Interim 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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EXECUTIVE SUMMARY

Efforts related to the safety and performance of oil sands tailings storage and transportation facilities have traditionally focused on preventing catastrophic failures. However, a recent death related to ground hazards near oil sands tailings facilities, dykes, and transport systems illustrates the need for improved worker safety during daily operations near these facilities. This interim report serves to provide an update on the creative sentencing project resulting from that fatality and represents an initiative between the oil sands industry, regional contractors, the Province of Alberta, and the University of Alberta.

A holistic approach to operations and worker safety is beneficial for identifying hazards in the dynamic tailings environment. Of particular concern are ground hazards in oil sands tailings operations as they can be invisible to and unexpected by workers with no training relevant to ground hazard identification operating near tailings facilities, dykes, and transport systems.

Data continue to be collected from four sources: the Energy Safety Canada tailings hazard inventory, the University of Alberta initial ground hazard assessment, interviews with tailings workers, and oil sands tailings operations incident databases. These four datasets are being compared to determine similarities and differences and enhance the current hazard identification tools and controls for ground hazards.

Process safety management tools such as Root Cause Analysis, Event Tree Analysis, and the Bowtie Risk Assessment Method are being used to cluster the tailings hazard inventory and identify areas for enhanced controls. Energy Safety Canada subject matter experts are reviewing the bowtie diagrams to ensure applicability to tailings operations.

Two work environment databases (summer and winter) of representative tailings facilities, dykes, and transport systems have been created. These include photos that identify ground hazards in the tailings operations. A general ground hazard database has also been created as the ground hazards in tailings operations are similar, but how they manifest is dependent on the working area and temporal factors.

Over 100 interviews have been completed to date with frontline tailings workers, safety personnel, engineers, supervisors, leadership, and regional contractors. Preliminary analysis indicates that workers are aware that tailings operations are a dynamic and high-risk work environment.

Tailings incident databases are being analyzed for leading indicators to identify precursory events that will ideally assist in the identification of hazards prior to the occurrence of high-consequence events. The data have been categorized by hazard type. Incidents in the ground hazard category include slips, trips, and falls; stuck or sunk equipment; pipeline leaks; and geotechnical hazards (i.e., berm breaches, washouts, and over-poured cells). Preliminary results indicate that one-fifth of incidents in the tailings area are related to ground hazards.

In phase two of the project, analysis of the datasets will continue and findings will be shared with the industry through workshops, conference presentations, and academic journal publications. This

research will be presented at four conferences in 2018, including the Petroleum Safety Conference, Canadian Institute of Mining conference, Geohazards 7, and GeoEdmonton.

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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
CIM	Canadian Institute of Mining
ESC	Energy Safety Canada
ETA	Event Tree Analysis
FLHA	Field Level Hazard Assessment
IAS	Industry Accepted Standards
IRP	Industry Recommended Practices
MOC	Management of Change
NORMs	Naturally Occurring Radioactive Materials
OHS	Occupational Health and Safety
OSSA	Oil Sands Safety Association
PFD	Personal Flotation Device
PPE	Personal Protective Equipment
PSC	Petroleum Safety Conference
RCA	Root Cause Analysis
REB	Research Ethics Board
TDA	Tailings Discharge Area
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.

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.

Ground Hazard: naturally occurring hazards, such as erosion gullies, differential settlement, 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 (OSSA, 2018)

Lagging Indicators: major injuries, minor injuries, and property damage incidents. These incidents include 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. These include 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 (AICHE, 2018).

Mature Fine Tailings: 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.

Spoon: 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.

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.

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

Slope Instability: when sentiment, tailings, rock, or snow moves downhill in response to gravity.

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

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 rates, 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 (OHS) 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 through the examination of four data sources:

1. A ground hazard assessment associated with tailings transport and storage facilities, to be conducted during field visits by the research team to oil sands operations;
2. Energy Safety Canada's tailings safety expert hazard inventories;
3. Interviews with employees and contractors at the company; and
4. Incident databases.

The field visits will have the secondary benefit of familiarizing the research team with site operations. Existing industry experience will be 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), an interim report is required at the halfway point of the project. The submission of this document serves to communicate the preliminary findings and progress of 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

Please see Appendix A for a copy of the 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 −45 °C in the winter months and as warm as 32 °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 the hot tailings are discharged into the 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). Days with precipitation make ground conditions more difficult for work and also reduce visibility. Precipitation events can be very dangerous 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
Precip (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 Precip ≥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 Precip ≥ 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	-58	-60	-57	-46	-21	-6	**-3**	-6	-16	-32	-50	-53

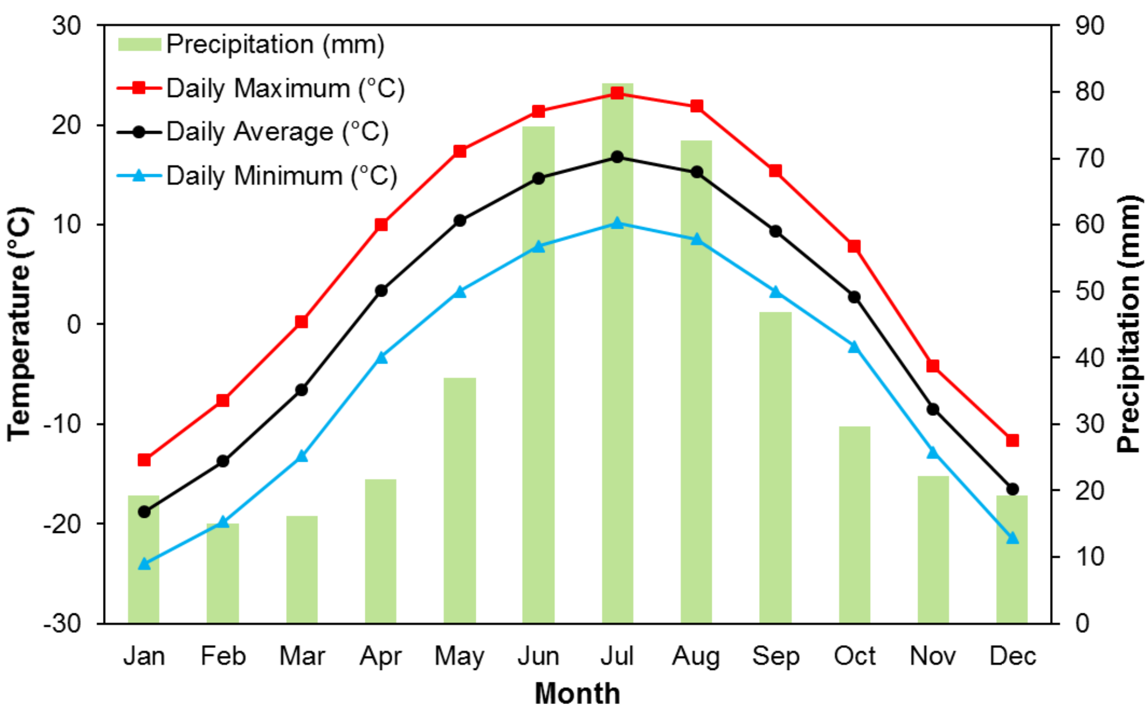


Figure 2. Temperature and precipitation graph for 1971 to 2000 Canadian climate normals, Fort McMurray (after Environment Canada, 2018).

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, 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 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 merge of the Oil Sands Safety Association and Enform) identified the lack of information surrounding worker safety at tailings operations (ESC, 2018). 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, 2018). They developed a prioritized inventory of hazards that were similar across all operations.

ESC created a risk matrix, shown in Figure 3, to 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 the likelihood of it occurring and the potential consequence. It was then assigned to a group, with Group 1 being an intolerable risk requiring immediate corrective action, Groups 2 and 3 being medium risk requiring reduction measures, and Group 4 as 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. This collaboration with ESC has allowed this project to become an industry-wide initiative with multiple oil sands companies and regional contractors involved.

2.4 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 3 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 don't shown an apparent decrease over the last 10 years (Table 3). These firms acknowledge that further improvements may arise through equipping front line workers with increased knowledge and understanding of hazards specific to their work environment; hence the work of this study to characterize tailings related hazards and mitigations.

Table 2. WCB reported disabling injury rate in Alberta by industry.

	Disabling injury rate						
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 these facilities tend to focus on the performance of the structures and the potential for catastrophic failures that have a large impact on the environment and 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, 2015). The industry also has best practices such as those outlined in the Canadian International Mining (CIM) guidelines, 1997. Table 4 summarizes the types of materials mentioned in each document. Only one of the documents analyzed—*Reasonable Actions: A Plan for Alberta's Oil Sands* (2009), a Government of Alberta publication—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 review highlights the apparent lack of overlap with respect to best practices or legislation in Alberta regarding worker safety and that regarding tailings operations.

POTENTIAL CONSEQUENCE		SAFETY / HEALTH	LIKELIHOOD A	B	C	D	E
			VERY LIKELY	**SOMEWHAT LIKELY**	**UNLIKELY**	**VERY UNLIKELY**	**PRACTICALLY IMPOSSIBLE**
			- 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
	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 3. Energy Safety Canada risk matrix (ESC, 2018).

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
Mining Association of Canada Guide for the Management of Tailings Facilities (Mining Association of Canada, 2011)	No	Yes	Yes

2.5 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 on tailings dam operation and worker safety directly (Tang et al. 2012; Li et al. 2010; Wei et al. 2003).

This gap has been confirmed in 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 a group of workers deemed "roving contractors". This 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.

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.

3 Methods

3.1 Energy Safety Canada Tailings Hazard Inventory

Once ESC provided the hazard inventory to the U of A research team, Process Safety Management principles were used to analyze the data. Tools such as Root Cause Analysis (RCA; Figure 4), Event Tree Analysis (ETA; Figure 5), and the Bowtie Risk Assessment Method (Figure 6) are being used to analyze the ESC inventory and cluster the hazards.

RCA is a structured technique to determine the cause of an incident; it can also be expanded to identify areas of improvement in a company (Wilson et al., 1993). Figure 4 is a general example of how to work through an RCA to determine the immediate, basic, and latent causes. To complete an RCA, the first step is identifying the loss (harm to people, impact to the environment, assets, or production) and determining what happened from incident investigation reports and consultation with ESC experts. The next step is determining what caused the incident, or the immediate causes, and if substandard practices and conditions played a role (Winkel et al., 2017). Once the immediate causes are identified, a larger picture is developed and more causes of the incident are identified; these are called basic causes or root causes and are related to personal, job, and design factors (Winkel et al., 2017). This process continues until latent causes (issues with the safety management system) are identified; these are the areas of improvement for the company. The majority of incidents will have different immediate causes, but basic and latent causes can be similar. By implementing changes to a safety management system after an incident, future incidents can be prevented. RCA is typically a reactive approach that is implemented after an incident occurs.

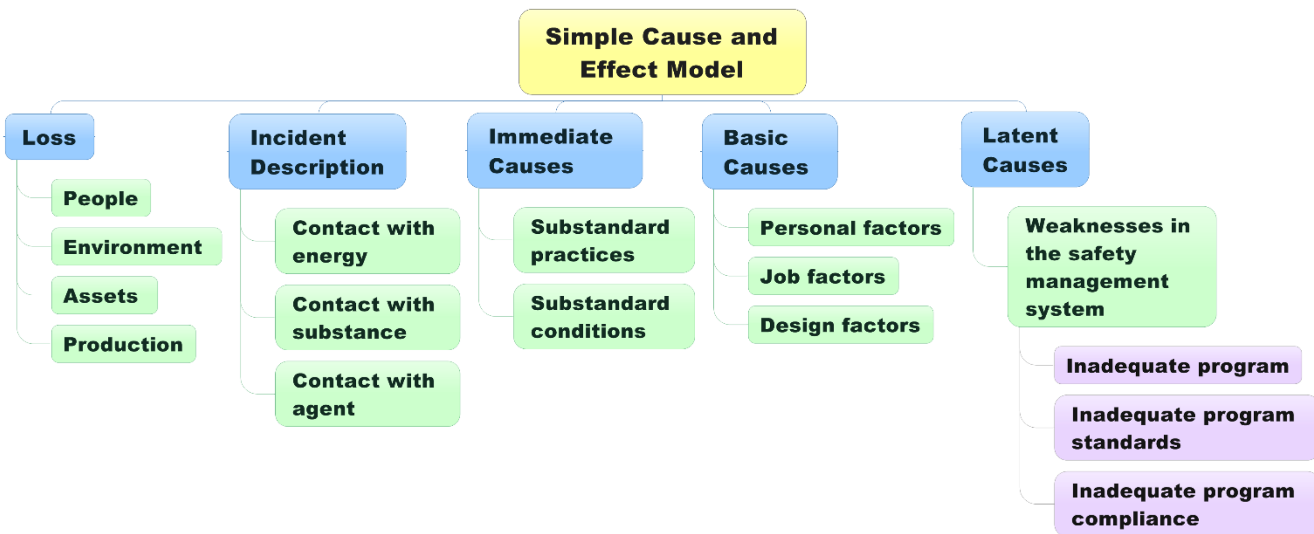


Figure 4. General root cause analysis (after Bird and Germain, 1992).

