Acid Rock Drainage and Climate Change: What's Next?

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Abstract

2011 in North America featured an astonishing array of extreme weather events, ranging from the Super Outbreak of tornados in April through to the Massachusetts tornados in June, and flooding in the Mississippi River system beginning in April and continuing into summer in the Northwestern United States, Saskatchewan, North Dakota and the Missouri River system. Although an individual weather event by itself is not evidence of the influence of climate change, the reality is the industry is making closure, reclamation and drainage treatment predictions based on a historic climate that no longer exists. The climate is a dynamic system and the likelihood and risk of extreme events seems to be on the rise. Risks associated with weather events that exceed historic norms may be significant and have to be considered.

In Montana, the Zortman-Landusky minesite experienced nearly 30 centimeters of precipitation over a two day period in May, causing nearly $ 4 million in damage to existing reclamation, water treatment collection and infrastructure systems. MEND, through its ongoing climate change work and Saskatchewan, through its Institutional Control Program for long term management of remediated mine sites appear to be at the forefront of attempting to understand and address the implications of climate change on mining activity and closure. Possible policy implications of this work for mines and abandoned sites will be discussed.

Key Words:Zortman-Landusky, extreme weather, mine closure

Introduction and Background

In spite of the increasingly polarized and politicized view of climate science and climate change in the United States, many of the principles behind the "theory" of Anthropogenic Global Warming (AGW) or Global Climate Change (GCC) are in fact firmly established both in fundamental physics and detailed observations and are widely accepted elsewhere.

The initial work on the theory that increasing carbon dioxide (CO_2) might be responsible for an increase in global temperatures dates back to the brilliant work of Swedish chemist Svante August Arrhenius in 1896. This was backed up by the additional brilliant work ofGilbert Callendar in the 1930s, and Gilbert Plass, Hans Suess and Roger Revelle in the 1950s. There is little scientific dispute about the physics by which this occurs: carbon dioxide in the atmosphere absorbs long wave radiation that would otherwise escape into space, thus warming the lower atmosphere and respective temperatures worldwide. The Intergovernmental Panel on Climate Change (IPCC), approximately 2500 climate scientists from around the world, has concluded that increases in carbon dioxide resulting principally from the burning of fossil fuels are responsible for most of the continuing increases in global temperatures (IPCC2007). NASA's Goddard Institute for Space Studies (GISS)states; "The ten warmest years all occur within the 12-year period 1997-2008" (GISS 2009).2009 was the second warmest year on record and 2010 was tied with 2005 for the warmest year on record(GISS 2010, 2011). The science is in fact settled; the earth has not cooled since 1998 as some have claimed. It continues to warm as evidenced by not only surface temperature records but also ocean temperature records as well as changes in physical and biological systems (IPCC 2007).

The figures belowillustrate the recorded changes in temperatures throughout the world up to 2005 (IPCC 2007).

