Past, Present and Future Vulnerability and Risk Assessment to Climatic Extremes for Potash Mines in the Qu’Appelle River Watershed: Literature Review

Prepared for Water Security Agency of Saskatchewan
as part of the Natural Resource Canada Research Project Topic 3.3 – Case Studies of Mining Sector Adaptation Actions

By V. Wittrock
Saskatchewan Research Council
Environment Division

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Abstract

Potash is Canada’s leading export mineral with a value of $8 billion in 2011. Thus, understanding the potential positive and negative impacts of extreme weather and changing climatic conditions is beneficial for the industries and for governments risk management strategies. The documents three objectives are:

- Examination of historic vulnerability and risk assessment of climatic risks to the potash industry;
- Estimation of future types of impacts on the potash industry due to extreme climatic events and assess possible solutions for these challenges; and
- Undertaking a preliminary cost/benefit analysis for undertaking the potential adaptation strategy.

The results are focused on the case study region of the Qu’Appelle River Watershed.

The potash industry is relatively new to Saskatchewan and therefore has not had to deal with some of the most extreme climatic conditions of the past 100 years including the extended droughts of the 1930s. In recent years, the Qu’Appelle River Watershed has had numerous excessive moisture years resulting in adaptation strategies for dealing with extreme excessive surface water so that the mines are able to maintain their closed hydrologic system. Potash mines have a limited number of ways of disposing excess water from the mine sites and these ways have been tested to their capacity in recent years.

Surface water in the Qu’Appelle River Watershed is extremely variable in nature and the mining and processing of potash requires a reliable water supply. As such, depending on location and type of mine, a few adaptation measures have been implemented to maintain the supply. Conventional mines sometimes use ground water as their primary water supply or use it to augment surface water. Solution mines require a larger quantity of water and therefore have utilized water from the South Saskatchewan River Basin to access a reliable water supply.

Several factors were found to be at preliminary stages including potash mines decommissioning. It is important that these strategies include climate variability and change so that the greatest benefits are attained. Another area that did not appear in the literature was the external factors including infrastructure that are required for a mine to operate. The author was unable to assess much of these potential impacts and adaptation strategies that have possibly been implemented due to a large amount of information are propriety. This factor also limited the cost-benefit analysis so only a very brief discussion was provided.
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Introduction and Objectives

Extreme drought and excessive moisture (DEM) conditions are a normal occurrence in the Canadian prairie environment. Saskatchewan can have both of these events, sometimes in the same year and in close proximity. DEM events can also be multi-year and thus requiring implementation of enterprise risk management procedures to adapt to these severe situations. In the past 100 years, the Qu’Appelle River watershed has had extreme droughts leading to some surface water quantity issues and extreme excessive precipitation events leading to flood situations (Wittrock 2013). It is projected that the next 100 years, in the life span of the potash mines, these extreme events will become more intense and will occur with more frequency (Wheaton et al 2013).

Canada’s leading mineral is potash with an export value of $8.0 billion in 2011 (Saskatchewan Mining Association 2012). Saskatchewan is the world’s largest producer of potash and has nearly 53% of the world’s potash reserves (Derek Murray Consulting & Associates 2011, Saskatchewan Mining Association 2012). Currently, there are 10 mines producing potash with eight conventional and two solution mines (Burton 2007, MacKenzie 2003). These ten mines were established in the 1960s and early 1970s (Warnock 2011). Potash mining industry is currently in an expansion phase both its existing mines (e.g., MDH Engineered Solutions 2009a, b, c, MDH Engineered Solutions 2008) and as well as establishing new ones (Derek Murray Consulting & Associates 2011, Krugel 2012, Vale ND) for the first time in 40 years. Saskatchewan’s potash production has increased from 8,700 kt K₂O in 2000 to 11,000 kt K₂O in 2011 (Saskatchewan Ministry of environment and Saskatchewan Ministry of Economy 2011).

The climatic variability of the Canadian Prairie Provinces could have both positive and negative impacts on the potash industry. The objectives of this document are three fold:

- examine the historical vulnerability and risk assessment of climatic risks to the potash industry;
- estimate future types of impacts on the potash industry due to extreme climatic events and assess possible solutions for these challenges; and
- undertake a preliminary cost/benefit analysis for undertaking the potential adaptation strategy.

The potash deposits are dispersed through the southern portions of the province (Figure 1). This study is focusing on the Qu’Appelle River Watershed. Currently, four potash mines are operational in the Qu’Appelle River watershed, three of which are conventional and one is a solution mine (Saskatchewan Mining Association 2012).
Methods

The above stated objectives are achieved by utilizing previously published and publicly accessible information including refereed journal articles, book chapters, grey literature published by the industry and government (provincial, national and international), media and non-refereed newsletters. As well, professional expertise is utilized.