Event Tree Analysis (ETA) is a proactive method to discuss potential outcomes and risks of a particular situation, with this analysis allowing appropriate controls to be implemented prior to an incident occurring (Winkel et al., 2017). ETA is a brainstorming tool to come up with as many possible outcomes of a situation as possible as well as the logical pathways an incident could take to lead to a certain consequence (Winkel et al., 2017). An example is provided in Figure 5. Probabilities can also be assigned to an ETA to assist in the classification of risk and help prioritize the most probable consequence.

Figure 5. Sample event tree analysis (after Winkel et al., 2017).

The Bowtie Risk Assessment Method creates diagrams, such as the one shown in Figure 6 (called ‘bowties’), 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 bowtie) 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 in order 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. Unfortunately for much of the front line work around tailings, the controls are administrative or personal protective equipment, in many cases, engineering controls are not available or not practical to implement. Thus, a diligent application of threat controls is crucial to prevent the top event from occurring.

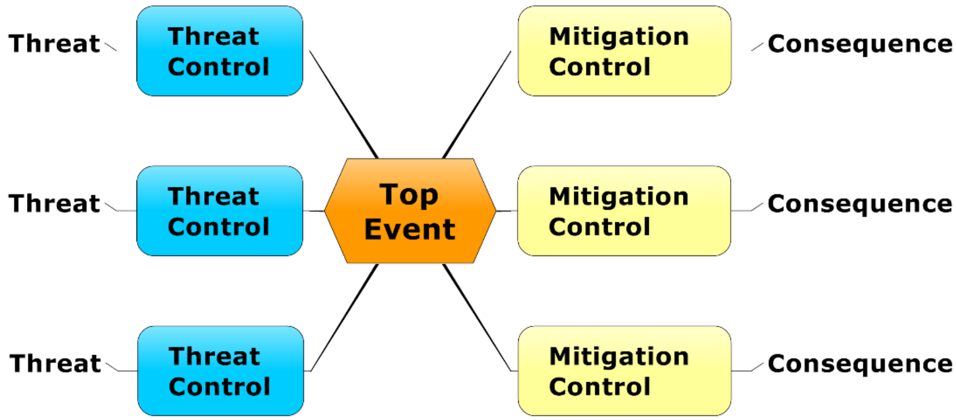


Figure 6. General Bowtie analysis (after Deighton, 2016).

3.2 University of Alberta Ground Hazard Inventory

An initial ground hazard inventory was compiled during field visits to oil sands companies and further analysis was conducted after returning to the U of A. Three main types of tailings facilities are used: tailings storage facilities, tailings transport facilities, and dykes. A geotagged database of representative facilities was created, which includes the following representative facilities from the oil sands mines participating in the study:

- Tailings Storage
  - Process water ponds
  - Fine tailings ponds
  - Tailings discharge area
  - Tailings recovery operations
- Tailings Transport Facilities
  - Tailings pipelines
  - Process water pipelines
  - Pumps
- Dykes
  - Slope of the tailings impoundment structures

A representative sample of tailings facilities, dykes, and transport systems from all of the mines was analyzed for ground hazards. Photos taken at the representative facilities were used to create a work environment database for training and familiarizing workers with ground hazards that include the following:

- descriptions of the facilities;
- identification of ground hazards;
- precursory events; and
- controls.

Descriptions of the facilities are based on site observations and documents from the oil sands operators. Precursory events are indicators that could help workers to identify changes in the ground proactively, prior to an incident occurring. Where possible, photographs of the precursory events were provided. The controls section includes the current controls the oil sands companies have in place as well as the recommended controls from the research team.

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.

3.3 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. Prior to conducting the interviews, Research Ethics Board (REB) approval was obtained through 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.

Different questions were developed for frontline workers, leadership, and roving contractors. Please see Appendix B for full 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 gathering information about safety practices and their level of concern regarding ground hazards.

Interviews lasted around 45-60 minutes. The majority of the interviews were conducted in person and the remainder over the phone. Depending on the worker's schedule, some interviews were conducted one-on-one while others were done with larger groups to ensure the research process did not interrupt tailings operations. The goal of these interviews was to determine the hazards workers see in their daily jobs, gauge their knowledge of ground hazards, and conclude if the interviewees' responses aligned with the ESC tailings experts hazard inventory and the U of A initial ground hazard inventory. NVivo qualitative text analysis software (QSR International, 2017,) was used to determine emergent themes from the interview data.

3.4 Tailings Incident Database

The oil sands companies provided access to their incident databases related to tailings. These databases were analyzed with the aim of identifying leading indicators (high frequency, low consequence events) that could help to predict ground hazards before they occur.

Incident pyramids, such as the one shown in Figure 7, are used to help identify leading and lagging indicators in the data. Lagging indicators include the normalized frequencies of major and minor injuries; 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 are substandard acts and conditions observed on the site, including unsafe acts/conditions, auditing of structured rounds, or the culture in the workplace.

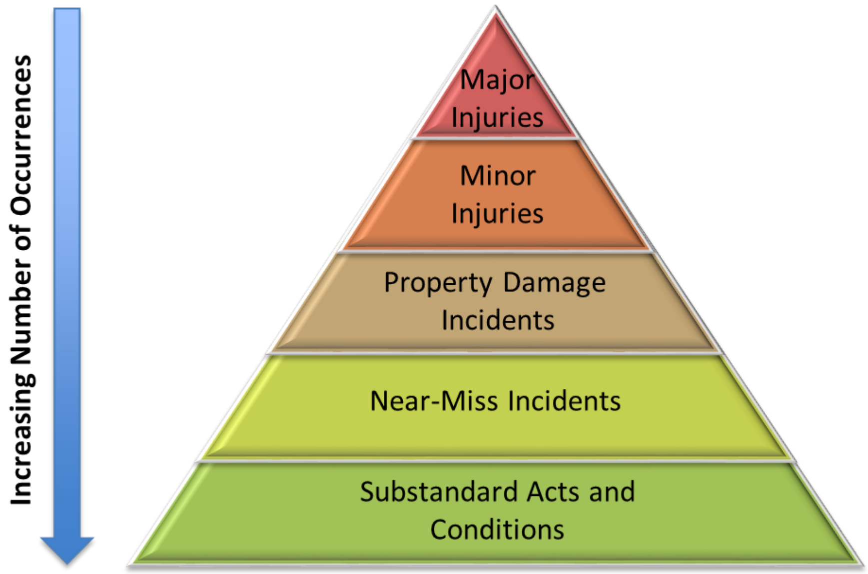


Figure 7. Incident pyramid (after Henderson, 2016).

4 Results

4.1 Preliminary Findings: Energy Safety Canada Tailings Hazard Inventory

Analysis of the ESC tailings hazard inventory indicated many of the hazards are similar across the participating oil sands operators. The activities identified as the highest risk and requiring enhanced controls to return the operation to an acceptable risk level are highlighted in Table 5, along with the potential hazard that the activity could pose to a person, the environment, assets, or production.

Table 5. Top four hazardous activities identified by tailings safety experts.

Priority	Activity	Hazard
1	Walking on frozen ground over wash outs / eroded areas	Loss of containment, Gravitational (slips, trips, or falls), Thermal, Chemical
2	Mount / dismount mobile equipment	Ergonomic, Gravitational (slips, trips, or falls)
3	Walkways in the fall, winter, and spring	Ergonomic, Gravitational (slips, trips, or falls)
4	Working around and / or operating pressurized equipment	Line of fire

Entries in the ESC database were classified according to process safety management definitions of hazards to cluster activities. The different types of hazards and definitions are listed in Table 6. Each item in the inventory was assigned a hazard(s) that people, the environment, assets, or production could be exposed to if the unwanted event were to occur. Some activities were associated with multiple hazards, as seen in Table 3. For example, gravitational, thermal, loss of containment, and chemical hazards are all listed for *walking on frozen ground over washouts /*

eroded areas. Specifically, the gravitational hazard classification is based on the potential for the worker to fall from ground level into the cavern; the thermal hazard is because the worker could fall into process water and tailings (this could be a hot or cold environment depending on the temperature of the tailings and the surrounding air); the loss of containment hazard is because the pipeline is no longer containing the process water and tailings due to the leak; and the chemical hazard is because the worker could be subject to asphyxiation or drowning in an oxygen-deficient environment or exposed to tailings (which can contain residual bitumen and other chemicals).

Table 6. 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 (OSSA, 2018)
Loss of containment	an unplanned or uncontrolled release of material from primary containment, including non-toxic and non-flammable materials (AICHE, 2018)
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

4.1.1 Root Cause Analysis

RCA was the first process safety management tool used to start clustering the hazards. The RCA for a loss of containment event is provided in Appendix C, Figure C1. A loss of containment event can occur in two ways in tailings operations: a pipeline leak or a cell berm failure in the tailings discharge area (TDA). Reasons why either of these events could occur were explored during the RCA. For example, a pipeline leak could occur due to loss of pipeline wall thickness from corrosion /abrasion, the pipeline being struck by equipment, or a poor pipe connection. The next level of the RCA considers reasons why any of these events would occur, which were explored until the underlying reason / root cause was identified.

4.1.2 Event Trees

The ETA is currently being updated to reflect findings from the most recent interviews. A draft ETA of a pipeline leak is provided in Appendix C, Figure C2.

4.1.3 Bowtie Analysis

To ensure the Bowtie analysis was useful and correct, brainstorming sessions were held at ESC tailings safety meetings. These brainstorming sessions were facilitated by members of the U of A research team, who solicited feedback on draft bowtie diagrams from oil sands operators and regional contractors. The ESC members also broke into smaller teams of subject matter experts to provide specific feedback on the Bowtie analysis. Creating bowtie diagrams is an iterative process, and at least one more iteration will occur prior to the creation of final versions. Draft bowtie diagrams for the following activities are provided in Appendix C:

- Pipeline leak (Figure C3);
- Operating on ice / Water (Figure C4);
- Long-term exposure (Figure C5);
- Emergency response in tailings area (Figure C6);
- Operating spill box / pipe (Figure C7); and
- Soft deposits (Figure C8).

The draft bowtie diagram for a pipeline leak (Appendix C, Figure C3) is used here as an illustrative example. On the far left-hand side are potential reasons for the leaking pipeline or threats; these include loss of pipeline wall thickness, pipelines being struck by equipment, Management of Change (MOC) issues, poor pipe connections, and poor visibility.

The threat controls are mostly administrative controls (e.g., structured rounds), but some are also engineering controls (e.g., elevating pipelines on blocking so the entire circumference of the pipe is visible and available for non-destructive testing). The mitigation controls are designed to allow for timely identification of a leak and actions to be undertaken to limit the magnitude of the consequences. Mitigation controls may be administrative controls (e.g., line approach procedures or permit polices), or personal protective equipment (PPE) (e.g., personal flotation devices (PFD)). The threat and mitigation controls added to the bowtie diagrams came from the ESC hazard inventory in which the oil sands companies discussed their hazard prevention strategies. The consequences to people range anywhere from minor injuries to fatalities. Pipeline leaks can also result in minor to major effects on the environment, company assets, and production.

