was also hidden by the snow- and ice-covered ground and early-morning darkness (OHS 2017).

Please see Appendix A for a copy of the full Occupational Health and Safety Report describing the fatality (OHS, 2017).

2.2 Athabasca Oil Sands Region

The Athabasca Oil Sands Region, situated in northeastern Alberta as depicted in Figure 1, contains approximately 90,000 km^2 of active oil sands deposits, making it the largest such deposit in the world (AER, 2018). This region experiences dynamic weather changes throughout the year, with average ambient temperatures of 16.8 °C in July and −18.8 °C in January, as seen in Table 1 and Figure 2. However, the air temperature can vary much more, leading to temperatures as low as −50.6 °C in the winter months and as warm as 37 °C in the summer (Alberta Agriculture and Forestry, 2018). This fluctuation in temperature makes the Athabasca Oil Sands Region a harsh climate for work and can also affect the visibility in the tailings operations. Steam is produced when hot tailings are discharged into cooler surrounding air. The winter months tend to correspond with the most variation in the discharge and air temperatures and therefore the most steam; however, cooler summer days can also lead to steam in the tailings operations.

The precipitation in the area ranges from a peak in rainfall of 81.3 mm in July to 29 cm of snow (26.6 mm snow water equivalent) in November (Table 1 and Figure 2). Precipitation makes ground conditions more difficult for work and also reduces visibility. Precipitation events can be very damaging as the roads are constructed out of sand and tailings and can become unpassable in the rain.

Figure 1. Map of the Athabasca oil sands deposit in northeastern Alberta (AER, 2018).

Table 1. Climate normals for Fort McMurray, 1971 to 2000 (Environment Canada, 2018).

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Daily Average (°C)	-18.8	-13.7	-6.5	3.4	10.4	14.7	16.8	15.3	9.4	2.8	-8.5	-16.5
Daily Maximum (°C)	-13.6	-7.6	0.3	10	17.4	21.4	23.2	21.9	15.4	7.8	-4.2	-11.6
Daily Minimum (°C)	-24	-19.8	-13.2	-3.3	3.3	7.9	10.2	8.6	3.3	-2.2	-12.8	-21.4
Extreme Maximum (°C)	13.1	15	18.9	30.2	34.8	36.1	35.6	**37**	32.4	28.6	18.9	10.7
Extreme Minimum (°C)	-50	**-50.6**	-44.4	-34.4	-13.3	-4.4	-3.3	-2.9	-15.6	-24.5	-37.8	-47.2
Rainfall (mm)	0.5	0.8	1.6	9.3	34.2	74.8	81.3	72.6	45	18.8	2.4	1.1
Snowfall (cm)	27	20.6	20.4	14.5	2.9	0	0	0	2.4	13.1	29	25.9
Precipitation (mm)	19.3	15	16.1	21.7	36.9	74.8	81.3	72.7	46.8	29.6	22.2	19.3
Average Snow Depth (cm)	28	31	26	6	0	0	0	0	0	1	9	20
Days with Precipitation ≥ 0.2 mm	12.3	10.3	9.2	8.1	10.9	14.1	15.8	13.5	12.6	11.1	12.2	12.4
Days with Precipitation ≥ 5 mm	0.8	0.6	0.7	1.4	2.3	4.7	5.1	4.3	2.9	1.5	1.1	0.6
Days with Visibility < 1 km	3.2	2.8	3.3	4.9	2.1	3.1	5.5	8.5	7.9	6	4.5	3
Wind Speed (km/h)	8.4	9.1	9.6	10.9	10.8	9.7	9	8.7	9.7	10.5	9	8.6
Extreme Wind Chill (°C)	-58	-60	-57	-46	-21	-6	**-3**	-6	-16	-32	-50	-53

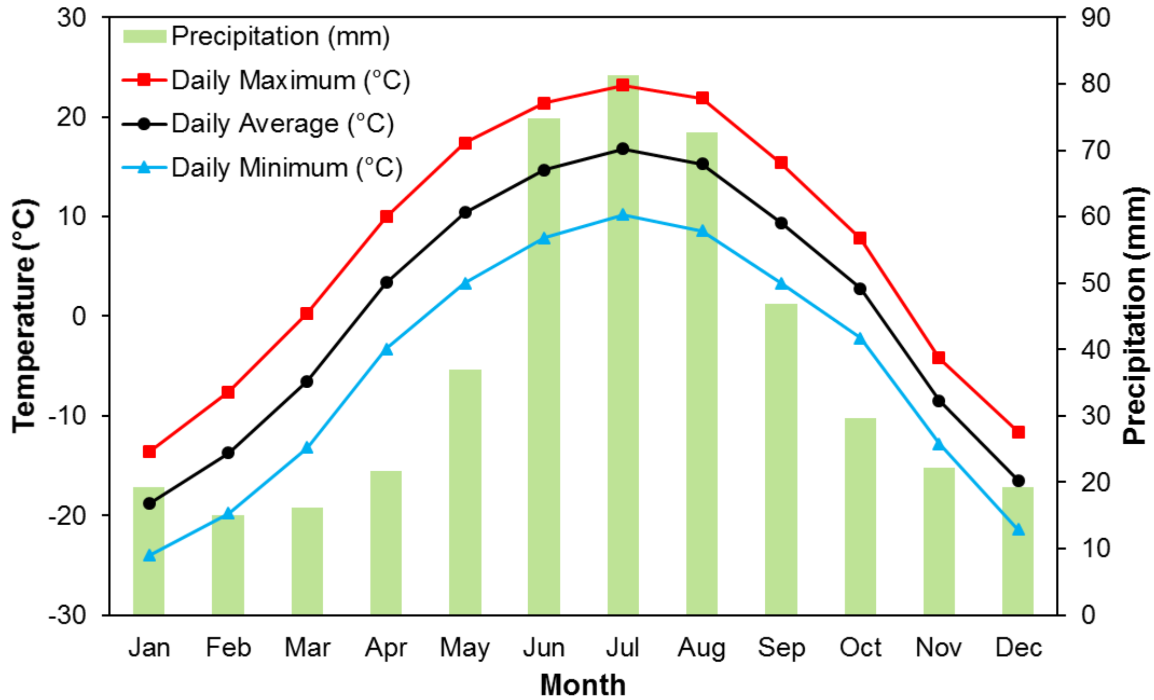


Figure 2. Temperature and precipitation graph for 1971 to 2000 Canadian climate normals, Fort McMurray (after Environment Canada, 2018).

This region has nine approved oil sands mines (AER, 2018). Each has unique operations and processing, but they all function on the same principle of mining oil sands, using open pit methods, then extracting and upgrading bitumen to produce other hydrocarbon products for use by consumers. They also all create tailings, which are a by-product of extracting the bitumen from the oil sands and consist of varying concentrations of water, silt, sand, clay, and residual bitumen (AER, 2018). Oil sands tailings are typically classified by their particle size and stored in tailings ponds on the mine site. Process water is also stored in these ponds for use in extraction and upgrading processes.

2.3 Tailings Operations Overview

The tailings operations in the Athabasca oil sands exist to manage the by-products of bitumen processing. Oil sands tailings consist of sand, process water, residual bitumen, and other chemicals used in the extraction process (Devenny, 2010). The tailings operations serve two functions: (1) capture sand for reclamation projects and (2) balance water around the facility for extraction and upgrading (Devenny, 2010).

The operations vary depending on the oil sands site. Some operations divide the tailings into coarse or fine fractions depending on particle size; other sites consider tailings discharge and process water as two separate streams and yet others use a combination of the two. For simplicity, any coarse tailings operations will be called “tailings discharge” and other tailings operations will be called "fine tailings". Both of these operations are comprised of multiple tailings facilities, dykes, and transport systems. Figure 3 is a simplified process flow diagram of the mining, extraction, and tailings production process.

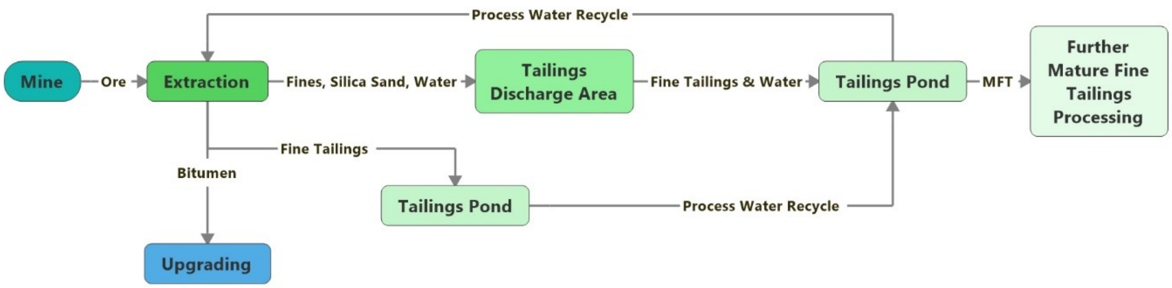


Figure 3. Simplified process flow of the mining, extraction, and tailings production process in the Athabasca oil sands.

2.3.1 Tailings Discharge Area

The tailings discharge area is where the larger particle size sand (>130 µm) is captured; these areas will eventually be reclaimed and must follow the Tailings Management Framework (Government of Alberta, 2015a). Planning engineers design these tailings facilities, which are comprised of dykes and benches such as those in Figure 4. Areas in the tailings discharge area known as cells are where tailings sand is stored, compacted using bulldozers to remove entrapped water, and eventually reclaimed (Devenny, 2010).

Figure 4. Cell construction in the tailings discharge area at an oil sands mine.

The tailings run down to the tailings discharge area or "cell" where sand is captured and the process water flows down to a small pond in the centre where a dredge then pumps water around the rest of the tailings operations for use in extraction or upgrading. To build these features, tailings are discharged from a pipe (hydraulically placed) that is typically equipped with an end of line device, sometimes called a spoon (Figure 5), into the cell in the tailings discharge area. The spoon is designed to dissipate kinetic energy and prevent the formation of surface erosion features, such as cuts, in the cell. The tailings discharge is a combination of silica sand, process water, residual bitumen, and other chemicals at a temperature between 45 and 50 °C.

Figure 5. End of line device (or spoon): out of service (top left), in service (top right), and inactive (bottom).

To build the dykes and benches in the tailings discharge area, bulldozers push the material and also compact, or track pack, to ensure the stability and optimal compaction of the facility for reclamation (Figure 6).

Figure 6. Bulldozer compacting sand in the tailings discharge area.

2.3.2 Fluid Tailings

The process water with some residual bitumen, small particle size sand (<44 µm), and chemicals is then transported via pipeline into tailings ponds around the tailings operations (Figure 7). These tailings ponds are contained by dykes and monitoring systems (e.g., piezometers) to ensure the performance of these structures and prevent releases that could affect the public or the environment. Dredges remove mature fine tailings (MFT) from the pond to manage the mudline and the water level. Water is also removed from the pond and pumped around the rest of the mine as process water. Workers obtain access to the dredges by walkway or boat.

2.3.3 Tailings Transport Systems

The tailings are moved from extraction to the tailings operations using tailings transport systems or pipelines (Figures 8 and 9). The transportation system is made up of permanent stainless-steel main line pipe (~28" diameter), and sometimes pipe that is lined with polymer or urethane to decrease the amount of pipe wear from the abrasive sand. There are also networks of friction fit pipe (nipple pipe, ~28" diameter) used for short-term operations in the tailings discharge area. Pipe in this area is moved quickly and frequently through pipeline advances, where more friction fit pipe is added as sand is discharged into the cell. The friction fit pipe is moved using equipment such as bulldozers or loaders.

Figure 7. Photo of a dredge and boat on a tailings pond in winter.

Figure 8. Photo of main line pipe.

Figure 9. Photo of out of service friction fit pipe.

2.4 Research Project Background

Tailings operations, specifically tailings facilities, dykes, and transport systems, are the focus of this creative sentencing project because minimal research has been conducted into worker safety at tailings operations. Energy Safety Canada (ESC) (a merger of the Oil Sands Safety Association and Enform) identified the lack of information surrounding worker safety at tailings operations (ESC, 2018b). In 2014, ESC created a tailings safety task force to tour oil sands mines and identify hazards in the tailings operations as well as share knowledge and best practices amongst operators (ESC, 2018b). They employed the Process Hazard Analysis technique, “What If Analysis”, to identify hazards and hazardous activities in oil sands tailings operations. With this information, they developed a prioritized inventory of hazards that were similar across all operations.

ESC agreed upon the risk matrix, shown in Figure 10, to conduct the risk review and prioritize the hazard inventory. This risk matrix is based on risk being defined as likelihood multiplied by potential consequence. Using the matrix, each hazard was discussed to determine its likelihood of occurrence and the potential consequence. It was then assigned to a group: Group 1 was intolerable risk requiring immediate corrective action, Groups 2 and 3 were medium risk requiring reduction measures, and Group 4 was risks that are currently being appropriately managed but must be monitored for continuous improvement. Hazards assigned to a group were then weighted to determine the final priority.

This hazard inventory was completed prior to the U of A's involvement in the project. In 2017, the U of A and regional contractors became involved with the project and ESC gave the hazard inventory to the U of A research group for further analysis.

The identification of ground hazards and enhanced controls was the focus of this research, as a ground hazard is what caused the fatality in 2014. Other members of the ESC task force identified the potential for a similar hazard to manifest on their sites and were keen to become involved in the project as well. This collaboration with ESC has allowed this project to become an industry-wide initiative involving multiple oil sands companies and regional contractors. This degree of collaboration is unprecedented and should serve as a model for other industries with respect to how to prioritize worker safety and implement industry best practices.

			LIKELIHOOD				
			A	**B**	**C**	**D**	**E**
			VERY LIKELY	**SOMEWHAT LIKELY**	**UNLIKELY**	**VERY UNLIKELY**	**PRACTICALLY IMPOSSIBLE**
		SAFETY / HEALTH	- Has occurred once or more in the region in the last 10 years or so - Has occurred several times in the industry in the last 10 years or so	- May occur more than once in the region in 10 - 40 years - Has occurred several times in the industry	- May occur once in the region in 10 - 40 years - Has occurred a few times in the industry	- Similar event may occur every 40 - 100 years at one of the regional sites - Have been isolated occurrences in industry	- Has not happened in the regional sites - Has happened a few times or not at all in industry
POTENTIAL CONSEQUENCE	**I**	Fatalities; Serious Injury to members of public	**1**	**1**	**1**	**2**	**3**
	II	Serious or Lost Time Injury / Illness	**1**	**1**	**2**	**3**	**4**
	III	Restricted Work or Medical Treatment	**2**	**2**	**3**	**4**	**4**
	IV	First Aid / Minor Injury	**3**	**4**	**4**	**4**	**4**

Group 1	Intolerable risk - immediate corrective a
Group 2	Incorporate risk-reduction measures
Group 3	Consider incorporating risk-reduction measures
Group 4	Manage for continuous improvement

Figure 10. Energy Safety Canada risk matrix (ESC, 2018b).

2.5 Regulatory

According to the Alberta Workers Compensation Board, in the 5-year period from 2011 to 2015 an average of one workplace incident fatality occurred and approximately 300 people sustained disabling injuries per year in the oil sands operations sub-sector (Government of Alberta, 2017). A concerted safety effort in the oil sands industry, spanning over three decades of continuous improvement, has significantly reduced incidents overall to the levels cited in Table 2. The industry has achieved leading safety performance when compared to other industries across the province, with a significant decrease in the disabling injury rate of 130% within the short 5-year period from 2011 to 2016. Leading firms in the oil sands contend that there is further opportunity to reduce injury frequencies. This opportunity is confirmed with the fatality statistics, which are relatively low, but do not show an apparent decrease over the last 10 years (Table 3). These firms acknowledge that further improvements may arise by equipping frontline workers with increased knowledge and understanding of hazards specific to their work environment; hence, this study aimed to characterize tailings related hazards and mitigative measures.

Table 2. WCB-reported disabling injury rate in Alberta by industry (disabling injury claims /100 person-years).

Disabling injury rate (disabling injury claims /100 person-years).							
Major Industry Sector	**2011***	**2012†**	**2013†**	**2014‡**	**2015§**	**2016§**	**Change 2011 - 2016**
Agriculture and Forestry	2.33	2.61	2.55	2.76	2.71	2.85	18%
Business, Personal and Professional Services	1.54	1.53	1.58	1.50	1.50	1.54	0%
Construction and Construction Trade Services	2.83	2.89	2.79	2.88	2.53	2.41	-17%
Manufacturing, Processing and Packing	4.54	4.48	4.10	3.97	3.30	3.10	-46%
Mining and Petroleum Development	1.86	1.44	1.30	1.46	0.90	0.81	-130%
Provincial and Municipal Government, Education and Health Services	2.81	2.83	2.89	2.88	2.87	2.91	3%
Transportation, Communication and Utilities	3.97	3.75	3.81	3.36	2.81	2.66	-49%
Wholesale and Retail	2.89	2.88	2.88	2.93	2.70	2.60	-11%

* Government of Alberta (2011b), † Government of Alberta (2013a), ‡ Government of Alberta (2015b), § Government of Alberta (2016a)

Table 3. Comparison of Province of Alberta (all sectors), mining and petroleum development sector, and oil sands operations sub-sector fatalities statistics by year.

	Fatalities by year accepted by WCB		
Year	**Province of Alberta- All Sectors**	**Mining and Petroleum Development Sector**	**Oil Sands Operations Sub-sector**
2006	124*	17[†]	1[†]
2007	154[‡]	10[‡]	0[†]
2008	164[‡]	13[‡]	0[†]
2009	110[‡]	13[‡]	4[†]
2010	136[‡]	15[‡]	0[†]
2011	123[§]	10[§]	1[¶]
2012	145[‖]	19[‖]	0[¶]
2013	188[‖]	18[‖]	1[¶]
2014	169[‖]	16[‖]	4[¶]
2015	125[‖]	9[‖]	1[¶]
2016	144[‖]	14[‖]	-
Total	**1582**	**153**	**12**

* Government of Alberta (2011a), [†] Government of Alberta (2011d), [‡] Government of Alberta (2011c), [§] Government of Alberta (2013b), [‖] Government of Alberta (2016b), [¶] Government of Alberta (2017)

The design and operation of tailings facilities tends to focus on the performance of the structures and the potential for catastrophic failures that have a large impact on the environment and the public, such as the Mount Polley tailings dam failure (Chambers, 2016). Legislation such as the Alberta Energy Regulator (AER) Tailings Management Framework, Oil Sands Conservation Act, and the Dam and Canal Safety Guidelines sets high standards for the safety management of tailings working environments (Government of Alberta, 1999, 2000, 2015a). The industry also has best practices such as those outlined in the Canadian International Mining (CIM) guidelines (1997) and the Canada's Oil Sands Innovation Alliance (COSIA) Oil Sands Tailings Technology Roadmap (COSIA, 2012). Table 4 summarizes the types of materials mentioned in each document. Only one of the documents analyzed—an Alberta government publication entitled 'Reasonable Actions: A Plan for Alberta's Oil Sands' (Government of Alberta, 2009)—mentions both worker safety and the oil sands, but not tailings safety directly. The other four documents do not mention workers operating in the tailings environment; their focus is instead on the performance and operation of the structures or reclamation of the tailings facilities. This report reviews the best practices and legislation in Alberta regarding worker safety, and specifically regarding tailings operations; importantly, it highlights the apparent lack of overlap in this regard.

Table 4. Mentions of "worker safety", "tailings safety", and "reclamation" in common regulations and best practices in the oil sands industry.

Document Title	**Worker Safety**	**Tailings Safety**	**Reclamation**
AER Tailings Management Framework (Government of Alberta, 2015a)	No	No	Yes
Oil Sands Conservation Act (Government of Alberta, 2000)	No	No	No
Responsible Actions: A Plan for Alberta's Oil Sands (Government of Alberta, 2009)	Yes	No	Yes
Dam and Canal Safety Guidelines (Government of Alberta, 1999)	No	Yes	No
COSIA Oil Sands Tailings Technology Development Roadmap (COSIA, 2012)	No	Yes	Yes

The Occupational Health and Safety (OHS) Code (2009) provides best practices for workers to identify and control hazards before completing their specific job tasks. This includes a section on hazard assessment, elimination, and control and the importance of identifying and managing hazards both related to the job and the worksite using tools such as the Field Level Hazard Assessment (OHS, 2009 and 2015). The subsequent sections of the code focus on hazards directly related to the job task; however, some sections, such as Part 32 on excavating and tunneling, discuss the job task, potential ground hazards, and the work environment, but this is a purposeful interaction with the work environment (OHS, 2009: Part 32). The part missing from the OHS Code is unintentional interactions with hazards, the manifestation of unidentified hazards in the work environment, and the effect of human factor considerations (safety challenges introduced by human behaviours) on the risk assessment process.

2.6 Tailings Safety

There is also a dearth of academic literature on the topic of worker safety and tailings operations. In fact, only three articles from researchers in China focus directly on tailings dam operation and worker safety (Wei et al., 2003; Li et al., 2010; Tang et al., 2012). These articles discuss factors that can impact worker safety including the technical nature of the tailings structure, but they do not analyze how these various factors interact.

This gap has been confirmed in the industry after site visits to multiple oil sands mines. While workers are following OHS legislation, a breakdown in communication occurs with respect to informing frontline tailings workers about potential and localized ground hazards. For example, a worker was observed connecting pipe next to a steep berm of hydraulically placed sand. The worker was following OHS protocol for the task but seemed to be unaware of the potential ground hazards in the area based on the way he positioned himself in relation to the steep berm. Increasing the level of communication between working groups (i.e., between geotechnical consultants and frontline workers) could result in a better understanding of the hazards in the work environment.

Of particular concern is the communication of ground hazards to two groups of workers, (1) "roving contractors" and (2) contractors who work on multiple sites. The "roving contractors" group includes mechanics, pipe fitters, welders, etc. who have a particular set of skills and are deployed to work in areas around tailings facilities, dykes, and transport systems, but have no knowledge of potential localized ground hazards that may not pose a risk to the performance of the structure but could put the worker at risk of injury or death. Contractors must also learn the processes and procedures for each site, which can be challenging when they do not align.

Tailings employees and contractors view tailings operations as a dynamic environment with a high potential of exposure to various hazards; however, they still have limited knowledge of the potential for ground hazards in their working environment.

2.7 Hazard Identification

The process of identifying and controlling hazards is displayed in Figure 11. To effectively control hazards, they must first be identified (Hallowell & Hansen, 2016). It is only after hazards have been identified that steps towards mitigation and control can be implemented. There is an important distinction between the next two steps of the hazard identification process. The hazard must be understood by the worker so they can decide if they tolerate the risk or not. The perception or understanding of risk is influenced by many external and internal factors, such as state of mind, inattention, training/knowledge of hazards, etc. (Sylvester, 2017). If internal factors such as perceived pressure, frustration, fatigue, or complacency are present, a worker may not be fully engaged in the task at hand (Sylvester, 2017). The result of this inattention could be increased exposure to risk as hazards are not being identified and are not controlled, eventually leading to harm (Sylvester, 2017).

However, even if a worker is mindful while working in hazardous environments and can identify and perceive the risk, there is still one more step before the risk can be managed, namely risk tolerance. Everyone has a different risk tolerance, which is influenced by both internal and external factors. Some workers may be predisposed to a higher risk tolerance compared to others or the company itself may unintentionally influence a worker's risk tolerance (e.g., by aiming to complete a job faster). The risk tolerance factors in Figure 11 are based on Sandman's outrage factors (1987), Jeelani and colleagues (2016) and ExxonMobil (2015).