The main impacts and risk assessment work explored is for excessive moisture and drought conditions on water supplies, waste water management strategies, risk assessment strategies and commodity management.

The preliminary cost / benefit analysis for adaptation utilizes the literature attained in this report as well as information from Wheaton et al. (2013), Wheaton (2013 draft), Wittrock (2013 draft) and Pittman et al. (2013 draft). Each mine will have different impacts and risks and therefore each mine would have different cost/benefit strategies to adapt to extreme water and climatic events. Much of the economic and environmental risk assessment information is propriety therefore this analysis is truncated and not mine specific.
Discussion and Results

Understanding the various facets of potash mining is important to determine the potential impacts of extreme drought and excessive moisture events on the industry and associated infrastructure on which it depends. This section is split into the following sub-sections:

- an overview of the life cycle of a potash mine;
- a general examination of mines and specifically potash mines as well as the various environmental influences and effects on the mining operations;
- potash mining operations in the Qu’Appelle River Watershed;
- the future of potash mining operations under a changed climatic environment and
- a preliminary examination of the costs and benefits of extreme climatic conditions is also presented.

Life Cycle of a Potash Mine

A potash mine’s life cycle is a complex production ranging from product need by the agricultural industry to exploration, mine establishment, ore removal and finally to mine closure and site remediation and returning land to other uses (Figure 2). The entire life-cycle process for potash mines can take more than 100 years. Therefore, potash mines can be influenced and affected by various environmental factors in its procurement of potash including extreme temperatures, extreme precipitation, both drought and excessive moisture conditions, as well as wind speed and direction resulting in the need for various environmental management and rehabilitation strategies.

Figure 2 Potash Mine Life Cycle (Higgins 2001)
Potash Mines and Environmental Influences and Affects

Higgins (2001) provides a good overview of the steps required in the potash acquisition process. Many of the processes have the potential of causing negative environmental effects and can be exacerbated due to extreme weather events and climatic variability (Figures 3 and 4).

Potash mine sustainability, economic assurance and the health and safety of its personnel (inner-most circle (figure 3)) are dependent on a variety of factors. The overall mine design and geohazards are key components and tend not to be overly influenced by extreme climatic events. Other portions of mining operations are more affected by extreme weather and changing climatic conditions including equipment and surface structure designs. The social impacts of the mine including interactions with nearby communities and the mines perceived corporate social responsibility can also be affected by geographically local and distant communities affected by extreme weather and changing climatic regimes. In addition, mining operations are dependent upon off-site infrastructure including roads, railways, electrical and gas lines, and water pipelines. Disturbances in this infrastructure supply lines can disrupt each of the mine life cycle operations (middle circle (figure 3)). The extreme events and changing climatic conditions that can disrupt mining operations include intense precipitation, multiple intense precipitation events, high temperatures, extended dry periods and high winds (outer circle (figure 3)).

Figure 3 Impacts of Extreme Weather and Climate Variability on Mine Sustainability (adapted and modified from Hodgkinson et al 2010)

The extreme climatic events can impact every mining operation but in different degrees and ways, depending on the events (figure 4). The extent of the impact depends on a variety of factors including the location of the mine and whether it is susceptible to surface flooding due to the local topography or extended droughts and thus any water withdrawal can impact the region and may impact nearby communities. The time-frame for the entire mine operation can be 100
years, therefore the mine risk management procedures should take into account a wide variety of extreme weather and changing climatic conditions.

Figure 4 Climatic influences, mining operations and environmental concerns (portions adapted from Higgins 2001)
Mine operations are somewhat impacted by various extreme climatic events, but what may be more influential on their operations is when the external to the mine site surface infrastructure is impacted. Infrastructure required at every mine includes rail, roads, natural gas, electrical and water, both potable and non-potable (Hatch 2012). While this infrastructure is needed at every mine, the mines themselves may not have control over the infrastructure and are therefore dependent upon other industries to maintain the required infrastructure. For example, in Saskatchewan, surface water pipelines are installed and maintained by the provincial government as are the electrical and natural gas lines. The roadways are maintained by the municipalities and province and the rail lines by the rail companies. While the potash mines do not have direct control over the infrastructure, the infrastructure does need to be considered by the companies in their risk management strategies if there is a negative or positive extreme weather or long term climatic event causing production and/or distribution delays or improvements for an extended period of time.

Australia’s Mining and Exploration (Hodgkinson et al 2010) has undertaken some preliminary assessments on the impacts of extreme weather and changing climate on the mining industry. They’ve noted that past weather or climate-related events had little impact on their operations but intense precipitation and resultant flooding did have moderate to significant impacts (Loechell et al 2013). Preliminary impacts include overflowing of tailings ponds, hazards to human life, equipment and environment and an impact on the revenue level of the mine. Secondary impacts of extreme climatic events include changes in agricultural production leading to either decrease or increase in the need for potash as well as changes in water resources leading to changes in potential water access and brine disposal processes. Australian mining officials also speculated about what types of adaptation strategies will need to be undertaken at mines taking into account future extreme climatic events (Moffat 2009).

