Protecting workers exposed to ground hazards through enhanced hazard identification and management 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
Industries, like the oil sands, see the importance of decreasing injuries on work sites and use tools like the Field Level Hazard Assessment 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 where unexpected ground hazards exist making them invisible to workers that have not been trained to identify or mitigate ground hazards. Oil sands tailings site visits, tailings safety expert hazard inventories, interviews with workers and company incident databases are being analyzed to determine similarities and differences in the recognition and prevalence of ground hazards. These findings will be used to develop risk communication tools to inform frontline workers of potential ground hazards in their working environment.

RÉSUMÉ
Les industries, comme les sables bitumineux, voient l'importance de réduire les blessures sur les chantiers et utilisent des outils comme l'évaluation des risques au niveau du terrain pour identifier visuellement les dangers connus et visibles, gérer les risques et déterminer les mesures appropriées pour assurer la sécurité Conditions. Un défi se pose dans certains milieux de travail, y compris les installations de stockage et de transport des résidus de sables bitumineux, où des dangers inattendus au sol les rendent invisibles aux travailleurs qui n'ont pas été formés pour identifier ou atténuer les risques au sol. Les sites de résidus de sables bitumineux, les inventaires des risques liés à la sécurité des résidus, les entrevues avec les travailleurs et les bases de données sur les incidents d'entreprise sont en cours d'analyse afin de déterminer les similitudes et les différences dans la reconnaissance et la prévalence des risques au sol. Ces résultats serviront à mettre au point des outils de communication des risques pour informer les travailleurs de première ligne des dangers potentiels au sol dans leur milieu de travail.

1 INTRODUCTION

Ground hazards may manifest in different ways like slope instability and soft ground but are an issue in many industrial workplaces like the oil sands in Fort McMurray, Alberta. In the five-year period from 2011 to 2015 there were 7 fatalities in the oil sands subsector (Baker et al. 2018a, Government of Alberta, 2017). At least one of these incidents was related to ground hazards in the tailings operations. This poses the question of, “how well understood are these ground hazards by workers in the tailings operation?”.

Researchers have determined that all workers have a difficult time identifying hazards in dynamic, complex environments (Jeelani et al. 2017) and novice workers were unable to recognize 53% of hazards in their work environments (Bahn 2013). These findings are concerning as they illustrate a failure in the communication of job related risks to workers and potential issues with current training methods. This breakdown in risk communication and training is also seen in the oil sands tailings operations with the communication of ground hazards to frontline workers from geotechnical experts and other working groups in the oil sands mines. To combat this issue, this research project is investigating alternative methods to communicate the risks of ground hazards to frontline workers.

There are numerous publications speaking on effective external communication to the public (Sandman, 1987, Morgan et al., 1992 and Jardine, 2008), however, there are relatively few publications on internal communication to workers and contractors (Schulte et al., 1993 and McMahan et al., 1996). The external communication principles can be applied to the communication of ground hazards to frontline workers. This paper serves as a follow up to a Geohazards 7 conference paper that will be presented in June 2018 (Baker et al. 2018a). The information presented here is part of a larger body of research developed over a two-year collaboration with the University of Alberta, Government of Alberta and the oil sands industry through Energy Safety Canada’s (ESC) involvement.

The aim of this research is to address the gap in the communication and identification of ground hazards in the oil sands tailings operations by developing training tools such as: photo databases, training modules and enhanced field level hazard assessment tools (FLHA). This will be done through site visits to multiple oil sands operators during seasons with varying ground conditions (summer, winter and spring), interviews with oil sands workers at all levels of the company (frontline workers, safety professional, leadership and contractors), analysis of company incident databases to determine leading and lagging indicators, and analysis of tailings safety expert hazard inventories.

The end goal of this research is to determine the overlap and discrepancies between the different datasets to better assess the gap in communication and identification of ground hazards and propose alternative methods to train workers on the hazards in their working environment. Part of the strategy to achieve this goal is strengthening ground hazard and risk communication to non-specialists that will be working on tasks in the field. This requires strong risk communication, which is one of the central topics of the research.

2 ATHABASCA OIL SANDS REGION

The Athabasca Oil Sands Region, situated in northeastern Alberta and contains approximately 90,000 km^2 of active oil sands deposits, making it the largest such deposit in the world (AER, 2018). This region has nine approved oil sands mines (AER, 2018). Multiple oil sands companies and regional contractors have participated in this research project.