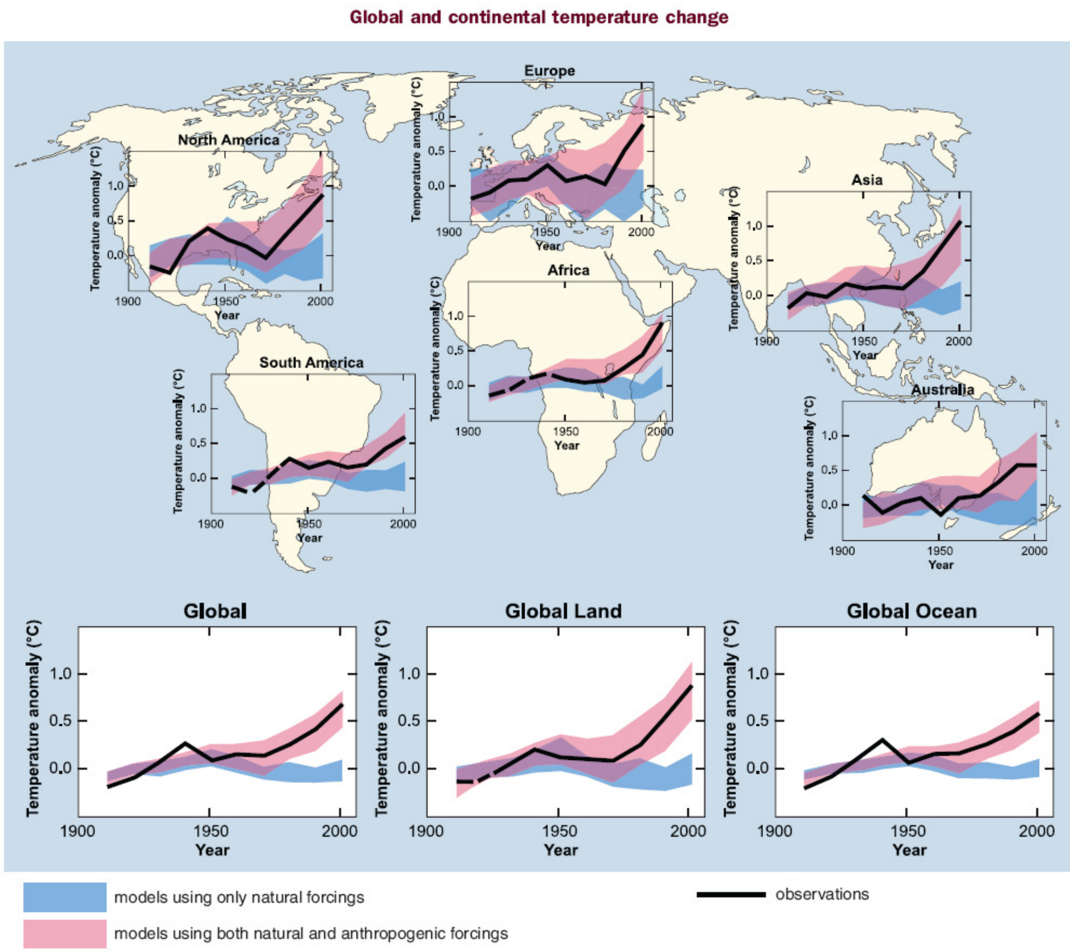


Figure 1. Global and continental temperature records compared with the expected natural forcings (IPCC 2007).

Climate Projections

General

General projections regarding climate change have focused on what an increased average temperature and changes in mean annual precipitation mean for different regions. In general these projected changes are reflected in the following IPCC figures (IPCC 2007).