**Potash Mining Operations in the Qu’Appelle River Watershed System**

**The Qu’Appelle River Watershed**

The Qu’Appelle River Watershed is located along the outer rim of the Palliser Triangle. As shown in Wittrock (2013) the region is susceptible to both extreme dry and wet spells, some lasting a limited about of time to occasionally years. In addition, the Qu’Appelle River system is largely fed by either spring run-off or heavy summer time rain events thus making water supply at times limited. In addition, water availability in the Qu’Appelle River watershed can be considered at risk as shown by Environment Canada based for the year 2009. The water availability indicator (Figure 5) is calculated by dividing water demand by water supply and does not include water withdrawn from lakes and groundwater (Environment Canada 2013). Flow in the Qu’Appelle River is controlled and augmented with water released from the Qu’Appelle Dam on Lake Diefenbaker (Rescan 2011). Water is transferred from the Qu’Appelle Dam through 35 km channel to Eyebrow Lake. The water then flows another 62 km along a natural channel to Buffalo Pound Lake (Water Security Agency NDc). This water augments the water
available for the various users including the cities of Regina and Moose Jaw, agricultural irrigation within and outside the Qu’Appelle Valley and a number of industries including mosaic Potash at Belle Plaine (Water Security Agency NDc). Most of the lakes on the Qu’Appelle have control structures which the Water Security Agency operates to manage flows (Rescan 2011). In 2010, the South Saskatchewan River Basin transferred

![Water Availability Indicator](image)

**Figure 5 Water Availability Indicator** (Environment Canada 2013)

As stated in the introduction, the Qu’Appelle River Watershed has four potash mines currently in operation with a few more being built or planned (Figure 6). They access water from various sources. The Mosaic Belle Plaine obtains its water from Buffalo Pound and ultimately the South Saskatchewan. PCS Rocanville gets its water from groundwater while Mosaic Esterhazy accesses its water from both surface water (Cutarm Creek) and groundwater (Water Security Agency 2012, Kulshreshtha et al 2012).
Two types of potash mining processes are used in the Qu’Appelle River Watershed: conventional and solution. Conventional operations can use a variety of techniques and equipment to access the ore body. Factors include ore body depth, geometry, thickness and consistency, the geological and geotechnical conditions of the ore and surrounding rock and the overlying aquifers (Higgins 2001). After the ore is extracted, it is transferred to the surface where it undergoes a variety of refining processes before it is exported off-site (Figure 7). Currently, the Qu’Appelle River Watershed has two conventional mines - Mosaic Esterhazy K1 and K2 as well as PCS Rocanville.
Solution mining process relies on the greater solubility at elevated temperatures in brine of sylvite in comparison to salt (NaCl). Typically, the brine is heated at the surface and then injected into the orebody through wells. The heated brine absorbs the sylvite from the orebody and then pumped back to the surface (Higgins 2001). Once on the surface the ore goes through a variety of processes to extract the potash from the brine before it is exported off site (Figure 8). Currently, the only solution mine in the Qu’Appelle River Watershed is Mosaic Belle Plaine.

Potash Mine Water Usage Requirements.

Water is required by many industries to bring their products to market. The potash industry is no different. For example, in 2010, water demand estimates for all of the Saskatchewan Potash mines was 18,696 dam$^3$ for surface water and ground water demand estimates were 3,363 dam$^3$ (Kulshreshtha et al. 2012). The Qu’Appelle River Watershed base flow of 13,999 dam$^3$ had its flow increased by water transferred from the South Saskatchewan River by 2,082 dam$^3$ to augment the water demand for potash production (Kulshreshtha et al. 2012).

The amount of water used by the potash mines varies considerably depending on the potash extraction method. For example, the two conventional mines in the Qu’Appelle River System use less water. PCS Rocanville has a current water allocation of 1,500 dam$^3$ to be expanded to 2,800 dam$^3$ by 2020 (Kulshreshtha et al. 2012). This water allocation is met by utilizing groundwater (Figure 6). Mosaic Esterhazy K1 and K2 has a current water allocation of 3,500 dam$^3$ to be expanded to 5,450 dam$^3$ by 2020 (Kulshreshtha et al. 2012) with the water being
obtained from a combination of surface water and groundwater (Figure 6). Mosaic Belle Plaine, the only solution mine currently in the watershed, has a water allocation of 12,000 dam$^3$ (Kulshreshtha et al. 2012) with the water coming from Buffalo Pound Lake.

