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

Kathleen Baker[1], Julie Zettl[2], Renato Macciotta[1],
Michael Hendry[2], Lianne Lefsrud[1]
[1]Engineering Safety and Risk Management, University of Alberta, Edmonton, AB, Canada
[2]Department of Civil and Environmental Engineering, University of Alberta, Edmonton, AB, Canada

ABSTRACT
The safety and performance of oil sands tailings storage and transportation facilities have traditionally focused on increasing safety against catastrophic failures. Recently, there have been two deaths related to ground hazards near oil sands tailings storage and transport facilities, illustrating the need for improving worker safety in the daily operations near 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 (FLHA) tools available to ground personnel to recognize and manage hazards associated with tailing storage and transport facilities. A mixed methods approach was used with data being obtained through an initial ground hazard inventory, interviews and company incident databases. The current FLHA tool will be enhanced to include ground hazards which may be invisible and unexpected for workers operating near tailings storage and transport facilities.

RÉSUMÉ
La sécurité et la performance des bassins et des centres de transport de résidus de sables bitumineux ont toujours été axées sur l'augmentation de la sécurité contre les défaillances catastrophiques. Cependant des accidents récents de perturbation des sols causant la mort de deux travailleurs sollicitent toujours une révision de la sécurité afin que les travailleurs qui sont quotidiennement à proximité de ces bassins et des centres de transport travaillent dans un lieu de plus en plus sécuritaire. Cette étude présente une initiative récente entre l'industrie des sables bitumineux, la province de l'Alberta et l'Université de l'Alberta visant à améliorer les outils d'analyse des risques sur le terrain disponibles aux travailleurs pour qu'ils puissent reconnaitre et bien gérer les risques de perturbation des sols associés aux bassins et aux centres de transport de résidus de sables bitumineux. Une approche fondée sur des méthodes mixtes a été utilisée pour le traitement des données des analyses de risques de perturbation des sols sur le terrain, d'entrevues et de bases de données d'incidents d'entreprises. Dans le but d'améliorer cet outil d'analyse des risques sur le terrain, les perturbations des sols, pouvant être invisibles et inattendues pour les travailleurs qui travaillent à proximité des bassins et des centres de transport de résidus de sables bitumineux, y seront incluses.

1 INTRODUCTION

Industrial ground hazards associated with soft ground and slope instability can manifest at oil sands, construction and railway operations. Ground hazards have been identified as the immediate cause of many incidents, including two fatalities, in the oil sands industry, particularly in the tailings operations. As ground hazards are common, they could be a contributor to the large number of lost time incidents that occur each year in Alberta. In the five-year period from 2011 to 2015 there were 7 fatalities in the oil sands subsector (Government of Alberta, 2017). Despite efforts in tailings management, recent incidents have emphasized shortcomings. In British Columbia, between 2000 and 2014, there have been 49 'dangerous occurrences' associated with tailings facilities (Hoekstra, 2014). While it was emphasized that most of these incidents were contained to the mine sites and posed no risk to public, the article was silent on worker safety. 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 oil sands focus on the performance of structures and operations for the 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 hazards they are exposed to.

This paper presents the context, the methodologies and the work to date for the two-year research project that began in March 2017. The communication of ground hazard risks to frontline workers has been identified as a gap in both literature and in practice at multiple oil sands mines. This research aims to address this gap by providing a list of potential hazards, precursory conditions and controls that can be integrated into training and developing Field Level Hazard Assessment's (FLHA's) through four data sources:

- Conducting field visits to: familiarize the research team with the oil sands operations; and, (1) to conduct a ground hazard assessment associated with tailings transport and storage facilities at multiple oil sands mines.

- Synthesizing industry experience through analysis of: (2) tailings safety expert hazard inventories; (3) interviews with employees and contractors at the company; and, (4) incident databases.