This region experiences extreme variations in the weather and temperature throughout the year (Figure 1), with temperatures reaching extreme lows of -50.6°C and extreme highs of 37°C (Environment Canada, 2018). 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 (Environment Canada, 2018).

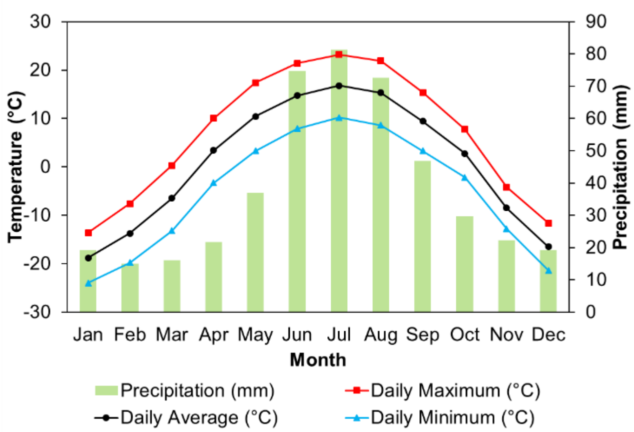


Figure 1. Temperature and precipitation graph for 1971 to 2000 Canadian climate normals, Fort McMurray (after Environment Canada, 2018).

3 METHODS

Using a mixed methods approach, four datasets are being analyzed to determine the level of concern regarding ground hazards and how this concern varies between different groups of people in the oil sands industry. Tools to better communicate the risk of ground hazards in the tailings operation are being developed to decrease the severity of an incident occurring.

The four datasets being analyzed from multiple oil sands companies are:

- Tailings ground hazard inventory
- Energy Safety Canada dataset
- Interviews with tailings workers
- Tailings incident databases

The details of the mixed methods approach that was designed for this research project have been reported elsewhere (Baker et al. 2018a). A brief overview and any updates to these methods are given below.

3.1 Tailings Ground Hazard Inventory

Site visits were conducted at multiple oil sands tailings operations. Photos of the different tailings facilities were taken to create a ground hazard database and further analysis was completed at the University of Alberta. Additional details can be found in Baker et al. 2018a and 2018b.

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

- Descriptions of the facilities: based on site observations and documents from the oil sands operators.
- Precursory events: indicators that could help workers to identify changes in the ground proactively, prior to an incident occurring.
- Controls: current controls the oil sands companies have in place as well as the recommended controls from the research team.

With the large fluctuation in both temperature and precipitation in the region, the oil sands tailings operations needed to be assessed for changing ground hazards over various seasons (summer, winter and spring). Summer and winter data are presented here as spring data collection had not been completed.

3.2 Energy Safety Canada Dataset

The ESC inventory is being analyzed by using Process Safety Management principles like bow ties (Figure 2). As described in detail in Baker et al. (2018a and 2018b) 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. 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 that prevent the top event from occurring. 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 a consequence from occurring. They are typically administrative controls or personal protective equipment.

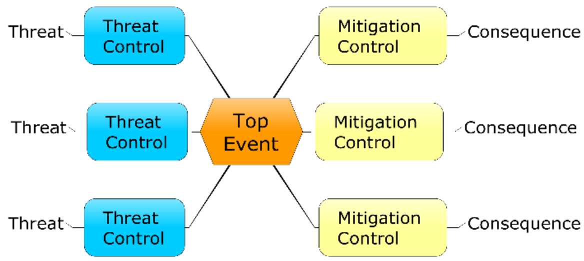


Figure 2. General Bow Tie Analysis (after Deighton, 2016)

3.3 Interviews with Tailings Workers

Detailed information regarding the methods for the interviews have been reported in Baker et al. 2018a and 2018b. The purpose of the interviews was to determine the hazards workers see in the tailings operations. Research Ethics Board (REB) approval was obtained from the University of Alberta prior to the interviews being conducted. The REB vetted the eight semi-structured interview questions that were developed. Frontline workers, safety personnel, leadership and contractors were interviewed.

Interviews were conducted in person or over the phone and with a duration between 45 – 60 minutes. The interview data was analyzed using a text analysis software called NVivo (SQR International, 2017).

3.4 Tailings Incident Databases

The incident databases were analyzed to determine the types of hazards associated with the incidents in the tailings operations as well as to determine leading and lagging indicators. These leading indicators could help identify hazards prior to catastrophic events occurring. The incident databases were clustered into similar hazard types and analyzed using Microsoft Excel to create visual representations of the data. More details regarding the methods can be found in Baker et al. 2018a and 2018b.