If the hazard has been identified, perceived, and not tolerated, then effective controls can be implemented using principles of a hierarchy of controls; elimination or substitution is the ideal mitigation strategy followed by engineering controls, administrative controls, and personal protective equipment (CCPS, 2018a; CDC, 2015). It is also important to build in redundancy and have multiple controls in place in case one or more fail, a process called the Layers of Protection approach (Baybutt, 2002; Summers, 2003).

Even with all of the processes in place to identify hazards, perceive decreased risk tolerance, and control hazards, incidents still occur, which indicates some hazards are not seen (Jeelani et al., 2016). Research has determined that all workers have difficulty identifying hazards in dynamic, complex environments (Jeelani et al., 2016; Namian et al., 2016) and novice workers are unable to recognize 53% of hazards in their work environments (Bahn, 2013). Jeelani and colleagues completed a study in the construction industry and found 14 factors that can lead to a hazard not being identified: dynamic environments, unfamiliarity with tools, hazards unassociated with the primary task, low perceived levels of risk, premature termination of hazard recognition, unexpected hazards, visually unperceivable/obscure hazards, unknown hazards, selective attention or inattention, multiple hazards associated with a single source or task, task unfamiliarity, latent and stored energy hazards, hazard source detection failure, and hazards without immediate outcome onset (Jeelani et al., 2016).

Many of the aforementioned factors can manifest in the tailings operations as well, indicating the need for increased hazard identification to mitigate risk and prevent incidents. Workers are exposed to many work environment hazards that are not associated with the primary job task, e.g., such as welding pipe at the base of a steep berm. The tailings operations are also constantly changing as the company works towards reclamation in these areas but also continues to produce tailings as a waste product. Having unknown hazards as well as working in a dynamic environment can lead to a high-risk tolerance as it is such a challenging environment. Many hazards are unexpected or cannot easily be seen because they have not been previously identified or manifest underground or in pipelines as stored energy. No tailings-specific hazard training exists, which could lead to task unfamiliarity and unexpected hazards.

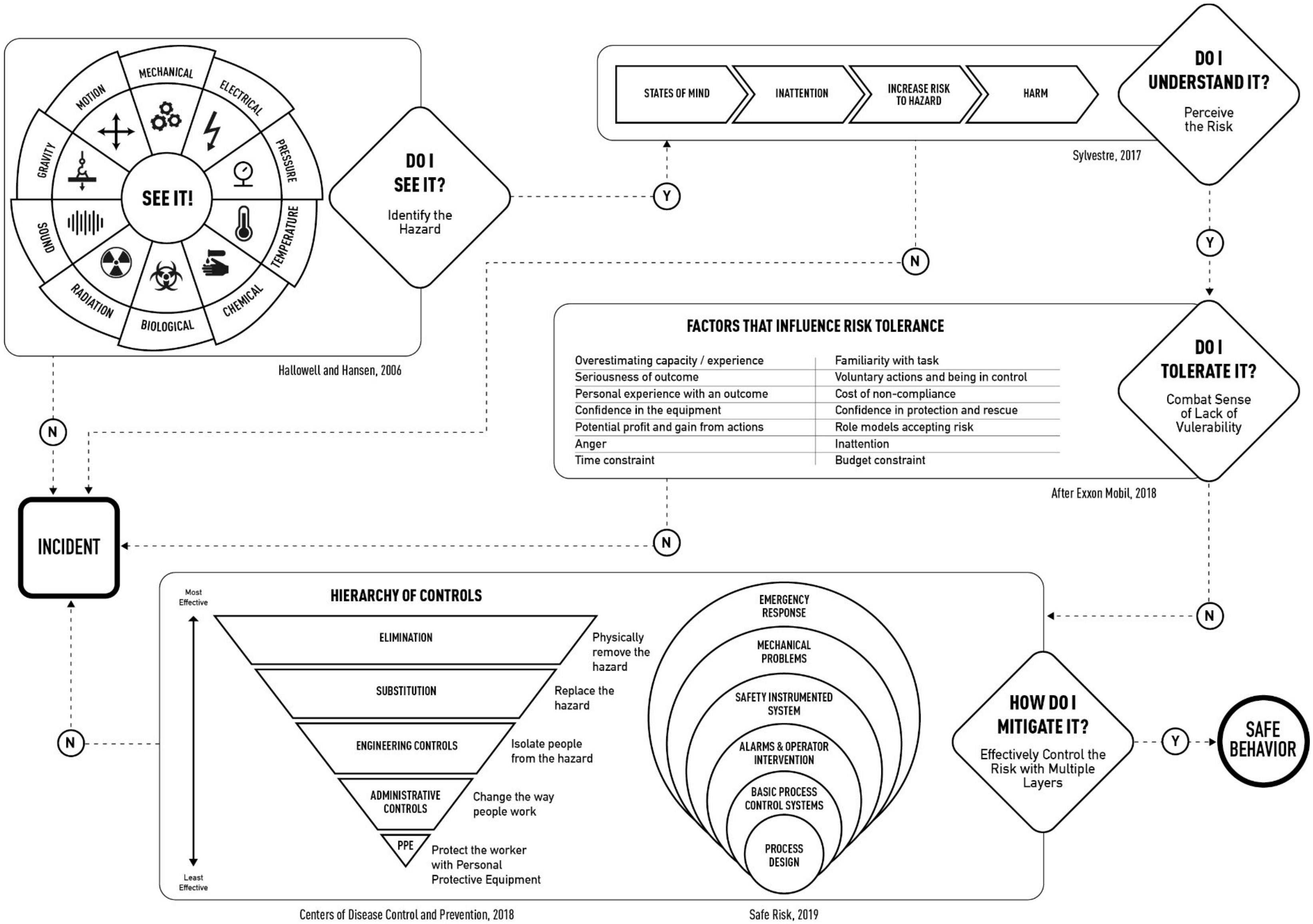


Figure 11. Hazard identification flow chart.

3 Methods

3.1 Energy Safety Canada Tailings Hazard Inventory

Once ESC provided the hazard inventory to the U of A research team, the Process Safety Management principle of Bow Tie Analysis (BT) was used to cluster the hazards and current controls. Analysis of the prioritized hazard list followed a method developed by Paltrinier and colleagues called the dynamic procedure for atypical scenarios identification (DyPASI), which is used to create bow ties to identify atypical scenarios (Paltrinieri et al., 2014). In this method, hazards that were previously undetected are identified. This process was conducted by ESC during site visits and resulted in the completion of the prioritized hazard inventory. The U of A classified this inventory of over 100 hazards according to process safety management definitions to ensure reliability (Table 5). Based on their expertise, site visits, and interview data, the U of A ranked the list of hazards. A facilitated discussion was held at ESC's office in Fort McMurray with the task force members to confirm the prioritized list and the current controls that are in place. Seven hazards were selected as top priority for mitigation: (1) pipeline leak, (2) soft ground, (3) working on water, (4) working on ice, (5) operating spill boxes, (6) long-term exposure, and (7) emergency response. Following Chevreau et al. (2006), local BT diagrams were created for each hazard and controls then added. Green, yellow, or red boxes were drawn around the controls to indicate the level of effectiveness (Paltrinier et al., 2014). Feedback on the BTs was solicited from the expert task force to ensure the analysis was useful and correct.

Table 5. Process safety management hazard definitions (after Winkel et al., 2017 unless otherwise stated).

Hazard	Definition
Administrative control failure	when an administrative control fails to work, resulting in a near miss or incident
Biological	poses a threat due to exposure to something in the environment, e.g., dust, wildlife, NORMs, etc.
Chemical	poses a threat that is toxic, corrosive, flammable, explosive, reactive, or creates an oxygen-deficient atmosphere
Electrical	poses a threat that could cause electrocution due to exposure to live circuits or stored energy in systems
Ergonomic	poses a threat to a moving body part or the moving body
Line of fire	direct contact between a person and a force their body cannot endure; includes contact with stored energy, striking hazards, and crushing hazards (ESC, 2018a)
Loss of containment	an unplanned or uncontrolled release of material from primary containment, including non-toxic and non-flammable materials (CCPS, 2018b)
Potential gravitational	poses a threat due to a fall to the same or a lower level
Thermal	poses a threat due to exposure to a hot or cold substance or enclosed environment
Worker error/ negligence	when worker error or negligence is one of the causes of an incident

The Bow Tie Risk Assessment Method creates diagrams, such as the one shown in Figure 12, as a visual representation of the top event (unwanted event), threats, and potential outcomes. The top event or unwanted event (orange polygon in the centre of the bow tie) is what could go wrong. On the far left-hand side is a list of all of the threats that could cause the top event or unwanted event. On the far right-hand side is a list of all of the possible consequences if the top event were to occur. Controls are then added. On the left-hand side are blue threat controls (e.g., engineering or administrative controls) put in place to avoid contact with the top event or hazard. Strong threat controls are important to avoid an occurrence of the top event. The yellow controls on the right-hand side are mitigation controls. If a threat occurs that could lead to the top event, these controls aim to prevent the undesired event from occurring.

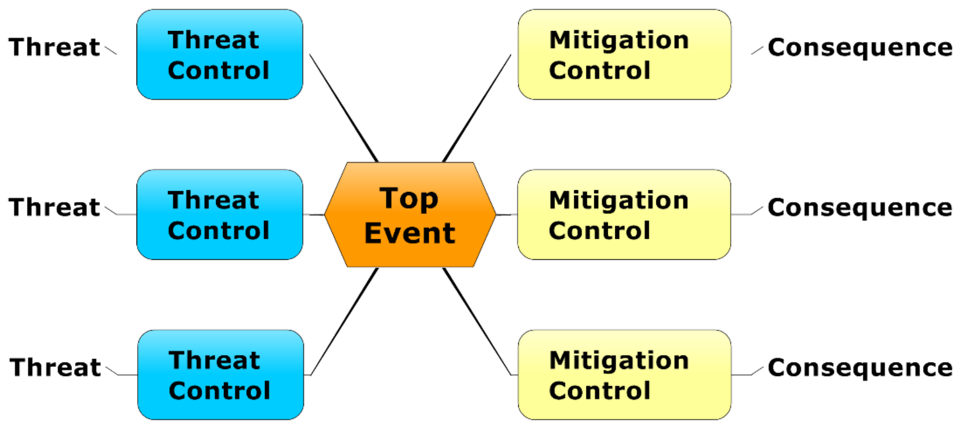


Figure 12. General bow tie analysis (after Deighton, 2016).

Different types of controls are showcased on the BT diagrams in accordance with the hierarchy of controls. The hierarchy of controls ranks the most effective controls at the top (elimination or substitution where the hazard is completely removed or substituted by something less hazardous), followed by other control types in order of decreasing effectiveness. Engineering controls are the next ideal choice to manage a hazard as they isolate the worker from the hazard; for example, a guard on a pump prevents a worker from being exposed to a pinch point. If the risk has still not been brought down to a level that is as low as reasonably practicable, administrative controls can be implemented. These are typically standard operating procedures (SOP), training, or permits. The last line of defense is personal protective equipment (PPE), which does not prevent the hazard from manifesting but mitigates the consequences to the worker, i.e., hard hat prevents injury if a worker were to be struck by an object. It is good practice to utilize multiple controls in a layer of protection approach, where if one control fails another is still in place to prevent an incident from occurring.

3.2 Tailings Incident Database

Multiple oil sands companies provided access to their incident databases related to tailings. These databases were analyzed with the aim of identifying what incidents were actually being reported and determining the likelihood of ground hazards manifesting in the tailings areas. Analysis was also completed to identify leading indicators (which measure high frequency, low consequence events) that could help to predict ground hazards before they occur.

Incident pyramids, such as the one shown in Figure 13, are used to help identify leading and lagging indicators in the data. Lagging indicators include the normalized frequencies of major and minor injuries, e.g., loss of containment with a consequence to people or the environment and/or costs associated with property damage, fatalities, serious injuries, or equipment damage. Leading indicators measure and trend substandard acts and conditions observed on the site, including unsafe acts/conditions, auditing of structured rounds, Serious Injury and Fatality Prevention (SIFp), or the culture in the workplace.

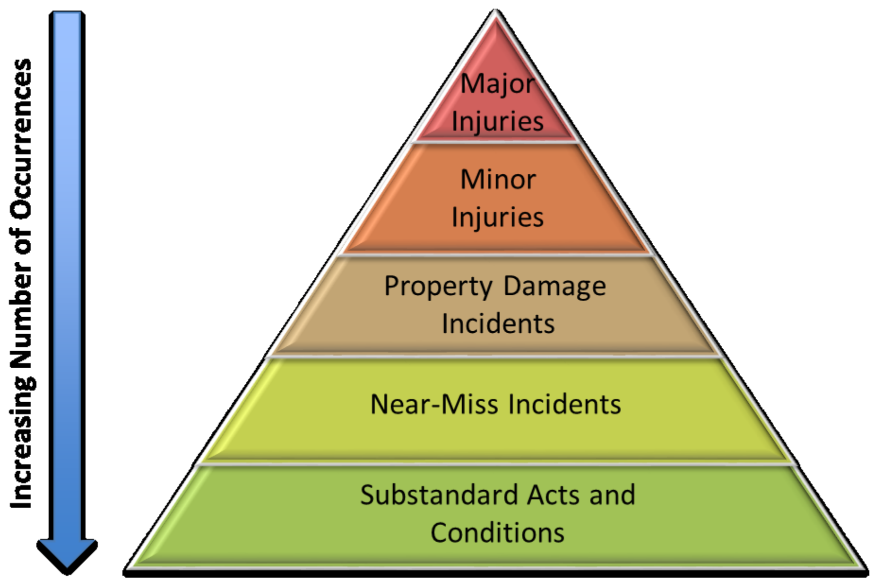


Figure 13. Incident pyramid (after Henderson, 2016).

The incident data were analyzed for keywords to ensure all tailings hazards were included and based on information from the preliminary interview analysis. The keywords used were as follows: tailings, ground, pipeline, leak, stuck, sunk, slip, trip, fall, washout, loss of containment, spool leak, steam, ice, and frozen.

The incident data were studied to determine the type of hazards to which workers would have been exposed (i.e., ground, chemical, line of fire, etc.). For reliability, these definitions were based on process safety definitions in Table 5 (from Winkel et al., 2017); these same definitions were used for the classification of the ESC tailings hazard inventory, with the addition of "ground hazard" (hazards, such as surface and subsurface erosion, soft ground, or slope instability, that could have an adverse effect on people, the environment, assets, or production in oil sands tailings operations). This method followed an approach by Cohen (2017), where incidents are read and categorized into a framework by subject matter experts. Each expert did their own analysis and any classifications that did not match, were discussed and agreed upon. All hazards were classified; however, only those relating to ground hazards were selected for further analysis.

3.3 Interviews

The purpose of interviews with frontline workers, contractors, safety advisors, leadership, and other employees was to determine which hazards in their work environment are of major concern. Recommendations to improve safety in the tailings operations were also discussed as well as “words of wisdom” that the interviewees would pass down to new workers. Prior to conducting the interviews, Research Ethics Board (REB) approval was obtained from the U of A. The REB vetted the interview questions, methodologies, and informed consent form. The consent form detailed how participant responses would be kept confidential and anonymous. Each participant was assigned a random number as an identifier, and the results reported in aggregate so no person or company could be identified. The consent form also stated that interviewees could withdraw from the study up to two weeks after the initial interview. No participants requested this; rather, many contacted the authors to add to their interview and to get more information about the status of the project.

Different questions were developed for frontline workers, leadership, and roving contractors. Please see Appendix B for a complete list of interview questions. The themes of the questions were all the same, but the questions were modified slightly to best fit the interviewee’s role. Eight interview questions (seven for leadership) were developed for the semi-structured interviews. All of the interviews started with the same question, which aimed to develop a rapport with the worker, and then proceeded to questions designed to gather information about safety practices and their level of concern regarding ground hazards.

The final dataset consisted of responses from 158 participants, including 78 frontline workers (heavy equipment operators, plant operators, and maintenance staff), 33 leaders (engineers, site leaders, management, and health and safety professionals), and 47 regional contractors (dredge and boat operators, geotechnical engineers, roving contractors, and embedded contractors). Demographic data are summarized in Figure 14. Interviews lasted between 30 and 90 minutes. The majority of the interviews were conducted in person, with only 12 done over the phone. Interviews also took the worker’s schedule into consideration. Most (n=129) were conducted one-on-one while others were done with larger groups (three focus-group style interviews had more than 4 participants; total n=29) to ensure the research process did not interrupt tailings operations.

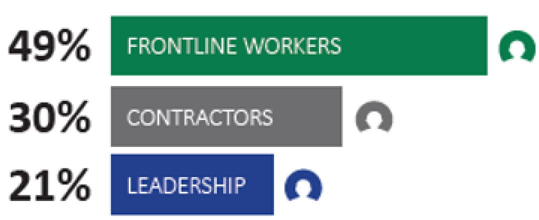


Figure 14. Demographics of the interview 158 participants.

Answers to the interview questions were hand written and transcribed for analysis (coding) using QSR NVivo 12.0 (QSR, 2017). Coding is a way to analyze the interviews to identify patterns and themes in the data. These themes are organized into folders called nodes that contain supporting quotes from the interviews and group similar information. Nodes were created for each of the interview questions during the initial round of coding. Each interview was read, and supporting quotes were coded into respective folders. From this initial analysis and literature review, emergent themes became apparent and further analysis was based on abductive reasoning and completed in stages. Following grounded theory methods, Ms. Baker and Dr. Lefsrud used NVivo to develop codes and test the plausibility of our hypotheses, that ground hazards are under reported in the tailings operations, tailings specific training is lacking and there are unidentified hazards in the oil sands tailings operations (Lok & de Rond, 2013; Huy et al., 2014; Reinecke & Ansari, 2015). The coding scheme was amended as the analysis progressed (Kreiner et al., 2009). This method of abductive analysis is “most suited to efforts to understand the process by which actors construct meaning out of intersubjective experience” (Suddaby, 2006: pp. 634). After multiple cycles of analysis were completed, the codes were collapsed into subtheme categories to help develop recommendations for best practices for worker safety in the oil sands tailings operations.

The range of tailings experience level of the interviewees was broad, with some having only a week’s worth of experience and others having over 40 years. Figure 15 shows the varied tailings worker experience levels. Notably, this reflects experience specific to tailings operations; many participants had more experience in other mining, oil and gas, and construction industries. This wide range in experience provided both a fresh outlook on the tailings operations as well as a more seasoned view.

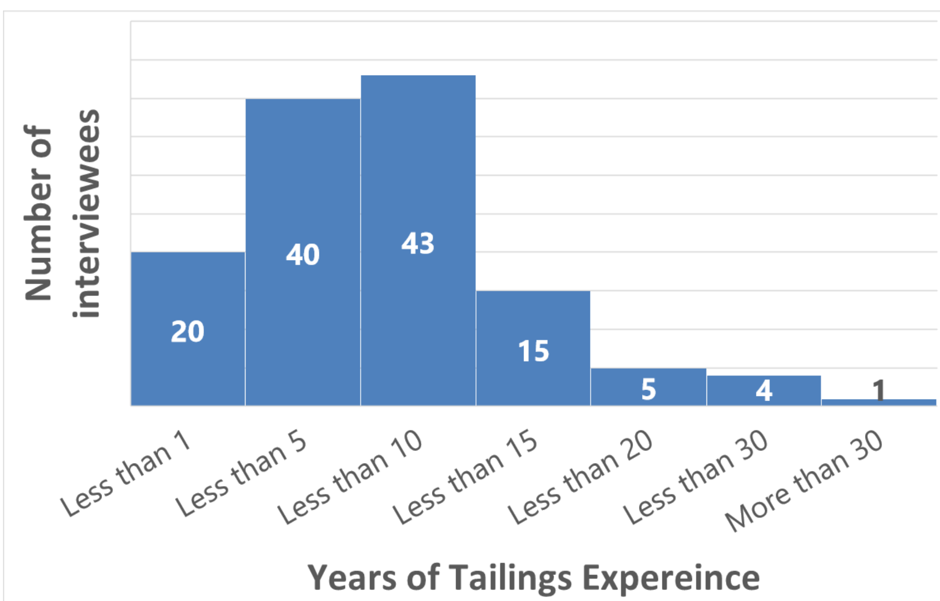


Figure 15. Tailings experience levels of the 128 interviewees (30 interviewees with unknown experience level).

3.4 University of Alberta Ground Hazard Inventory

A ground hazard inventory was compiled during field visits to oil sands companies in summer, winter, and spring utilizing the action research model, where further analysis was conducted after returning to the U of A. In this approach, ground hazards were observed in the field and then reflected upon after the site visits to determine the types of ground hazards that were manifesting (Zuber-Skerritt, 2001). This action research cycle continued after each site visit. Upon investigation of the photos from all of the sites, three main types of tailings facilities were identified: tailings storage facilities, tailings transport facilities, and dykes. Four main groups of ground hazards that manifested at these facilities: soft ground, surface erosion, subsurface erosion, and slope instability. These ground hazards do not appear in isolation, as multiple hazards can occur simultaneously. For ease of discussion and because frontline workers are not formally trained in geotechnical engineering, these four groupings were used rather than the more technocratic ground hazard classifications used by geotechnologists. This framework included the four ground hazard grouping incident descriptions of potential ground hazards and how they manifest as well as temporal factors that could adversely affect the risk (decreasing the likelihood of a worker identifying the hazard or increasing the likelihood of a ground hazard manifesting). Differential settlement was also included initially; however, it was removed as other ground hazards better identified the manifestations that were seen. For example, cavern formation is covered by subsurface erosion, uneven ground can be classified as surface erosion, and misalignment of pipelines can lead to areas of high abrasion in the line and a leak that causes soft ground, surface, or subsurface erosion features. Other manifestations of differential settlement are more of a maintenance issue or covered by slips, trips, and falls by the other ground hazards.

Based on this framework, a photo database of ground hazards at representative examples of tailings facilities, dykes, and transport systems at all participating mines was created. This database is meant to be a training tool to familiarize workers with ground hazards in their work environment. It includes descriptions of the ground hazards, potential consequences, precursory events, and temporal factors. Descriptions of the ground hazards are based on site observations noted in a field journal and documents from the oil sands operators. Precursory events are indicators that could help workers to proactively identify changes in the ground, prior to an incident occurring. Where possible, photographs of the precursory events were provided.

Due to the considerable seasonal variation, it was determined that site visits to the oil sands mines were required in summer, winter, and spring, as well as during night shifts. The research team could therefore capture the dynamic nature of the tailings operations in the oil sands mines and ensure that the database contains a comprehensive list of the ground hazards in these areas, no matter the season or time of day.

3.5 Tailings Safety Symposium

On November 29, 2018, the inaugural Tailings Safety Symposium (TSS) was held in Fort McMurray, Alberta. This was a joint initiative between ESC and the U of A to share the findings of the project with the most important stakeholders: the frontline workers. The flyer that was provided to the participating companies is provided in Appendix C. A total of 105 participants from 15 companies attended, including owners, regional contractors, and representatives from ESC and the U of A. The session was opened by Murray Elliot (CEO of ESC), Shelley Powell (Suncor Sr. VP Base Plant), and a friend and colleague of the person who died in the 2014 fatality.

In addition to listening to presentations, the participants of the symposium were asked to validate the recommendations and participate in two brainstorming sessions to answer some additional research questions: (1) why are hazards not identified or reported in the oil sands tailings operations and (2) how can elimination and substitution controls be implemented to manage the top seven hazards identified by ESC?

3.5.1 Sprint Brainstorming Activity

Participants were assigned to tables by ESC staff to ensure a mix of experience, job function, and company. There were 15 tables with six people per table on average. Attendees participated in a modified sprint brainstorming activity (after Knapp et al., 2016). Everyone was provided with Post-it® notes and given 5 minutes to anonymously write down as many answers as possible to the following question: "Why are hazards not identified or reported?". After the 5 minutes were up, tables randomly joined each other at a large, blank poster on the wall (six were spread out around the conference room). At these posters, facilitators began clustering the responses into emergent themes. At the end of the session, each group reported their findings back to the whole symposium.