Unlike other industries, such as agriculture, water used in potash production does not get released back into the downstream environment. Potash mines in Saskatchewan are designed to be a closed hydrologic system as per provincial pollution control regulations meaning that all water brought into the mine site or precipitated onto the site cannot be discharged to the downstream surface hydrological systems (Reid 1984, Saskatchewan Mining Association 2012). Surface water on the site is related to either on-site precipitation or the water used in the facility for mining and processing (Higgins 2001). Tailings are discarded from the mill in the form of salt brine that is 70% solid waste and 30% liquid (PotashCorp 1 June 2008). Water in the tailings/brine ponds is reduced through either evaporation or through injecting water into underground caverns that are 1300 to 1900 m deep (Reid 1984, Saskatchewan Mining Association 2012) or more recently recycling. Injection wells into deep geological formations are used to keep brine ponds at manageable levels (Reid 1984).

Potash mine officials in Saskatchewan have stated that because potash is a subsurface extraction, the mining process is not considered to be affected by climatic conditions (Pearce et al. 2009). Extreme weather events may damage surface infrastructure or delay surface operations but are in general considered not significant due to their irregularity (Pearce et al. 2009). Saskatchewan potash mines have taken into account excessive moisture data for their mine designs and because of Environmental Impact Assessments (EIAs) requirements (e.g., MDH Engineered Solutions 2009a, MDH Engineered Solutions Corp 2009b, MDH Engineered Solutions 2009c, MDH Engineered Solutions 2008). For example, the tailings management area (TMA) water balance assessment utilized three precipitation parameters: the annual water balance based on data from the closest long-term climate station, a 1:100 year rainstorm event and a single rain event of 300 mm. These parameters are based research developed by Hogg and Carr (1985) and Hopkinson (1999) and approved by the Ministry of Environment, Saskatchewan. The EIAs do not analyze low precipitation years probably due in part to the water is allocated and supplied to the mines either via groundwater or via surface water pipelines managed by Water Security Agency of Saskatchewan and SaskWater. In addition, Pittman et al. (2013) documented from their interviews with various potash personnel the potash mines in the Qu’Appelle River Watershed did not report any historic stresses in relation to potash production due to water shortages.

The various stages of a mine’s life cycle requires critical decisions at specific phases. For example, when a mine is in the design phase, severe storms are taken into account to determine ultimate and staged capacity of the tailings pond (Ali et al 2013). Ali et al (2013) did not get into specifics on the severity of the extreme events that should be designed for. When many of the potash mines in Saskatchewan were planned and built in the 1960s, no decommissioning and reclamation (D & R) plan was required. It was not until 1993 that the Province of Saskatchewan
amended its Mineral Industry Environmental Protection Regulation to include existing mines requiring them to submit a D & R plan by 1997 with provision of financial assurances by 1998 and every five years thereafter as necessary (Reid and Getzlaf 2004). It was found, due to a variety of reasons, that the long projected life (approximately 100 years) of a potash mine made D&R planning difficult (Reid and Getzlaf 2004).

The possibility of water conflict between potash mines and other industrial users was noted by Reid (1984). He speculated at the possibility of irrigation expansion and potash industry water requirements may lead to water conflicts, especially in extended drought periods when limited surface water becomes a concern. It was noted that there is a need for increased water conservation for both industries and the utilization of more non-potable groundwater for the potash industry. This allocation issue may have been resolved depending on the agreements between the various industries and the provincial government. The “first in time, first in right” water allocation strategy was rescinded in 1985 being replaced a potentially more flexible strategy for water allocation strategy (Saskatchewan Watershed Authority 2012).

**External extreme weather and climatic events**

Mining operations are sometimes more influenced by weather and climatic trends that do not directly effect on-mine operations. For example, when major transportation arteries are severed due to extreme weather, this can influence the way product is shipped to market. In 2011 and 2013, major highways and rail lines were severed due to extreme rainfall events. These events were in June 2010 when Highway 1 by Maple Creek (Leader Post 5 July 2011) was severed disrupting travel to the west coast of Canada. In June 2011 Highway 1 east of Regina (Anonymous 21 June 2011) was flooded again disrupting truck travel. The intense precipitation event in June 2013 in Southern Alberta resulted in many highways and the Canadian Pacific Rail’s main routes either washed out or in deed of major repairs delaying and or re-routing traffic for weeks (Schmidt 22 June 2013, Passifiume 20 June 2013). It is not just roads and rail lines that are impacted by extreme events, power transmission and distribution lines can also be impacted such as what occurred in July 2011. These can events result in higher power costs for the users (Leader Post 5 July 2011). The level of the impact and costs of these delays and price increases on mines is not known to the writer.