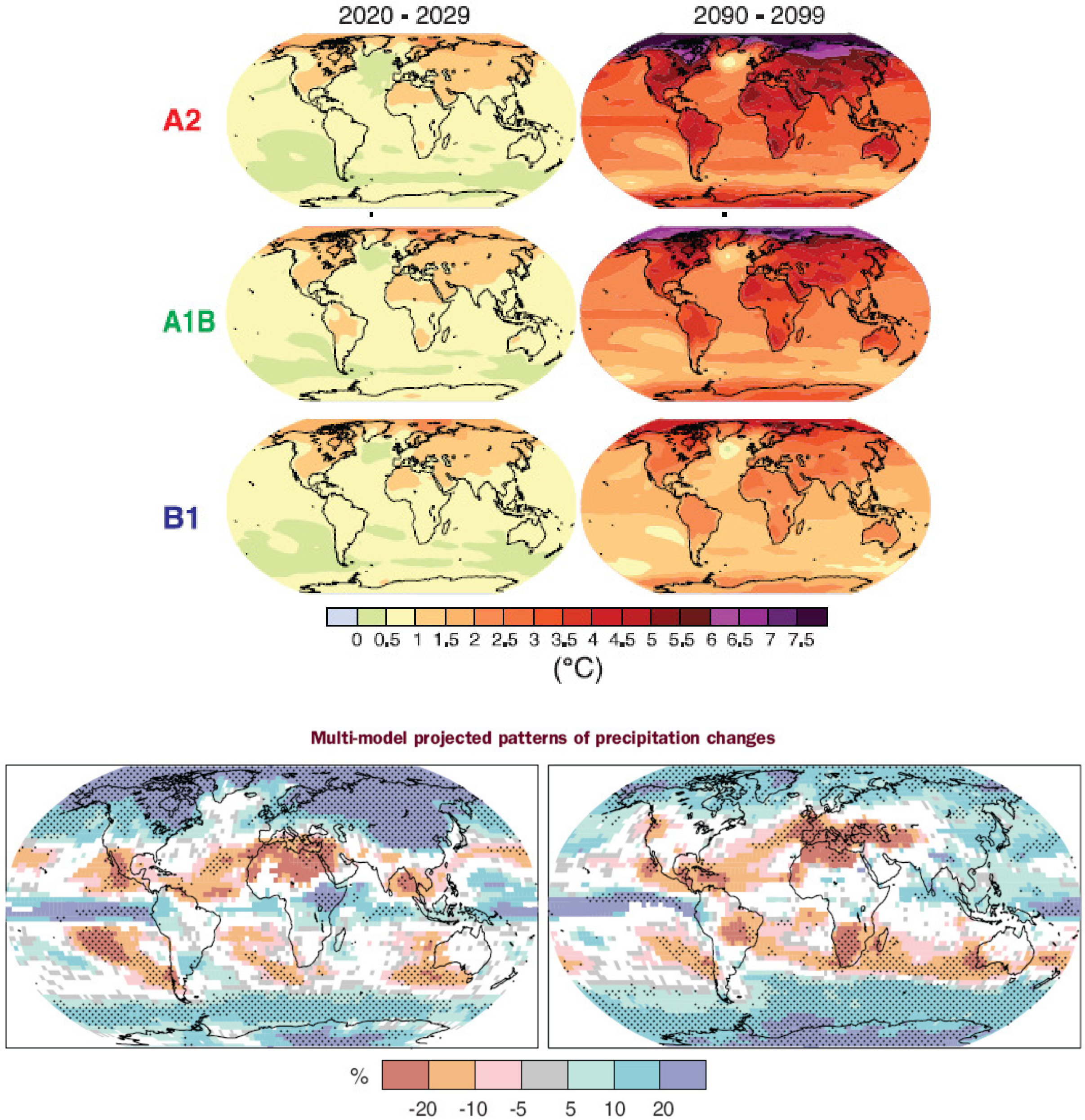
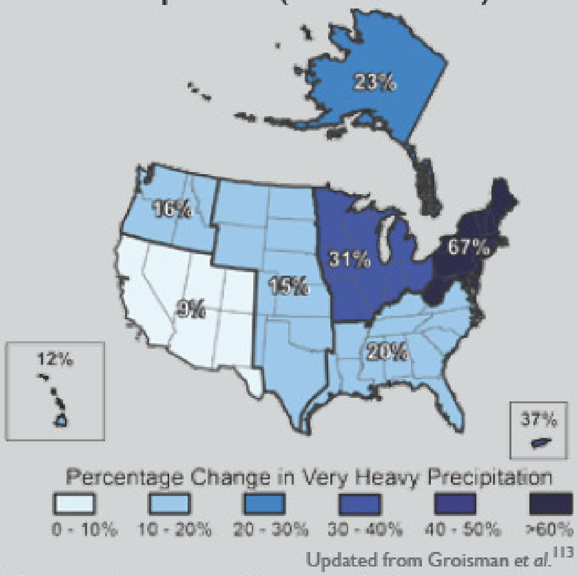


Figure 2.Projected changes in temperature for different model emission assumptions (A2, A1B and B1) and multi-model projections for anticipated changes in precipitation (IPCC 2007).

There are several sources for regional estimates (IPCC2007, NRCAN 2007, Karl, *et al* 2009, CSIRO2010,Iglesias *et al* 2009, Ciscar*et al* 2011, Ashton 2010) but in general they can all be summarized as projecting that past climatic norms will routinely be eclipsed with warmer temperatures, more intense precipitation events, more severe episodes of drought, more pressure on water resources as well as physical and biological resources over the next century. Some specifichistorical data and projectionsfor the United States and Canada are presented in the figures below.

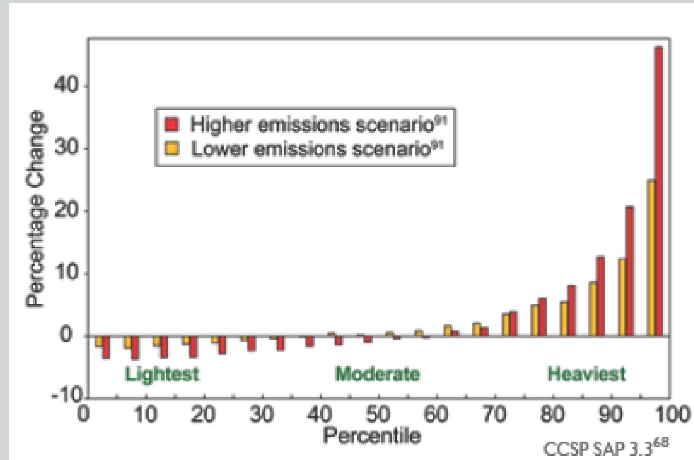
Increases in Amounts of Very Heavy Precipitation (1958 to 2007)



The map shows percent increases in the amount falling in very heavy precipitation events (defined as the heaviest 1 percent of all daily events) from 1958 to 2007 for each region. There are clear trends toward more very heavy precipitation for the nation as a whole, and particularly in the Northeast and Midwest.