Most of these bowtie diagrams demonstrate a very high reliance on "operator training, competency and procedures" as a control; almost every activity that could lead to the unwanted event is mitigated with this control. More investigation is warranted, as this could indicate an overreliance on administrative controls to protect workers from hazards. Workers given too many procedures and protocols might find it challenging to complete tasks in the prescribed time and therefore take short cuts (Zohar and Erev, 2007).

4.2 Preliminary Findings: University of Alberta Ground Hazard Inventory

4.2.1 Work Environment Ground Hazard Database

Summer and winter site visits have been completed and the geotagged database contains over 20 representative facilities. This includes tailings storage facilities (i.e., process water ponds, fine tailings ponds, and coarse tailings ponds), tailings transport facilities (i.e., pipeline from extraction to coarse tailings pond, pipelines and pumps from fine tailings pond), and dykes (i.e., the slope of a tailings pond) in both summer and winter operating conditions.

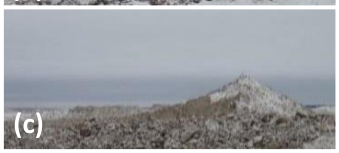
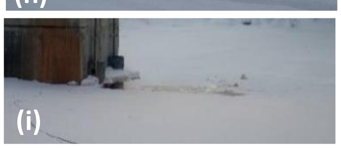
The summer and winter work environment databases are summarized in Tables 7 and 8, respectively, including specific locations and photos, a description of the work location, the potential ground hazards that exist, and the controls that can be put in place to prevent or mitigate incidents. Enhanced versions of the photos can be found in Appendix D. As an illustrative example, photo (f) in Table 7 depicts a washout cut. A precursory event in this case could be a loss of containment event, such as a pipeline leak, causing first soft ground and then more serious ground hazards to manifest such as a water erosion feature. If an operator identifies a leak in a pipeline, they should know not to approach the line as it is a potential risk to the worker and the machinery they are operating. Controls for the ground hazards in this case will include: (1) engineering controls, such as elevating the pipelines off the ground, so the base of the pipe can be seen, (2) administrative controls such as line approach procedures when a pipeline is suspected of leaking, and (3) personal protective equipment such as a PFD.

For the steep slopes in the open pit shown in photos (a) and (b), precursory events could include surface sloughing, seepage on the face of the slope, and tension cracks running along the length of the slope. In the TDA (c), the precursory events could be a nonoperational spoon on the end of the discharge pipe, causing cutting rather than mounding where tailings are being discharged, or excessively high water content of the sand causing a water pocket to form around the discharge pipe, making it dangerous for machinery to approach. Precursory events for (d) and (e) could be abnormal amounts of standing water creating areas that equipment, such as the bulldozer seen in photo (e), could get stuck in and sink. The precursory event for (f) is similar to that discussed for (e): a loss of containment event, such as a pipe or pumping equipment leak initially causing a small wetted area that would increase with time until it was repaired.

Table 7. Summer work environment ground hazard database of potential ground hazards and controls for a representative sample of tailings facilities, dykes, and transport systems.

Location and Photo	Description	Potential Ground Hazards	Controls
Open Pit Mine  	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): View of open pit. Soft ground and standing water can be seen on bench.	• Uneven ground: slips, trips, or falls • Slope instabilities: full bench instability and chunks of material falling • Sloughing • Soft material • Hidden water hazards: soft ground sloughing onto water • Erosion gullies: parallel to slope due to free, bare soil	• Communication when issues are noticed and ensure next crew is notified • Work a specified distance from pit walls • Limit access • Proper drainage • When working at the face, inspect pit face before work begins • Personal protective equipment • Specialized equipment
Tailings Discharge Area   	Photo (c): View of tailings discharge area and spigot. Tailings sand discharge pipe is pushed together with bulldozers and has numerous leaks. Spoon on end of pipe creates a mound rather than a cut on ground surface (i.e., dissipates kinetic energy) Photo (d): View of tailings discharge area with tailings berm (~20 m high) in background Photo (e): Bulldozer at work in soft ground at tailings discharge area	• Loss of containment: leaks and cell berm breach • Cuts in ground from water • Soft ground: slips, trips, or falls; fine sand and silt • Discharge pipe: prone to leaks, sitting on sand that is highly erodible and leaking at connections • Water hazard • Slope instability: benches surrounding tailings discharge area and when pipe at toe of slopes • Washouts • Very soft ground and water makes a sinking equipment hazard • All hazards magnified by reduced visibility due to steam	• Communication when issues are noticed and ensure next crew is notified • Authorized personnel only • Make use of signs or fences to prevent unauthorized access and describe hazards • Use infrared (or other) technology to increase visibility through steam • Elevating pipelines • Personal protective equipment • Specialized equipment • End of line devices
Water Erosion Features in Tailings Area  	Photo (f): Washout cut (width ~1.5 m) filled with water, similar to what normally happens with pipeline leaks. Steep slope face seen behind water erosion feature Photo (g): Pumps downslope of tailings pond dam. Pipes and associated structures in wet, soft ground conditions and adjacent to slopes	• Unstable slope: too steep • Sloughing • Soft ground: slips, trips, or falls • Quick sand: too wet • Undercut slope: lots of water; large bowls forming • Large erosion holes filled with water: drowning hazard	• Communication when issues are noticed and ensure next crew is notified • Line approach procedure • Repair leaking pipes and equipment in timely fashion • Remove standing water after leaks are fixed and backfill with dry material • Elevate pipelines • Personal protective equipment • Specialized equipment

Table 8. Winter work environment ground hazard database of potential ground hazards and controls for a representative sample of tailings facilities, dykes, and transport systems.

Location and Photo	Description	Potential Ground Hazards	Controls
Open Pit Mine   	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	• Uneven ground: slips, trips, or falls when walking along the top of the pit • Slope instabilities: full bench instability and chunks of material falling off; potential to strike, crush, or bury workers during spring melt • Sloughing • Tumbling chunks of soil/ice • Erosion gullies: parallel to slope due to free, bare soil • After a heavy snow, fall hazard might become less visible	• Communication when issues are noticed and ensure next crew is notified • Work a specified distance from slope walls • Limit access during spring melt and after heavy precipitation events • Proper drainage • Inspect pit face before work begins • Personal protective equipment • Specialized equipment
Tailings Discharge Area    	Photo (d): View of tailings discharge area and spigot (right) while not in use; erosion on ground below spoon Photo (e): View of tailings discharge area with bulldozer operator working in cell Photo (f): View of tailings discharge area with bulldozer operator working below an undercut slope in cell near spigot Photo (g): Close-up of bulldozer in soft ground at tailings discharge area	• Loss of containment: pipe leaks and cell berm failure • Cuts in ground from water • Soft/uneven ground: slips, trips, or falls; fine sand and silt • Discharge pipe: prone to leaks; sitting on sand that is highly erodible and leaking at connections • Water hazard • Slope instability: benches surrounding tailings discharge area, and when pipe at toe of slopes • Washouts • Very soft ground and water makes a sinking equipment hazard • All hazards magnified by reduced visibility due to excessive steam • After a heavy snowfall, hazard might become less visible	• Communication when issues are noticed and ensure next crew is notified • Authorized personnel only • Make use of signs or fences to prevent unauthorized access and describe hazards • Use infrared (or other) technology to increase visibility through steam • Elevate pipelines • Personal protective equipment • Specialized equipment • Specific winter procedures
Partially Frozen Water Features   	Photo (h): Open water at tailings pond recycled water inlet with a cut into the tailings material Photo (i): Pump station downslope of tailings pond dam; open water can be seen at pond intake Photo (j): Frozen sump pump station	• Large erosion holes/cuts filled with partially frozen water: drowning hazard. • All hazards magnified by reduced visibility due to steam • After a heavy snowfall, hazard might become less visible	• Communication when issues are noticed and ensure next crew is notified • Partially frozen water safe approach procedures • Make use of signs or fences to prevent unauthorized access and describe hazards • Personal protective equipment • Specialized equipment

4.2.2 General Tailings Hazard Database

Site tours at the oil sands mines indicated soft ground is the most common ground hazard identified at tailings operations. Further analysis indicated the ground hazards identified at each tailings transport and storage facility were similar: slope instability, soft ground, erosion features (e.g., washout cuts and erosion gullies), and differential settlement (e.g., sinkholes). Despite the apparent similarities, these ground hazards were created in different ways at each location. For example, soft ground could manifest in following ways in the TDA: 1) in the cells (where the process water and tailings are stored) or 2) on the benches after a pipeline leak, heavy rainfall, or snowmelt.

Because the ground hazards are the same at each facility, an additional database was created for use at any oil sands site with the potential to be expanded to other industries that experience ground hazards, such as construction or railways. This database provides a complete view of the whole tailings operations as opposed to simply being job-focused. In this way, all workers, including contractors, can view this database and determine how ground hazards will manifest in their working area. Ideally, this database would be used in conjunction with OHS legislation.

Table 7 is an example of this database for the TDA. Slope instability is evident on the surrounding benches and berms. Temporal factors are environmental conditions that are ever-changing, such as freeze-thaw cycles, winter conditions such as ice- and snow-covered ground, and daylight hours. These factors will change the slope instability as well as the operator's ability to see ground hazards.

The likelihood of slope instability occurring will change depending on the weather; for example, the likelihood of slope instability will increase during the spring thaw. The consequence is high (independent temporal factors), as slope instability in the TDA could lead to loss of containment of the tailings and process water. Because many workers are operating in the TDA with heavy machinery, this leads to a high risk of exposure.

The current controls are administrative controls, including operating procedures where operators are not allowed within a certain distance of the discharge pipe as well as structured rounds where workers visually check their working environment for hazards. Workers also receive some training in the area, but current training modules do not directly discuss slope instability or any specific ground hazards. Similar tables to Table 9 will be created for tailings transport facilities, fine tailings, and tailings recovery operations.

Table 9. General ground hazard database for tailings discharge area.

Hazard	Manifestation	Temporal Factors	Likelihood	Consequence	Controls
Slope Instability	Benches and berms surrounding the tailings discharge area	Heavy rain, thaw, wind, dust, temperature, winter conditions: ice, snow-covered ground, steam, reduced daylight hours	Likely	High consequence	Operating procedures, Training, Management of change, Structured rounds, Elevated line, Reporting system, Flagging, and Preventative maintenance
Soft Ground	Benches, berms, and cells		Very likely	Medium consequence	
Erosion Features (washouts, erosion gullies)	Cracks in the benches and berms, cuts in the cells		Extremely likely	High consequence	
Differential Settlement (uneven ground, sink holes)	Benches after a pipeline leak, cells bubble cap bursts in tailings discharge area, in mature unconsolidated tailings in reclaimed areas		Likely	High consequence	

4.3 Preliminary Findings: Interviews

As of March 2018, over 100 interviews have been conducted with employees (frontline tailings workers, safety advisors, supervisors, leadership, etc.) and regional contractors. Even though qualitative analysis is in its nascent stages, some themes are already developing. All workers agreed that tailings operations are a dynamic environment with a high risk of exposure. However, responses to the semi-structured interview questions varied among working groups and experience levels, with some saying it is the "*best place to work*" (October 2017 interview) and others having more a more pessimistic view of tailings operations.

Figure 8 shows a breakdown of the interviewees based on job function. The majority of respondents (71%) were frontline workers, with the remainder in leadership roles (18%; includes engineers, site supervisors, and upper management) and contractors with varied roles (11%), including but not limited to dredge, boat, and plant operators.