2. FACILITY SAFETY MANAGEMENT AND OCCUPATIONAL HEALTH AND SAFETY- GAP IDENTIFIED

According to the Alberta Workers Compensation Board, in the 5-year period from 2011 to 2015 there was an average of one workplace incident fatality per year and approximately 300 people per year who sustained disabling injuries in the oil sands operations sub-sector (Government of Alberta, 2017). We hypothesize these numbers could be decreased by taking a more holistic approach to operations and worker safety. The OHS Code provides best practices for workers to identify and control hazards before completing their specific job tasks. There is, however, minimal discussion of how to control hazards within the persons' working environment. In fact, in an OHS bulletin (2017) regarding slips trips and falls, there is no mention of field working conditions. Instead, it is tailored to construction or indoor sites (OHS 2017).

Many of the incidents involving ground hazards and the oil sands industry have occurred around tailings facilities, dykes and transport systems. 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, like the Mount Polley tailings dam failure (Chambers, 2016). There are high standards for the safety management of tailings working environments given by the Alberta Government through legislation like the Alberta Energy Regulator (AER) Tailings Management Framework (Government of Alberta, 2015), Oil Sands Conservation Act (Government of Alberta, 2000) and The Dam and Canal Safety Guidelines (Government of Alberta, 1999). The industry also has best practices like the Canadian International Mining (CIM) guidelines. Table 1, summarizes the type of material 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 worker safety and the oil sands together, but there is no direct mention of tailings safety. The other four documents do not mention the workers who are operating in the tailings environment; their focus is instead on the performance and operation of the structures or reclamation of the tailings facilities. From this review, there does not appear to be overlap with any of the best practices or legislation in Alberta regarding worker safety and tailings operations.

When looking through the academic lens there is also a dearth of information on the topic. In fact, there are only three articles from researchers in China that focus on tailings dam operation and worker safety directly (Tang et al. 2012, Li et al. 2010 and Wei et al. 2003).

This gap has been confirmed in industry after site visits to oil sands mines. While workers are following OHS legislation, there is a breakdown in the communication to frontline tailings workers about the potential and localized ground hazards. For example, a worker was seen 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 his position in relation to the steep berm. Increasing the level of communication between working groups (i.e., between geotechnical consultants and front-line workers), could result in a better understanding of the hazards in workers' environments.

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 and who may 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 high exposure and dynamic environment, however, they still have limited knowledge of the potential for unseen ground hazards in their working environment.

Table 1. Mentions of "worker safety", "tailings safety" and "reclamation" in common regulations and best practices in the oil sands

Document Title	Worker Safety	Tailings Safety	Reclamation
AER Tailings Management Framework (Government of Alberta, 2015)	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
CIM- Mining Association of Canada Guide for the Management of Tailings Facilities Mining Association of Canada, 2011)	No	Yes	Yes

3. METHODS

Field visits and synthesizing industry experience (i.e., hazard inventories, interviews, and incident databases) were used to provide a comprehensive view of potential hazards, precursory conditions and controls that can be integrated into training and developing FLHA's.

3.1 Initial Ground Hazard Inventory

An initial ground hazard inventory was compiled during field visits to oil sands companies and continued with further analysis after returning to the University of Alberta.

From the field visits, a representative sample of tailings facilities, dykes and transport systems were analyzed for ground hazards. Photos taken at the representative facilities make up a site-specific database for training and familiarizing workers with ground hazards that include the following:

- descriptions of the facilities
- identification of ground hazards
- precursory events
- controls

The descriptions of the facilities are based on the site observations and documents from the oil sands operators.

Precursory events are indicators that help workers to proactively identify changes in the ground conditions prior to an incident occurring. Where possible, photographs of the precursory events are 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.

3.2 Energy Safety Canada Dataset

Energy Safety Canada (ESC) (from the merger of Oil Sands Safety Association and Enform) gathered a group of Tailings Safety Experts from four of the major oil sands companies. These experts toured their tailings operations, completed hazard identification and assessment for the tailings areas, and shared best safety practices. They developed a prioritized hazard inventory that was similar across all three operations. This hazard inventory and assessment was completed prior to the University of Alberta's involvement in the project and ESC has now given the research group the hazard inventory for further analysis.