External extreme weather and climatic change events also deal with the safety aspect of mining personnel off-site. For example, severe flooding may result in personnel not being able to get to or leave the mine site due to infrastructure issues like water treatment facilities in a near-by community being compromised. Or with the changing climatic regime, more and different vector-borne diseases (e.g., West Nile virus and Lyme disease) may become more of a concern (Wheaton 2013).
Potash Mining Operations in the Future under a Changed Climatic Environment:

Potash mines can have a life span of 100 years (Reid and Getzlaf 2004). Therefore, the mines will be operational during future extreme weather events and changing climate conditions. Wheaton et al (2013) has documented the characteristics of future possible extreme precipitation and droughts in southeastern Saskatchewan. Some highlights include:

- increased intense dryness where drying will likely overwhelm projected increases in average precipitation amounts;
- the frequency of long duration droughts of five years or longer will likely more than double in the next 75 years;
- increase in wet periods similar to those of the 1950s and 1970s will occur by the 2030s;
- the probable maximum precipitation events will increase in amount by at least 5%;
- Future droughts and future extreme precipitation events may exceed the extremes of the instrumental record.

Specific examples of extreme climatic events and how they will influence the various stages of mining operations were put forward by Moffat (2009) and Ebinger and Vergara (2011). They separated the extreme events into temperature, mainly higher maximum temperatures, precipitation, mainly rain events and other including items such as local community and mine relationships (Table 1). Some of the examples they brought forward that could impact a mine are impacts that may not be within the mine’s management including such things as higher temperatures may result in transmission loss of electricity from generation source to the mine site. If the mine is a conventional mine, more energy will be required to cool underground mines because the surface temperature is warmer.

Table 1 Examples of possible impacts and adaptation strategies for various mine production stations (adapted from Moffat 2009 and Ebinger and Vergara 2011))

<table>
<thead>
<tr>
<th>Extreme Event</th>
<th>Pre-mine planning</th>
<th>Mine planning and development</th>
<th>Production</th>
<th>Mine closure</th>
<th>Post-mine closure / Rehabilitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>Transmission loss of electricity from generation source to site under higher temperatures</td>
<td>Planning will need to accommodate greater tolerances for infrastructure and mine design for more extreme weather events</td>
<td>More energy required to cool underground mines</td>
<td>Tolerances for mine design need to be higher to withstand post-mine weather events and change</td>
<td>Planning for rehabilitation a challenge due to current vegetation may not grow well when mine closes</td>
</tr>
</tbody>
</table>

Planning for use of alternative energy generation technologies on site

Reduced efficiency of machines under higher summer temperatures

Loss of machine efficiency under hotter conditions
<table>
<thead>
<tr>
<th>Extreme Event</th>
<th>Pre-mine planning</th>
<th>Mine planning and development</th>
<th>Production</th>
<th>Mine closure</th>
<th>Post-mine closure / Rehabilitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation</td>
<td>Water supply security</td>
<td>Water supply security</td>
<td>Water supply security</td>
<td>Waste ponds, tailings dams may fail from flooding</td>
<td>Erosion of rehabilitation areas with intense precipitation</td>
</tr>
<tr>
<td></td>
<td>Compromised waste ponds and tailings dams</td>
<td>Water conflicts with other users</td>
<td>Drainage issues may develop</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Siting of Infrastructure</td>
<td>Designing mines with greater tolerances for higher precipitation variability is more expensive</td>
<td>Waste ponds and tailings dams compromised due to too much/too little precipitation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(buildings, roadways, tailings pile/pond, rail lines, water pipelines etc)</td>
<td></td>
<td></td>
<td>Threats to transportation infrastructure (washouts of roads, railways, bridges)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Improved groundwater monitoring and modelling</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Flexible planning and response required to operate with more frequent extreme weather events</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Emergency planning</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The mining industry is cognizant of the relationship between mining and climate. Mine drainage, tailings and holding ponds as well as transportation are highly sensitive to climatic variability (Hennessey et al 2012). However, mine planning and design in Canada, in general terms, has assumed a climatic “steady state” where climate does not change (Hennessey et al 2012).