Figure 3.Increases in the amount of precipitation falling in very heavy precipitation events 1958 - 2007 (Karl, *et. al*, 2009).

Projected Changes in Light, Moderate, and Heavy Precipitation (by 2090s)



The figure shows projected changes from the 1990s average to the 2090s average in the amount of precipitation falling in light, moderate, and heavy events in North America. Projected changes are displayed in 5 percent increments from the lightest drizzles to the heaviest downpours. As shown here, the lightest precipitation is projected to decrease, while the heaviest will increase, continuing the observed trend. The higher emission scenario[91] yields larger changes. Projections are based on the models used in the IPCC 2007 Fourth Assessment Report.

Figure 4. Projected changes in the pattern of precipitation based on various emission scenarios (Karl, *et. al*. 2009)

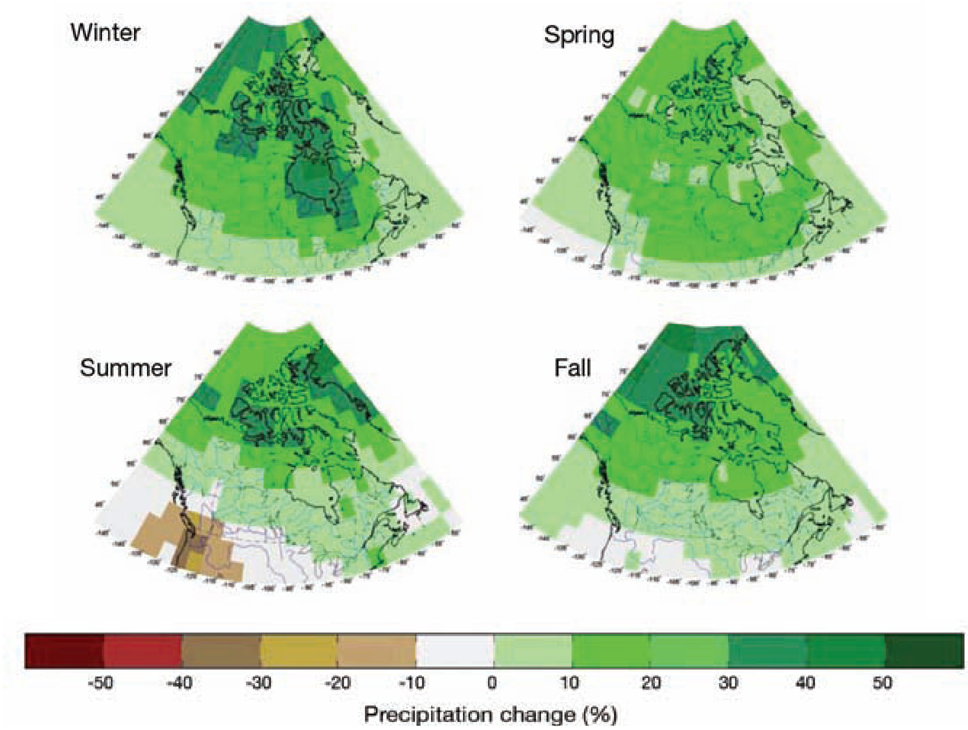


Figure 5. Seasonal change in precipitation by 2050 relative to the late 20th century values (NR Canada 2007).

Severe weather events

As is obvious from the projections regarding changes in precipitation patterns, severe weather events are also projected to increase in the future (IPCC 2011). An indication of the likelihood of these projections can be seen in the following indicators detailing recent trends: Figure 6: Number of declared disasters (FEMA2011), Figure 7: Insured losses due to weather related catastrophes. Note that Figure 7is not current, however recent events have only enhanced the trend.

The projections regarding the increasing likelihood of severe weather events may be one of the most important projections for the mining sector. The impact of severe weather events was particularly prominent in the United States in 2011. The year 2011 in the United States ranks as the year with the most billion dollar weather disasters, ten, eclipsing 2008, with three months left in the year as this is written and the damage from Hurricane Irene and Tropical Storm Lee (September 2-5, 2011) still being tabulated.