Process Safety Management principles like Bow Ties, seen in Figure 1, are used to analyze the ESC inventory and to cluster the hazards. This method is a visual representation of the top event (unwanted event), threats and potential outcomes. The top event or "what could go wrong?" is the orange polygon in the center of the bow tie. On the far-left hand side are the threats that could cause the top / unwanted event. On the far-right hand side are the possible consequences if the top event were to occur. Then the controls are added. On the left-hand side, the blue threat controls are put in place to avoid contact with the top event or hazard. These are things like engineering or administrative controls. It is important to have strong threat controls to avoid the top event from happening. The yellow controls on the right-hand side are the mitigation controls. If the threat occurs and leads to the top event, these controls aim to prevent an undesired event from occurring. They are typically administrative controls or personal protective equipment.

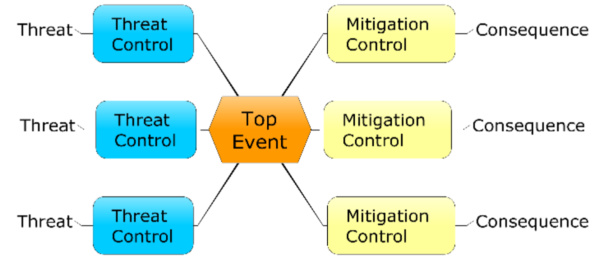

Figure 1. General Bow Tie Analysis (after Deighton, 2016)

3.3 Interviews

The purpose of the interviews with the front-line workers, contractors, safety advisors, and other employees is to determine which hazards in their work environment are of major concern to them. Prior to conducting the interviews, Research Ethics Board (REB) Approval was obtained through the University of Alberta. The REB vetted the interview questions, methodologies and informed consent form. This form detailed how the participants responses would be kept confidential and anonymous. Each participant was assigned random numbers, so they were not identifiable, and the results were reported in aggregate, so no person could be identified.

Eight interview questions were developed for the semi structured interviews. The interviews started with questions targeted to develop rapport with the worker and then proceeded to gather information about their safety practices and what level of association there was with ground hazards. The rest of the questions were tailored depending on the persons job description. There were different questions for frontline workers, leadership and roving contractors. The themes of the questions were all the same, but questions were tweaked slightly to best fit the individual's role.

Interviews lasted around 45-60 minutes. The majority of the interviews were conducted in person with some conducted over the phone with personnel from multiple oil sands companies. The goal of these interviews is to determine what hazards the workers are seeing in their daily jobs, gauge their knowledge of ground hazards, and see if interviewees' responses align with the ESC tailings expert hazard assessment and the University of Alberta initial ground hazard inventory.

A qualitative text analysis software, NVIVO produced by QSR International, is used to determine emergent themes from the interview data.

3.4 Incident Database

The oil sands companies have also provided access to their incident database related to tailings. These databases were analyzed to identify leading indicators (high frequency, low consequence events) that could help to predict ground hazards before they occur.

Incident pyramids, like the one seen in Figure 2 are used to help identify leading and lagging indicators in the data. Lagging indicators are major injuries, minor injuries and property damage incidents. These correspond to Levels I, II, and III, respectively. These incidents include fatalities, serious injuries, equipment damage or loss of containment with a consequence to people or the environment. The leading indicators are the near miss incidents - Level IV and the substandard acts and conditions. These include incidents like loss of containment without consequence, or stuck equipment without damage in addition to unsafe acts or unsafe condition or the culture in the workplace.