4 RESULTS

The initial results of this research project have been reported in a GeoHazards conference paper (Baker et al. 2018a) and interim report (Baker et al. 2018b). This paper illustrates the progress in the research since these publications.

4.1 Tailings Ground Hazard Inventory

Site visits to multiple oil sands companies have been completed in summer and winter. Each database 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 ponds pipelines and pumps from fine tailings pond), and dykes (i.e., the slope if the tailings pond) (Baker et al. 2018b).

The summer work environment ground hazard database can be found in Baker et al. 2018a and is provided here as comparison to the winter conditions. The summer and winter work environment ground hazard databases are summarized in Tables 1 and 2, respectively. These databases include specific locations and photos in the oil sands tailings operations, description of the work location, the potential ground hazards that exist in that area and the controls that can be implemented to prevent or mitigate incidents. An illustrative example for the summer conditions has been provided in Baker et al. (2018a and 2018b). For the winter conditions an illustrative example will be discussed for, photo (h) in Table 2 which depicts the partially open water/slurry at the recycled water inlet to a tailings pond. A precursory event in this case could be a leaky inlet pipe or a significant change in the flow rate or temperature of the recycled water entering the tailings pond. The higher the flow and temperature of the recycled water entering the pond the more extensive the cuts/erosion of the snow/ice cover and the underlying tailings material.

Controls for the ground hazards in this case will include: (1) engineering controls, such as making the inlet a safe distance away from any road or walkways and making use of signs or fences to prevent unauthorized access, (2) administrative controls such as partially frozen water safe approach procedures when a pipeline is suspected to be leaking, and (3) personal protective equipment such as a personal floatation device.

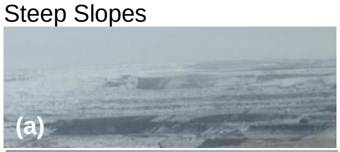
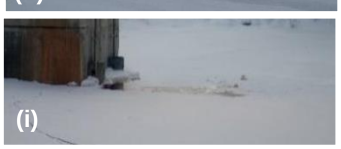
The precursory events for summer conditions are discussed in Baker et al. 2018a. The precursory events for the winter conditions may be as follows. For the steep slopes in photos (a), (b), and (c) the precursory events may be: surface sloughing of snow/soil, and tension cracks in the snow/soil running along the length of the slope. In photos (a) and (b) ice lenses on the face of the slope representing seepage may also be considered a precursory event. In photo (c) spring conditions can lead to very wet ground conditions if the snow pile is not hauled to a different location. In the tailings discharge area (d) 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. A large difference in the ambient air and tailings discharge temperatures causes excessive steam to develop such as the dozers cloaked in steam seen in photos (e) through (g), this will increase the likelihood of stuck or sunk equipment. The precursory event for (i) and (j) are similar to that discussed for (h): a change in the pumping conditions (i.e. flow volume, temperature), or a fresh snow fall where hazards become hidden especially in cases where they are not signed or portioned off in any way.

Some of the photos taken in the winter may be considered precursory events for the spring or summer. These connections are currently being developed so workers can identify conditions that are out of the ordinary in the field and notify the appropriate personnel to mitigate the ground hazard prior to a catastrophic event occurring.

Table 1. Summer work environment ground hazard database of potential ground hazards and controls for a representative sample of tailings facilities, dykes, and transport systems (after Baker et al. 2018a).

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 2. Winter work environment ground hazard database of potential ground hazards and controls for a representative sample of tailings facilities, dykes, and transport systems (after Baker et al. 2018b).

Location and Photo	Description	Potential Ground Hazards	Controls
Steep Slopes   	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 Energy Safety Canada Dataset

To ensure bow tie analysis was useful and correct, brainstorming sessions were held with ESC members and subject matter experts gave their feedback on the original pipeline leak bow tie (Baker et al. 2018a). The updated bow tie is depicted in Figure 3.

The threats that could possibly cause a pipeline leak were clustered into three main topics: (1) controlled release: when a rupture disk bursts in order to stop the pressure inside the pipeline from increasing and potentially causing an explosion, (2) pipeline failures: when a pipeline is stuck, crushed or splits due to internal or external corrosion or interaction with other pieces of equipment in the tailings operations and (3) process line up incorrect: which can occur when a drain is left open, wrong switch gate is opened, or when other worker errors occur.