3.5.2 Brain Writing or "8-1-2" Group Brainstorming

In the afternoon, the attendees were asked to address the second question: "How can elimination and substitution controls be implemented to manage the top seven hazards identified by ESC?". The brain writing or "8-1-2" ground brain storming method from John Donald (University of Guelph) and the National Initiative on Capacity Building and Knowledge Creation for Engineering Leadership (NICKEL) is an efficient way to generate and enhance solutions to common problems (Donald, 2018). Each person at the table comes up with an answer to the question, writes the solution down on a provided brainstorming sheet (Appendix D), and then passes this sheet to the person on their left. This person then has 2 minutes to enhance the original solution. The "8-1-2" moniker stems from eight people, one solution, and two-minute rotations. At the end of the session, the brainstorming sheets were provided to the U of A and typed up for analysis. The proposed elimination and substitution solutions were then added to the BT diagrams.

4 Results

4.1 Energy Safety Canada Tailings Hazard Inventory Results

Analysis of the ESC tailings hazard inventory indicated many of the hazards are similar across the participating oil sands operators, even though there is considerable variation in how each operator handles their tailings. The top seven hazards identified during facilitated discussions with the U of A were: (1) pipeline leak, (2) soft ground, (3) working on water, (4) working on ice, (5) operating spill boxes, (6) long-term exposure, and (7) emergency response. Local BT diagrams were created for each hazard based on the tailings operations. Qualitative analysis was completed as these diagrams are intended for use across the oil sands industry regardless of the level of experience or job function of the person using them. These diagrams will be used to visually showcase the hazardous events, potential threats, potential consequences, and mitigation techniques employed to prevent the hazardous event from occurring. They can also be used as a leading indicator tool, where management can use the bow tie to see if any controls are missing and fix these controls prior to an event occurring.

The following sections (§4.1.1-§4.1.7) are excepts from Baker et al. (2019) and provide detailed information about the BT diagrams as well as the visual tools. These tools should be displayed close to the job site as it is easier for workers to identify a pre-identified hazard (as per the Hazard Identification Transmission technique developed by Albert et al., 2014). The BT diagram for a pipeline leak is provided in the text below; the remaining six BT diagrams can be found in Appendix E.

4.1.1 Pipeline leak

Figure 17 is a BT diagram illustrating an unwanted event of a pipeline leak. The threats that could cause a pipeline leak were clustered into two main topics: (1) pipeline failures when a pipeline is struck, crushed, or splits due to internal or external corrosion or interaction with other pieces of equipment in the tailings operations and (2) process line up incorrect, which can occur when a drain is left open, a rupture disc overpressures because a valve is accidentally left closed, or when other worker errors occur.

The threat controls that prevent a pipeline leak from occurring are engineered controls such as design specifications, elevating pipeline on blocking (Figure 16), equipment strategies, or material selection. Threat controls could also include maintenance, such as quality assurance/control programs, joint integrity, and preventative maintenance programs (e.g., line rotation). The last threat control is operating procedures, such as structured rounds, predetermined operating envelopes, open-air calls to notify workers when operations are occurring, and proper housekeeping in the tailings area. All workers, including contractors, in tailings areas should have access to a radio so they can be notified when different operations are occurring.

If a pipeline leak were to occur in a tailings operation, mitigation controls would prevent a consequence from occurring. A typical pipeline leak response is implemented when a leak occurs. This procedure is designed to mitigate unwanted events such as worker injury or death. The steps in a typical pipeline leak response are as follows: (1) leak identified by worker, (2) notification procedure followed to ensure supervisors and other appropriate personnel are aware of the leak, (3) system is shut down, so there is no flow in the leaky line, and (4) a line approach procedure is followed to investigate the leak further.

Additional mitigation controls in the tailings area to prevent consequences affecting people are the permit policy, proper visibility so that leaks can be identified and managed, the area and hazards are known to workers, and there is a timely emergency response. If the area and the hazards are unknown to workers, there is an increased probability of a more severe consequence occurring because they are going into the situation blind. The permit policy attempts to mitigate this hazard by having a risk-based approach for when workers are working alone as well as a call-in procedure.

During typical rounds, the worker will be alone; however, if there is anything out of the ordinary such as a known line leak or steam, they will be buddied up. Some pipes are put on blocking, and windrows are not pushed up against the side of the pipe. Elevating the pipe allows the whole pipe to be easily seen during rounds so leaks can be more easily identified. The speed at which first responders can arrive at a location will also influence the outcome of an incident.

Tailings operations are dynamic, and ESC members have identified the need for increased training in tailings operations to ensure area familiarity. Line names are unknown to people not involved in operations or planning. Some suggestions to mitigate this issue from ESC constitute maps with line names, cell names, and landmarks to be made available to workers, potentially in the permit office. There should also be increased supervision, area tours, and a permit process specific to the tailings area. There are rules and expectations for crossing pipelines on foot; training is required to ensure area personnel are aware of these expectations. People working in tailings operations also need to be aware of the soil subgrades that are more likely to erode and create underground caverns. More research should be done to determine how the different subgrades, such as clay and sand, react to a pipeline leak. There also needs to be radio training and awareness as new workers can be uncomfortable using radios.

Figure 16. Example of a pipeline elevated on blocking for a full 360° view.

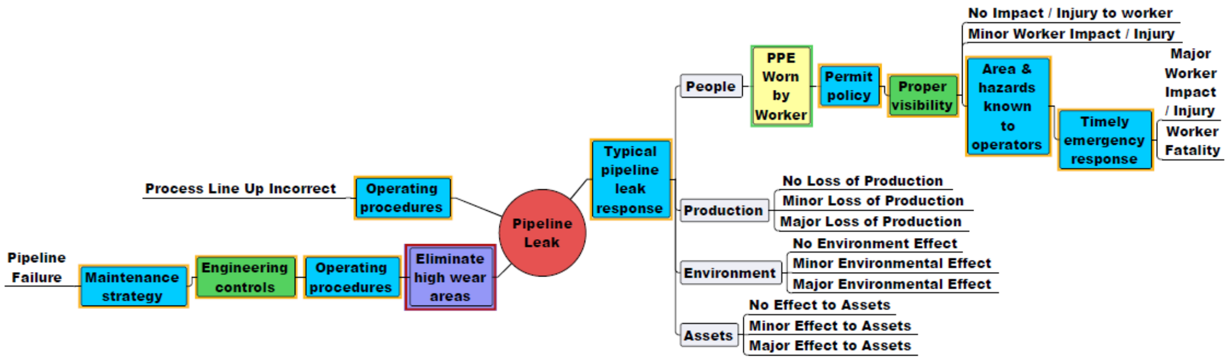


Figure 17. Pipeline leak bow tie diagram.

Green, yellow, and red boxes can be seen around the controls in the BT diagram (Figure 17). These coloured boxes indicate the level of effectiveness of each control (after Paltrinier at al., 2014). The effectiveness of each control was analyzed from an industry level. Some companies have more controls in place than others, but ESC felt more work could be done to mitigate these seven hazards across the oil sands tailings industry. For this reason, the majority of the controls are yellow, indicating they are in place but there is room for enhancement. Any controls in a red box are not in place or are ineffective. In this analysis, the controls are elimination and substitution suggestions from respondents who attended the TSS; this process will be discussed in more detail in Section 4.3.

4.1.2 Soft ground

The four types of threats that could cause soft ground are: (1) abandoned sumps around tailings operations, (2) variations in the quality of discharge (different viscosities with higher or lower ratio of water and solids will lead to different construction ability; for example, less dense tailings (more water) have a liquid consistency that makes it difficult to build cell berms in the tailings discharge area), (3) cell construction (creation of containment areas for sand to be used for reclamation), and (4) heavy precipitation events or snowmelt leading to soft ground in the tailings areas. All of these are shown in the bow tie diagram Figure E1. The most important area of worker exposure is in the cells of the tailings discharge area, as soft ground is created daily by discharging wet tailings onto the sand. Soft ground can also be found in tailings recovery operations (TRO), in Accelerated De-Watering (ADW) operations, in cake production and storage areas, and on tailings roads, especially after heavy precipitation events or spring melt.

Threat controls to prevent soft ground from being created are engineered controls such as end of line devices (e.g., spoons) to dissipate the energy (Summer Photo (c), pp. F3) or sumps to drain the water. Maintenance strategies such as proper clean up to limit the amount of standing water in the tailings area and road maintenance are also used. The last two types of threat controls are administrative controls, including procedures where dozers are track packing or putting the discharge on overboard when the viscosity is too low and timely placement of reclamation materials to stabilize the ground.

Soft ground frequently manifests and affects people, environment, assets, and production. The consequences to people will be the focus here, the severity of which varies depending on the softness of the ground. People can become stuck in soft ground if they are surveying or monitoring pipelines on foot; they can also become stuck or sunk in a bulldozer or light vehicle depending on the softness of the sand in the cells.

The mitigation controls in place include a cell construction plan to increase the stability of the ground. Procedures are used to keep people away from the soft ground near the tailings ponds and the discharge in the tailings discharge area. The procedures differ depending on the location. For example, the low beach (area closest to the pond, with the highest fines content and lowest water table/saturation) requires more precautions to keep workers safe. Procedures state there is to be no foot traffic and no terrestrial equipment access. These procedures are taught during training. Training is an essential mitigation control as new employees may not know that an area is soft ground. For example, the top looks as dry as the desert in the TRO cells and cake areas, but this is a thin crust and a worker could very easily get stuck; for this reason, no one is allowed to walk in this area. Specialized equipment is required, and a geotechnical engineer should be involved in work planning. Restrictions also limit how close operators can get to a tailings discharge in a dozer.

On the other hand, care is still required at the high beach (area closest to the dyke, with lower fines content and the highest water table) as soft spots are possible as there is little or no compaction effort in this area. Even though the risk level is lower in this area, a trafficability assessment is still required before work can begin. Operators should watch for signs of liquefaction (boils, cracking, ground deformation, water rising to the surface). Geotechnical engineers may need to be involved in work planning.

Permit policies are used to keep track of who is in the area, determine if they are competent to work in the area, and what jobs or tasks they are doing. They also include proper PPE and whether a geotechnical engineer should be involved in the work planning. The permit department is also responsible for putting up signage and fencing to mark soft ground. This is a challenging job as tailings operations are continually changing, and therefore so is the location of soft ground. Access signs and a check-in procedure near active cells are used at some sites. Many visitors are also accompanied by a cell operator who knows the hazards of the area. Deepwater sump signs can be seen at the majority of the sites, and any area that is impassable is barricaded off. Timely emergency response to rescue workers who are stuck on foot or in a dozer includes the potential use of snow fencing for self-rescue or a rescue skid (discussed below). Snow fencing is coiled within the cabs of operating equipment and can be laid out on soft ground to permit egress from the area; the increased surface area of the path created by the laid-out fencing allowing for temporary traverse of the soft area (much like a snow shoe). Drills and simulations should be conducted to train first responders. The different ways a person could get mired in the tailings operations should be considered when creating emergency response plans (ERPs) and conducting simulations. Some possible scenarios are a person ejected from a boat in a collision with a submerged obstacle, getting stuck walking on foot in tailings operations from stuck equipment or when surveying, or falling off equipment or a boat.

4.1.3 Working on water

Working on water is a regular part of tailings operations (see bow tie diagram in Figure E2). The threats of concern that could cause issues while working on water are as follows: (1) fuel lines in tailings ponds, (2) live power lines in tailings ponds, (3) floating obstacles in tailings ponds, and (4) other environmental conditions.

The controls for these four threats are mostly administrative controls, such as procedures, training, and minimum distance requirements from fuel and power lines that supply the barges or dredges and from the edge of the tailings ponds, as well as flagging and signage to notify workers where water and lines could be located. Some engineering controls such as buoys are also used to keep the lines on top of the water; ground faults can mitigate any issues with live power lines. Good housekeeping is also essential to prevent boats from contacting floating obstacles in the ponds.

It is currently impossible to avoid working on water in tailings operations. Some consequences of water work could be a person ejected from a boat after a collision with a submerged obstacle, falling off walkways or boats or dredges, or becoming stuck on the pond because of intense fog or lightning.

The majority of the time, workers are aware they are working on or around water, and the risk is quite low as the hazards are well managed through the use of engineering controls such as guard rails. Administrative controls such as a rescue plan, lanes of entry for emergency evacuation, standby rescue boats or shore watch, and working alone policies are also important to keep people safe. Self-rescue, ARGO training, and proper PPE and rescue equipment such as immersion suits, personal flotation devices (PFDs), communication radios, and life rings also help to mitigate consequences.

The ponds are well marked, but the permit office plays a crucial role in informing new workers and contractors of the hazards in the area. Administrative controls also include notification systems when environmental conditions such as fog or lightning can affect operations on the ponds. At most sites, it is standard for anyone on the pond to evacuate to shelter, away from the pond, in such situations. Dredge operators are to shelter in place in the cab of the dredge until the situation subsides.

Timely emergency response is also crucial. Life ring/throw rope familiarity and training is important because life rings will not be helpful if workers do not know how to throw it or the rope is damp or sun rotten. Mock drills are also helpful to ensure workers have practice pulling in dummies from the tailings pond into a boat.

4.1.4 Working on ice

Working on ice is a large part of the tailing operations as the Athabasca oil sands region experiences below-freezing temperatures for a significant part of the year. The bow tie diagram in Figure E3 show the threats that are of concern and could cause issues while working on ice: (1) tailings ponds in winter, (2) underutilized roads, (3) pipes leaking in cells in a low spot, (4) areas of standing water (precipitation, spring melt or runoff), (5) sumps, and (6) tailings beaches in winter.

The controls for these six threats are mostly administrative controls such as procedures, training, and minimum distance requirements from sumps and the edge of tailings ponds. Additional measures include flagging and signage to notify workers where standing water, sumps, ice, and tailings ponds are located and making sure that workers are working on the stable beach, and not ice, in the winter.

Engineering controls are also in place to prevent beaches from being overbuilt, which can cause water to pond at the discharge point. Cell maintenance also helps to prevent issues from occurring when operators are working on ice or water. The dozers clear travel routes and turn up sand to minimize hazards in the cells. Road maintenance is also essential, especially in underutilized areas; closures and temporary deactivation can occur if roads are not maintained.

Avoiding working on ice in tailings operations is difficult, and such work can introduce different potential consequences such as a person or equipment falling through the ice. Two scenarios when a person could be working on ice are as follows: (1) Worker knows they are over ice, and (2) Worker does not know they are over ice.

If workers are aware they are working over ice, then the risk is quite low and the hazards are well managed by engineering controls such as an engineered ice pad and gas detection when boring holes in the ice. Administrative controls such as ice thickness checks, monitoring, rescue plans, strength testing, lanes of entry for emergency evacuation, standby rescue boats or shore watch, and working alone policies are also important to keep people safe. Ice awareness training from the Government of Alberta, self-rescue, ice rescue, and proper PPE and rescue equipment such as immersion suits, PFDs, communication radios, and life rings also help to mitigate consequences.

However, if workers do not know they are working on the ice, then the risk is very high, and the hazards can be poorly managed. Workers typically end up on ice by accident when they are unfamiliar with the area or are unaware of the existence of a standing body of water. To prevent severe consequences, hazard awareness, signage, area familiarity, and the permit office are very important to communicate the risk to people in the area. To prevent a significant worker injury or even a fatality, training for the area as well as self-rescue training is extremely important. Workers should also be provided with the proper PPE, such as a PFD or immersion suit. However, this can be challenging because workers may not have this equipment if they are unaware they are working on the ice.

Timely emergency response is also important if a person falls into water or through the ice. The 1-10-1 rule states that there is 1 minute to catch a breath and relax, 10 minutes to self-rescue before muscle failure, and 1 hour to receive emergency assistance before death from hypothermia. If self-rescue is not possible, then emergency response teams only have 1 hour to complete a rescue, which is a tight timeline in tailings operations.

First responders should also be practicing thin ice and on-water rescue simulations to keep themselves safe if an incident were to occur. Ice rescue technician training for high-risk over-ice work is valuable for workers, contractors, and emergency services. Life ring/throw rope familiarity and training is also important because the life ring will not be helpful if workers do not know how to it or the rope is frozen or sun rotten.

4.1.5 Operating spill boxes

A spill box is a device, similar to a weir, that is designed to capture sand and allow water to flow into the tailings pond for use as recycled process water (Figures 18 and 19). The operation of spill boxes was identified as one of the top hazardous activities across all oil sands operators. This respect and concern for the operation of a spill box indicates that workers have a low-risk tolerance for this activity and are concerned with the operation, making them extra vigilant when installing the boards.

Figure 18. Out of service spill box with handrails installed.

Figure 19. Spill box being installed for service.

The bow tie diagram in Figure E4 shows the four main activities that could cause an issue with the operation of a spill box: (1) crushing during install of the spill box, (2) slipping off the dozer when adding boards to the box, (3) wrist issues when adding boards to the box, and (4) becoming stuck in soft ground.

Spill boxes act as a weir to capture sand while allowing process water to flow through and be recycled for use in the rest of the mine. As more sand is added to the tailings discharge area, the spill box must be modified accordingly to continue capturing sand; this is done by adding 2' × 10’ boards to the spill box. To add the boards to a spill box, a worker must stand on the side of the dozer push arm and install the board. Engineered and administrative controls are used to mitigate the consequences of this activity. The engineered controls include the construction of a platform over top of the spill box and installing handrails (Figure 18). The administrative procedures include training and a spill board maintenance procedure (indicating to switch out and drain the cell, i.e., putting the cell on overboard).

Administrative controls such as spill board and cell maintenance, and procedures prevent the dozer from contacting the spill box while setting up and prevent the spill box from washing out into the pond.

If an issue with spill box operation were to occur, many threat controls are in place to prevent a serious consequence from occurring. The first are related to emergency response: a shore watch must be in place and workers accessing the area must carry a radio and always use the buddy system. Administrative controls include permit policies, including dozer and/or equipment operation only being permitted within a certain proximity of ponded water, spill boxes, and live pours.

Mitigation controls also include appropriate PPE. For example, all personnel are required to have a PFD when working within 15 m of any shoreline, boat, or water access point. Engineering controls such as tailings dyke and deposition cell design are in place to optimize cell spill box location and effectiveness for water drainage/watershed.

4.1.6 Long-term exposure

Long-term exposure hazards in the oil sands industry are becoming a popular topic and area of concern. Historically, this was more of an occupational hygiene area, but is becoming more prominent in the worker safety domain. Five long-term exposure threats to people have been identified (see bow tie diagram in Figure E5): (1) respirable silica and other particulates, (2) respirable coke dust, (3) Naturally Occurring Radioactive Materials (NORMs), (4) hydrocarbons and other chemicals (volatile organic compounds (VOC), hydrogen sulfide (H_2S), etc.), and (5) noise.

Controls have been implemented to prevent workers from coming into contact with these threats. These threat controls include specific awareness training for all five of these threats, standards and procedures, dust suppressants (water or chemical), specific exposure monitoring (in both high- and low-risk areas), and housekeeping of equipment. Handheld monitors can be rented for a nominal cost to complete testing; workers also appreciate a copy of this report. Housekeeping can include keeping equipment clean and filter changes on flight vehicles and heavy equipment. The controls for coke dust controls and silica dust are the same.

The main pathway for exposure to hydrocarbons is falling into a tailings pond or being covered in tailings and bitumen if there is a pipe leak. Engineering controls such as hand and guard rails prevent workers from easily falling into the ponds. Housekeeping and maintenance of equipment are also important to prevent contact with the hazard. Hydrocarbon fumes can still be inhaled, and for this reason exposure monitoring occurs on the ponds. Providing easy access to Safety Data Sheets (SDS) can help to change worker perceptions of the contents of the tailings ponds.

Despite these threat controls, workers will still be exposed to these hazards. To mitigate the consequences, the following controls have been put in place: availability of proper PPE, minimizing exposure, regular health assessments, audits of standards and procedures to ensure they are being followed (including exposure limits), use of survival suits, decontamination/hygiene controls, and timely emergency response.

The PPE required to mitigate consequences associated with long-term exposure threats includes Tyvek, rubber boots, respiratory protective equipment (RPE), hearing protection, PFDs, survival suits, etc. The majority of the sites have protocols for when to mask up, even in low-risk areas. When it is dusty, workers are expected to put their masks on or, if possible, remain in the cab of their vehicle, dredge, or boat.

Threats such as silica and coke dust are inherent to tailings operations, so workers must do their best to minimize exposure by doing things such as driving with their windows up, turning the cabin air filter to recirculate, and avoiding on-ground work in tailings in extreme dry/windy times.

Health assessments such as audiometry for noise and hearing loss and X-ray testing and pulmonary lung function testing after exposure to silica or coke dust (as coke and silica often travel together, especially in tailings environments) are used to assess the detrimental effects of long-term exposure hazards.

Survival suits, decontamination after exposure, and hygiene controls are fundamental strategies for preventing significant worker impact/injuries or even fatalities. Timely emergency response is also significant, especially if someone falls into a tailings pond. Standardization for self-rescue training across sites could be valuable and could include ladders on boats and dredges as well as mock drills for the rescue of conscious and mobile workers, immobile workers, and unconscious workers.

4.1.7 Emergency response

Emergency response or the ability to rescue in tailings operations is a topic that was brought up by multiple frontline workers at multiple operations during the interview process as well as the ESC task force. Six threats could cause issues with emergency response (see bow tie diagram in Figure E6): (1) preparedness of emergency response personnel to rescue workers, (2) road conditions, (3) access to equipment, (4) access to rescue equipment, (5) weather, and (6) emergency meeting points.

One of the biggest concerns regarding emergency response in the tailings operations is the preparedness of emergency response personnel to rescue workers. The best way to mitigate this hazard is by completing mock drills where workers and emergency response personnel work together to rescue a worker from a realistic situation.

The roads are ever-changing in tailings operations, and getting stuck in soft ground or mud is very easy. To mitigate issues with road conditions, engineered controls such as using different materials for road construction can help to improve the road quality. Graders can also be used to maintain the road quality and make it easier for vehicles to travel. Dozers carrying a pipe to compact the sand and even out the road are used to make the roads passable. The permit office also plays an important role by letting people know about changes to road configuration, the location of potential traffic issues, and other poor road conditions for which responders should be prepared.

Redundancy and availability are important to ensure that the equipment is available when it is needed and not being used elsewhere in the mine. It is also essential to have an Emergency Management Program (EMP) in place so responders know what type of equipment is needed and to ensure worker competency. One of the best ways to ensure worker competency is by conducting simulations and drills. Weather can also delay emergency response. Fog, smoke, lightning, and wind can make rescue very difficult, if not impossible, until weather conditions improve. Therefore, it is vital that EMPs take changing weather conditions into account and contingency plans are in place.

The last threat that can cause delayed emergency response is the location of the emergency meeting point and the ability of first responders to find the location. Escorts from the tailings operations are key to making sure that first responders can find the meeting point and be taken quickly to the location of the emergency in the tailings operations. An EMP is important in addition to drills and simulations, so that workers and first responders know how to react to an incident as quickly, safely, and efficiently as possible. Without the practice and the plan, it will be much more difficult to conduct a rescue.