Potash mine officials in Saskatchewan are not concerned that climate change will impact their operations (Pearce et al. 2009, Pearce et al. 2011). Even though potash production is dependent on water availability, company representatives are not concerned and potash extraction will continue as usual without any significant modifications or adaptations needed (Pearce et al. 2009, Pearce et al 2011). Saskatchewan based potash mines are set up and follow provincial regulations and standards. In order to step above or go one or two grades higher than the guidelines and regulations, any adaptation measures put in place regarding extreme weather events and the changing climatic environments must make economic sense in the business environment (Pittman et al. 2013 draft).
Several new potash mines are in the design and developmental stage. Currently, 12 additional potash mines are being considered for Saskatchewan. The Qu’Appelle River Watershed could see as many as seven new potash mines built (Figure 1). This increase in mine numbers and the expansion of many current mine sites may have an impact on the amount of water required to produce potash. Kulshreshtha et al. (2012) projected the new mines will utilize larger portions of ground water by the 2040s (Table 2)

Table 2 Water demand estimate for Saskatchewan (2020s, 2040s and 2060s) (Kulshreshtha et al. 2012)

<table>
<thead>
<tr>
<th>Source of Water</th>
<th>Amount of Water (dam$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2020</td>
</tr>
<tr>
<td>All of Saskatchewan</td>
<td></td>
</tr>
<tr>
<td>Existing Mines</td>
<td>Surface</td>
</tr>
<tr>
<td></td>
<td>Ground</td>
</tr>
<tr>
<td>New Mines</td>
<td>Surface</td>
</tr>
<tr>
<td></td>
<td>Ground</td>
</tr>
<tr>
<td></td>
<td>Combination</td>
</tr>
</tbody>
</table>

Kulshreshtha et al. (2012) also projects that water demand estimates in the Qu’Appelle River Watershed will increase with more water being transferred from the South Saskatchewan River Basin into the Qu’Apple River Watershed by 2060 (Table 3)

Table 3 Water demand estimates based on current operating procedures for existing and new mines in the Qu’Appelle River Watershed (Kulshreshtha et al. 2012)

<table>
<thead>
<tr>
<th>Amount of Water Demand (dam$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>South Saskatchewan River Basin</td>
</tr>
<tr>
<td>transferred to Qu’Appelle River</td>
</tr>
<tr>
<td>Watershed</td>
</tr>
<tr>
<td>Qu’Appelle River Watershed</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

Estimating the amount of water required from the South Saskatchewan River Basin is important because it is projected that stream flow in the South Saskatchewan River will change both in spring melt timing and amount of average runoff into the South Saskatchewan watershed (Lapp et al 2005, Burn 1994). The results of the analysis are not available. In addition, the South Saskatchewan River Basin and the Qu’Appelle River Watershed is utilized by a wide variety of industry and municipalities. Currently, the largest water users in the Qu’Appelle River Watershed is agriculture, this is not projected to change over the next fifty years compared to the other users (Figure 10). However, the amount of water projected to be required is projected to increase, particularly for agriculture and the industry and mining sectors. This will require water management strategies and the Water Security Agency of Saskatchewan is currently assessing
The new mines are examining ways to utilize non-traditional water sources or improving the processes of water recycling. For example, Western Potash is planning on developing a new potash mine south of Regina. They have developed an agreement with the City of Regina to purchase treated waste-water from the city for usage in the mine (Grace 13 June 2012, Western Potash Corp ND). In addition, many potash mines are active in terms of water reuse and recycling such as the utilization of excess water from the tailing management area being used in the milling process (Pittman et al. 2013draft). One approach for future fine tailings management is to pump the tailings into a containment cell and allow the brine to flow freely through a permeable barrier constructed at the downstream end of the cell. The brine would then be recovered and the remaining fine tailings would consolidate into a solid form (PotashCorp 1 June 2008). The specifics on the amount of water are recycled and other possible methods involved in recycling are not known as it is proprietary information (Pittman et al. 2013draft).

The objective for potash operators after mine closure is to prevent off-site contamination, particularly salt from leaving the TMA (Reid and Getzlaf 2004). They state that large volumes of brine can be produced when precipitation falls on tailing piles. Containment of the liquid phase is more difficult than the solid phase. In addition, the potash mines and the regulatory agency foresee uncertainty in the next 100 years, especially when predicting the volume of tails generated in the TMA. It was therefore decided to restrict the decommissioning plan to current
TMA. Each mine’s TMA is capable of holding a finite amount of waste. Each mine would also undertake a cost/benefit analysis for determining the best course of action for decommissioning. Generally, the base case D&R plan for each mine recommends sealing the shafts, demolition and removal of the service and production facilities, re-contouring and re-vegetation of the site, as well as maintenance of brine and salt containment facilities until all salt in the TMA has been removed or stabilized. Salt tails present at closure would be dissolved in the water used to produce potash and precipitation followed by injecting the resulting brine to the deep geological formations (Reid and Getzlaf 2004).

Figure 10 Flow Chart for Decommissioning Potash Mines in Saskatchewan (Reid and Getzlaf 2004). Note: the flow lines are of equal in strength, the red and blue lines are there to better discern paths that intersect.