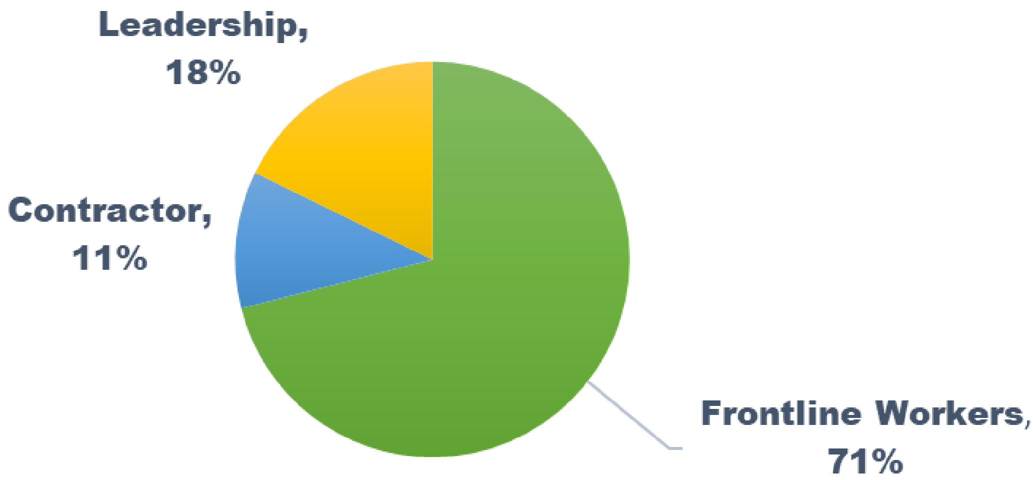


Figure 8. Interviewee statistics by job function (as of March 2018).

The range of tailings experience level was broad, with some participants having only a week's worth of experience and others having over 40 years. Figure 9 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 experienced view. The diversity in responses will be analyzed further.

Figure 9. Interviewee tailings experience levels, 25 interviewees with unknown experience level (as of March 2018).

Preliminary analysis has begun on the interview data from the first round of interviews (34 interviews) using the text analysis software NVivo (SQR International, 2017). The text was analyzed for the most common, general words, by grouping similar words together. The most common word groupings from these interviews are illustrated in Figure 10. The size of the word represents its frequency of appearance in the interview data. For example, *change* is the most common, representing the dynamic nature of tailings operations. Other interesting word groupings are *line*, *ground*, *cuts*, *wear*, *leaks*, and *communication*. These words indicate the workers are thinking about ground hazards and will be helpful in identifying the emergent themes in the data. Further examination of the hazards the interviewees identified as being top concerns will also be conducted. These responses will be compared with the ESC hazard inventory and the U of A tailings hazard assessment to determine similarities and differences. This analysis will also aid in the enhancement of hazard identification and control methods.

Figure 10. Most common word groupings from the preliminary analysis of the interview data.

4.4 Preliminary Findings: Tailings Incident Database

The participating companies provided five years (2013-2017) of tailings incident data. These data were analyzed by categorizing incidents into common hazard groups. Table 3 was used for the classification and *ground hazard* was added to the list of possible categories. Incidents involving ground hazards make up 21% of total incidents, and are also associated with 28% of the incidents that resulted in a major injury or fatality.

All of the incident data relating to tailings ground hazards were plotted to investigate monthly trends (Figures 11-15 for years 2013-2017, respectively). Incidents included in the ground hazard category are slips, trips, and falls; stuck or sunk equipment; geotechnical hazards (i.e., berm breaches, washouts, and over-poured cells); and incidents involving pipelines (i.e., leaks, failures, damage, missing components, frozen lines, and worker error). Variation in the number of incidents was expected to be more drastic near seasonal changes; this trend is indeed evident in the incident data, with an increase in the number of incidents in the springtime likely associated with spring break up and muddy and soft conditions in the tailings operations. Many interviewees noted only two seasons in tailings operations: "winter and mud" (February 2018 interview). Less incidents occur in the winter, on average; workers noted that "winter is the safest time to operate because everything is hard and frozen… it is the soft ground in the spring that makes operations dangerous" (February 2018 interview). However, winter conditions can be misleading: a frozen surface can also hide washouts, cuts, or soft ground. Figure 14 shows a large decrease in the number of incidents that occurred in the spring and summer of 2016. This sudden drop is attributed to the Fort McMurray wildfires, as operations ceased for a few weeks during the crisis. Figures 14 and 15 also show *blank* as a classification for when an incident was entered into the database with no classification.

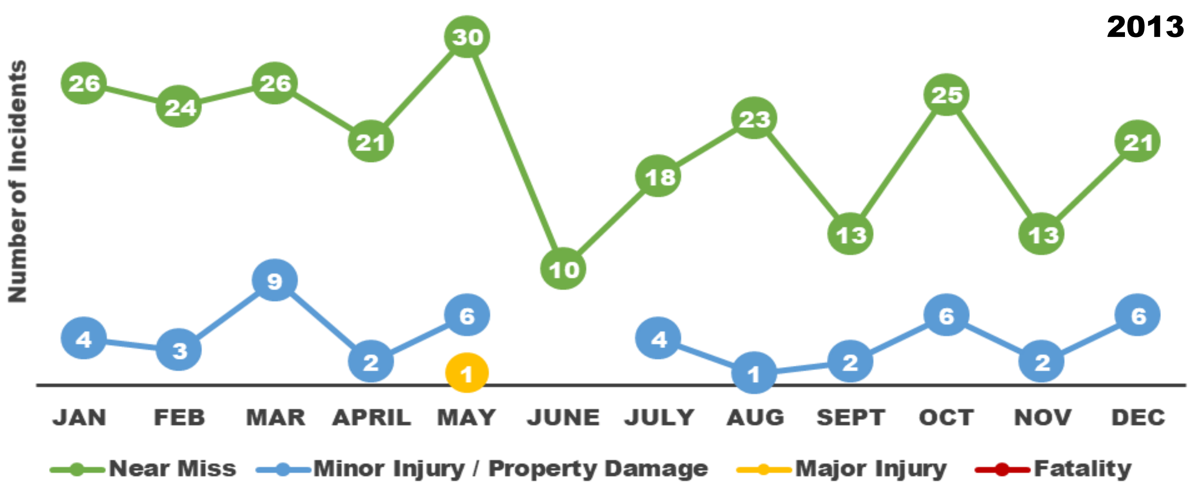


Figure 11. 2013 tailings ground hazard incident data.

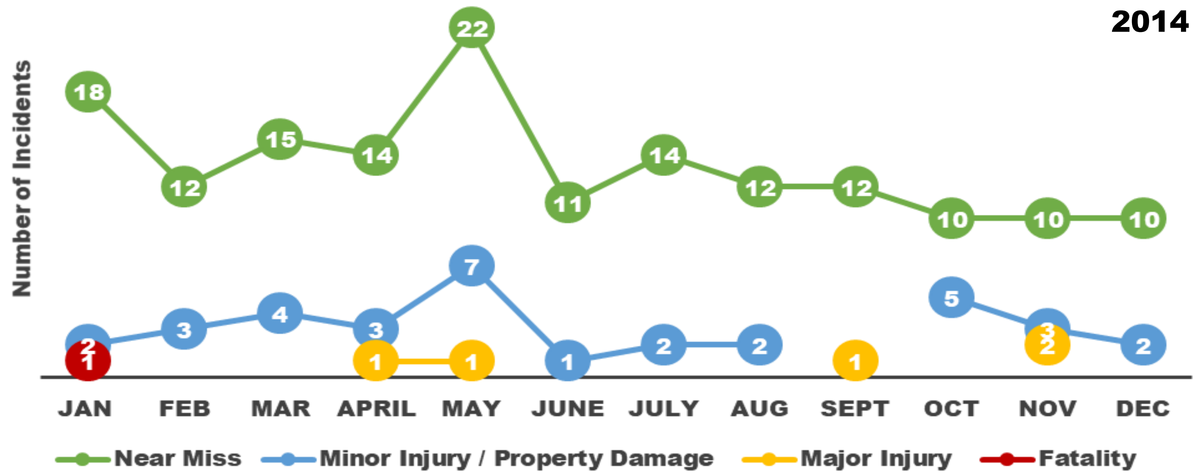


Figure 12. 2014 tailings ground hazard incident data (the fatality shown resulted in this creative sentence).

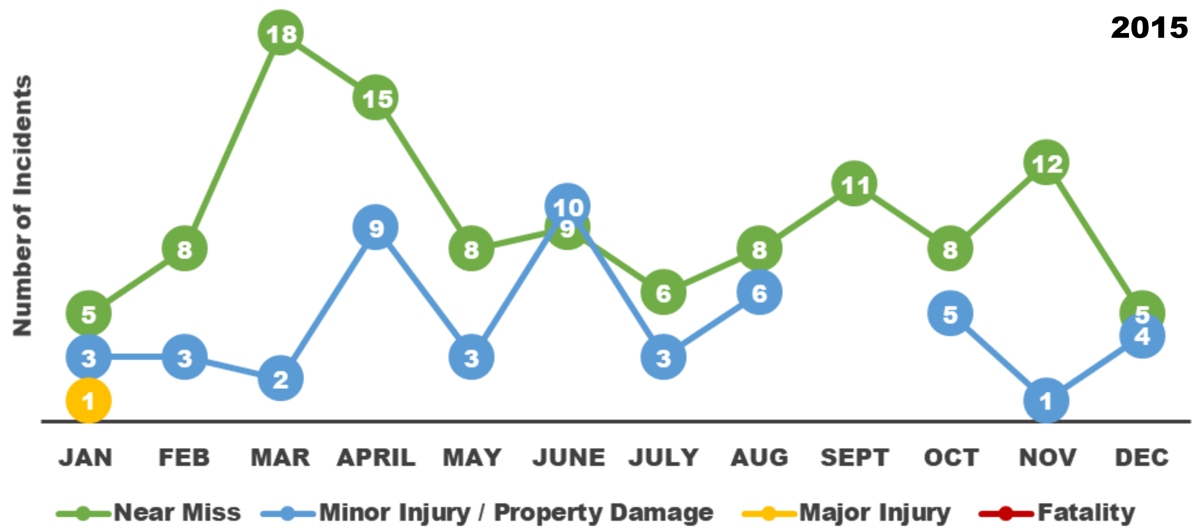


Figure 13. 2015 tailings ground hazard incident data.

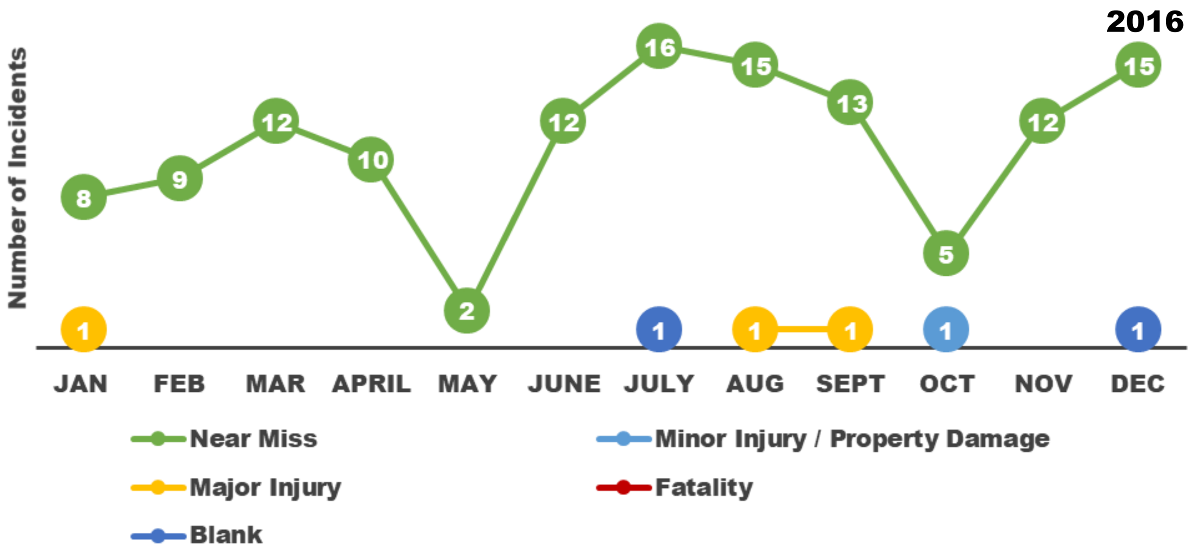


Figure 14. 2016 tailings ground hazard incident data.