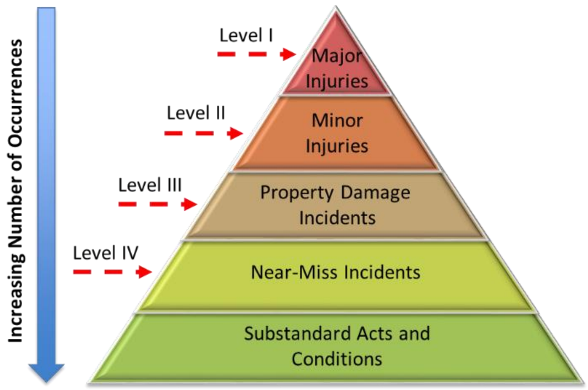

Figure 2. Incident Pyramid (after Henderson, 2016)

4. RESULTS

4.1 Work to date

This research project began in March 2017 with a literature review and site visits to the oil sands companies began in August 2017. These site visits served two purposes: (1) to familiarize the research team with the operations at multiple sites and (2) to conduct an initial ground hazard inventory in the tailings area with University of Alberta Geotechnical team. Winter site visits will be completed in early 2018 as the ground hazards and operations in the tailings area will change with the seasons. In October 2017, additional site visits were conducted to interview workers from multiple companies. Frontline workers, contractors, safety representatives and supervisors were interviewed to determine the hazards they see during their daily tasks at the different oil sands mines. Finally, the company incident databases are being analyzed to identify leading indicators (low consequence, high frequency events), to predict and prevent catastrophic incidents.

4.1.1 Initial Ground Hazard Inventory

During the site visits a geotagged database containing twenty representative facilities was created. 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).

A portion of the site-specific database can be seen in Table 2 with the site location and photos, a description of the site, the potential ground hazards that exist, and the controls that can be put in place to prevent or mitigate incidents.

As an illustrative example, photo (f) in Table 2 depicts a washout cut. A precursory event in this case could be a loss of containment event, like 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 to be leaking, and (3) personal protective equipment such as a personal floatation device.

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

After further analysis, the ground hazards identified at each tailings transport and storage facility were essentially the same: slope instability, soft ground, erosion features (e.g., wash out cuts and erosion gullies) and differential settlement (e.g., sink holes). Despite the apparent similarities, how each of these ground hazards manifested themselves at each location differed. For example, soft ground could manifest in following ways in the sand dump: 1) in the cells (where the process water and tailings are stored) or 2) on the benches after a pipeline leak, heavy rain fall or snow melt Since the ground hazards are the same at each facility, it was decided that an additional database would be created to be used at any oil sands site and potentially 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 being simply job focused. This way, all workers, including contractors can look at this database and see how the ground hazards will manifest in their working area. Ideally, this database would be used in conjunction with OHS legislation. Table 3 is an example of this database for the sand dump. Slope instability can be seen on the benches and berms surrounding the coarse tailings area. Temporal factors are 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, rain and snow will increase the likelihood of

Table 2. Site specific 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 (~30m 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 when walking along the top of the pit • Slope instabilities- full bench instability and chucks of material falling off potential to strike, crush, or bury workers • Sloughing • Soft material • Hidden water hazards- soft ground slough 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
Sand Dump   	Photo (c): View of sand dump and spigot. Tailings sand discharge pipe is pushed together with dozers and has lots of 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 sand dump with tailings berm (~ 20 high) in background. Photo (e): Dozer at work in soft ground at sand dump.	• Loss of containment- leaks and cell berm failure • Cuts in ground from water • Soft ground- slips, trips or falls, fine sand and silt • Discharge pipe- prone to leaks, sitting on sand which is highly erodible and leaking at connections • Water hazard • Slope instability- benches surrounding dump, 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
Water Erosion Features in Tailings Area  	Photo (f): Washout cut (width of ~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 back fill with dry material • Elevating pipelines • Personal Protective Equipment

slope instability. The consequence is high (independent temporal factors) as slope instability in the sand dump would lead to loss of containment of the coarse tailings and process water. There are many workers operating in the coarse tailings area with heavy machinery leading to a high risk of exposure.

Table 3. General ground hazard database for sand dump

Hazard	Manifestation	Temporal Factors	Likelihood	Consequence	Controls
Slope Instability	Benches and berms surrounding the course tailings dump	Heavy rain, thaw, winter conditions: ice, snow covered ground, steam, reduced daylight hours	Likely	High consequence	Operating Procedures & Training
Soft Ground	Benches, berms and cells		Very likely	Medium consequence	
Erosion Features (wash-outs, 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 on coarse tailings, in mature unconsolidated tailings in reclaimed areas		Likely	High consequence	

The current controls are administrative controls in the form of operating procedures where operators are not allowed within a certain distance of the discharge pipe. They also have some training in the area, however, the current training modules do not directly discuss slope instability or any specific ground hazards. More recommendations for the controls section will be added as more analysis is completed.