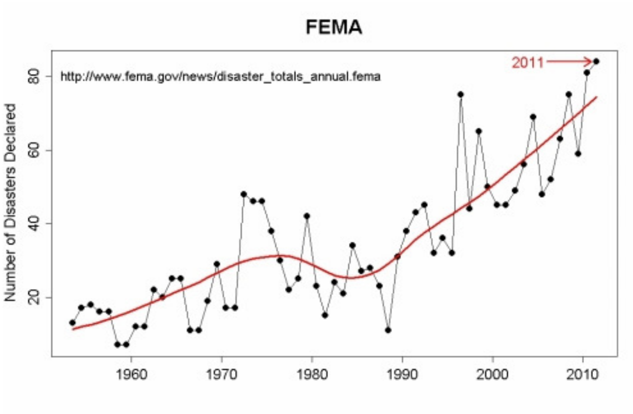
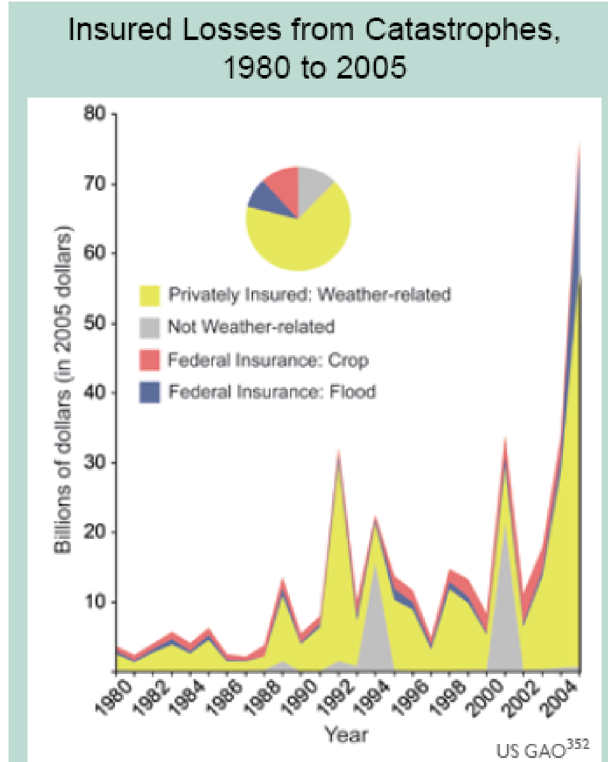


Figure 6: Number of declared disasters (U.S.), (FEMA 2011)



Weather-related insurance losses in the United States are increasing. Typical weather-related losses today are similar to those that resulted from the 9/11 attack (shown in gray at 2001 in the graph). About half of all economic losses are insured, so actual losses are roughly twice those shown on the graph. Data on smaller-scale losses (many of which are weather-related) are significant but are not included in this graph as they are not comprehensively reported by the U.S. insurance industry.

Figure 7. Insured losses due to weather related catastrophes (Karl, *et. al*. 2009).

Potential Impacts/Mitigations to Mining Sites

Climate change is relevant for mine design, operations and closure because climate change will impact the average temperature and the amount, nature and timing of precipitation. All aspects of water management are critical issues at minesites and the projected changes in the nature of precipitation have the potential to impact all facets of mining activity.

What are the risk drivers for potential impacts to mines throughout the life-of-mine?

1) Warmer temperatures (NRTEE 2010), (Stratos 2009)
2) More precipitation (IPCC2007, Karl, *et. al*. 2009, NRTEE 2010, Stratos2009)
3) More frequent drought conditions (IPCC2007, Karl, *et. al*. 2009, NRTEE 2010)
4) More extreme weather events (IPCC2007, 2011, Karl, *et. al*. 2009, NRTEE 2010,IPCC 2011)
5) For northern climates, loss of permafrost (NRTEE2010), (Stratos 2009)

6) For coastal operations, higher sea levels (IPCC2007, Karl, *et. al*. 2009)

While increased temperatures and precipitation could potentially provide a more favorable setting for acid rock drainage (ARD), it is not likely increased temperatures and precipitation alone represent the critical issue with respect to climate change. These factors could potentially complicate water treatment and reclamation options, but the likely larger issues are extreme weather events and less reliable precipitation.