The threat controls that prevent a pipeline leak from occurring are engineered controls like design specifications, elevating pipeline on blocking, equipment strategies or material selection. Threat controls could also be maintenance like quality assurance / control programs, joint integrity and preventative maintenance programs like line rotation. The last threat control is operating procedures like structured rounds, predetermined operating envelopes, open air calls to notify workers when operations are occurring and proper housekeeping in the tailings area.

If a pipeline leak were to occur in the tailings operations, the mitigation controls prevent a consequence from occurring. Consequences from a pipeline leak can have effects on people, the environment, assets and production. The potential consequences to people will be the focus of this paper. Companies have a typical pipeline leak response that is implemented when a leak occurs. This procedure is a mitigation control used to decrease the severity of an unwanted event like worker injury or death. The steps in the typical pipeline leak response are:

1. Leak identified by worker
2. Notification procedure followed to ensure supervisors and other appropriate personnel are aware of the leak
3. The system is shut down so there is no flow in the leaking pipeline
4. A line approach procedure is followed to further investigate the leak

Additional mitigation controls in the tailings area that are used to prevent consequences to people are: permit policy, proper visibility (so leaks can be identified and managed), the area and hazards are known to workers and there is timely emergency response. If the area and the hazards are unknown to workers, there is an increased probability of a more serious consequence occurring since they are going into the situation blind. The speed at which first responders can arrive at a location will also influence the outcome of the incident.

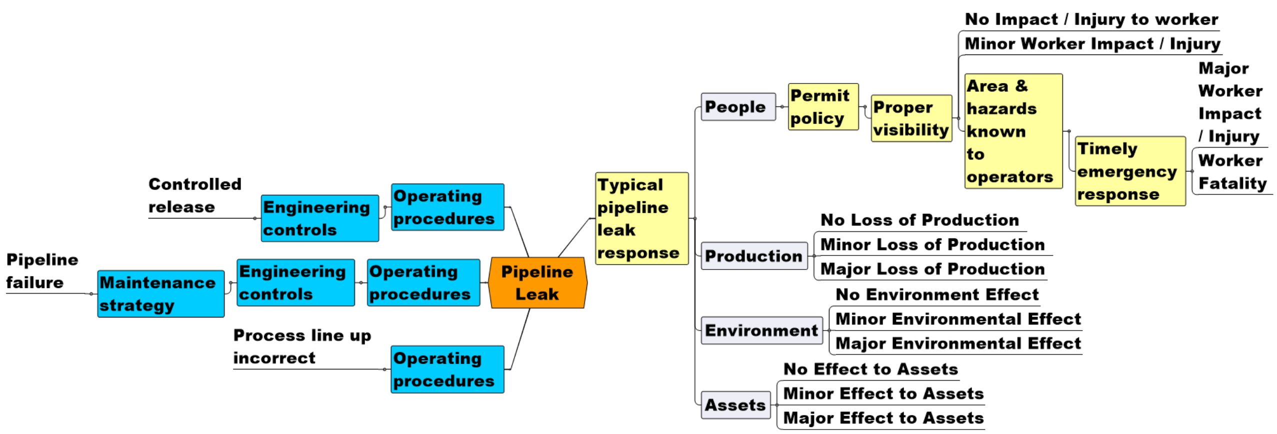


Figure 3. Pipeline leak bow tie.

4.3 Interviews with Tailings Workers

Over 100 interviews have been conducted with frontline tailings workers (71%), safety representatives, leadership (18%) and regional contractors (11%) at multiple oil sands companies (Baker et al. 2018b).

Experience levels among interviewees were diverse, some workers had over 40 years of experience and others had just a week (Baker et al. 2018b).

Analysis is ongoing using NVivo quantitative analysis software (SQR International, 2017). Seventeen interviews have been analyzed based on the semi structured interview questions and other themes that became apparent during the analysis.

Forty-one hazards in the tailings operations were identified by the seventeen interviewees (majority were frontline workers). Of the total hazards reported, 14% were related to ground hazards (soft ground, differential settlement, erosion gullies, seepage, washouts and cuts). One or more of these ground hazards was identified by 65% of respondents during the interview process.

Interviewees also discussed the current training and FLHA process. Many interviewees (53%) mentioned that in-field training, mentoring and coaching could be beneficial additions to the web based and classroom training as traditional training methods alone are “not sufficient to identify hazards” (October 2018 Interview) and “don’t stick as much” (October 2018 Interview). Some interviewees (60%) also discussed the FLHA process, with the majority of these respondents (60%) having constructive feedback for the FLHA tool. Many interviewees felt that the FLHA process was repetitive and people are very complacent when completing the forms.