One of the critical mitigation controls to prevent consequences related to delayed emergency response is having the correct rescue equipment; PPE must be available and in good repair, and workers must know how to use it. Rescue equipment includes items such as defibrillators, stretchers, blankets, ring throw ropes, PFDs/immersion suits/life jackets, snow fencing, rescue skids, etc. Some operators have built rescue skids (Figure 20), which are floating platforms that can be pulled behind a dozer and are available at all live cells. Workers receive training in how to hook up the rescue skid and drive out to a stuck or sunk bulldozer to rescue the operator. Each skid is equipped with a backboard in case of a serious incident.

Worker competency is an important mitigation control to prevent a situation from escalating during an emergency, including workers following the appropriate notification and alert system and workers being fit for duty, so their response time is quick and cognitive abilities are not impaired.

Not having people work alone in tailings operations will significantly impact the consequences of an incident. Having a shore watch or redundant staff allows for quick notification of an issue as well as ensuring a first responder is on the job site as opposed to waiting for fire and rescue to reach the location of the emergency.

Administrative controls such as permit policies, emergency shut down procedures, and call in/sign in are very important for keeping people safe in tailings operations. Emergency shut down procedures can be challenging as they are tied to the control room. Call in/sign in allows for a roster to be created for who is in the area and ensures all employees are accounted for. If working alone cannot be avoided, call-in procedures can notify dispatch that a worker is unresponsive; however, the time delay associated with a call-in system means that this should not be the only mitigation strategy.

The last mitigation strategy is training. Emergency response training but also first aid, ice rescue, self-rescue, and Marine Emergency Duties Survival Systems Training (MEDA3) can be mandatory depending on the site and area of tailings where a worker is located. Self-rescue is one of the most essential aspects of training that can be completed.

Figure 20. Rescue skids for a tailings discharge area that can be hooked up to a bulldozer.

4.2 Tailings Incident Database Results

The participating companies provided four years (2014-2017) of tailings incident data. These data were analyzed by categorizing incidents into common hazard groups. Table 5 was used for the classification and ground hazard was added to the list of possible categories. Incidents involving ground hazards made up 23% of total incidents, one of which was the 2014 fatality.

The frequency of the total incidents from 2014-2017 related to ground hazards was normalized based on tailings area (m^2) of each site and plotted in Figure 21. Slip/trip/fall (purple bar) made up 2% of the total incidents, which occurred on varying terrain (ice, mud, uneven ground, and water). Stuck and sunk equipment (yellow bars) made up 13 and 3% of incidents, respectively, with 83% of those incidents being stuck or sunk dozers. Reported ground hazards made up 11% of the incidents, with the largest causes making up this category being soft ground (49%), surface erosion features (22%), subsurface erosion features (6%), and slope instability (23%). Damage through contact and geotechnical instrument damage (red bars) made up 5 and 1% of incidents, respectively, with the majority of the damaged instruments being piezometers. The damage through contact category included a range of objects from pipeline components to berms. Pipeline component leaks, failures, and damage made up 38, 17, and 1% of the incidents, respectively, and pipeline missing components, frozen pipelines, and worker error made up 0.4, 4, and 1%, respectively. Leaving drain valves open represented the majority of incidents of pipeline worker error.

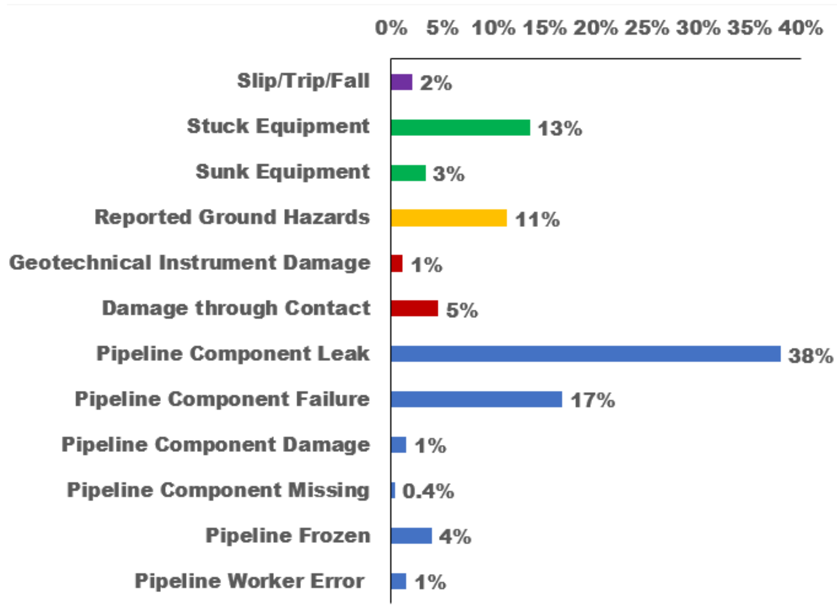


Figure 21. Incidents related to ground hazards, with data from the incident databases of multiple oil sands companies, 2014-2017.

To make this information useful to companies, specific figures were created for the top four incidents caused by ground hazards: pipeline component leak, pipeline component failure, stuck equipment, and reported ground hazards. We subdivided these sections into the particular component that is leaking or failing, piece of equipment becoming stuck, and reported ground hazard, so companies can prioritize appropriately in their maintenance, quality assurance programs, and communications regarding high-risk areas to workers.

Pipeline leaks and failures are the most common hazard in the incident database. If not caught quickly, they become a precursory event to a ground hazard in the form of soft ground, surface erosion, subsurface erosion, or slope instability. The components identified as leaking in the incident database are plotted in Figure 22. The leaks were mainly the pipelines themselves, followed by pipeline connections (gaskets, flanges, seals, couplers, etc.). Miscellaneous items include drains, vents, and pumps. Based on this analysis, leaks in the pipes themselves are the most common (13% of all component leaks). This could lead quality assurance and maintenance to change their programs and potentially rotate pipes more often or check the thickness of the pipes at a different rate. Elimination and substitution principles could also be applied to minimize the number of connections (12% of all component leaks) as these are high wear areas from internal abrasion and prone to leaking.

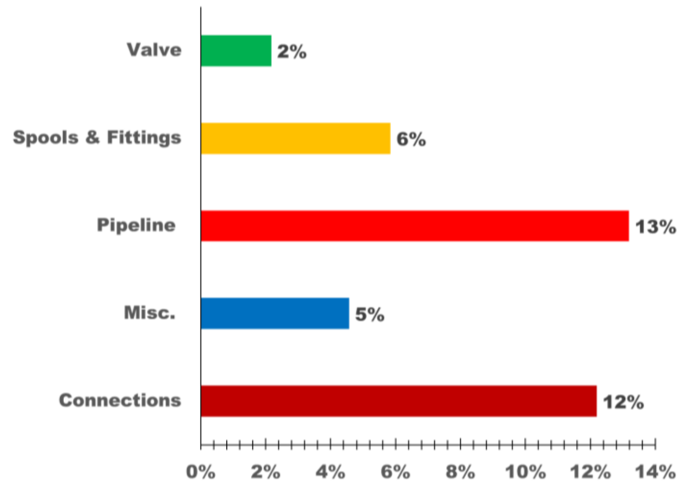


Figure 22. Reported pipeline component leaks from tailings incident databases.

The same method was applied for a more detailed analysis of pipeline component failures (Figure 23). Rupture disc failures were the most common occurrence (7% of component failures), the root cause of which is probably worker error instead of process over pressuring. Rupture disc overpressures typically occur in tailings operations because a valve is accidentally left closed. The second most common are failures of spools, elbows, and other fittings (4% of component failures). Again, quality assurance programs could change their procedures to focus on these high wear points to decrease the occurrence of line failures; design engineers could also attempt to limit the number of spools and fittings in the design.

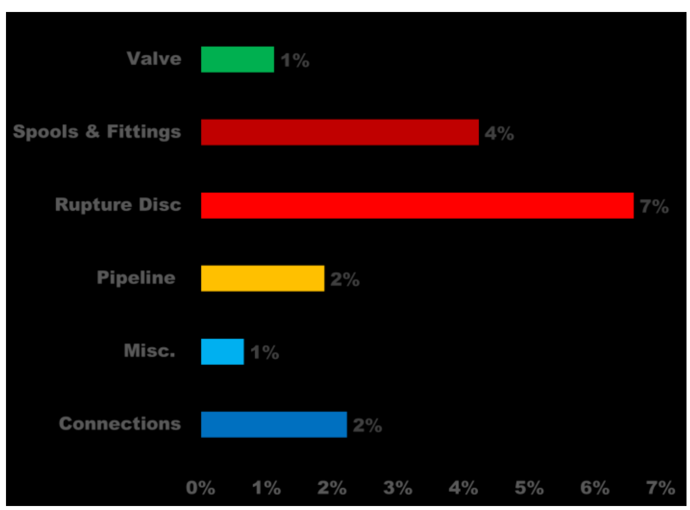


Figure 23. Reported pipeline component failures from tailings incident databases.

Stuck equipment was the next most frequent type of incident reported in the database that relates to a ground hazard. The types of equipment reported as stuck are shown in Figure 24. The most common piece of equipment getting stuck in the tailings operations is bulldozers (11% of total ground hazards). Bulldozers most commonly become stuck in soft ground or cuts (erosion features) in the cells. Trucks can become stuck on any of the roads in tailings areas (1% of total ground hazards). Workers noted the existence of "three seasons: muddy, dusty, and frozen". Each season can cause equipment to become stuck, and heavy precipitation events and spring melt cause extremely deep and muddy soft ground conditions that make driving very challenging. Workers also noted that the dry sand in the summer is akin to driving on flour and can also lead to trucks becoming stuck. Some workers told us that the best driving conditions are actually in the winter when there is hard ice on top of the sand. The other category (1% of total ground hazards) includes one-off occurrences of other equipment becoming stuck in the tailings area, such as a loader, skid steer, back hoe, haul trucks, wiggle wagon, and graders.

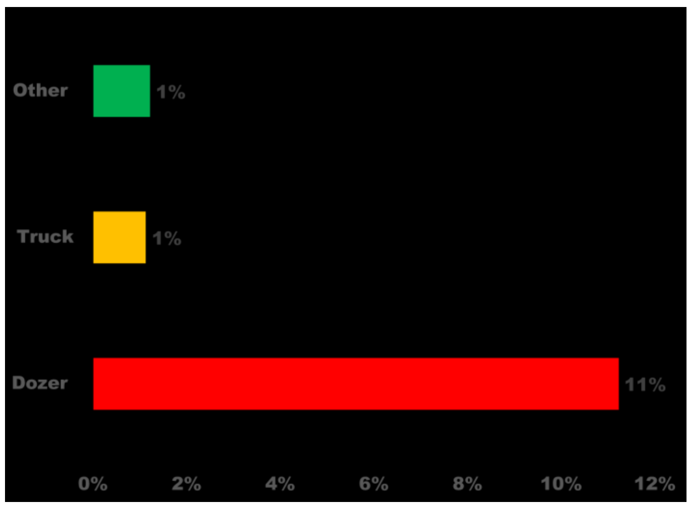


Figure 24. Reported stuck equipment from tailings incident databases.

The last category analyzed in greater detail was reported ground hazards (Figure 25). For the purposes of this project, as the reported ground hazards were explicitly stated by the workers in the incident database and classified into four main categories as per the U of A's ground hazard assessment: soft ground, surface erosion, subsurface erosion, and slope failures. This analysis was completed a little differently to determine the likelihood of reported ground hazards occurring at oil sands tailings operations. All of the reported incidents could cause or did cause a ground hazard; however, there is insufficient detail in the incident database to state that as fact. Any of the incidents classified in the other categories could cause multiple ground hazards simultaneously, and so were not included to determine the likelihood values. Soft ground was the most common ground hazard reported (49% of all reported ground hazards), with incidents including standing water on roads and drainage problems. Slope instability and surface erosion were close in terms of reported incidents (23 and 22% of the total reported ground hazards, respectively). Incidents classified in these categories included cell berm breaks for slope instability and washouts for surface erosion. Subsurface erosion occurred the least of the four categories (6% of all reported ground hazards). Incidents in this category included the formation of sinkholes and the cavern that caused the 2014 fatality.

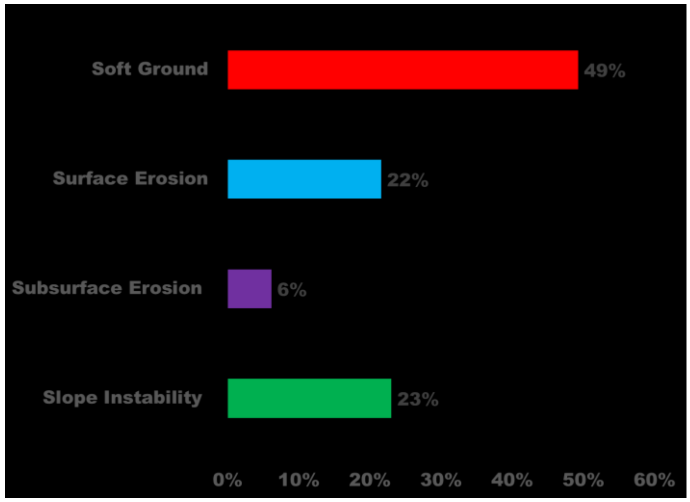


Figure 25. Reported ground hazards from tailings incident databases.

4.3 Interview Results

A total of 158 employees (frontline tailings workers, safety advisors, supervisors, leadership, etc.) and regional contractors were interviewed. All workers agreed that tailings operations are a dynamic environment with a high risk of exposure to hazards. The overall impression after analyzing the interviews is one of juxtaposition. People who work in tailings feel like they are forgotten: "tailings is the missing piece of the puzzle". They understand tailings is a waste stream: "The tailings are called the a**-end of the operation. All the good stuff has been taken out and we're dealing with what is left". But there is also an overarching sense of pride, evident in the way workers talk about the operations: "I am proud of what we are doing" and "people don't realize the magnitude and importance of tailings. The long-range plan runs the show and mine life, tailings is everything". This pride is also seen in the respect that the workers have for each other: "Got everyone's back. Everyone is watching out for each other" and "Great guys. Great group of people".

Word clouds were used to ensure we were on the right track with our theorized codes for hazards in the tailings operations (Figure 26). The size of the word represents its frequency of appearance in the interview data. For example, ground, pipe, line, water, and sand were some of the most common hazards mentioned when interviewees were asked what hazards they saw around tailings facilities, dykes, and transport systems. This indicates these hazards are relatively well known to the participants. However, further analysis indicated that 15% of participants did not identify a single ground hazard in their interview. This is concerning as ground hazards are prominent in tailings operations (23% of reported incidents related to ground hazards) and the top two hazards indicated by tailings safety experts were ground hazards (pipeline leak and soft ground). This gap signifies the need for enhanced tools to assist in the identification of ground hazards. These specific tools will be discussed further in Section 4.4.

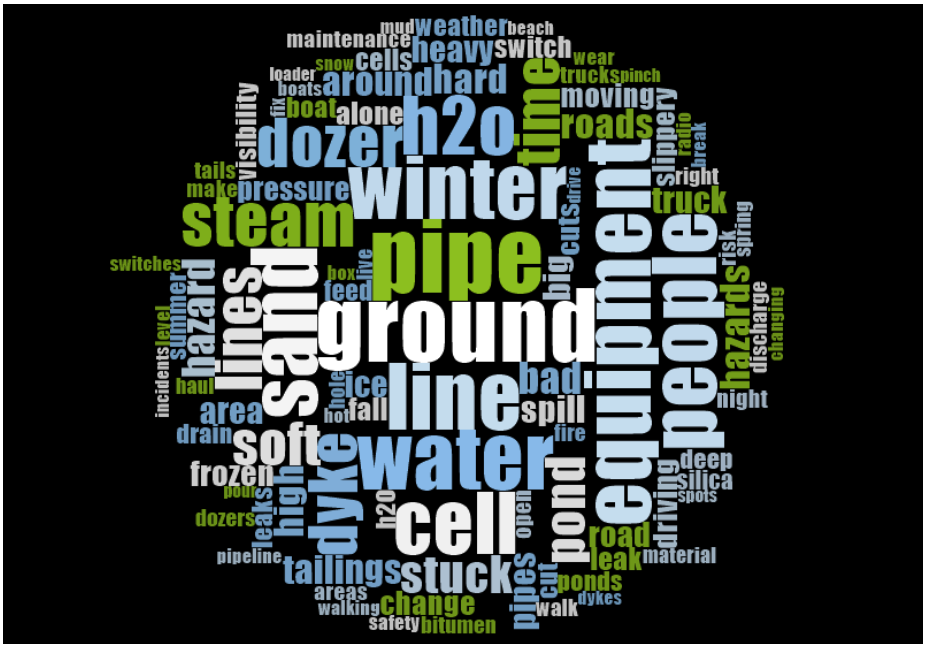


Figure 26. Word cloud of the 100 most common hazards identified when interviewees were asked what hazards they saw around tailings facilities, dykes, and transport systems.

Questions were also posed to the interviewees to assist in the development of recommendations for oil sands tailings safety best practices. The results of this analysis are shown in Figure 27. Seven recommendations emerged from the data analysis: (1) increased communication within industry, (2) increased communication within companies, (3) enhancements to hazard identification tools, (4) critically evaluate current operations, (5) increase resources, (6) tailings-specific training, and (7) regional standardization. On the left-hand side of the figure are representative quotes from the NVivo analysis. These quotes were coded into first-order themes (in the middle of the figure). Once these first-order themes were identified, they were then combined to determine the aggregate dimension or recommendations. These recommendations are for the oil sands industry as a whole, and are not directed at any one organization.

All of these recommendations have an undertone of increasing tailings-specific communications. Many of the procedures that are currently in place to protect workers are related to the mine or the plant. A comment from one participant, noting that "[p]rocedures are black and white, but tailings is a grey area. It is hard to make it black and white", indicates the need for tailings-specific procedures, training, and safety interventions.

Themes of safety culture also emerged in each of the recommendations. Safety culture is an intricate topic, unique to the organization; however, a similar culture is evident across the oil sands tailings industry. This is an important finding that must be shared with the industry. When it comes to safety, all operators and regional contractors are similar; there is no competitive advantage to be had in this regard. The prevention of incidents in tailings operations as well as this shared industrial safety culture are common goals that will hopefully allow for the continued collaboration of the participants in this study.

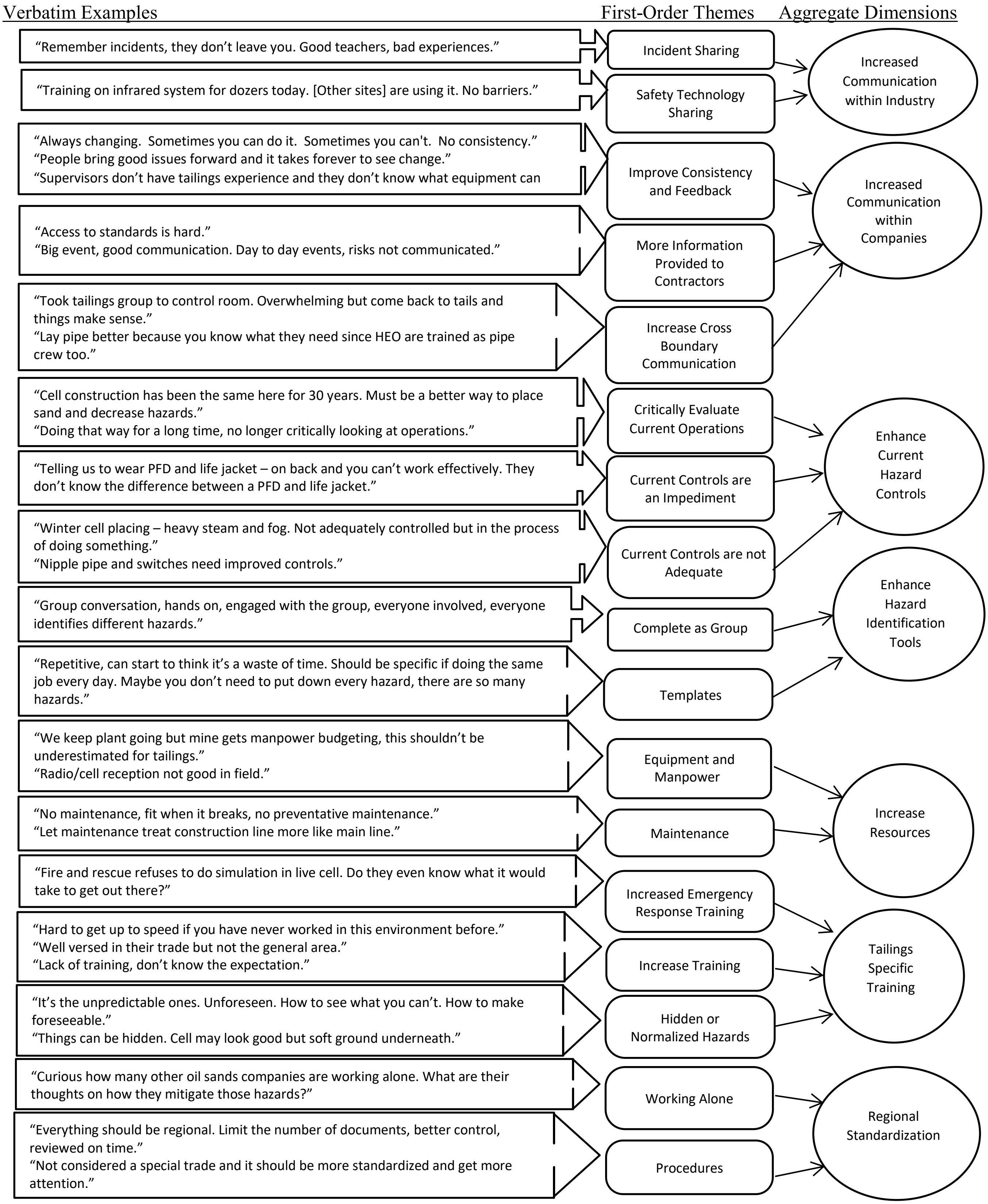


Figure 27. Data structure: representative quotes, themes, and aggregate dimensions for recommendations from interview data.

4.4 University of Alberta Ground Hazard Inventory Findings

As tailings operations are unique and constantly changing, summer, winter, and spring site visits were completed and a photo database of over 1000 photos from the different tailings operations was compiled. Geotechnical engineers are well aware of the ground hazards that can manifest in tailings operations, but 15% of the interviewees did not identify a single ground hazard in their interview. Workers with 5-10 years of experience identified 10 ground hazards on average but workers with other levels of experience identified only two ground hazards on average. Additionally, 23% of the incidents in the database related to tailings, indicating that current controls to mitigate ground hazards could be enhanced along with training. Tables 6-9 were developed to inform workers of the ground hazards in their work environment, allowing them to be more effectively controlled. These tools are meant to be used in combination with current hazard identification tools, such as field level hazard assessments (FLHAs) that assist workers in identifying hazards related to their job task. The goal of these ground hazard tools is to increase awareness of work environment hazards that can pose a significant risk to worker safety.

Table 6 discusses the four main ground hazards identified in the oil sands tailings operations: soft ground, surface erosion features, subsurface erosion features, and slope instability. It is important to note that multiple ground hazards can manifest simultaneously. Temporal factors such as heavy precipitation events, dust, spring thaw, and winter conditions (ice, snow-covered ground, steam, and darkness) affect the likelihood of a ground hazard manifesting, such as an increase in soft ground after a heavy precipitation event. Snowfall and steam can mask erosion features such as cuts in the tailings discharge area.