**Preliminary Examination of Costs of Changing Climatic Conditions to the Potash Mining Industry**

The potash mining industry is an important resource to the Saskatchewan and Canadian economies. Potash was Canada’s leading mineral by value of production in 2011 at $8.0 billion with Saskatchewan producing 85% of Canada potash production (Saskatchewan Mining Association 2012). As such, capitalizing on changing climatic conditions and decreasing the potential costs of extreme weather events would be beneficial to the industry, communities and province. The specific costs of mining in Saskatchewan are propriety so this analysis is general overview and assessment of possible costs that could be incurred due to changes in climate and extreme weather events.

The United National Environmental Programme published a high level examination of the impacts of a changing environment on the corporate world (Grossman 2012). Extractives including mining, financial well-being and agriculture were examined in a general sense and several operational implications of a changing climate were assessed in terms of risks and opportunities to corporations (Table 4). Several of the risks and opportunities have already be
examined in previous sections but certain items have not such as there may be increased liability risks and costs associated with decommissioning a mine due to changing weather patterns. The financial risks associated with increased climate variability and extreme weather deal directly with insurance companies and the potential increased uncertainty of underwriting by insurance companies as well as the increased cost of insurance claims. The social aspect of climate change is also important and can be viewed as both a risk and as an opportunity; it depends on how companies choose to deal with the situation and how they are portrayed by external forces. Also, because potash is used primarily by the agricultural sector, climate variability and extreme weather events have a tremendous impact on agriculture and thus, through the domino effect, on potash. Changes in availability, quality, prices and sources of agricultural products due to climate change and other environmental changes can influence the usage of potash but also, new markets may appear with the changing climatic regime and therefore improve business opportunities for potash usage expansion. It is therefore important to undertake climate risk management where the negative impacts are mitigated or adapted to and promote the positive impacts of weather and climate variability and change (Ebinger and Vergara 2011).
Table 4 Risks and Opportunities of the Extractive, Financial and Agricultural Sectors (adapted from Grossman 2012)

<table>
<thead>
<tr>
<th>Risks</th>
<th>Opportunities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Extractives</strong></td>
<td></td>
</tr>
<tr>
<td>• Increased cost of fossil fuel-based energy for some mining operations</td>
<td></td>
</tr>
<tr>
<td>• Infrastructure damage and business interruption due to extreme weather</td>
<td></td>
</tr>
<tr>
<td>• Business interruption due to water scarcity</td>
<td></td>
</tr>
<tr>
<td>• Limits on access to resources in water scarce areas</td>
<td></td>
</tr>
<tr>
<td>• Stricter regulatory limits on air emissions and water discharges</td>
<td>• Reputational advantage for companies seen as part of the solution to climate change</td>
</tr>
<tr>
<td>• Increased liability risks and costs of decommissioning due to changing weather patterns</td>
<td></td>
</tr>
<tr>
<td>• Reputational damage and potential loss of social license to operate for companies seen as major contributors to climate change or major water users in water scarce areas</td>
<td></td>
</tr>
<tr>
<td><strong>Finance</strong></td>
<td></td>
</tr>
<tr>
<td>• Increased uncertainty of underwriting by insurance companies due to changing weather patterns</td>
<td></td>
</tr>
<tr>
<td>• Increased cost of insurance claims resulting from more severe weather events</td>
<td></td>
</tr>
<tr>
<td>• Increased pressure on lenders and investors to improve consideration and disclosure of client companies’ impacts on and from environmental trends</td>
<td></td>
</tr>
<tr>
<td>• Reputational damage for companies providing lending for environmentally damaging activities</td>
<td></td>
</tr>
<tr>
<td><strong>Agriculture</strong></td>
<td></td>
</tr>
<tr>
<td>• Changes in availability, quality, price and sources of agricultural products due to climate change and other environmental changes</td>
<td>• New markets for alternative supplies or more climate-resilient food varieties</td>
</tr>
<tr>
<td></td>
<td>• Opportunities for businesses in new agricultural growing zones</td>
</tr>
<tr>
<td></td>
<td>• Expanded markets for sustainable food productions</td>
</tr>
</tbody>
</table>
As stated in the introduction, it is very difficult to undertake a cost/benefit analysis of the potash industry under a changing climate because much of the information is proprietary. The Potash industry has contracts with the provincial government regarding water allocation (Reid 1984). These contracts specify a minimum usage thus no cost savings would result from using less water than the minimum (Reid 1984). A large portion of potash mines operating costs is the cost of water both through water supply to mine the potash as well as the associated infrastructure. Currently, industrial water use charges for water taken from the South Saskatchewan River, Lake Diefenbaker, Buffalo Pound Lake and the Qu’Appelle River is $46.20 per 1,000 metres$^3$ effective 1 January 2009 (Water Security Agency NDb). Water taken from any sources with total dissolved solids in excess of 4,0000 mg/L, except water taken from the Blairmore or deeper ground water formations is $1.86 per 1,000 metres$^3$ effective 1 January 2009 (Water Security Agency NDb).