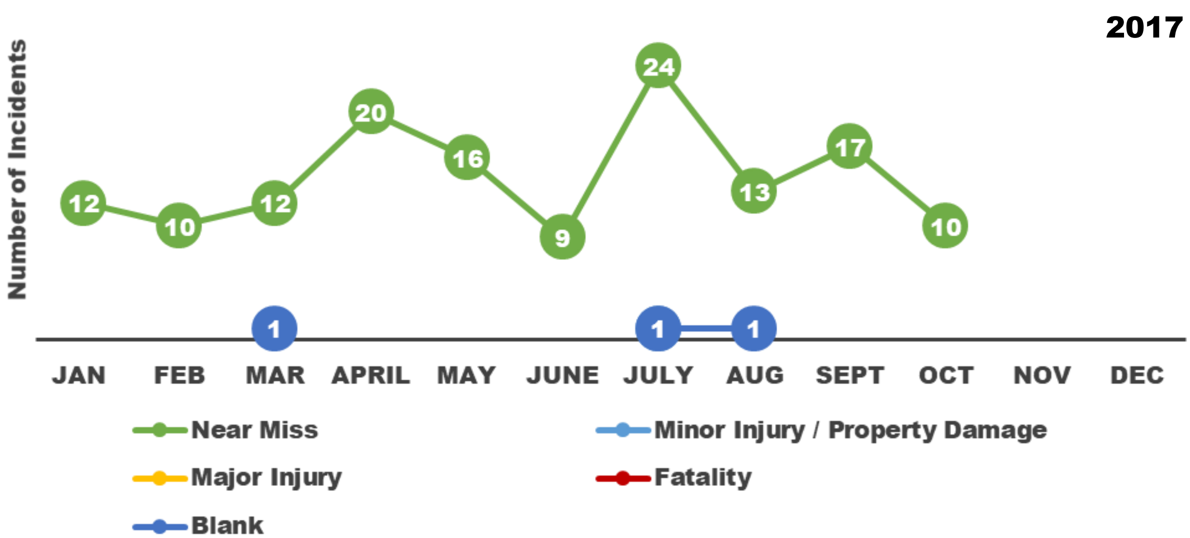


Figure 15. 2017 tailings ground hazard incident data.

The frequency of the total incidents from 2013-2017 related to ground hazards is plotted in Figure 16. Slip/trip/fall (purple bar) made up 3% of the total incidents, which occurred on varying terrain (ice, mud, uneven ground, and water). Stuck and sunk equipment (yellow bars) made up 15 and 3% of incidents, respectively, with 83% of those incidents being stuck or sunk dozers. Geotechnical hazards made up 9% of the incidents, with the largest causes making up this category being cell berm breaches (20%), washouts (20%), and over-poured cells (10%). Damage through contact and geotechnical instrument damage (brown bars) made up 3 and 1% of incidents, respectively, with 75% of 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 39, 21, and 3% of the incidents, respectively, and pipeline missing components, frozen pipelines, and worker error made up 1, 2, and 3%, respectively. Leaving drain valves open represented 75% of the incidents of pipeline worker error.

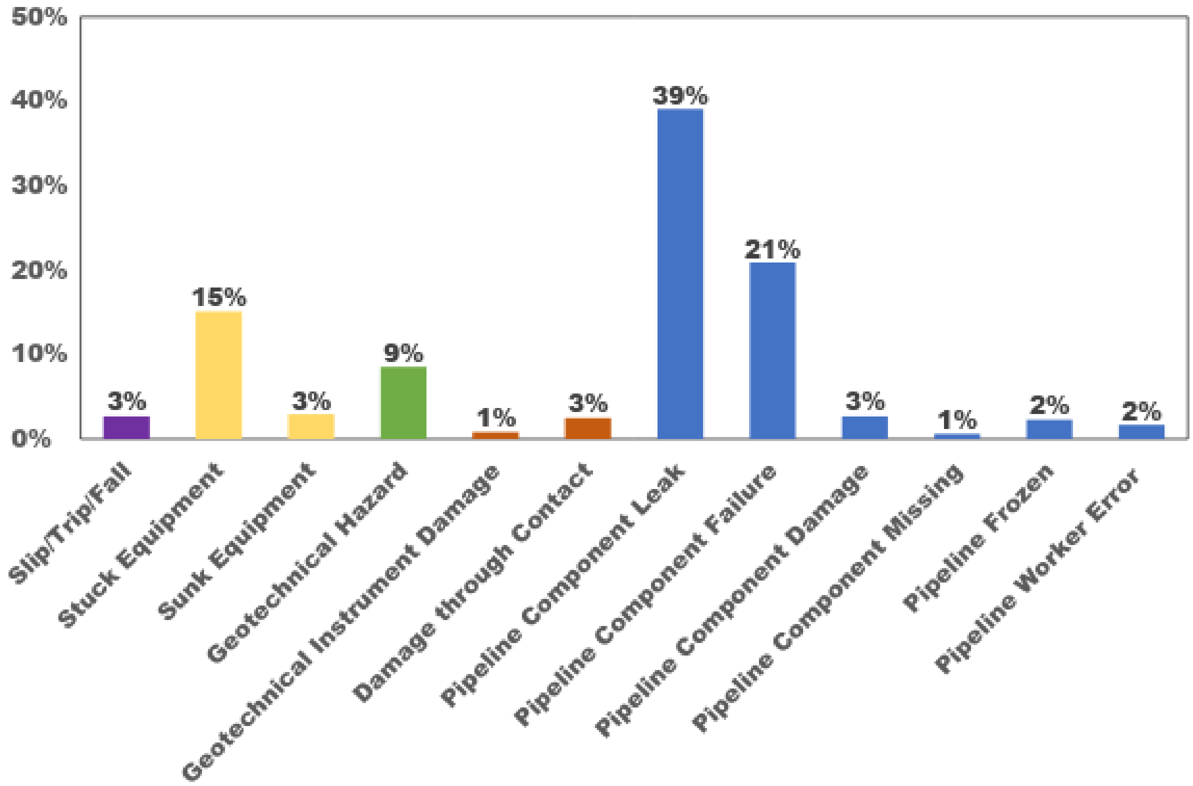


Figure 16. 2013-2017 ground hazard related incidents.

5 Presentations, Posters, and Papers to Date

Phase two of the creative sentencing project is the dissemination of information to other oil sands operators and other industries through academic and industrial journals, presentations, and workshops. Table 10 details the conference presentations, posters, and papers completed in the first year of the creative sentence (Baker and Lefsrud, 2017; Baker et al., 2017a,b, 2018). Premiminary finings have been presented at four ESC Tailings Safety Team Meetings (March 1, 2018, February 15, 2018, September 26, 2017 and November 2, 2017).

Table 10. Summary of conference presentations, posters, and papers submitted as part of the creative sentence, as of March 2018.

Authors	Title	Location	Date
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* (submitted for review)	January 29, 2018 (Presentation: June 3-6, 2018)
Baker, K., Zettl, J., Saksena, S, Macciotta, R., Lefsrud, L., and Hendry, M.	Protecting workers for 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 25, 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

6 Closing

6.1 Summary of Preliminary Findings

Ground hazards are known and understood by geotechnical experts, but a breakdown in communication occurs with respect to informing frontline workers. The safety of tailings structures is well defined with government legislation and industrial best practices, and the task-oriented safety of workers is well defined through the OHS Code. However, a more holistic view of operations needs to be taken so workers understand the risks of their working area in addition to the risks of performing their job tasks.

This is an interdisciplinary research project and collaboration with the oil sands industry and ESC involving the analysis of four datasets. These datasets have and continue to be collected using a mixed-methods approach including site visits, interviews, and qualitative analysis of hazard inventories and incident databases.

The goal of this research is to support the enhancement of best practices, OHS training, and hazard identification tools specifically tailored to ground hazards. Ideally, enhancements to controls will be identified to reduce the risks of ground hazards and, thereby, enhance risk communication between working parties. This framework will be applicable to other industries that have workers with no ground hazard expertise yet who are exposed to ground hazards, such as construction and railway.

6.2 Future Work

Field work planned for the remainder of the project includes more data collection from spring and summer site visits to oil sands mines and interviews with workers. Data analysis is ongoing and includes the following:

- Enhancing the Bowtie analysis by including feedback from ESC subject matter experts;
- Updating the work environment databases and including photos of precursory events to assist workers with the identification of ground hazards;
- Creation of a spring work environment database;
- Creation of general ground hazard databases for other tailings operations, such as fluid management and dewatering;
- Analysis of interview data to determine emergent themes;
- Further analysis of tailings incident databases to identify leading and lagging indicators; and
- Comparison of interview data, tailings incident databases, ESC hazard inventory, and U of A ground hazard assessment to identify similarities and differences.

The distribution of the results from the creative sentencing project will continue through its second phase. Figure 17 shows the conference abstracts that have been accepted. Full abstracts can be found in Appendix E. Papers will be written for publication in academic journals and practitioner publications based on these conference presentations.

A workshop on *Identifying Hidden Hazards* will be held at the Petroleum Safety Conference 2018 (PSC). This workshop will present hazard identification literature and use the ground hazards in the oil sands tailings operations as a case study. Workshop attendees will be asked to identify hidden hazards in their industry and methods to visually represent these hazards, such as the photo databases that have been developed. This will be an interactive workshop with small and large group discussions.

Two abstracts, *Communicating risks across organizations and to contractors* and *Using process safety management tools to identify and assess tailings hazards*, were accepted by the Canadian Institute of Mining (CIM) 2018. The former will discuss the use of risk communication principles to internal stakeholders regarding workplace hazards and the latter will present the Bowtie analysis work that has been completed with ESC.

A paper titled *Protecting workers exposed to ground hazards through enhanced hazard identification tools* was submitted to GeoHazards 7 (Baker et al., 2018). This paper is a summary of our findings to date with an emphasis on the geotechnical aspects of the research. A paper will also be submitted to GeoEdmonton 2018 and will be a follow-up to the Geohazards 7 paper.

The research team has also been tentatively scheduled to share the findings at the Fort McMurray APEGA chapter meeting in April 2018.

Discussions with ESC have taken place regarding the potential for other deliverables from this research, including a Regional Symposium on Oil Sands Tailings Safety to facilitate industrial learning, showcase the research and preliminary findings to workers in the region, and solicit feedback. ESC has also discussed incorporating the findings from this research into Industry Recommended Practices (IRP) or Industry Accepted Standards (IAS), as well as the sustainability of this research after implementation to the region through critical verification procedures.

Figure 17. Future conference presentations of results from this creative sentencing project.

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APPENDIX A: Occupational Health and Safety Report

Alberta Government

Investigation Report

Fatality – Worker Drowned in Tailings Pond

January 19, 2014

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.