The likelihood values in Table 6 were determined using the incident database. The likelihood of the reported ground hazards was 49% for soft ground, 23% for slope instability, 22% for surface erosion, and 6% for subsurface erosion. The consequences were also determined using the incident database and considering the severity of the incidents related to each ground hazard. Slope instability was ranked as a high consequence, as this could lead to a loss of containment event in the tailings discharge area or at a tailings pond. Loss of containment could have a detrimental affect on workers, environment, and potentially the public. Soft ground is a low consequence event as it usually results in stuck equipment with minimal impact to workers and assets. Surface erosion is ranked as medium consequence as incidents include stuck equipment but also sunk equipment if bulldozers fall into a large cut. Subsurface erosion is high consequence as this can result in the formation of underground caverns similar to the one that led to the fatality in 2014.

The controls for these hazards are similar, and are mainly comprised of operating procedures (including preventative maintenance, structured rounds, and reporting systems) and training. Workers identified hazard mitigation strategies in their interviews, 54% of which related to administrative controls such as safe operating distances from discharge lines or working alone procedures. Engineers confirmed this high proportion of administrative controls. Elimination/substitution controls are incorporated into the design stage, but controls for daily field operations are usually administrative. Engineering controls are also used to manage risk, including end of line devices to dissipate kinetic energy and decrease the severity of cuts forming in the cells

(Figure 5), elevating the pipelines on blocking for full visibility (Figure 16), and infrared cameras on bulldozers to increase visibility in steam.

Table 6. Framework for hazards at oil sands tailings operations.

Hazard	Manifestation	Temporal Factors	Likelihood	Consequence	Controls
Soft Ground	Poor/not-trafficable roads, flooded cells, overpoured cells, spill and uncontrolled releases, drainage problems, bubble cap burst in cell, water coming up through the ground	Heavy rain, dust, spring thaw, winter conditions: ice, snow covered ground, steam, reduced daylight hours	Very Likely	Low	Operating Procedures, Training & Engineering Controls
Surface Erosion Features	Washouts, erosion gullies, cell berm breach, cracks in the benches and berms, cuts in the cells, uneven ground		Likely	Medium	
Subsurface Erosion Features	Sink holes, ground instability, caverns		Unlikely	High	
Slope Instability	Sloughing/failures of benches and berms surrounding the tailings discharge areas and tailings ponds, berm, cell and dyke breeches		Likely	High	

In addition to the ground hazard framework, three ground hazard photo databases were created to visually show how these four ground hazards can manifest at tailings operations in different seasons (Tables 7-9). Each photo database contains representative photos of the ground hazards; enhanced versions of the photos can be found in Appendix F as well as potential consequences if the ground hazard were to manifest and not be adequately controlled. Precursory conditions that could indicate a potential ground hazard are listed, and the final column is the temporal factors that affect the likelihood of a hazard manifesting or being identified in the work environment. Similar to the BTs, these photos are another visual tool to increase the probability of hazards being identified in the work environment. They should also be displayed close to the work environment as per Albert et al. (2014).

An illustrative example of information in the ground hazard photo database is given for the manifestation of both surface erosion and soft ground in the tailings discharge area in winter and summer. Spring was not included as the spring manifestation is similar to that in summer. A comparison of photo (c) in Table 7 (summer) shows the tailings being discharged into a cell in the tailings discharge area. The discharge is comprised of silica sand, process water, fine tailings, residual bitumen, and other chemicals at approximately 40-50 °C (depending on the ambient temperature and discharge temperatures from the extraction facility). When this mixture hits the sand, there is the potential for surface erosion features called cuts to form. Cuts can range in size depending on the quality of the feed and the level of compaction of the sand; some interviewees told us that cuts can be as large as ~6 m deep, 9-91 m long, and 9-12m wide. Soft ground also forms in this area as the silica is suspended in water for fluidized transport. The tailings discharge is designed to have water flow to the middle so it can be pumped to other areas of the operation; however, some of the process water becomes entrapped with the silica sand and bulldozers must travel back and forth over the sand ("track packing") to squeeze out the water and achieve the desired level of compaction for reclamation. Interactions between the water, residual bitumen, fines, chemicals, and sand are not fully understood so achieving compaction can be challenging; the cells can feature very soft ground and areas full of material that has a soup-like consistency. With both the soft ground and erosion features, bulldozers can become stuck; if the piece of equipment cannot move, another operator must come out (by track packing) to collect the worker and tow the stuck bulldozer back to solid ground. This consequence is relatively minor, representing decreased efficiency as two operators are not working and potential minor worker injury. However, the potential for more severe consequences can manifest if the bulldozer becomes sunk. Water and sand can rush in and fill a dozer quickly, resulting in the potential for worker injury or even fatality and hefty expenses to recover and refurbish the bulldozer. Water can also rush out of seemingly compacted ground and result in a sudden drop in ground level. This phenomenon can also lead to a bulldozer becoming stuck or sunk.

Photo (d) in Table 8 (winter) also shows the discharge into the tailings operations, but the temperature differential between then discharge and the air (which can be ~80 °C, as temperatures of -30 °C and colder are common in the Athabasca region) creates a thick steam making it extremely challenging to operate let alone identify the soft ground and erosion features mentioned above. Such is an example of a temporal factor that decreases the likelihood of a worker identifying a hazard and could increase the consequences depending on the size of the cut or softness of the ground. Operating in the dust in the summer and at night year-round also decreases the likelihood of a hazard being identified.

Table 7. Summer ground hazard database of potential consequences, precursory conditions, and temporal factors for a representative sample of tailings facilities, dykes, and transport systems.

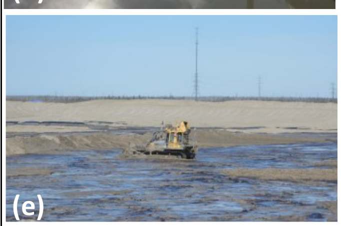
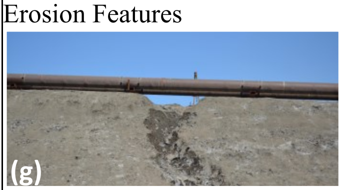
Photo of Ground Hazard	**Description**	**Potential Consequences**	**Precursory Conditions**	**Temporal Factors**
Slope Instability  	Photo (a): View of the open pit (~30 m deep). Steep slopes (~55°) typical of mining operations. A failed slope can be seen (top) at an inactive pit area Photo (b): Bull dozer creating steep cell walls in tailings discharge area	• Worker injury or fatality by crushing &/or equipment damage • Loss of containment: leaks and cell berm breach	• Sloughing • Soft material created in the cell from tailings discharge • Erosion gullies	• Heavy precipitation events increase instability • Dust and wind reduce visibility • Visibility decreases at night
Soft Ground   	Photo (c): View of tailings discharge area and end of line device (dissipates kinetic energy) Photo (d): Pumps downslope of tailings dam. Pipes and associated structures in wet, soft ground conditions adjacent to slopes Photo (e): Bulldozer working in soft ground at tailings discharge area	• Worker injury by slips, trips, or falls • Light vehicles become stuck in fine sand • Workers becoming stuck in mud or soft ground • Bull dozers will often become stuck in soft ground; worker injury &/or equipment damage • Bull dozers will occasionally sink in soft ground; worker injury or fatality by drowning &/or equipment damage	• Friction fit pipe is pushed together with bulldozers and has numerous leaks • Pipeline leaks • Excess water in tailings discharge area • Heavy precipitation	• Heavy precipitation events increase soft ground • Dust and wind reduce visibility • Visibility decreases at night
Erosion Features  	Photo (f): Washout (width ~1.5 m) filled with water Photo (g): Photo of a cut in the tailings discharge area	• Worker injury by slips, trips, or falls • Worker injury or equipment damage from undercut slope failing • Bull dozers will often become stuck in cut; worker injury &/or equipment damage • Bull dozers will occasionally sink in cut; worker injury or fatality by drowning &/or equipment damage • Worker injury by falling into a washout	• Friction fit pipe: prone to leaks, sitting on sand that is highly erodible • Pipeline leak	• Heavy precipitation events increase erosion • Dust and wind reduce visibility • Visibility decreases at night

Table 8. Winter ground hazard database of potential consequences, precursory conditions, and temporal factors for a representative sample of tailings facilities, dykes, and transport systems.

Photo of Ground Hazard	Description	Potential Consequences	Precursory Conditions	Temporal Factors
Slope Instabilities   	Photo (a): View of the open pit. Steep slopes (~55°) typical of mining operations and snow-covered benches Photo (b): View of snow-covered eroded slopes of tailings dam Photo (c): Steep slopes produced when pushing frozen soil and snow	• Worker injury by slips, trips, or falls • Worker injury or fatality by crushing &/or equipment damage • Loss of containment: pipeline leaks and cell berm failure	• Sloughing • Erosion gullies	• Ice and snow reduce visibility • Excessive steam reduces visibility • Visibility decreases at night
Soft Ground   	Photo (d): Close-up of bulldozer in soft ground at tailings discharge area with steam from hot tailings discharge Photo (e): Frozen tailings pond (not clear where beach ends and water begins) Photo (f): Frozen sump pump station	• Bull dozers occasionally sink in soft ground; worker injury or fatality by drowning &/or equipment damage • Bull dozers will often become stuck in soft ground; worker injury &/or equipment damage • Worker injury, exposure to chemicals or death by breaking through ice and falling into the water • Worker injury by slips, trips, or falls	• Hot tailings discharge hitting frozen sand • Ice • Workers do not know that they are on ice because the frozen deep-water sumps and tailings ponds are not marked • Mounds of tailings material form on pipelines from leaks	• Ice and snow reduce visibility • Excessive steam reduces visibility • Tailing ponds not visible in winter because of snow and ice • Ice thickness unknown • Visibility decreases at night
Erosion Features   	Photo (g): View of tailings discharge area and end of line device (right) while not in use; erosion on ground below end of line device Photo (h): View of tailings discharge area with bulldozer operator working below an undercut slope Photo (i): Open water at tailings pond recycled water inlet with a cut into the tailings material	• Worker injury by slips, trips, or falls • Bull dozers will often become stuck in a cut; worker injury &/or equipment damage • Bull dozers will occasionally sink in a cut; worker injury or fatality by drowning &/or equipment damage • Worker injury by falling into a washout	• Friction fit pipe: prone to leaks, sitting on sand that is highly erodible • Pipeline leak	• Ice and snow reduce visibility • Excessive steam reduces visibility • Visibility decreases at night

Table 9. Spring ground hazard database of potential consequences, precursory conditions, and temporal factors for a representative sample of tailings facilities, dykes, and transport systems.

Location and Photo	**Description**	**Potential Consequences**	**Precursory Conditions**	**Temporal Factors**
Slope Instability   	Photo (a): Seepage at the toe of dyke with some unstable areas (middle) seen on the face Photo (b): Seepage from face of dyke with ice and standing water at the toe Photo (c): Water ponding (right) at the toe of loose sand	• Worker injury or fatality by crushing &/or equipment damage • Loss of containment: pipeline leaks and cell berm failure	• Sloughing • Erosion gullies • Standing water at the toe of slopes	• Heavy precipitation events and spring melt increase instability • Snow and ice reduce visibility • Visibility decreases at night
Soft Ground   	Photo (d): Truck stuck in mud and soft ground from spring melt Photo (e): Standing water on road with ice melting on the side Photo (f): Muddy and soft ground conditions between pipelines in working area	• Worker injury or fatality by falling into deep standing water • Stuck vehicles in soft ground conditions or deep water on roads • Bull dozers occasionally sink in soft ground; worker injury or fatality by drowning &/or equipment damage • Bull dozers will often become stuck in soft ground; worker injury	• Difficult to identify standing water in freeze-thaw • Spring thaw: difficult to distinguish between wet areas and soft ground conditions • Heavy precipitation • Spring melt	• Unknown depth of water • Snow and ice reduce visibility • Heavy precipitation events and spring melt increase soft ground • Visibility decreases at night
Erosion Features  	Photo (g): Slope in the tailings discharge area with pipeline and erosion features Photo (h): View of pipeline that has fallen into an erosion feature next to a road	• Worker injury by slips, trips, or falls • Bull dozers will often become stuck in a cut; worker injury &/or equipment damage • Bull dozers will occasionally sink in a cut; worker injury or fatality by drowning &/or equipment damage • Worker injury by falling into a washout	• Friction fit pipe: prone to leaks, sitting on sand that is highly erodible • Pipeline leak • Spring run-off and melt	• Snow and ice reduce visibility • Spring run-off increases erosion • Heavy precipitation events and spring melt increase erosion • Visibility decreases at night

4.5 Sprint Brainstorming Activity Results

As the six groups shared their findings at the TSS, it quickly became apparent that the reasons hazards are not reported or identified are very similar across oil sands tailings operations. There are systemic cultural roots for why hazards are not identified or reported. These roots are lack of training, fear, risk tolerance, external pressures, cultural inaction, complacency, lack of accountability and dynamic work environments. An application for an Alberta Occupational Health and Safety Futures Grant has been submitted with the aim of further analyzing these data.

4.6 Brain Writing or "8-1-2" Group Brainstorming Results

It was apparent after reading the "8-1-2" brainstorming documents that people in tailings are critically analyzing the operations and thinking of methods to eliminate or reduce the risk to protect workers. Each participant (105) ended up with enhancements to their original solution to mitigate the risk for the top seven hazards in tailings operations. Some of the responses were enhancements to or suggestions for new administrative controls, such as increasing emergency response training by cross training tailings personnel to be first responders. Many of the respondents discussed the need to implement more automation and remote-controlled vehicles, which would eliminate hazards by removing people from the tailings operations. Suggestions to work with design and planning engineers to completely change the operations and setup of tailings were also common. These suggestions included ideas such as changing the footprint of tailings and providing windbreaks, thoroughly cleaning ponds on start-up, completely redesigning spill boxes, and installing permanent roads in tailings. These suggestions may not be feasible for current operations, but could be implemented for new mines.

Implementing amphibious vehicles was a common suggestion for most of the top seven hazards, as ground hazards would then not be as much of a concern nor would determining the interface between solid ground, ice, and water in winter. These vehicles could also assist with emergency response and spill box operation.

Other suggestions included using new technology such as infrared cameras to detect pipeline leaks; monitoring the quality of feed to the tailings discharge area to obtain better compaction; implementing solar, wind, and battery power as opposed to using cables in the water; installing an agitator to stop the formation of ice on ponds; and using HEPA filters and positive pressure cabs to prevent silica dust from entering the equipment.

These elimination and substitution suggestions were added to the BT diagrams (Figures E1-E7 in red boxes to indicate they have not yet been implemented in daily operation as per DyPASI (Paltrinier et al., 2014).

5 Discussion

Each dataset was analyzed in a holistic approach to determine recommendations to improve worker safety at oil sands tailings operations. The recommendations followed the themes generated from the interview data and literature for incident database best practices: (1) increased communication within industry, (2) increased communication within companies, (3) enhancements to hazard identification tools, (4) critically evaluate current operations, (5) increase resources, (6) tailings-specific training, (7) regional standardization, and (8) enhancements to incident databases.

Increased Communication Within Industry

Workers know that operations are similar across sites and are curious to know what other operators are doing to mitigate hazards. There is already informal sharing of information (technical and incident) as Fort McMurray is a small town, but interviewees would like to see this dissemination of information formalized so sustainable changes can be implemented.

Increased Communication Within Companies

The oil sands sites are large, and the vastness of the operations makes it physically challenging to communicate information. Everyone on these sites is also very busy; time is a valuable resource. Interviewees would like to see this change, and would like to see more engineering and management presence in the field so they have a better understanding of the operations. One way to increase field visits could be to make "time spent in the field" a regional key performance indicator. Participants would also like more consistency from management with regards to plans, deliverables, goals, and job functions. The existing ambiguity can make it challenging for workers to complete their job or identify and report hazards. Accessing the correct information and procedures is also challenging according to some workers, especially contractors, who do not have direct access to the same information as workers at the owner company. Frontline workers mentioned silos in communication with other frontline groups (e.g., heavy equipment operators (HEO) to pipe crew). Some companies cross-train their employees in multiple job functions; workers noted this is a way to bridge the gap between the different working groups and such implementation could be valuable to many operations.

Enhance Current Hazard Controls

Many controls were also mentioned over the course of the interviews. The majority (56%) of respondents mentioned administrative controls, such as standard operating procedures, permits, and training. End of line devices such as spoons were a very common engineering control that was mentioned (33%), and PPE such as PFDs, dust masks, and traction aids represented 11% of the controls discussed. Some people discussed elimination and substitution alternatives (3%) but many interviewees felt that it was time to start looking more critically at the operations and making some design changes to the fundamental way tailings are handled. This was confirmed by the "8-1-2" brainstorming method at the TSS. There was also a discussion about the appropriateness and effectiveness of current controls. Some controls, such as PFDs and life jackets, actually pose an impediment to completing work as they are bulky and not specifically designed for the job task. A recent fatality investigation shared by Teck recommends the use of inflatable life vests that facilitate machinery cab egress in emergency situations where a cab submerges (Teck, 2018). For certain tasks, these more compact life vests may mitigate the impediment of more bulky models, if the person is not otherwise incapacitated. Interviewees also identified other hazards that they felt were not adequately controlled, including friction fit pipe and spill box board installation. The level of effectiveness and appropriateness of controls is another area that companies should investigate further.

Enhance Hazard Identification Tools

Hazard identification tools are widely used in many industries (OHS, 2009 and 2015). They encourage workers to analyze their work environment and job task prior to beginning work. Many workers felt that the current hazard identification tools (FLHA, LPSA, FLRH, JSA, etc.) are not effective for the tailings environment. They felt that these tools were a “pencil whipping” exercise. To combat the sense of complacency with these tools, many workers told us that they preferred to complete the hazard identification as a group since they could identify more hazards together than alone. Another suggestion was for hazard identification tools to be created for specific job tasks, with the common hazards already identified. The workers can then focus on changes in the job task and environment and add “fresh ink” to the templates. The initial template should be created with safety professionals and frontline workers, following a similar process as a hazard and operability study (HAZOP), to ensure all typical hazards are identified. Workers would then be able to look for variations from the typical work environment, allowing them to identify hazards that may have been previously unseen/unknown.

The ground hazard photo databases and framework were designed to enhance current hazard identification tools and increase mindfulness of the hazards in the work environment that may not necessarily be related directly to the job task. Research has found that workers more easily identify hazards after they have seen examples, and this benefit is amplified when the hazards are displayed near the worksite itself (Albert et al., 2014). Therefore, it is recommended that the visual tools (BT diagrams and ground hazard photo databases) be displayed in the lunch shacks at tailings operations.

Increase Resources

A lack of resources in the form of workforce, equipment, and maintenance was identified by the majority of interviewees. They felt they were working short staffed and did not have access to the appropriate tools to complete the job, which could lead to shortcuts. Lack of maintenance in the form of preventative maintenance on pipelines and other equipment was also identified. A workforce shortage was noted on the maintenance side, with personnel only working day shifts and having to split their time with the mine. A dedicated tailings maintenance staff may be worth investigating, not only to handle maintenance issues but also to create a pool of personnel who would also be more familiar with the hazards in the tailings operations and therefore decrease the potential for incidents.

Tailings-Specific Training

Administrative controls, including training, are one of the most ubiquitous controls across the tailings operations and, yet, no tailings-specific training exists. Instead, all employees and contractors go through mine orientation and training. Workers noted that the tailings environment is extremely different than the mine environment, even for seemingly simple tasks such as driving: “Roads are made of K-spec (trace oil sands) which are slippery like grease. At 3 km/hr the truck can go sideways. Unless you’ve driven, you can’t know how bad it is. Not much driving training for tailings, take mine driving training instead, but it is very different to drive on K spec vs. haul roads”.

There are also hazards that are unique to the tailings operations, such as heavy steam off discharge lines in the tailings discharge area. Known hazards also manifest differently in this area, including ground hazards: "Some ground conditions are bottomless (soft, soft, soft). Hard to get solid ground".

Given the frequency of exposure in these operations, e.g., "we aren't building pianos, this is dangerous and heavy work", the risk tolerance of operations can be high. This is seen through the normalization of hazards such as leaking pipelines. Some hazards are unknown and unseen, including the cavern formation that caused the 2014 fatality.

Given the unique, ever-changing, and challenging nature of tailings operations, time should be spent to develop specific training and procedures that fit the operations. ESC also identified the need for regional tailings training.

Discussions have already begun on the best method to deliver tailings-specific training. Given the seasonality of the hazards, the seasonal workforce, and turnover rates, it was decided that online microlearning modules would be the best way to disseminate this training. Four modules will be created: a general tailings hazard awareness module to be taken during onboarding and then a module for each of the seasons (summer, winter, and spring). Workers will take this training each year, three weeks prior to the season change to refresh their memory about the hazards in their work environment. The photos, ground hazard database, and BT diagrams will be used in these training modules.

Regional Standardization

The processes used to produce tailings may vary from site to site, but the hazards are very similar. This similarity was identified by both the interviewees and the ESC tailings safety task force. Both of these groups are calling for the regional standardization of policies to protect worker safety in tailings operations. Interviewees would like standardized procedures to decrease confusion, limit the number of documents, and treat tailings as a special trade. The interviewees are especially curious about the working alone procedures and what other companies are doing to mitigate hazards. ESC task force members also agree with the need for standardization in the form of regional tailings training as well as with respect to the procedures for different sites (i.e., leaking pipeline approach procedures, at what distance from water PFDs need to be used). By standardizing the procedures, there will be less confusion, especially among contractors, making it easier to complete job tasks and identify hazards.

Enhanced Pipeline Leak Controls

It is recommended that all oil sands tailings operations, through facilitation by ESC, implement the following controls that have been developed as part of the U of A's research project. These controls have been implemented by some industry members and have been very effective at mitigating pipeline leaks and improving collaboration within companies. The suggestions include four small but effective changes for continuous improvement in tailings areas.

1. Elevating the pipeline using a combination of pipe supports/pipe saddles/wooden blocking to provide a full 360° view of the pipeline. The benefits of this practice are twofold, as any

leaks that do occur are easier to see as the line is not laying in the sand and there is less external abrasion on the line from the sand in the work environment.

2. Changing snow clearing and grading procedures so windrows cannot be pushed up against the pipeline. This change also makes it easier to identify leaks as the whole line is visible.
3. Implementing a standardized line approach procedure. This procedure ensures that no leak is investigated by a worker working alone. This procedure includes identifying the leak, notifying the correct personnel about the leak, including the control room operators who can shut down the line to stop the flow of tailings, and bringing in additional workers and heavy equipment to investigate the leak by testing the ground within a safe setback distance from the pipeline.
4. Using larger flag markers to identify the location of drain valves. The areas near drains have a higher potential to see soft ground or erosion features manifesting because of their designed use.

Where these changes have been implemented, they have been extremely effective in promoting a cultural shift towards open, honest, transparent discussions within the tailings operations, not only at the frontline level but between all levels of the organization. There has also been a shift towards the support of questioning attitudes, which has broken down barriers and increased communication within the tailings operations to better identify and control hazards.

Enhancements to Incident Databases

Every company used a different type of database software to collect and house incident data. Therefore, each company had their own definitions for incident level, consequence, likelihood, and risk. These definitions aligned with the process safety definitions for refineries. Many of these definitions are not appropriate for use in tailings operations as incidents in this area occur at a higher frequency and have lower consequences relative to the refinery. By using the refinery's definitions, the severity of the incidents in tailings operations could be masked by trying to fit these incidents into categories that are inappropriate. This could also be leading to the occurrence of more incidents with similar root causes, because the definition provided does not prompt further investigation or remedial action from the company.

In their current form, the incident databases show some incident trends; however, there is room for improvement. To improve the quality of data analysis from the incident databases, the level of reporting in the operations needs to increase. Many of the reported incidents related to production outages and did not provide enough information to be used as an indicative leading indicator. A gap in the level of reporting was identified by interviewees, who noted "no reporting of near misses; such a big tell". The number of ground hazards mentioned in the interviews was higher than the reported values in the incident database; 60% of interviewees mentioned soft ground (compared to 49% in the database), 52% mentioned surface erosion (compared to 22%), and 39% mentioned slope instability (compared to 23%). Subsurface erosion was mentioned at consistent rates in both cases, at 6%. There is also some discrepancy in terms of the classification of the incidents from company to company and even within companies.