4.4 Tailings Incident Databases

Multiple oil sands companies provided five years (2013 – 2017) of tailings incident data. 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 (Baker et al. 2018b).

In Baker et al. 2018a, all the incidents in the databases were plotted to determine trends in the data. Further analysis was completed to look at the incidents related specifically to ground hazards (Figure 4). These incidents included: 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).

As expected, the majority of the variation is seen around the seasonal changes, particularly in spring. This increase is most 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” (Baker et al. 2018b, February 2018 interview). 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” (Baker et al. 2018b, February 2018 interview). This trend is also seen in the data. However, winter conditions can be misleading: a frozen surface can also hide washouts, cuts, or soft ground (Baker et al. 2018b).

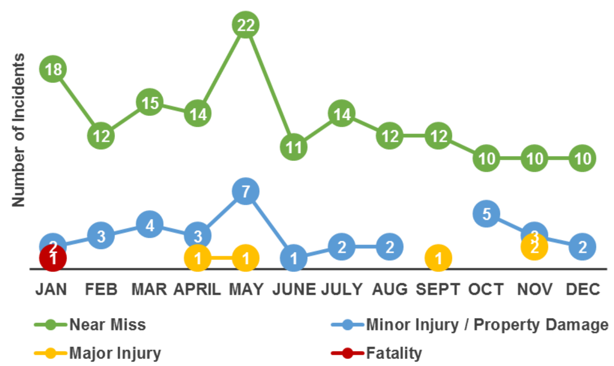


Figure 4. 2014 tailings ground hazard incident data (the fatality shown resulted in this creative sentence) (Baker et al. 2018b).

The frequency of the ground hazard related incidents is plotted in Figure 5 (Baker et al. 2018b). 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.

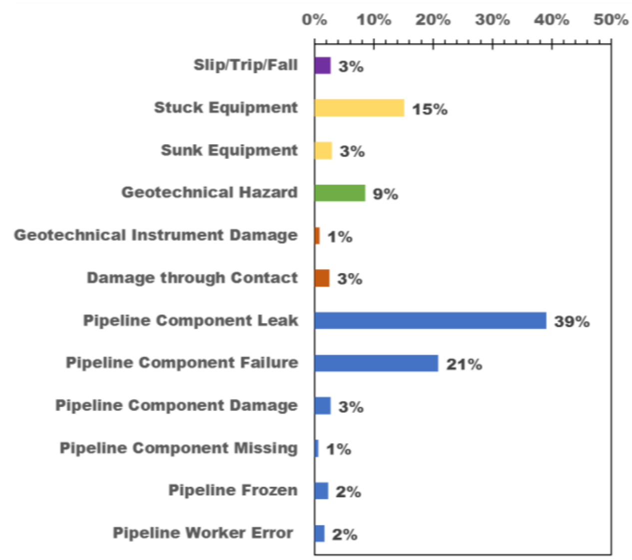


Figure 5. 2013 – 2014 Tailings ground hazard related incidents (after Baker et al. 2018b)

5 SUMMARY & CONCLUSION

Initial comparison of the datasets is showing a breakdown in the identification of ground hazards by frontline workers. It is interesting that 65% of workers identified ground hazards during the interview process and that ESC tailings safety experts prioritized “pipeline leak” (an unwanted event that can cause many ground hazards) for further investigation, and yet ground hazard related incidents still account for 21% of the incidents in the tailings operations. Further research is required to investigate this hazard identification and potential communication failure.

External communication principles from Sandman (1987), Morgan et al. (1992) and Jardine (2008) will be applied to develop alternative tools for the identification and communication of ground hazards to workers in the oil sands tailings operations as 60% of interviewees mentioned that the FLHA is not a useful tool to identify hazards in their work environment. Coaching and mentoring programs are also recommended as 53% of interviewees mentioned that this type of training would be valuable. Implementing some of the recommendations from workers is valuable as it illustrates positive stakeholder involvement. This could lead to increased buy in from frontline workers with regards to safety in the tailings options.

Photo work environment databases (Tables 1 and 2) are being developed to show workers the ground hazards that could be present in their work environment. Additional recommendations to improve hazard identification and communication tools will be put forward at the end of this research project.

6 ACKNOWLEDGEMENTS

ESC provided valuable information to this research project and the participating companies have been generous with their time and resources. This research would not have been possible without the involvement of the oil sands industry and regional contractors.

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