4.1.2 Energy Safety Canada Dataset

An example of a Bow Tie for a pipeline leak in the coarse tailings sand dump is given in Figure 3. This is an event that could result in a ground hazard (soft ground) if not properly addressed. On the far-left hand side are the potential reasons for the leaking pipeline. These include, loss of pipeline wall thickness, pipelines being struck by equipment, change in operating parameters like velocity or layout, poor pipe connections and poor visibility.

The threat controls are mostly administrative controls like quality assurance or procedures, but there are also engineering controls like elevating pipelines on blocking so the entire pipe circumference is visible. These will ideally prevent and aid detection of leaks. However, if a leak were to occur, the mitigation controls are designed to control consequences. These are mostly administrative controls or conditions that would allow an operator to be successful in safely identifying a leak from a distance. The consequences range anywhere from minor injuries to fatalities.

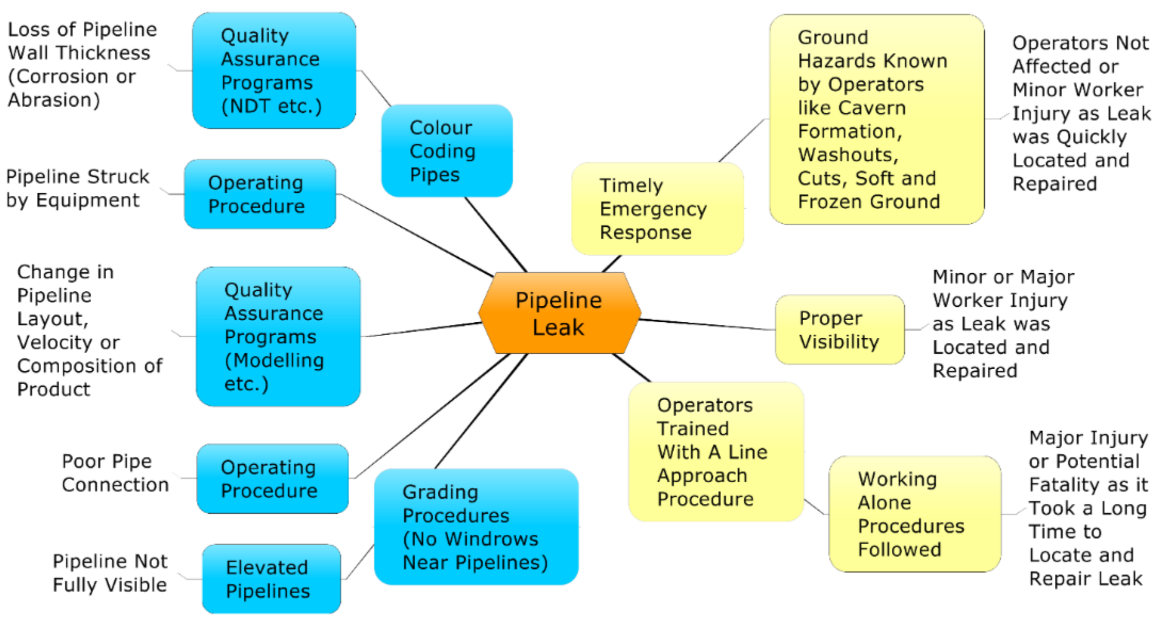

Figure 3. Bow tie analysis for a pipeline leak that could cause a ground hazard in the coarse tailings sand dump

4.1.3 Interviews

Thirty-seven interviews, across multiple companies, were conducted in October 2017 with frontline, tailings workers, safety advisors, supervisors and contractors. Additional interviews with people in leadership roles will be completed in early 2018. Even though qualitative analysis has just begun, there are already some themes developing. Workers all agree that the tailings operation is 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 tailings is the "*best place to work*" (October Interview, 2017) and others having more a more pessimistic view of the tailings operation.