To increase the quality of data analysis and trending, incidents and near misses should be ranked on a potential hurt scale, with multiple employees at higher levels determining the incident level if agreement cannot be reached amongst site supervisors. Near misses should also be included in the reporting process as they serve as learning opportunities without injury outcome occurrence (Hinze, 2002). This way, unique and novel cases are being brought to the attention of upper management prior to the occurrence of potentially serious issues. Utilizing a risk matrix that better reflects the higher frequency events occurring in tailings operations is also suggested. The level of reporting also needs to increase. To better cluster and utilize near misses to trend leading indicators and proactively implement mitigation strategies companies may consider standardizing and sharing incident data.

Work is being done to automate classification of the incident database to identify incident trends and develop a risk matrix (Figure 28) that combines the participating companies and better reflects the tailings operations. This work will be completed within the year and results will be shared with participating companies through ESC. Incident trending with improved reporting and consistent classification will identify higher frequency risk exposures and otherwise unknown hazards for mitigation. "Incidents are a signal that we don't have it right yet" (personal correspondence with Gord Winkel) and in themselves constitute a leading indicator for driving improvement.

	5	4	3	2	1
Health/Safety	Minor injuries or illnesses that do not require first aid treatment or may require basic first aid treatment	One or more injuries or illnesses requiring medical treatment or resulting in restricted work.	One or more injuries or illnesses resulting in lost time	Single fatality or one or more long term disabilities	Multiple fatalities
Environmental	Inconsequential or no adverse effects, clean up confined to site or close proximity	Minor adverse effects, local emergency response, 0-6 months clean up	Medium adverse effects, local emergency response, short to medium term effects, 7-12 months clean up	Medium to significant adverse effects, intermediate emergency response, 1-4 years clean up	Off property impact requiring remediation taking 5 years or more. Major emergency response with significant adverse effects.
Reputation	No media coverage. Single stakeholder involvement with concerns addressed in the normal course of businesses. Temporary side road closure.	Local media coverage. Multiple stakeholders involved with concerns addressed in the normal course of business. Secondary road closure lasting < 24 hours	Extended local media coverage or one-time national media coverage. One or more key stakeholder involvement with concerns being addressed outside the normal course of business. Extended secondary road closure (> 24 hours)	National media coverage. Involves multiple key stakeholders. Operations interrupted. Major road closure < 24 hours.	International media coverage. Multiple key stakeholders involved. Operations shutdown and/or potential of future operations being prevented. Extended closure of major road.
Financial	C < $1M	$1M < C < $10M	$10M < C < $100M	$100M < C < $500M	C > $500M

Figure 28. Risk matrix designed to reflect the tailings operations (Kurian, 2019).

6 Future Work

There are many opportunities for future work with these four datasets.

Similar methods could be applied to other tailings hazards utilizing the incident databases and interview results. Site visits could be conducted to compile photo databases for these hazards as well. This could be taken one step further, with each of the different areas of tailings (tailings discharge area, fluid tailings, etc.) analyzed individually as there are unique hazards associated with each working area.

Additionally, the energy wheel mechanism to identify hazards, from Figure 11, could also be applied to classify the incident database based on incident type. The potential consequence and likelihood (or risk) could be determined from the current incident data and a hybrid fuzzy logic approach applied to determine quantitative risk values from incident databases. Hybrid fuzzy techniques are a popular method for quantitatively analyzing data that are qualitative in nature. Incident databases contain thousands of incident reports ranging from near misses to fatal accidents, and these databases continue to expand on a regular basis. While some contributing factors are unavoidable, many are in fact preventable – or at the very least, possible to mitigate. Future research in this area could involve using some aspects of fuzzy logic to quantify incident reports by applying keyword analysis and machine learning and using different numerical analysis techniques to analyze the quantitative data. Quantitative analysis could range from basic statistical analysis (e.g., regression or multivariate ANOVA) to neural networks or applying Bayesian logic. These methods can be applied to search for trends pertaining to certain incidents, to identify leading indicators for incidents that can be avoided, and to increase awareness of the risks involved in working in certain situations.

A grant application has been submitted to Alberta OH&S for a Futures Grant to continue analysis of the sprint brainstorming results from TSS.

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APPENDIX A: Occupational Health and Safety Report

Alberta Government

Investigation Report

Fatality – Worker Drowned in Tailings Pond

January 19, 2014

Report No-F-OHS-056980-A5B24
June 2017

Contents of this report

This document reports Occupational Health and Safety's (OHS) investigation of a fatal incident on January 19, 2014. It begins with a short summary of what happened. The rest of the report covers this same information in greater detail.

Incident summary

During a night shift, a worker noticed water flowing from an unknown source at the base of a tailings pond area in a large oil sands project. The worker parked the company truck and followed the water stream on foot back to the source of the water flow. A leak in a pipeline was the cause, and the leak had undercut the ground under an elbow in the pipeline creating a considerable hole filled with a slurry mixture of sand and water covered by a thin layer of ice and snow. The worker approached the source of the leak and fell through the ice into the slurry mixture and subsequently drowned.

Background information

Suncor Energy Inc. (Suncor) is a Canadian energy company based in Calgary, Alberta (AB) that extracts and upgrades oil sands material into bitumen products for further refining and processing. The deceased worker was an employee of Suncor.

The incident occurred at approximately 5:30 a.m. on January 19, 2014, in a location identified as Sand Dump 8 at Suncor - East Tailings Millennium Mine facility approximately 50 kilometres (km) north of Fort McMurray, AB.

Worker 1 – the deceased worker had worked as an upgrade supervisor for Suncor and had approximately 13 years' experience, as well as several years' experience working specifically as a tailings operator.

Suncor had provided numerous training courses, including the Line Patrol course, to worker 1 over the 13 year period.

Equipment and materials
Suncor - East Tailings area – Sand Dump 8 – Millennium Mine area consisted of coarse tailings produced as a result of the bitumen extraction process (approximately 250 feet deep of sand granular type material)

Pipeline "Line 16" was a 28 inch carbon steel pipeline which transported water mixed with tailings (fine and coarse granular sand type material) from Plant 300, approximately 10km, to Sand Dump 8 area where the tailings material was deposited.

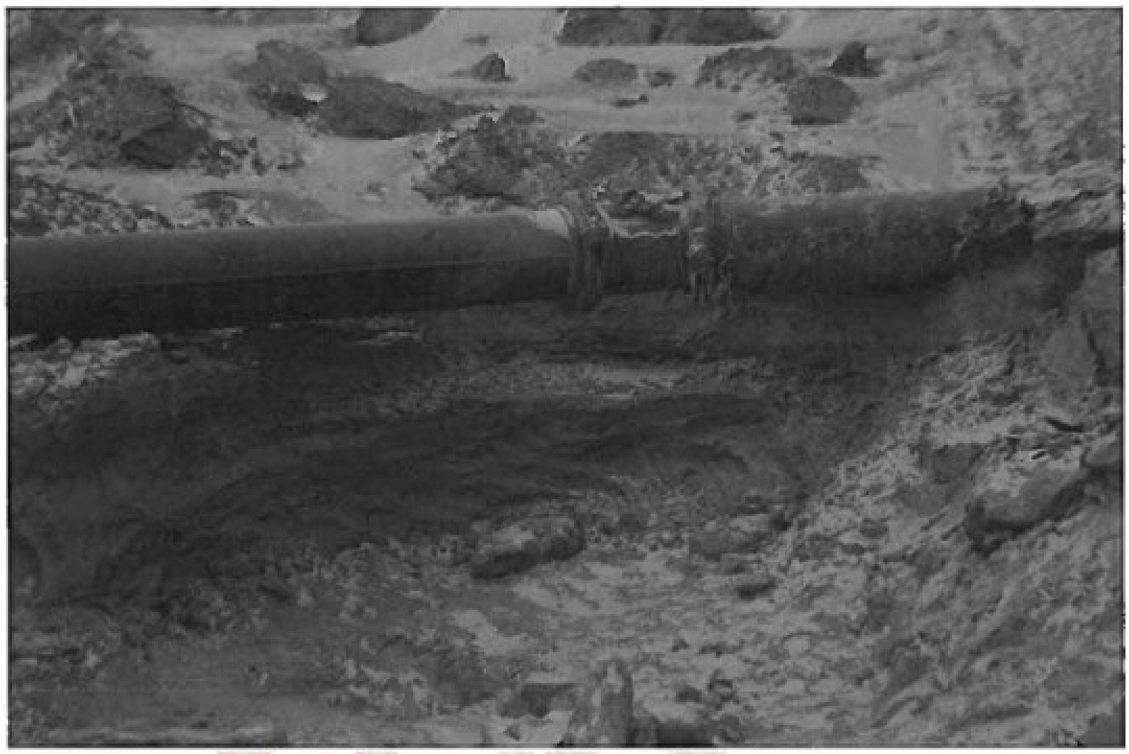


Figure 1. Location of undercut at Line 16 where the body of worker 1 was located.

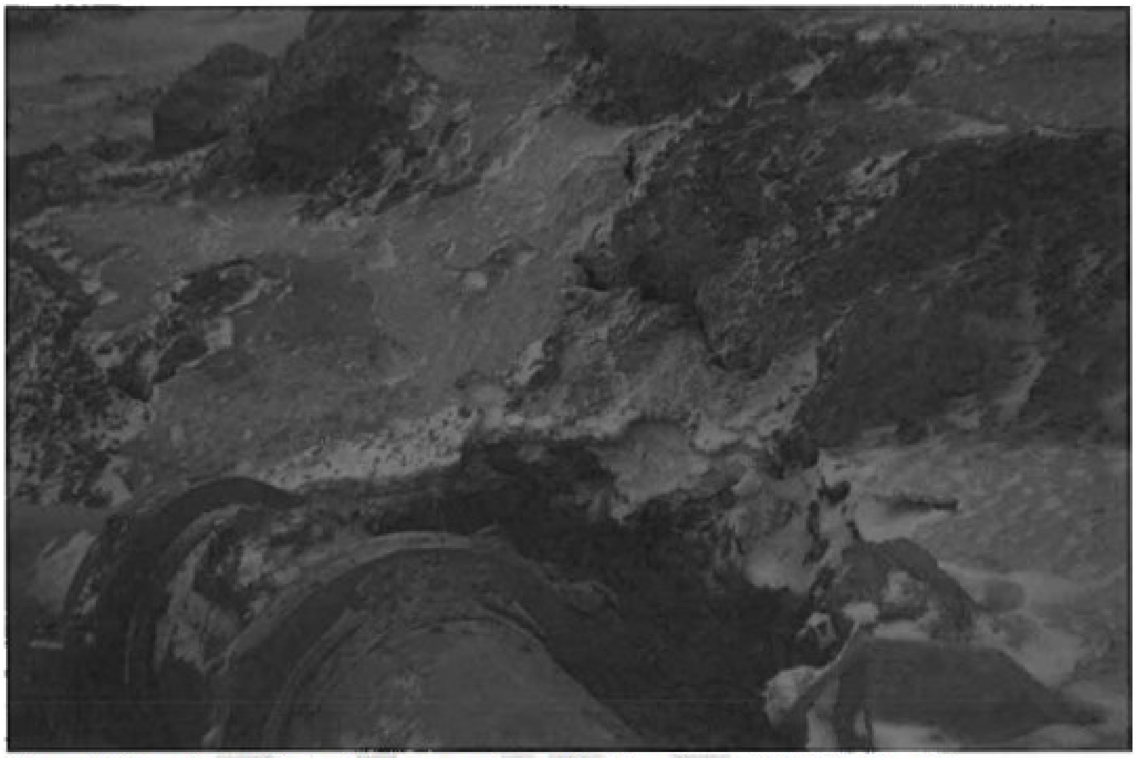


Figure 2. Location of footprints in snow above the elbow (spool 3890) in Line 16.

Sequence of events

On January 19, 2014, worker 1 performed job duties as an upgrade supervisor on the night shift rotation in the coarse tailings operations and operated a company pickup truck on a road within the area referred to as Sand Dump 8.

While driving the truck, worker 1 noticed a trail of water flowing below a tailings pond and suspected a breech in a nearby support dyke.

At about 5:10 a.m., worker 1 made a cell phone call to the shift supervisor to inform the shift supervisor of the flowing water and that worker 1 was going to follow the water to locate the source.

No further radio communication was heard from worker 1 after 5:10 a.m.

Between 5:45 a.m. and 6:00 a.m., several 2-way radio call attempts were made to contact worker 1.

Shortly after 6:00 a.m., Suncor's Line Patrol conducted a search for worker 1.

At 6:41 a.m., Suncor Emergency Services Department (ESD) received a dispatch call that worker 1 was missing.

An abandoned pickup truck with the driver's door open was found by Line Patrol parked off the road. Footprints in the snow were seen to lead away from the pickup truck towards the pipeline area of Line 16.

At 7:50 a.m., a 911 phone call was made by Suncor's onsite ESD for Royal Canadian Mounted Police (RCMP) assistance to locate missing worker 1.

Searchers followed footprints in the snow from the parked company truck which led up to Line 16 where a safety vest and a hooded jacket were located in the pipeline area under Line 16. The footprints in the snow, which led to Line 16, ended at the elbow in the pipe referred to as spool 3890.

Based on the footprints, vest and hoodie discovery, it was assumed by Suncor's Line Patrol that worker 1 may have fallen into an undercut in the dyke structure created by the water leak in Line 16.

Two excavators were called in from nearby operations to dig into the tailings material to drain the slurry tailings material and water under spool 3890. The body of worker 1 was not located at that time.

At 8:16 a.m., ESD called for vacuum trucks to come to Line 16, specifically to the elbow in the pipe (spool 3890). Vac trucks started to suck up the remaining pool of tailings and water.

At about 10:19 a.m., the body of worker 1 was located in the bottom of an undercut hole approximately 10 to 12 feet deep in the tailings sand under Line 16, spool 3890.

At 10:46 a.m., the RCMP searched the nearby abandoned company pickup truck and found a wallet inside the cab on the front seat which contained identification belonging to worker 1.

At about 11:09 a.m., the unresponsive body of worker 1 was recovered by Suncor's ESD personnel with RCMP present on site.

Worker 1 showed no vital signs of life upon removal from the hole.

The body of worker 1 was placed on a stretcher and taken to a nearby waiting Suncor ESD ambulance.

RCMP verified the identity of worker 1 from the identification found in the pickup truck that was parked by the road.

Worker 1 was taken by ambulance to Northern Lights Regional Hospital.

OHS was called and informed of the incident.

Completion
Occupational Health and Safety investigators completed the investigation and swore charges on January 13, 2016.

On April 24, 2017, Suncor Energy Inc. was convicted under Section 2(1)(a)(i) of the *Occupational Health and Safety Act*. At sentencing, Suncor Energy Inc. was fined $15,000 inclusive of a victim fine surcharge; a creative sentence was also levied against Suncor Energy Inc. under Section 41.1 of the *Occupational Health and Safety Act* in the amount of $285,000 in favour of the Lynch School of Engineering Safety University of Alberta to conduct a two year research project into tailings storage facilities in the oil sands.

This file was closed on April 26, 2017.

Signatures

<u>ORIGINAL REPORT SIGNED</u>	<u>July 4, 2017</u>
Lead Investigator	Date
<u>ORIGINAL REPORT SIGNED</u>	<u>July 12, 2017</u>
Manager	Date
<u>ORIGINAL REPORT SIGNED</u>	<u>July 14, 2017</u>
Director	Date

APPENDIX B: Semi-Structured Interview Questions and Detailed Interview Demographics Infographic

Frontline Workers

1. What is your role at your company, and how long have you been in this role?

2. What hazards do you see around tailings facilities, dykes, and transport systems?

3. If you could make one change with regards to tailings workplace safety practices, what would it be?

4. What are the barriers to implementing this change?

5. What do you think your supervisor's answer would be?

6. What do you deal with daily that you don't get support from management on?

7. Do you ever need to take shortcuts to get your work done? (Potential questions for elaboration: Please describe (what, when, how, why). If they answer "no"- Do you ever take short cuts? Does your supervisor know you take these short cuts? If they did, what do you think would happen?)

8. Knowing what you know now, what do you wish you were told on day 1 of your job (in regards to safety or operations with tailings facilities, dykes, and transport systems)?

Leadership

1. What is your role at your company, and how long have you been in this role?

2. What hazards do you see around tailings facilities, dykes, and transport systems?

3. In regards to tailings facilities, dykes, and transport systems safety, what keeps you up at night?

4. If you could make one change with regards to tailings workplace safety practices, what would it be?

5. What are the barriers to implementing this change?

6. If you had more resources for tailings safety and management, what would you ask for?

7. Knowing what you know now, what do you wish you were told on day 1 of your job (in regards to safety or operations with tailings facilities, dykes, and transport systems)?

Roving Contractors

1. What is your role at your company, and how long have you been in this role?

2. What hazards do you see around tailings facilities, dykes, and transport systems?

3. Are you treated differently compared to employees at your company? (Potential question for elaboration: In what ways?)

4. Are there additional demands on your time that employees don't have?

5. If you could make one change with regards to tailings workplace safety practices, what would it be?

6. What are the barriers to implementing this change?

7. Do you ever need to take shortcuts to get your work done? (Potential questions for elaboration: Please describe (what, when, how, why). If they answer “no”- Do you ever take short cuts? Does your supervisor know you take these short cuts? If they did, what do you think would happen?)

8. Knowing what you know now, what do you wish you were told on day 1 of your job (in regards to safety or operations with tailings facilities, dykes, and transport systems)?

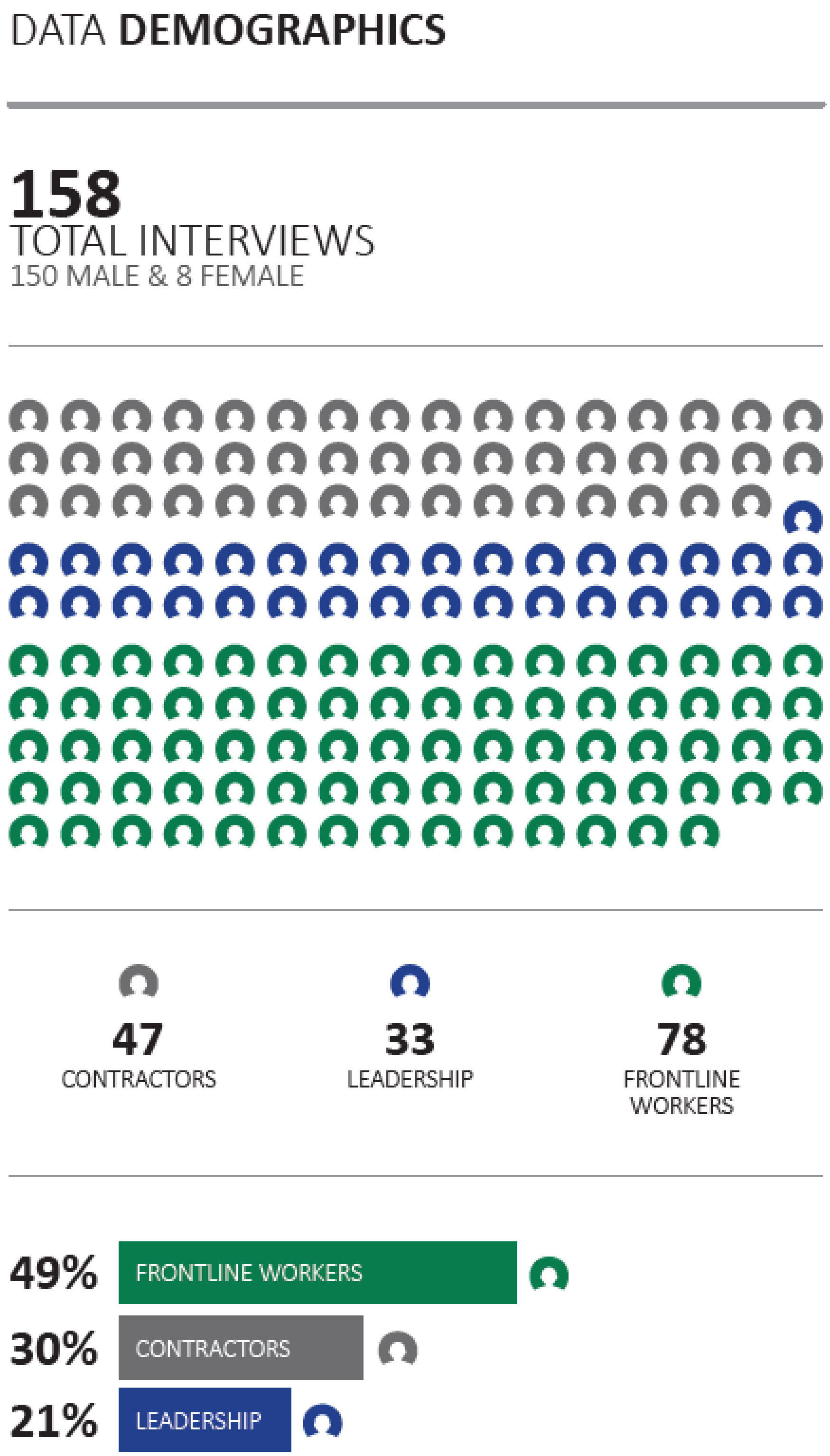


Figure B1. Detailed interview demographics for 158 interviewees.

APPENDIX C: Tailings Safety Symposium Flyer

Tailings Safety Symposium

WHERE: **Quality Hotel & Conference Centre**, Fort McMurray
WHEN: **November 29**, 2018
TIME: Breakfast **Starts At 7:30 am | Day Will Wrap Up At 4:30 pm**

Why Attend?

Influence the enhancement of tailings safety in the oil sands

A one – day symposium that will bring together frontline workers, contractors, safety professionals, leadership and academia to share their knowledge and expertise about working in or around the oil sands tailings operations.

University Of Alberta Research

The University of Alberta has been conducting research with four key oil sands operators and ten regional contractors since August 2017. We have completed the following in the past year:

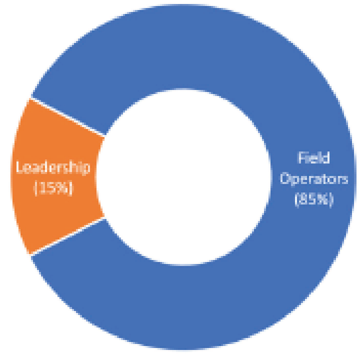
- Six site visits have been conducted in summer, winter and spring to assess the ground hazards and observe how the operations and risk drastically change with the seasons
- Over 140 frontline workers, safety professionals, contractors and people in leadership roles have been interviewed
- Key oil sands companies have provided us with their incident databases and we have analysed
- them to determine leading indicators of hazards in the tailings operations
- Energy Safety Canada provided us with a prioritized hazard list from their own site visits and we have created Bow Tie tools to help communicate the risks in the tailings operations

UNIVERSITY OF ALBERTA

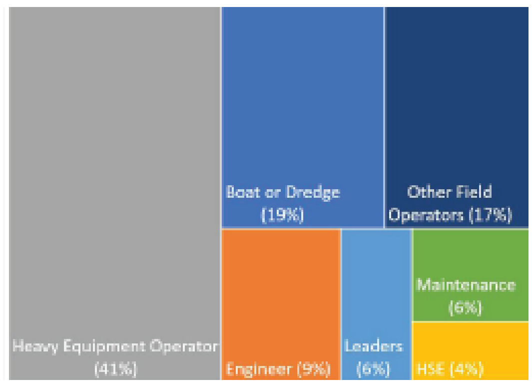
David and Joan Lynch School of Engineering Safety and Risk Management

ENERGY SAFETY CANADA

Findings



We have heard from many workers, leadership and safety professionals across the different organizations that there is a sense that the tailings operations are sometimes forgotten. We have found that people are aware of the hazards and risks in the tailings operations, but there appears to be some breakdown in the communication of these risks to workers who do not spend much time in tailings. There is also a disconnect between what is being reported in the incident databases and what workers and safety experts are identifying as high-risk activities in their working environment. Our goal is to bridge these gaps in communication. We want to provide recommendations to the oil sands operators that are useful, implementable and what the workers who interact with the tailings operations daily want to see. To do this, we need your help and input on this research project.