The water infrastructure also contains considerable costs. If a mine utilizes ground water, they incur all of the infrastructure costs directly. If a water pipeline is required the costs of the pipeline are dependent upon the distance from the water source, which in some cases in Buffalo Pound Lake, to the mine site. These costs include the pipelines, pumping stations as well as booster stations if they are required (Avery, p. comm. 2013). Again, it depends on the mine and much of the associated costs are proprietary. It is however known that SaskWater’s largest industrial customer is the potash industry. SaskWater provides non-potable water to six of the operating potash mines in Saskatchewan (Anonymous 13 Dec 2012).

Potash companies incur large operating costs from other utilities as well including natural gas, and electrical. These two utilities are also dependent upon changing climatic regimes thus further compounding the domino effect. For example, SaskPower incurred additional costs in 2011 due to the extreme weather e.g., high winds impacting infrastructure (Leader Post 5 July 2011).

In addition, the road and railway infrastructure is a major component for exporting potash to market. Transportation costs are a major component of potash price. Approximately 10,000 cars are need for potash shipment with about 90% of overseas exports going through Vancouver (MacKenzie 2003). In recent years, there have been major floods (Wittrock 2013) and major flood events are projected to become intense in the future (Wheaton 2013). The costs of flooding in Saskatchewan largely unknown (Leader Post 5 July 2011), however, the estimated cost of the flood in the Maple Creek area due to the June 2010 flood $10 million in (Leader Post 5 July 2011). This cost does not include items such as increased trucking fees for re-routing of goods transported.

The author discovered that undertaking a true cost-benefit analysis is difficult as much of the relevant information is proprietary or has not been released to the public. Therefore, more work needs to be done in this area. Areas of interest include incorporating the external risks such as
infrastructure that is susceptible to weather and climatic conditions as well as the impact of negative and positive climatic and weather conditions on the agricultural industry throughout the world. This also has an impact on the potash industry and should and may already be utilized in the companies risk management strategies. Another risk management strategy is the potential perceived threat to the water supply if and when there is limited supply due to extended and severe drought conditions.

**Conclusion and Recommendations**

The potash industry is relatively new to Saskatchewan and therefore has not had to deal with some of the most extreme climatic conditions of the past 100 years including the extended droughts of the 1930s. In recent years, the Qu’Appelle River Watershed has had numerous excessive moisture years resulting in adaptation strategies for dealing with extreme excessive surface water so that the mines are able to maintain their closed hydrologic system. Potash mines have a limited number of ways of disposing excess water from the mine sites and these ways have been tested to their capacity in recent years.

Surface water in the Qu’Appelle River Watershed is extremely variable in nature and the mining and processing of potash requires a reliable water supply. As such, depending on location and type of mine, a few adaptation measures have been implemented to maintain the supply. Conventional mines sometimes use ground water as their primary water supply or use it to augment surface water. Solution mines require a larger quantity of water and therefore have utilized water from the South Saskatchewan River Basin to access a reliable water supply.

Several factors were found to be at preliminary stages including potash mines decommissioning. It is important that these strategies include climate variability and change so that the greatest benefits are attained. Another area that did not appear in the literature was the external factors including infrastructure that are required for a mine to operate. The author was unable to assess much of these potential impacts and adaptation strategies that have possibly been implemented due to a large amount of information are propriety. This factor also limited the cost-benefit analysis so only a very brief discussion was provided.

This document brought forward several areas that should be examined and/or re-examined in further detail including:

- review the extreme events risk assessment criteria (drought, flood, etc)
- Cost – benefit analysis is lacking due to unavailability of information (proprietary)
- mining potash may not be overly influenced by extreme events or long term variability except for water availability. Too much precipitation and water on the mine site results in having to deal or adapt to excess water conditions.
- the impact on external infrastructure may have more impact on mining operations than the impact of extreme weather events on mining operations. The financial cost of these is not known.
• the EIA’s may need to be reassessed. Coping with a one in 100 year extreme event is manageable; however, coping with back-to-back and multi-years excessive moisture conditions requires costlier adaptation measures. The author does not know the ramifications of discharging water into the watershed are but the potash mines are required to operate as a closed hydrologic system other than disposing of excess water into deep underground caverns.

• the changing climate in other locations may have an influence on the amount of potash the world requires. This topic was not examined and would be beneficial for an in-depth cost-benefit analysis. For example, if large portions of the agricultural community are affected by severe weather/climate, the potential of less product is purchased impacting the amount mined and thus the economic viability of the mine site.

• the potential for water conflicts may increase with decreased water availability. As shown in Wheaton 2013), the potential for less water is very realistic. The impact of less water may result in mines having to find alternative water sources.

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