4.1.4 Incident Databases

Multiple oil sands operators provided five years of tailings incident data from 2013-2017. The database was analyzed to identify common incident themes. The incident data was plotted to see monthly trends. All five years of data looked similar to Figure 4. It was anticipated that a variation in the number of incidents would be more drastic around the change of the seasons. This was not conclusively seen in the data, however, there was an increase in the number of incidents during the construction season, which was to be expected.

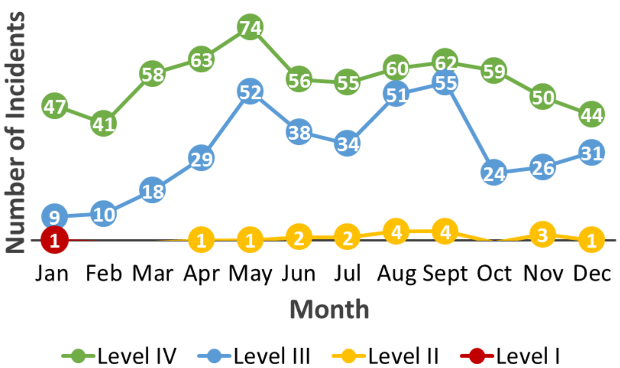

Figure 4. 2014 Tailings area incident data including all the incidents from near misses to fatalities that occurred from January to December 2014

A similar process of clustering the tailings incident data as was used for the ESC hazard inventory was completed. The incidents were grouped into common hazards and then the frequency of the incidents was plotted, like the graph seen in Figure 5.

This data set includes incidents where equipment was dropped, drainage was an issue, workers slipped on soft ground, washouts occurred or where equipment or pipelines sunk into soft ground. Figure 5 shows that sunken and stuck equipment is the highest incident that is related to soft ground. This correlates with interviewee responses, that it is common to see bulldozers stuck in the live coarse tailings sand dump cells.

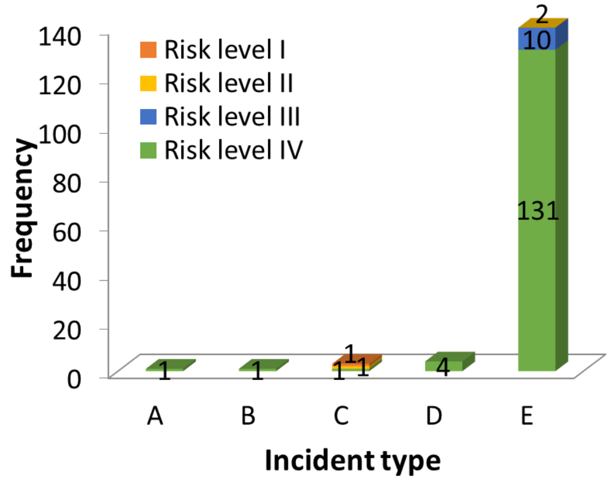

Figure 5. 2013-2017 soft ground incidents. Incident type definitions: (A) dropping equipment, (B) drainage (i.e. water coming up through ground), (C) worker slipping, sinking into soft ground, (D) washouts, and (E) sunken equipment and lines

5. SUMMARY & CONCLUSION

Ground hazards are known and understood by geotechnical experts, but there is a breakdown in the communication of these hazards to frontline workers across the oil sands industry. The safety of tailings structures is well defined with the 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 prepares workers to understand the risks of their working area in addition to the risks of performing their job tasks.

This is an interdisciplinary research project where four datasets are being analyzed. These datasets are being collected from multiple oil sands companies using a mixed methods approach with 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 FLHA's specifically tailored to ground hazards. Ideally, enhancements to controls will be identified to reduce the risks of ground hazards and by this, enhance risk communication between working groups. This framework will be applicable to other industries that have workers with no geohazard expertise exposed to ground hazards, like construction and railway.

6. ACKNOWLEDGEMENTS

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