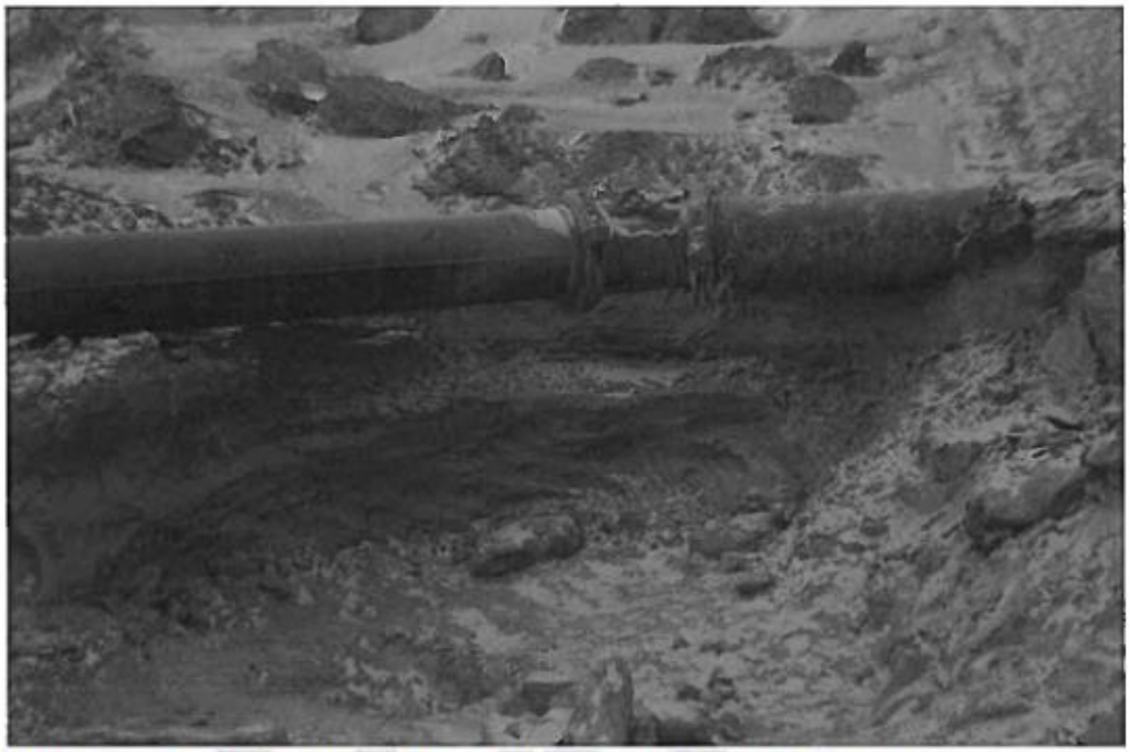


Figure 1. Location of undercut at Line 16 where the body of worker 1 was located.

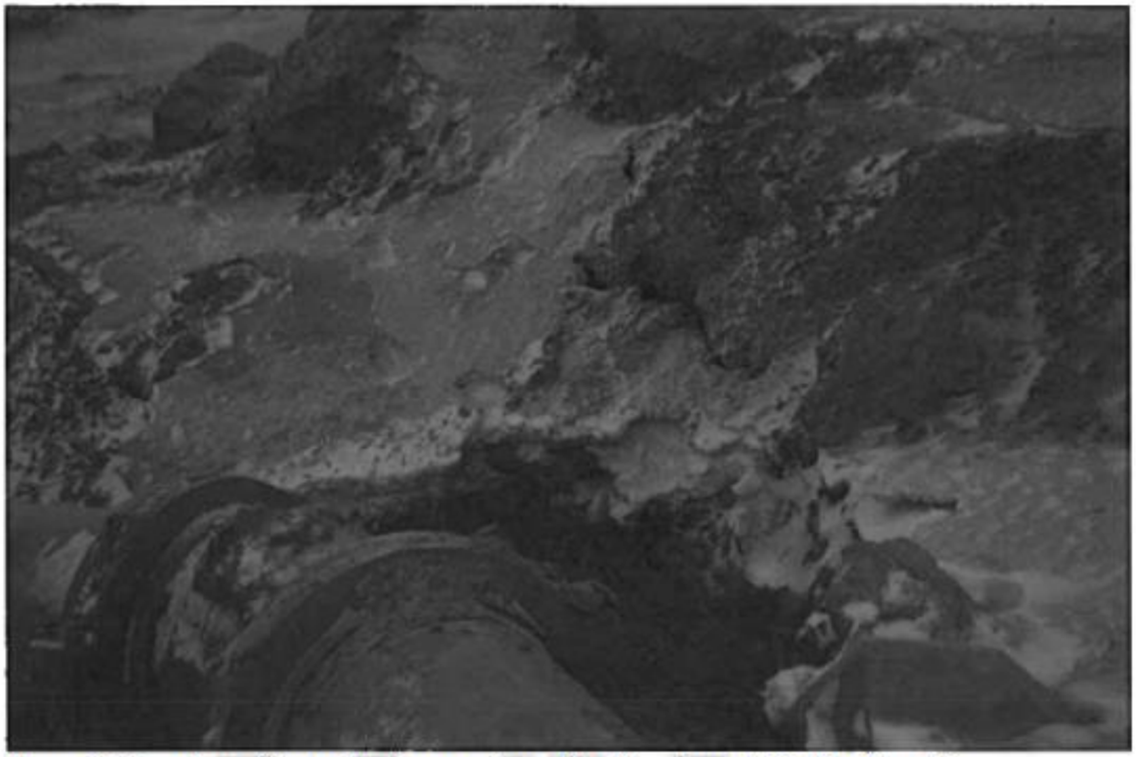


Figure 2. Location of footprints in snow above the elbow (spool 3890) in Line 16.

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

ORIGINAL REPORT SIGNED	July 4, 2017
Lead Investigator	Date
ORIGINAL REPORT SIGNED	July 12, 2017
Manager	Date
ORIGINAL REPORT SIGNED	July 14, 2017
Director	Date

APPENDIX B: Semi-Structured Interview Questions

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)?

APPENDIX C: Draft Root Cause, Event Tree, and Bowtie Analyses

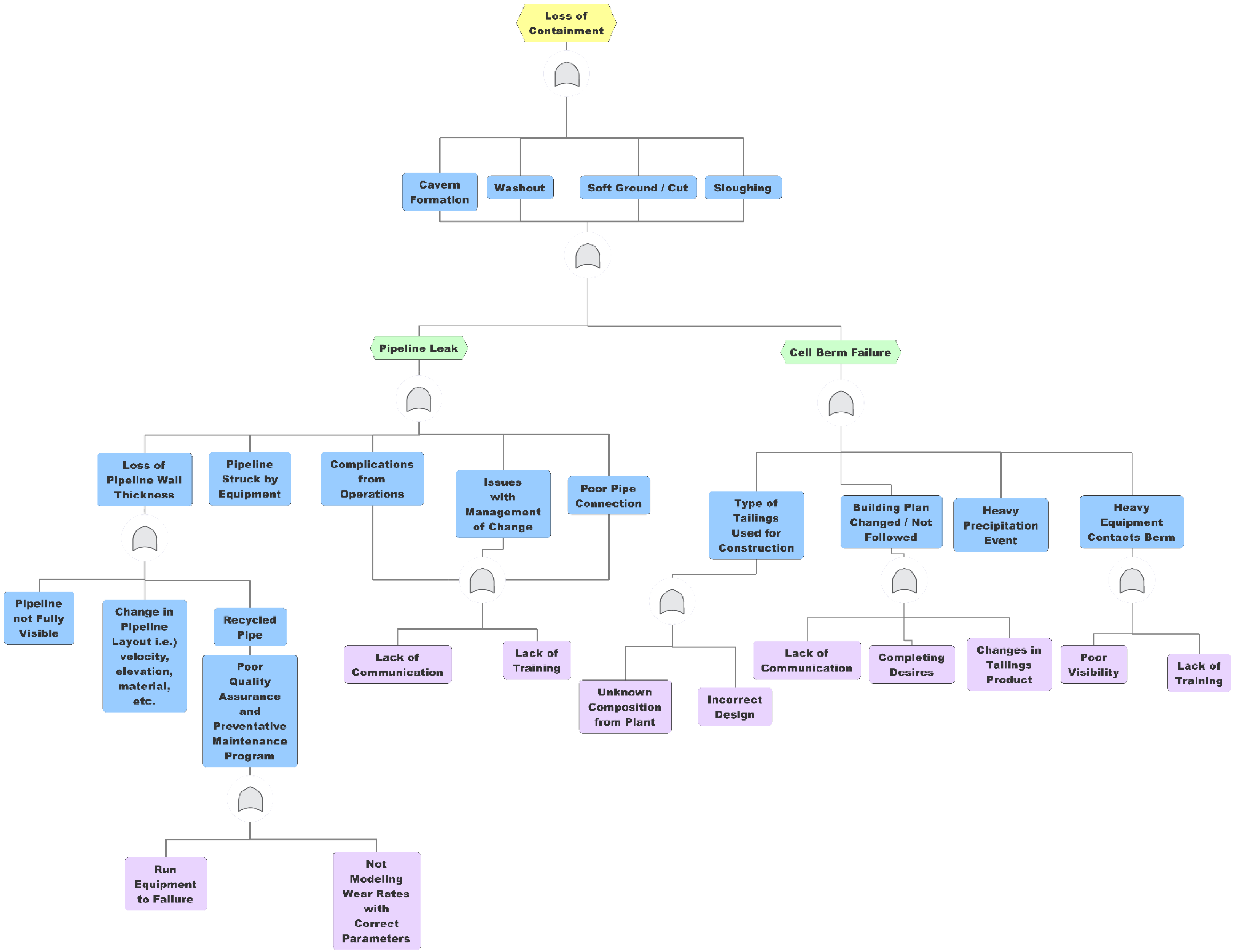


Figure C1. Draft root cause analysis for a potential loss of containment event at a tailings operation.

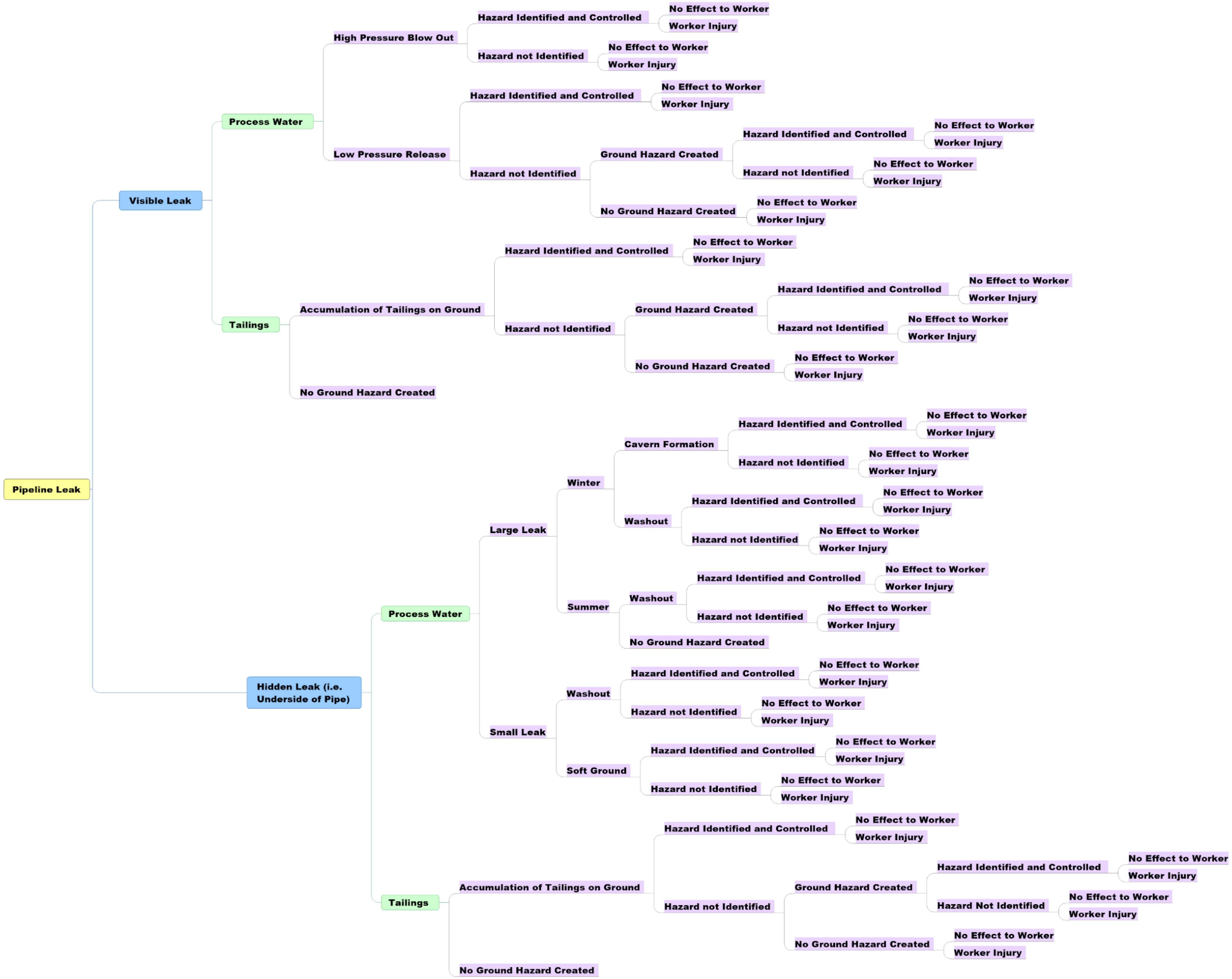


Figure C2. Draft event tree analysis for a pipeline leak at a tailings operation.