Benefits

The benefits to attend this one-day symposium are:

- You will be involved in a unique experience where workers from all levels and different companies are together in one space discussing issues, incidents, learnings and best practices and working together as an industry to make the tailings operations a safer place to work
- Your feedback over this day will be used to confirm findings and any identify gaps in our work to date
- This input will be used to identify next steps in enhancing tailings safety in the oil sands
- There will be the opportunity to network with people from different oil sands companies and regional contractors

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Contact Information

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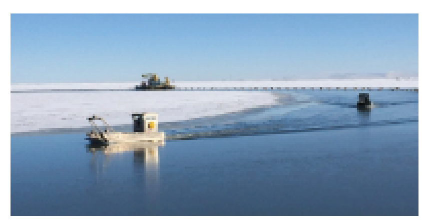


UNIVERSITY OF ALBERTA

David and Joan Lynch School of Engineering Safety and Risk Management

ENERGY SAFETY CANADA

APPENDIX D: “8-1-2” Brainstorming sheet example

Table # __________

“8-1-2” Method – Structured Brainstorming

Problem Statement:
How do you eliminate or substitute for certain hazards in the _________ bow tie?

Name	Idea
Person 1	
Person 2	
Person 3	
Person 4	
Person 5	
Person 6	
Person 7	
Person 8	
Person 9	
Person 10	

APPENDIX E: Bow Tie Diagrams for the Top Seven Hazards in Tailings

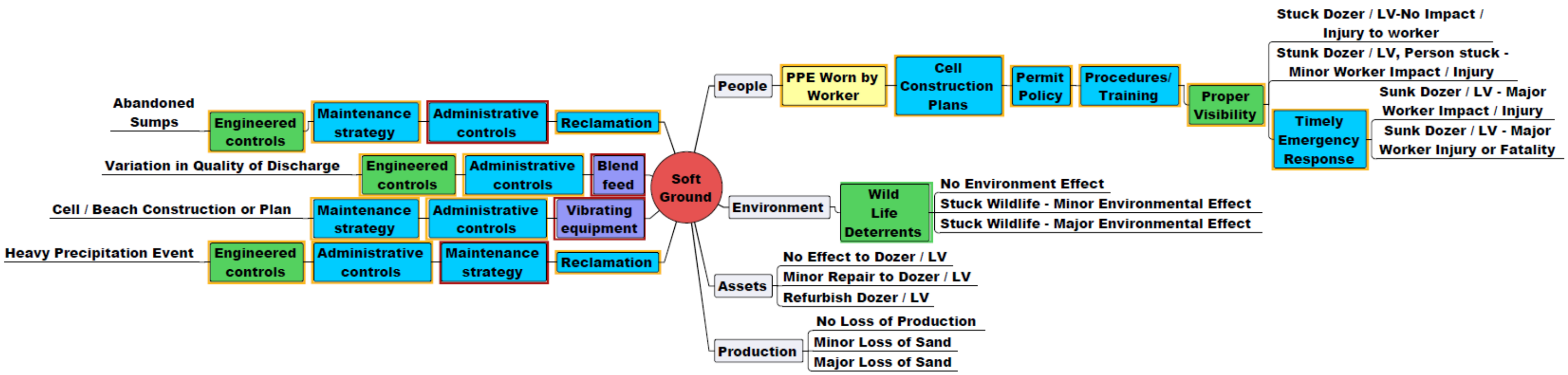


Figure E1. Soft ground bow tie diagram.

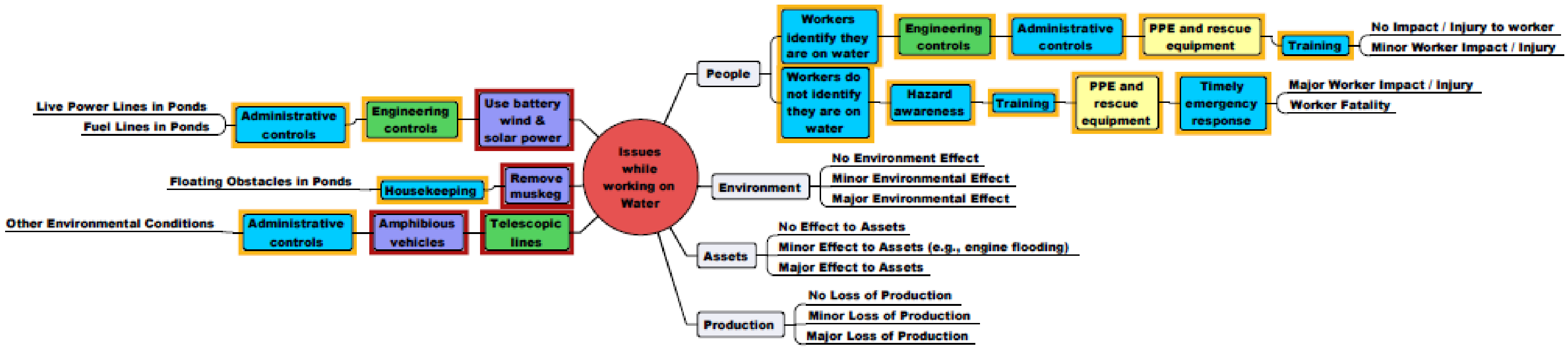


Figure E2. Working on water bow tie diagram.

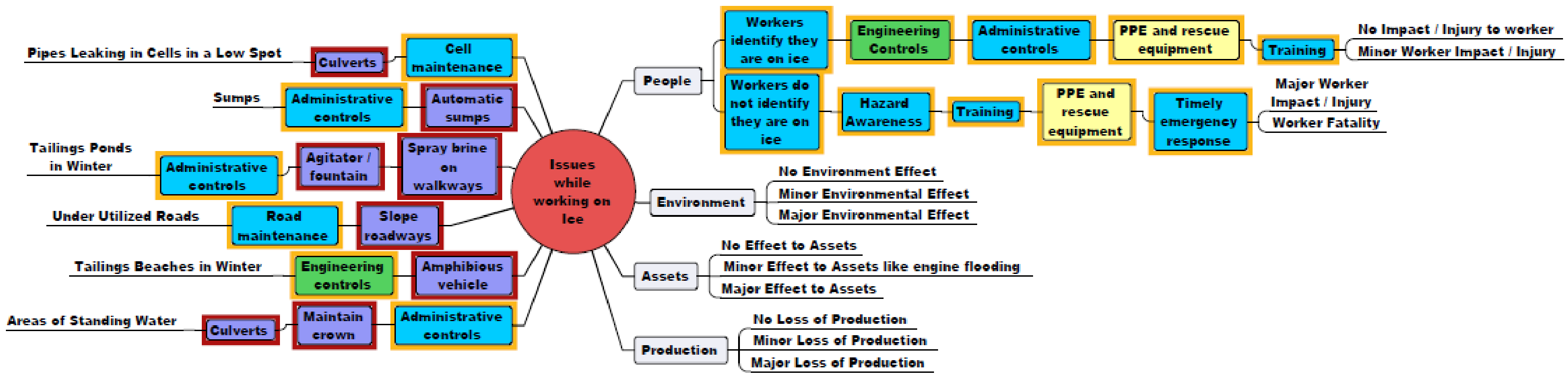


Figure E3. Working on ice bow tie diagram.

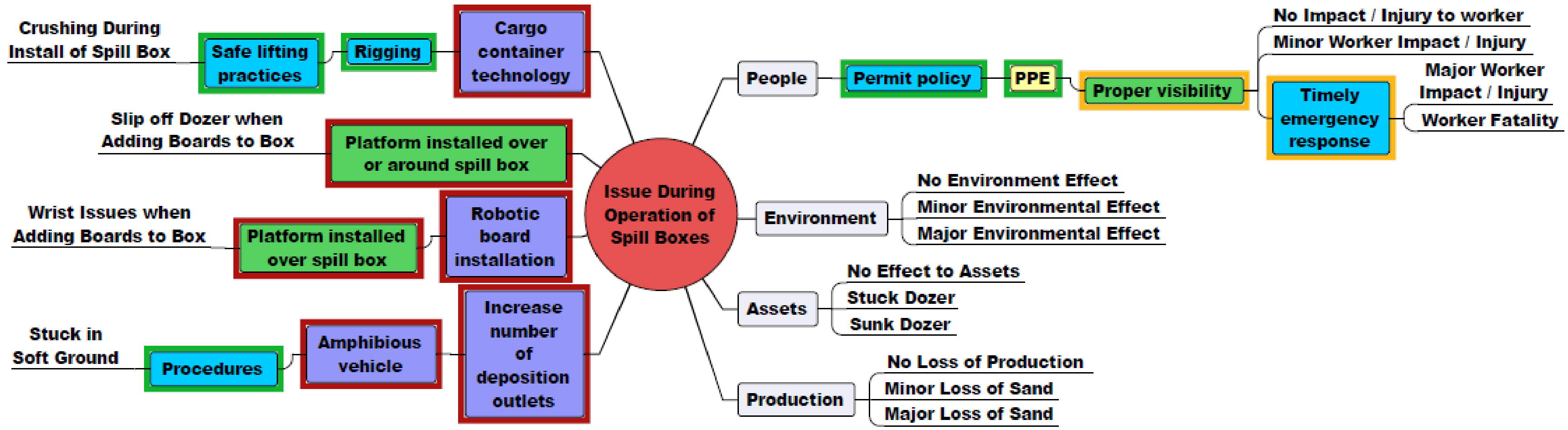


Figure E4. Spill box operation bow tie diagram.

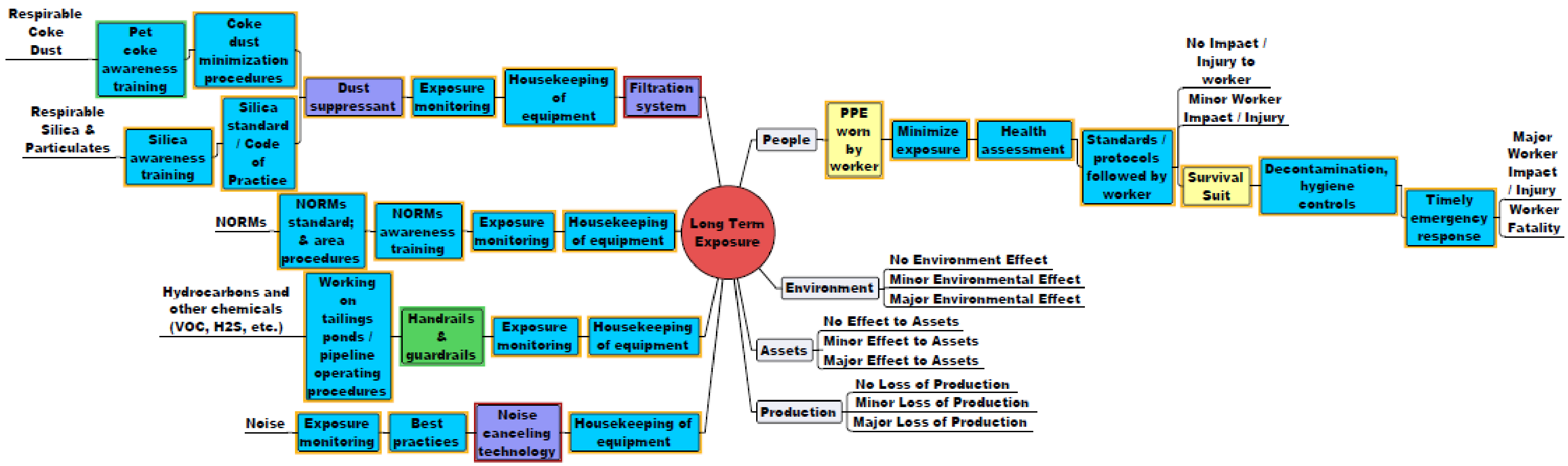


Figure E5. Long-term exposure bow tie diagram.

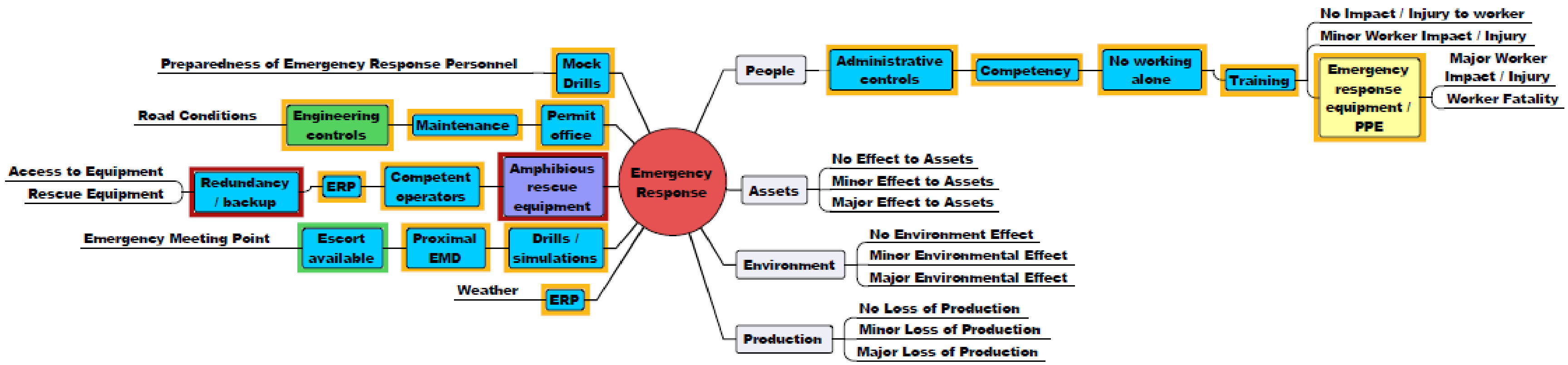


Figure E6. Emergency response bow tie diagram.

APPENDIX F: Ground Hazard Database- Enlarged Photos from Tables 7, 8, and 9

Summer Photo (a), Table 7. View of the open pit (~30 m deep). Steep slopes (~55°) typical of mining operations. A failed slope can be seen (top) at an inactive pit area

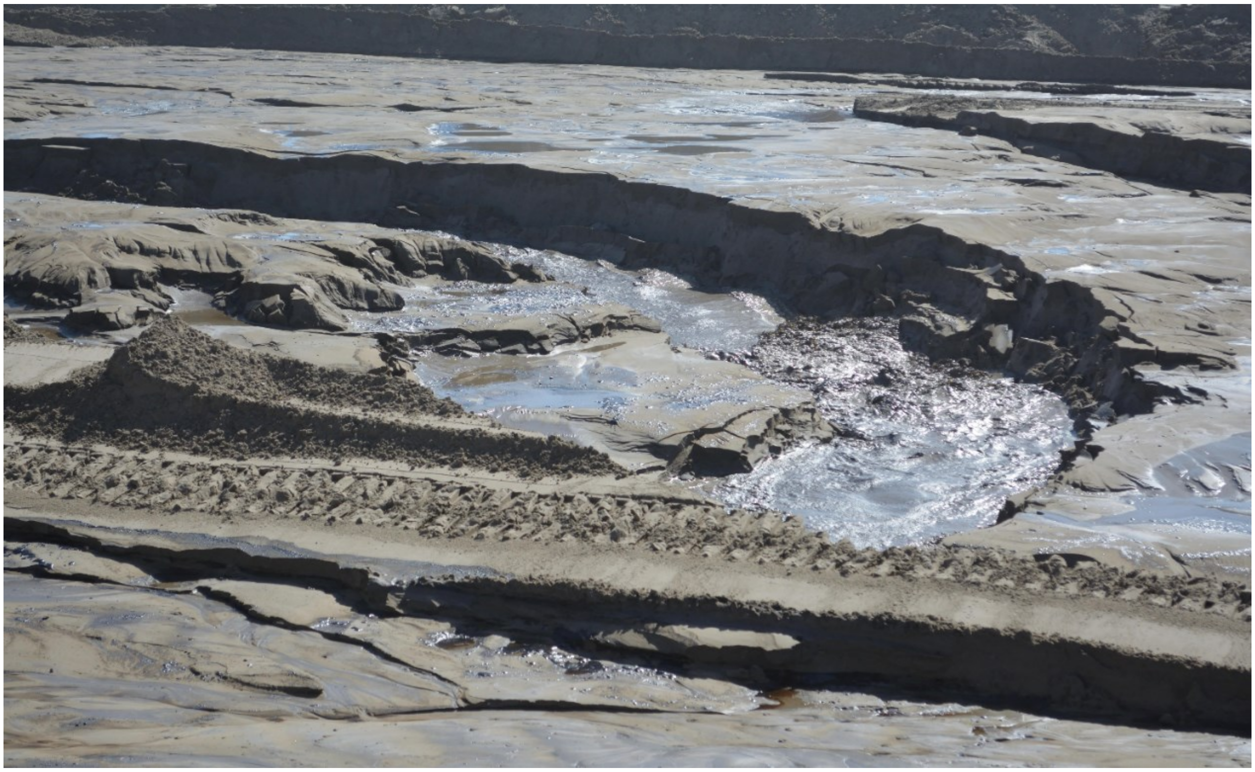
Summer Photo (b), Table 7. Bulldozer creating steep cell walls in tailings discharge area.

Summer Photo (c), Table 7. View of tailings discharge area and end of line device (dissipates kinetic energy).

Summer Photo (d), Table 7. Pumps downslope of tailings dam. Pipes and associated structures in wet, soft ground conditions adjacent to slopes

Summer Photo (e), Table 7. Bulldozer working in soft ground at tailings discharge area.

Summer Photo (f), Table 7. Washout (width ~1.5 m) filled with water.



Summer Photo (g), Table 7. Photo of a cut in the tailings discharge area.

Winter Photo (a), Table 8. View of the open pit. Steep slopes (~55°) typical of mining operations and snow-covered benches.

Winter Photo (b), Table 8. View of snow-covered eroded slopes of tailings dam.

Winter Photo (c), Table 8. Steep slopes produced when pushing frozen soil and snow.

Winter Photo (d), Table 8. Close-up of bulldozer in soft ground at tailings discharge area with steam from hot tailings discharge.

Winter Photo (e), Table 8. Frozen tailings pond (not clear where beach ends and water begins).

Winter Photo (f), Table 8. Frozen sump pump station.

Winter Photo (g), Table 8. View of tailings discharge area and end of line device (right) while not in use; erosion on ground below end of line device.

Winter Photo (h), Table 8. View of tailings discharge area with bulldozer operator working below an undercut slope.

Winter Photo (i), Table 8. Open water at tailings pond recycled water inlet with a cut into the tailings material.

Spring Photo (a), Table 9. Seepage at the toe of dyke with some unstable areas (middle) seen on the face.

Spring Photo (b), Table 9. Seepage from face of dyke with ice and standing water at the toe.

Spring Photo (c), Table 9. Water ponding (right) at the toe of loose sand.

Spring Photo (d), Table 9. Truck stuck in mud and soft ground from spring melt.

Spring Photo (e), Table 9. Standing water on road with ice melting on the side.

Spring Photo (f), Table 9. Muddy and soft ground conditions between pipelines in working area.

Spring Photo (g), Table 9. Slope in the tailings discharge area with pipeline and erosion features.

Spring Photo (h), Table 9. View of pipeline that has fallen into an erosion feature next to a road.

APPENDIX G: Full List of Academic Presentations and Accepted Abstracts

Table 10. Summary of conference presentations, posters, and papers submitted as part of the creative sentencing project.

Authors	Title	Location	Date
Baker, K., Macciotta, R., Hendry, M., and Lefsrud, L.	Update of Creative Sentencing Project and Tailings Safety Symposium Workshop	Tailings Safety Symposium Fort McMurray, AB	November 29, 2018
Baker, K., Macciotta, R., Hendry, M., and Lefsrud, L.	Communicating risks across organizations and to contractors in the oil sands tailings operations	68th Canadian Chemical Engineering Conference Toronto, ON	October 29, 2018
Baker, K., Macciotta, R., Hendry, M., and Lefsrud, L.	Using Process Safety Management tools to identify and assess oil sands tailings hazards	68th Canadian Chemical Engineering Conference Toronto, ON	October 29, 2018
Baker, K., Macciotta, R., Hendry, M., and Lefsrud, L.	Leveraging of Incident Databases to Enable Best Practices in Safety and Risk Management	68th Canadian Chemical Engineering Conference Toronto, ON	October 31, 2018
Baker, K., Zettl, J., Macciotta, R., Hendry, M., and Lefsrud, L.	Protecting workers exposed to ground hazards through enhanced hazard identification and management tools	GeoEdmonton (Conference Paper) Edmonton, AB	September 24, 2018
Baker, K., Zettl, J., Macciotta, R., Hendry, M., and Lefsrud, L.	Protecting workers exposed to ground hazards through enhanced hazard identification tools (Paper)	Geohazards 7 (Conference Paper) Edmonton, AB	June 4, 2018
Baker, K., Zettl, J., Macciotta, R., Hendry, M., and Lefsrud, L.	Using Process Safety Management tools to identify and assess tailings hazards	Canadian Institute of Mining Convention 2018 Vancouver, 2018	May 8, 2018
Baker, K., Zettl, J., Macciotta, R., Hendry, M., and Lefsrud, L.	Leveraging of Incident Databases to Enable Best Practices in Safety Risk Management	Canadian Institute of Mining Convention 2018 Vancouver, 2018	May 8, 2018

Baker, K., Zettl, J., Macciotta, R., Hendry, M., and Lefsrud, L.	Communicating risks across organizations and to contractors	Canadian Institute of Mining Convention 2018 Vancouver, 2018	May 8, 2018
Baker, K., Zettl, J., and Lefsrud, L.	Workshop on Identifying Hidden Hazards	Petroleum Safety Conference Banff, AB	May 3, 2018
Baker, K., Zettl, J., Saksena, S, Macciotta, R., Lefsrud, L., and Hendry, M.	Protecting workers from ground hazards by enhancing hazard identification and management tools (Presentation)	Railway Ground Hazard Research Program Kingston, ON	December 13, 2017
Baker, K., Lefsrud, L., Macciotta, R., and Hendry, M.	Protecting worker safety by enhancing hazard identification and management tools (Presentation)	67th Canadian Chemical Engineering Conference Edmonton, AB	October 23, 2017
Baker, K. and Lefsrud, L.	Improving the sustainability of tailings operations: protecting worker safety by enhancing field level hazard assessment tools (Poster) *Received award for "Best Sustainable Research"	Faculty of Engineering Graduate Studies Research Symposium (FERGS) Edmonton, AB	June 26, 2017

Accepted Abstracts

1. **Center for Risk, Integrity and Safety Engineering (C-RISE 2019 Workshop), July 15-17, 2019**

Combining process safety and person safety to bring hazards into focus
Baker, K., Macciotta, R., Hendry, M., and Lefsrud, L.