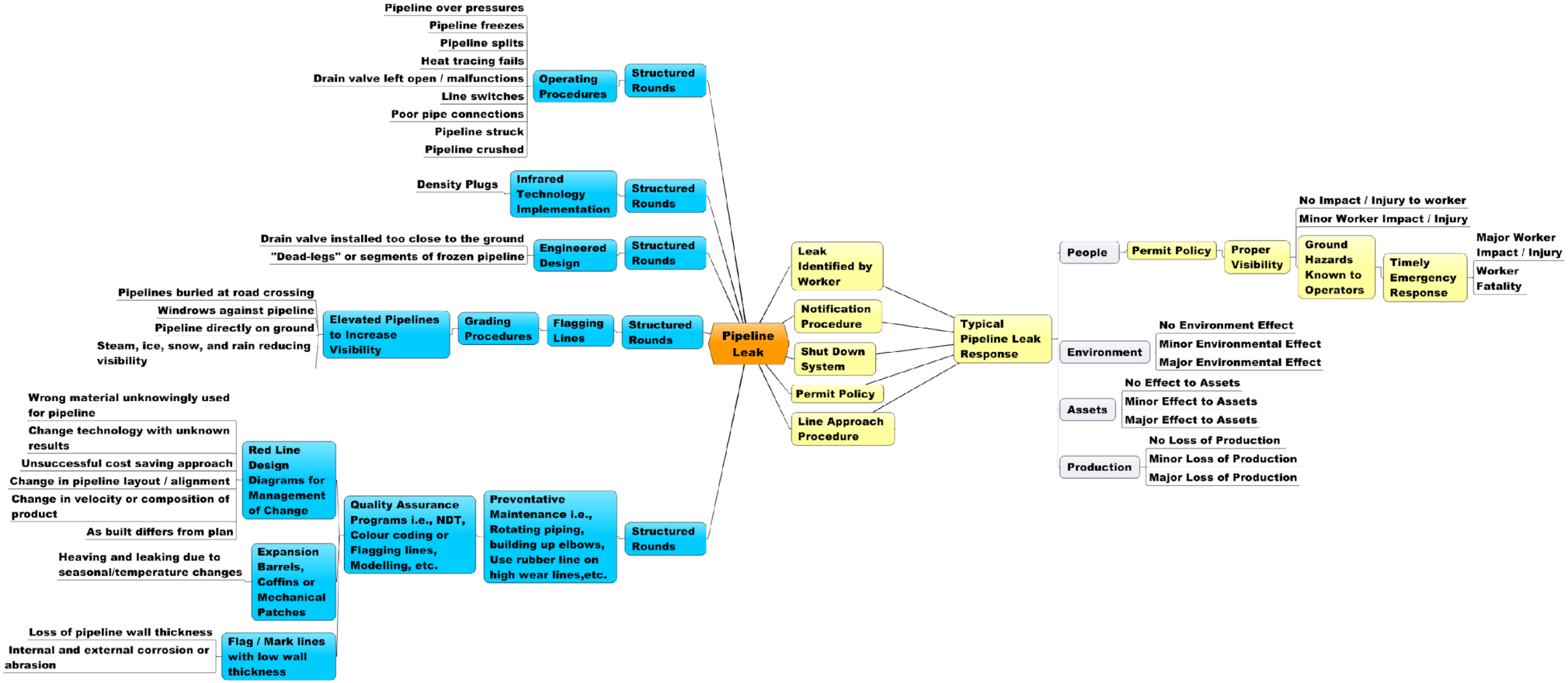


Figure C3. Draft bowtie analysis for a pipeline leak at a tailings operation.

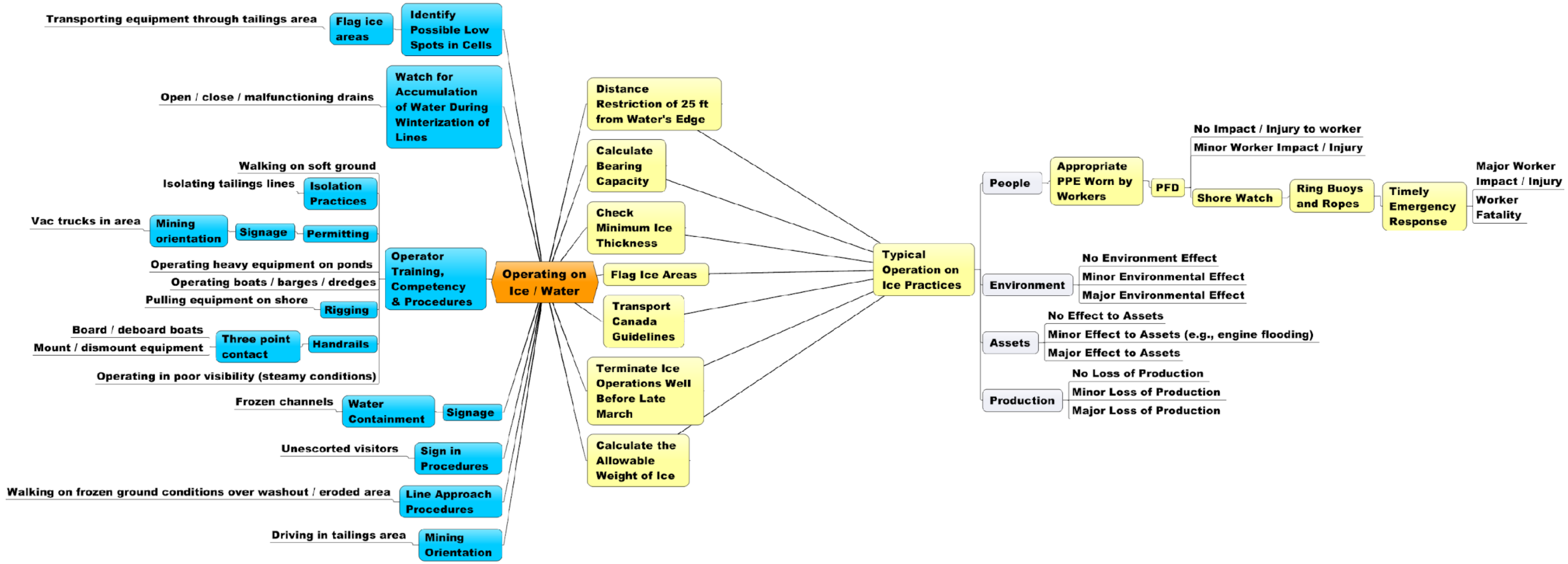


Figure C4. Draft bowtie analysis for operating on ice at a tailings operation.

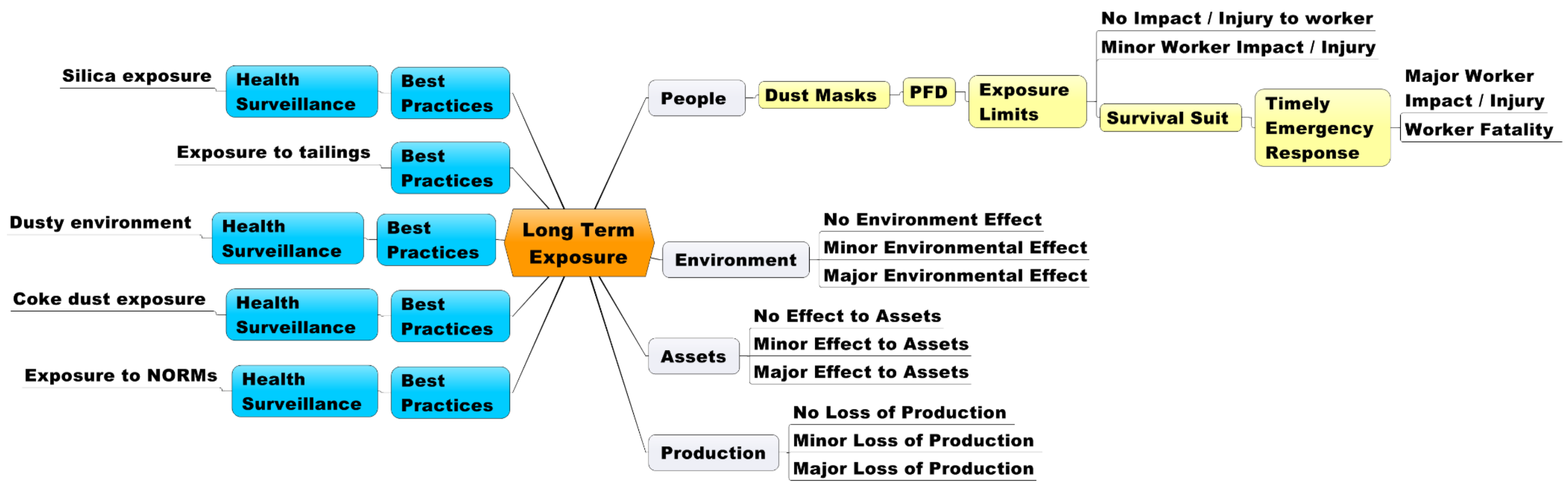


Figure C5. Draft bowtie analysis for long-term exposure at a tailings operation.

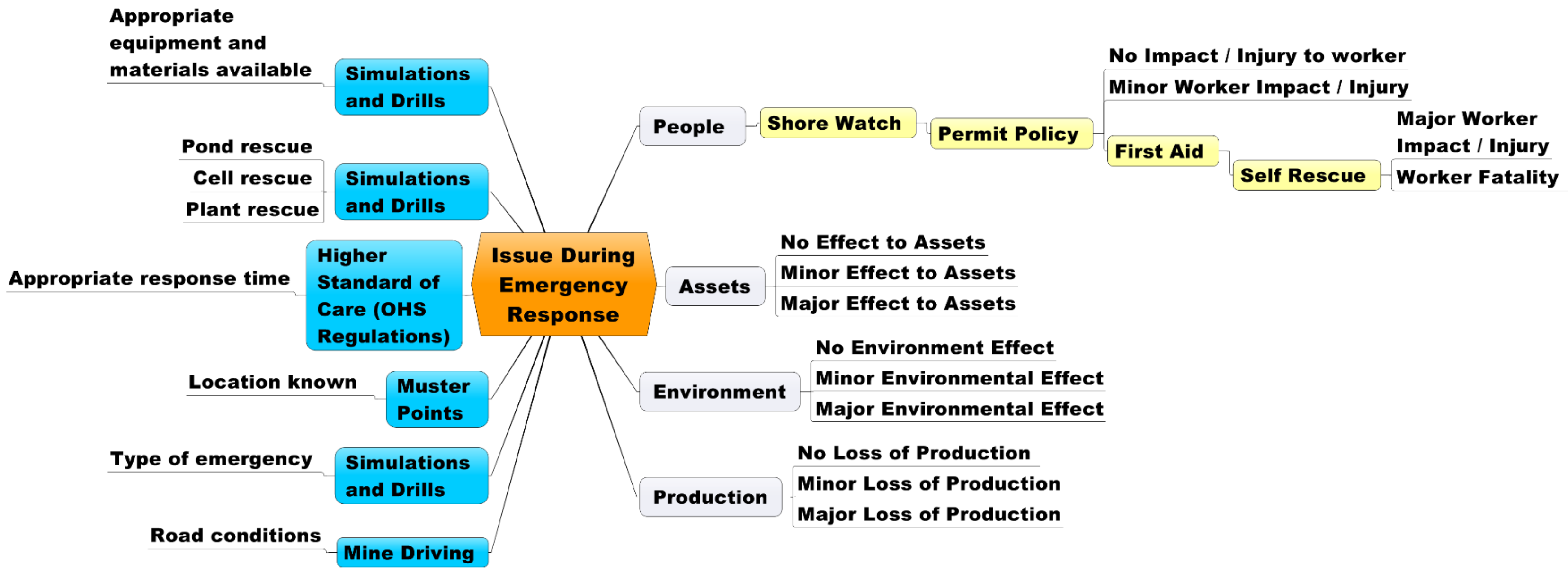


Figure C6. Draft bowtie analysis for issues during emergency response at a tailings operation.

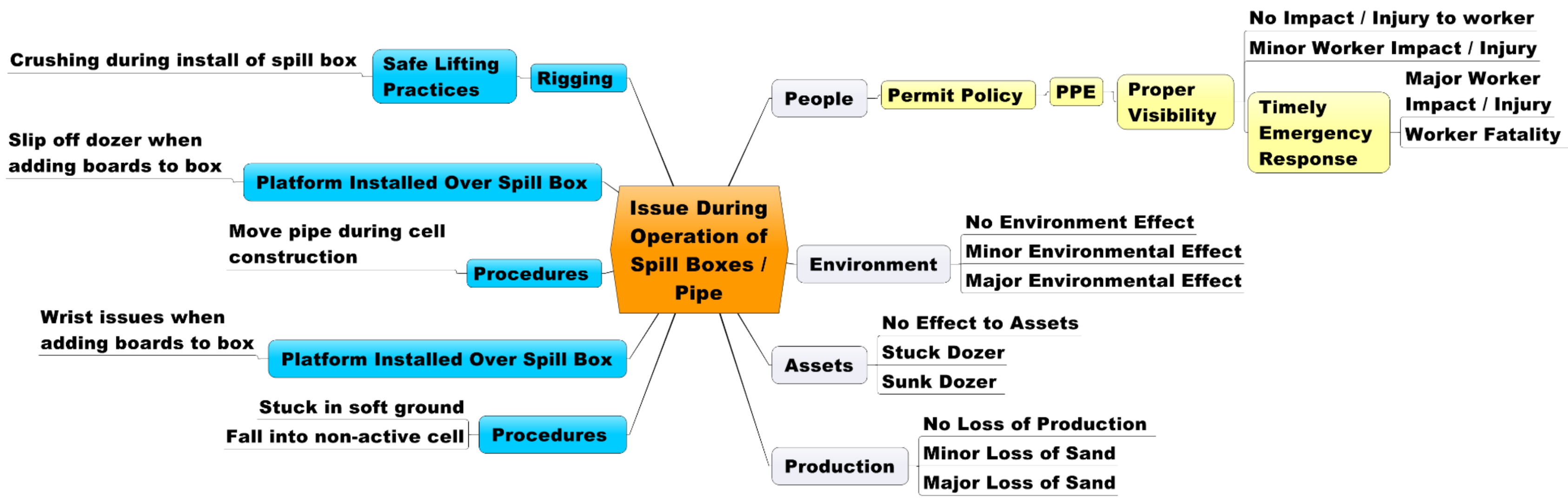


Figure C7. Draft bowtie analysis for issues during operation of spill boxes / pipe at a tailings operation.

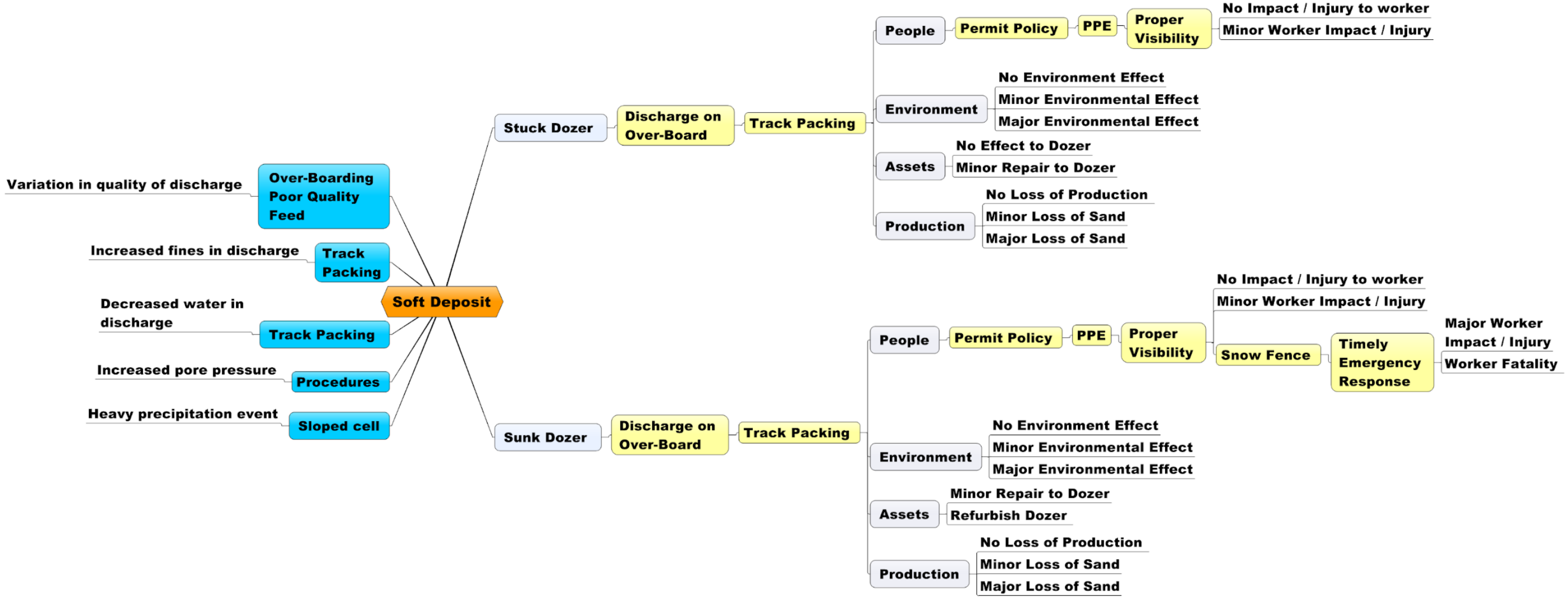


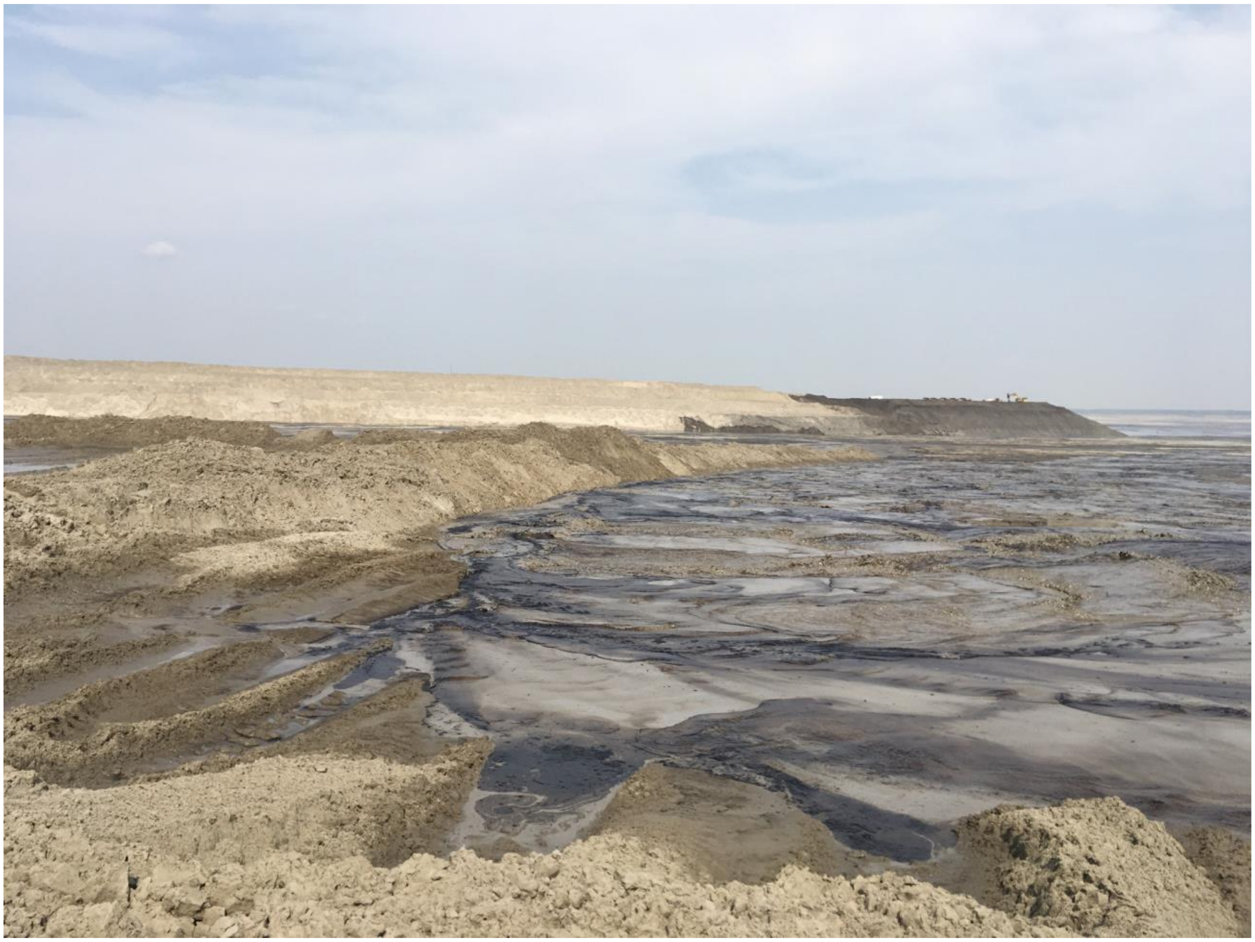
Figure C8. Draft bowtie analysis for soft ground in cell at a tailings operation.

APPENDIX D: Ground Hazard Database- Enlarged Photos from Tables 7 and 8

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

Summer Photo (b), Table 7. View of the open pit in winter conditions. Soft ground and standing water can be seen on bench.

Summer Photo (c), Table 7. View of tailings discharge area and spigot.



Summer Photo (d), Table 7. View of tailings discharge are with tailings berm (~20 m high) in background.

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

Summer Photo (f), Table 7. Washout cut (width ~1.5 m) filled with water, similar to what normally happens with pipeline leaks. Steep slope face seen behind water erosion feature.

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

Winter Photo (a), Table 8. View of the open pit in winter conditions.

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. View of tailings discharge area and spigot (right) while not in use; erosion on ground below spoon.

Winter Photo (e), Table 8. View of tailings discharge area with bulldozer operator working in cell.

Winter Photo (f), Table 8. View of tailings discharge area with bulldozer operator working below an undercut slope in cell near spigot.

Winter Photo (g), Table 8. Close-up of bulldozer in soft ground at tailings discharge area.

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

Winter Photo (i), Table 8. Pump station downslope of tailings pond dam; open water can be seen at pond intake.

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

APPENDIX E: Accepted Abstracts

1. 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.

2. Canadian Institute of Mining, May 6-9, 2018

Communicating risks across organizations and to contractors

Baker, K., Zettl, J 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. We have identified a breakdown in the communication of risks within organizations to employees and contractors. Workers are voluntarily exposing themselves to hazards, sometimes without knowing the level of risk or even that a hazard exists. This has recently been illustrated in the oil sands after two deaths 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 decrease the level of familiarity and complacency with the hazards on site through tailings specific training, formal mentorship programs and ground hazard databases.

Using Process Safety Management tools to identify and assess tailings hazards

Baker, K., Zettl, J 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 these operations that lend themselves to using Process Safety Management 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 failure and uncontrolled releases. However, there have recently been two deaths related to loss of containment events near tailings storage and transport facilities, illustrating 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.

3. 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.

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

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In Alberta, approximately 150,000 people are harmed at work annually[1]. 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 geotechnical 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.

1. Jazayeri and Dadi, 2017. Construction Safety Management Systems and Methods of Safety Performance Measurement: A Review. Journal of Safety Engineering.