In the Canadian mining industry, from 2000 to 2014, there have been 49 dangerous occurrences associated with tailings facilities. Upon further investigation it was found that there is a dearth of information on worker safety around tailings storage and transport facilities. These incidents and the lack of literature illustrate the need for increased attention for worker safety in the oil sand tailings operations as well as enhancements to current hazard identification tools.

Workers in the oil sands tailings operations are exposed to hazards like loss of containment and line of fire, the difference between traditional process industries and the tailings operations are the pressures, volumes and temperatures. Process Safety Management tools like bowties can be applied to the tailings operations to visually identify unwanted events, potential threats, consequences and the controls to prevent incidents from occurring. They also serve as a tool for continuous improvement and show any over-reliance on one type of control such as administrative or personal protective equipment. In this research, seven hazardous activities have been selected for the bowtie analysis. This process has facilitated sharing of tailings safety best practices among oil sands operators and regional contractors.

2. **Center for Risk, Integrity and Safety Engineering (C-RISE 2019 Workshop), July 15-17, 2019**

Risk communication in the Athabasca oil sands tailings operations
Baker, K., Macciotta, R., Hendry, M., and Lefsrud, L.

The oil sands operations consist of many working groups that can result in silos and can make effective risk communication challenging. Additionally, workers are exposing themselves to unidentified hazards without knowing the risk level. This has been illustrated with the fatalities in the oil sands related to unseen ground hazards at tailings storage and transport facilities. Thus, in this research we ask: How can we identify gaps in communication between different working groups and effectively disseminate information about risks to workers who interact with these facilities?

We are analyzing four datasets to identify areas for enhanced risk communication. The aim is to determine the hazards that workers see on the job site and compare their responses to tailings safety experts, geotechnical analysis and the recorded incidents. This will allow for the design of effective risk communication strategies in the oil sands tailings operations.

Traditional risk communication principles to disseminate information to external stakeholders will be applied to an internal audience like workers in the tailings operations. The aim is to enhance the dialogue regarding risks across the organization. This will be done by increasing the level of familiarity and decreasing the risk tolerance associated with hazards on the site.

3. **Society of Risk Analysis Benelux Conference, March 25-26, 2019**

Communicating risks across organizations and to contractors in the oil sands tailings operations
Baker, K., Macciotta, R., Hendry, M., and Lefsrud, L.

The oil sands operations are made up of many working groups that each have an important role to play for the extraction and production of bitumen. Each of these operations are dynamic, demanding and required for oil sands companies to run an efficient operation and to be profitable. These qualities can lead to a very effective workforce, but they can also result in some silos between the different working groups on large sites like the oil sands tailings operations. These silos can cause breakdowns in communication across organizations and to contractors and can make effective risk communication challenging. Additionally, workers are voluntarily exposing themselves to unidentified hazards, potentially, without knowing the risk level. This has recently been illustrated with the fatalities in the oil sands tailings industry related to unseen and unknown ground hazards at tailings storage and transport facilities. Thus, in this research we ask: How can we identify gaps in communication between different working groups and effectively disseminate information about these risks not only to workers who interact with these facilities daily but also to contractors and other workers who are intermittently exposed?

We are analyzing four datasets to determine similarities and differences and to identify areas for enhanced risk communication. These four datasets include: (1) tailings safety expert hazard inventory, (2) interviews with frontline workers, safety advisors, supervisors, leadership and contractors, (3) ground hazard inventory and (4) company incident databases. The aim is to determine the hazards that workers see on the job site and compare these responses to the tailings safety experts, geotechnical analysis and the incidents that are being recorded. This will allow for the design of effective risk communication strategies in the oil sands operations, particularly in tailings

The traditional risk communication principles to disseminate information to external stakeholders will be applied to an internal audience like workers in the tailings operations. The aim is to enhance the dialogue regarding risks between workers, contractors and across the organization. This will be achieved by increasing the level of familiarity and decreasing the risk tolerance associated with the hazards on site through tailings specific training, formal mentorship programs and a visual ground hazard database. Additionally, increased communication should help to break down the silos to allow an easier flow of information between working groups in the oil sands.

4. **Society of Risk Analysis Benelux Conference, March 25-26, 2019**

Using Process Safety Management tools to identify and assess oil sands tailings hazards
Baker, K., Macciotta, R., Hendry, M., and Lefsrud, L.

In the Canadian mining industry, there have been 49 dangerous occurrences from 2000 to 2014 associated with tailings facilities (Hoekstra, 2014). At least two of these occurrences resulted in deaths at the oil sands tailings operations. Upon further investigation it was found that there is a dearth of information on worker safety around tailings storage and transport facilities. The majority of the research to date focuses on the potential for catastrophic failures and uncontrolled releases that could affect the public and the environment. However, this work and the mitigation strategies implemented are not preventing the occurrence of tragic worker fatalities and other incidents due to loss of containment events and other hazards near tailings storage or transport facilities. These incidents illustrate the need for increased attention for worker safety in the oil sand tailings operations as well as enhancements to current hazard identification tools.

Workers in the oil sands tailings operations are exposed to hazards like loss of containment and line of fire just like in any other refinery or upgrader. The difference between traditional process industries and oil sand tailings operations are the pressures, volumes and temperatures. Process Safety Management tools and principles like: Root Cause Analysis, Event Trees and bowties, are well used in the process industry to identify and manage hazards, but their application is not widely used in the oil sands tailings operations. In this research, bowties are being used to visually identify unwanted events, potential causes, consequences and the controls to prevent unwanted events from occurring. Seven unwanted events / hazardous activities in the tailings operations have been selected for the bowtie analysis. They include: (1) pipeline leak, (2) long term exposure, (3) soft ground, (4) emergency response, (5) issues while working on water, (6) issues while working on ice, and (7) operating spill boxes. These hazardous activities were selected based on a tailings safety expert hazard inventory, company incident databases and based on feedback from interviews with frontline workers, safety professionals, engineers and leadership at multiple oil sands operators and regional contractors.

Bowties illustrate the controls that are currently in place as well as areas for enhancement. They also serve as a tool for continuous improvement as companies have documentation of the controls in place to prevent an unwanted event and can revisit them to ensure the effectiveness of these controls. Additionally, they show any over-reliance on one type of control such as administrative or personal protective equipment. This process has helped to facilitate the sharing of tailings safety best practices among oil sands operators and regional contractors. Findings from this research will be used to create oil sands industry best practices for tailings safety and can be applied to the oil sands industry and mining industries more broadly.

5. Canadian Society of Chemical Engineering Conference 2018, October 29-31, 2018

Communicating risks across organizations and to contractors in the oil sands tailings operations

Baker, K., Macciotta, R., Hendry, M., and Lefsrud, L.

The oil sands operations are made up of many working groups that each have an important role to play for the extraction and production of bitumen. Each of these operations are dynamic, demanding and required for oil sands companies to run an efficient operation and to be profitable. These qualities can lead to a very effective workforce, but they can also result in some silos between the different working groups on large sites like the oil sands tailings operations. These silos can cause breakdowns in communication across organizations and to contractors and can make effective risk communication challenging. Additionally, workers are voluntarily exposing themselves to unidentified hazards potentially, without knowing the risk level. This has recently been illustrated with the fatalities in the oil sands tailings industry related to unseen and unknown ground hazards at tailings storage and transport facilities. Thus, in this research we ask: How can we identify gaps in communication between different working groups and effectively disseminate information about these risks not only to workers who interact with these facilities daily but also to contractors and other workers who are intermittently exposed?

We are analyzing four datasets to determine similarities and differences and to identify areas for enhanced risk communication. These four datasets include: (1) tailings safety expert hazard inventory, (2) interviews with frontline workers, safety advisors, supervisors, leadership and contractors, (3) ground hazard inventory and (4) company incident databases. The aim is to determine the hazards that workers see on the job site and compare these responses to the tailings safety experts, geotechnical analysis and the incidents that are being recorded. This will allow for the design of effective risk communication strategies in the oil sands operations, particularly in tailings

The traditional risk communication principles to disseminate information to external stakeholders will be applied to an internal audience like workers in the tailings operations. The aim is to enhance the dialogue regarding risks between workers, contractors and across the organization. This will be achieved by increasing the level of familiarity and decreasing the risk tolerance associated with the hazards on site through tailings specific training, formal mentorship programs and a visual ground hazard database or an app. Additionally, increased communication should help to break down the silos to allow an easier flow of information between working groups in the oil sands.

6. **Canadian Society of Chemical Engineering Conference 2018, October 29-31, 2018**

Using Process Safety Management tools to identify and assess oil sands tailings hazards
Baker, K., Macciotta, R., Hendry, M., and Lefsrud, L.

In the Canadian mining industry, there have been 49 dangerous occurrences from 2000 to 2014 associated with tailings facilities. At least two of these occurrences resulted in deaths at the oil sands tailings operations. Upon further investigation it was found that there is a dearth of information on worker safety around tailings storage and transport facilities. The majority of the research to date focuses on the potential for catastrophic failures and uncontrolled releases that could affect the public and the environment. However, this work and the mitigation strategies implemented are not preventing the occurrence of tragic worker fatalities and other incidents due to loss of containment events and other hazards near tailings storage or transport facilities. These incidents illustrate the need for increased attention for worker safety in the oil sand tailings operations as well as enhancements to current hazard identification tools.

Workers in the oil sands tailings operations ae exposed to hazards like loss of containment and line of fire just like in any other refinery or upgrader. The difference between traditional process industries and oil sand tailings operations are the pressures, volumes and temperatures. Process Safety Management tools and principles like: Root Cause Analysis, Event Trees and bowties, are well used in the process industry to identify and manage hazards, but their application has not yet been implemented into the oil sands tailings operations. In this research, bowties are being used to visually identify unwanted events, potential causes, consequences and the controls to prevent unwanted events from occurring. Seven unwanted events / hazardous activities in the tailings operations have been selected for the bowtie analysis. They include: (1) pipeline leak, (2) long term exposure, (3) soft ground, (4) emergency response, (5) issues while working on water, (6) issues while working on ice, and (7) operating spill boxes. These hazardous activities were selected based on a tailings safety expert hazard inventory, company incident databases and based on feedback from interviews with frontline workers, safety professionals, engineers and leadership at multiple oil sands operators and regional contractors.

Bow Ties illustrate the controls that are currently in place as well as areas for enhancement. They also serve as a tool for continuous improvement as companies have documentation of the controls in place to prevent an unwanted event and can revisit them to ensure the effectiveness of these controls. Additionally, they show any over-reliance on one type of control such as administrative or personal protective equipment. This process has also facilitated sharing of tailings safety best practices among oil sands operators and regional contractors. Findings from this research will be used to create oil sands industry best practices for tailings safety and can be applied to the oil sands industry and mining industries more broadly.

7. **Canadian Society of Chemical Engineering Conference 2018, October 29-31, 2018**

Leveraging of Incident Databases to Enable Best Practices in Safety and Risk Management
Baker, K., Macciotta, R., Hendry, M., and Lefsrud, L.

The old saying “what is measured gets managed” can be applied to many companies and operations and it is extremely relevant for hazards on industrial sites. On most sites, incidents are documented in a database that has information about the incident, investigation, risk level and corrective actions. In some cases, not much more done with this information aside from calculating metrics for management meetings or identifying lagging indicators. Incident databases can be used as much more than a metric, they can be used as a tool to identify, analyze and reduce risks thereby obtaining safe operating levels. Currently, oil sands companies tend to utilize tools like Field Level Hazard Assessments, Standard Operating Procedures, toolbox meetings etc. to ensure site and worker safety. These tools are effective to a certain extent but may fail to identify reoccurring incidents that could be prevented. High frequency, low consequence incidents can provide valuable information to workers and help to inform safety and risk management decisions. Thus, in research, we ask: How can we identify and control the low risk incidents to mitigate the occurrence of fatalities and enable better practices in safety and risk management?

We have been given access to multiple oil sands operators incident databases relating to tailings. Through analysis of these databases, we can identify low risk incidents that could be used as leading indicators. By investigating and remediating the root causes of these events, some catastrophic failures could be prevented. Additionally, we will be comparing the recorded incidents to our other datasets including tailings safety expert hazard inventory and interview responses from frontline workers, safety personnel and leadership to determine gaps and areas for enhancement in the incident recording process. There are also slight differences between how each company manages and utilizes these databases. Our goal is to create best practices for the tailings operations on how to leverage incident databases to enable optimized safety and risk management programs. These findings can be applied to the oil sands industry and other heavy industries more broadly.

8. **GeoEdmonton 2018, September 23-26, 2018**

Protecting workers exposed to ground hazards through enhanced hazard identification and management tools

Baker, K., Zettl, J., Macciotta, R., Hendry, M., and Lefsrud, L.

In Alberta, approximately 150,000 people are harmed at work annually (Jazayeri and Dadi, 2017). Industries, like the oil sands, see the importance of decreasing injuries on work sites and use tools like the Field Level Hazard Assessment (FLHA) to visually identify hazards that are known and visible, manage risks, and determine appropriate actions to ensure safe conditions. A challenge lies in some workplaces, including oil sands tailings storage and transport facilities (TSTF) where unexpected ground hazards exist making them invisible to workers that have not been trained to identify or mitigate ground hazards. Two recent deaths due to ground hazards in TSTF indicate the need for further work in this area. Ground hazards such as: soft ground, slope instability, erosion and sink holes have been identified at almost all the TSTF but these hazards manifest in different ways depending on the location, weather and operations.

A joint initiative with the Crown, industry and the University of Alberta has been undertaken to enhance tools used to identify and control ground hazards associated with tailings operations. Site visits were conducted to identify ground hazards at representative TSTF and employees were interviewed to determine their recognition of ground hazards associated with tailings operations. Suggestions to enhance current hazard identification and management tools like the FLHA and training to include ground hazards will be discussed. The aim of this research is to motivate change in best practices through dissemination of information to the oil sands industry, academics and other industries that are exposed to ground hazards. The methodologies developed to identify ground hazards and enhance controls will be discussed. An example of an enhanced FLHA tool based on a ground hazard database and interviews will be presented.

9. **Geohazards 7, June 3-6, 2018**

Protecting workers exposed to ground hazards through enhanced Field Level Hazard Assessment tools

Baker, K., Zettl, J., Macciotta, R., Hendry, M. and Lefsrud, L.

Risk acceptability is often technically defined 'As Low as Reasonably Practicable' and companies utilize many tools and procedures to obtain these safe operating levels. One such engineering safety and risk management tool is the Field Level Hazard Assessment. This tool allows employees to efficiently assess a worksite for hazards to ensure the site's safety. This method is effective for hazards that are known and visible. A subset of workers and operators performing tasks around certain facilities (e.g. oil sands tailings storage and transport facilities) are not likely to be trained in assessing potential ground hazards, and these would be invisible and unexpected for them.

Much work has been focused on the safety and performance of tailings storage and transportation facilities, which has led to increasing safety against catastrophic failure and uncontrolled releases. However, there have been two recent deaths related to ground hazards near tailings storage and transport facilities, illustrating the need for improving worker safety in their day-to-day tasks in the vicinity of these facilities. This paper presents a recent initiative between the oil sands industry, the Province and the University of Alberta to enhance Field Level Hazard Assessment tools to recognize and better manage hazards associated with tailing storage and transport facilities. This research aims to increase the priority of worker safety by creating a usable and implementable hazard assessment tool.

10. **Canadian Institute of Mining Convention 2018, May 6-9, 2018**

Using Process Safety Management tools to identify and assess tailings hazards

Baker, K., Zettl, J., Macciotta, R., Hendry, M. and Lefsrud, L.

Oil sands tailings may not be the typical case study that comes to mind when thinking of Process Safety Management, but there are many aspects of tailings operations that could benefit from the use of these principles to identify and manage hazards. Much work has been focused on the safety and performance of tailings storage and transportation facilities, which has led to increasing safety against catastrophic failures and uncontrolled releases. However, despite this good work, tragic tailings related fatality incidents persist due to loss of containment events near tailings storage and transport facilities. These fatalities illustrate the need for improving hazard identification and management in the vicinity of these facilities.

This research uses Process Safety Management tools like Root Cause Analysis, Event Trees and Bow Ties to identify the hazards associated with oil sands tailings operations. These tools were used to analyze hazard inventories from three sources: oil sands tailings safety experts, employees and company incident data. The results were compared to determine common themes, hazards and gaps in controls. Findings from this research will allow for enhancements to the current safety management systems, the development of prioritized action lists and will ideally enhance industry standards.

11. Canadian Institute of Mining Convention 2018, May 6-9, 2018

Leveraging of Incident Databases to Enable Best Practices in Safety Risk Management
Baker, K., Zettl, J., Macciotta, R., Hendry, M. and Lefsrud, L.

Incident databases can be used as a tool to identify, analyze and reduce risks thereby obtaining safe operating levels. Currently, oil sands companies tend to utilize tools like Field Level Hazard Assessments, Standard Operating Procedures, toolbox meetings etc. to ensure site and worker safety. These tools are effective to a certain extent but may fail to identify reoccurring incidents that could be prevented.

Many companies use their incident databases to monitor high consequence, low probability events or lagging indicators. As a result, high frequency, low consequence incidents are often overlooked. These near miss or low risk incidents could be used as leading indicators and by investigating and remediating the root causes of these events, some catastrophic failures could be prevented. Thus, in research, we ask: How can we identify and control the low risk incidents to mitigate the occurrence of fatalities and enable better practices in safety risk management.

Analysis was completed using a company's incident database to determine the actual hazards encountered by the worker at the time of the incident. This research could help foster a continuous improvement safety culture where hazards are recognized and enhancements to controls are implemented prior to high consequence events occurring.

12. Canadian Institute of Mining Convention 2018, May 6-9, 2018

Communicating risks across organizations and to contractors
Baker, K., Zettl, J., Macciotta, R., Hendry, M. and Lefsrud, L.

Risk communication is the dissemination of information from an organization to its stakeholders. Typically, this is open two-way communication of known hazards from an organization to the public. However, we have identified a gap in the communication of risks within organizations to employees and contractors. Workers are voluntarily exposing themselves to unidentified hazards, sometimes without knowing the risk level. This has recently been illustrated in the oil sands industry after tragic fatalities related to unseen and unknown ground hazards at tailings storage and transport facilities. Thus, in research, we ask: How can we identify and communicate risks not only to workers who interact with these facilities daily but also to contractors who are intermittently exposed?

We have conducted interviews with frontline workers, safety advisors, supervisors, leadership and contractors to determine the hazards the workers see on the job site. Responses varied significantly across working groups and experience levels. We will be using traditional risk communication practices to enhance the dialogue regarding risks between workers, contractors and across the organization. We aim to increase the level of familiarity and decrease complacency with the hazards on site through tailings specific training, formal mentorship programs and geohazard databases.

13. Petroleum Safety Conference, May 1-3, 2018

Workshop on Identifying Hidden Hazards
Lefsrud, L., Baker, K., and Zettl, J.

The Petroleum Industry uses tools such as the Field Level Hazard Assessment to allow workers to visually identify hazards, mitigate risks or take corrective steps prior to beginning work. These tools work well for hazards that are known and visible, there are however, some workers who are exposed to hazards that are unknown and invisible such as ground hazards. Two recent deaths associated with ground hazards at tailings storage and transport facilities in the oil sands illustrate the need for enhanced ground hazard identification and controls.

The Crown, University of Alberta and oil sands industry are working together to enhance the current hazard identification tools and controls. Site visits identified ground hazards such as: soft ground, slope instability, erosion and sink holes at almost all of the tailings transport and storage facilities. All of these hazards manifest themselves in different ways depending on the operation, location and weather. Employees and contractors of all levels at multiple oil sands operators have been interviewed to determine the hazards workers are exposed to on a daily basis. Process Safety Management techniques like bow ties and event trees have been used to cluster hazards from a hazard inventory created by Energy Safety Canada tailings safety experts. Data from the above sources will be analysed together and used to enhance current field level hazard assessment, other hazard identification tools and controls. The aim of this research is to enhance the current best practices related to tailings operations and ground hazards.

Learning Objectives/ Takeaways

1. Ground hazards are well understood by geotechnical experts, but there is a gap in the communication of these risks to workers. Ground hazards can be seen in the conventional petroleum industry as well, the same gap could be present, and these methods could be applied to other sites to increase ground hazard awareness.

2. Leading indicators like unsafe acts and substandard conditions that can inform maintenance and operations of potential hazards and allow workers take corrective action prior to a high consequence occurring.

3. Occupational Health and Safety and Process Safety are two distinct and important aspects of a safety program. However, techniques from both can be used to gain a holistic understanding of the hazards workers are exposed to during their daily operation opposed to worker safety being job task oriented.

Target Audience

Our target audience is diverse with representation from frontline workers, supervisors, safety representatives, upper management and leadership. We feel that it is important to facilitate discussion between these groups to increase awareness and enable enhanced risk communication between working groups. This presentation would be valuable not only to those working in the oil sands industry but also to those working in the conventional petroleum industry as ground hazards can be seen in both of these operations.

14. Canadian Chemical Engineering Conference 2017, October 22-25, 2017
Protecting Worker Safety by Enhancing Field Level Hazard Assessment Tools
Baker, K., Macciotta, R., Hendry, M. and Lefsrud, L.

Risk acceptability is often technically defined 'As Low as Reasonably Practicable' and companies utilize many tools and procedures to obtain these safe operating levels. One such engineering safety and risk management tool is the Field Level Hazard Assessment. This tool allows employees to efficiently assess a worksite for hazards to ensure the site's safety. This method is effective for hazards that are known and visible. Currently, there is no contingency built into the tool for invisible, unexpected hazards, like ground hazards associated with oil sands tailings storage and transport facilities. There have been two recent deaths related to ground hazards near these facilities, illustrating the need for the improvement of these tools. Companies tend to focus on catastrophic failures, posing risks to the public and environment (i.e., Mount Polley). As a result, worker safety during tailings operations is often overlooked. Thus, in this research, we ask: How can we enhance Field Level Hazard Assessment tools to recognize and better manage hazards associated with tailing storage and transport facilities. Data will be collected using a mixed methods approach. With input from workers, the current Field Level Hazed Assessment tools will be modified to include practical identifiers so operators can recognize and appropriately manage ground hazards prior to beginning work. This research aims to decrease the number of incidents associated with tailings facilities and protect workers from unseen and potentially unknown ground hazards.

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Improving the Sustainability of Tailings Operations: Protecting Worker Safety by Enhancing Field Level Hazard Assessment Tools
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The sustainability of mine sites and tailings facilities tends to focus on catastrophic failures, posing risks to the public and environment (i.e., Mount Polley). As a result, worker safety during tailings operations is often overlooked. Thus, in this research, we ask: How can we enhance Field Level Hazard Assessment tools to recognize and better manage hazards associated with tailing storage and transport facilities.

To answer this question, we will collect data using a mixed methods approach: surveying ground hazards during field visits, semi structured interviews with various employees, and assessing their risk management techniques for oil sands companies with tailings facilities. With input from workers, the current Field Level Hazed Assessment tools will be modified to include practical identifiers so operators can recognize and appropriately manage ground hazards prior to beginning work. This research aims to increase the priority of worker safety by creating a usable and implementable hazard assessment tool.

Phase one of this research consists of gathering data on ground hazards, precursory events and current industry best practices. Interviews with employees will also be conducted in this phase to determine current operating conditions. Phase two will include the development of the Field Level Hazard Assessment tool with consultation from industry. Phase three will contain the implementation and optimization of the tool as well as industry sharing and education.

Most importantly, this work will help to decrease the number of incidents associated with tailings facilities and protect workers from unseen and potentially unknown ground hazards. This research will be applicable to all companies that operate tailings facilities and dams more generally. Our findings will be translated into training modules which will hopefully enhance industry standards.