Most mines have an operational life in the 20 to 30 year range and thus are well below the likely timeframe of the expected maximum climate change impacts. Mines can be expected to be able to effectively plan and manage climate change impacts during the operational life of the mine because; they have money available, they have manpower and equipment available, and they have an incentive to prevent disruptions to mining and milling operations.Over the course of a 20 year life-of-mine the likelihood of a fatal defect in dealing with climate change may be low since the mine facilities are likely designed with a longer return interval than the anticipated life of the mine.

The following mine life cycle events are evaluated for relative risk:

Exploration: Likelihood for adverse impacts is low because surface disturbance is generally limited,there is generally little rock exposed to trigger ARD and the time window is relatively brief.

Development: Increasing likelihood of minor impacts during development as surface disturbance increases and water management infrastructure may not be fully implemented. The time window is relatively brief but the increased disturbance and incomplete infrastructure raises the risk level.

Operations: limited likelihood of minor impacts due to fully implemented water management infrastructure and ready availability of staff and equipment. The relatively higher risk due to the longer time window is at least partially offset by the mine's ability to more effectively manage precipitation events.

Closure: Increasing likelihood of minor/major impacts as reclamation is completed and the site is potentially returned to other ownership following release of the financial assurance instrument.Longer timeframes increase the likelihood of severe events.

The potential impacts to mine facilities would vary depending on the mine life cycle timeline and the facilities/structures and equipment at risk.

1) Exploration: features at risk include roads and drill pads. Equipment at risk is generally mobile.

2) Development: Features at risk include all areas under construction; mill and office facilities, transportation infrastructure, and tailing impoundments (if included). Facilities and equipment at risk are less mobile and could be exposed depending on the nature of severe weather.

3) Operations: Facilities at risk include all mine structures and facilities. The risks are likely lower than during development, because all erosion and water management infrastructure is in place, functional and maintained. Facilities are at risk. Equipment may have less flexibility for mobility than during exploration and development.

4) Closure/Post Closure: Virtually all constructed and reclaimed features are at risk. The risk is highest before the reclamation is fully established and facilities may be in salvage. Longer term risk is again counter-balanced by the longer time window, perpetuityfor extreme weather events to occur.Foreseen or unforeseen changes in temperatures and precipitation patterns may dramatically impact revegetation and cover performance, which may impact water management and related costs. Equipment at the site is generally mobile.

5) To what extent will operators be responsible for long term effects, which may impact water management that can be clearly projected but are outside the range of normal longer term effects?

6) Lastly; what are the potential legal implications of these collective uncertainties?

An Extreme Weather Event: Zortman-Landusky Case History

The Zortman-Landusky mines are located in the Little Rocky Mountains in North-Central Montana, U.S.A.

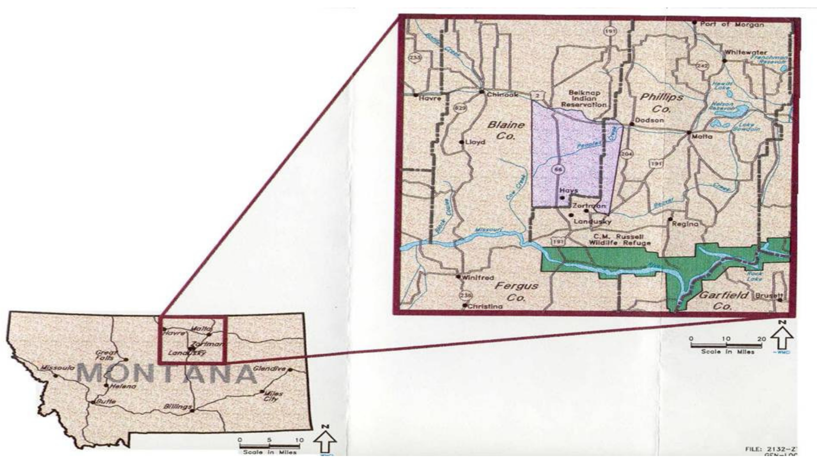


Figure 8. General location of Zortman-Landusky mines in north-central Montana, U.S.A

The Little Rocky Mountains are one of several "Island Mountain Ranges" that rise above the Northern Great Plains east of the main Northern Rocky Mountains in Montana.

1979 the State of Montana approved an Environmental Impact Statement for large scale open pit heap leach mining by both Zortman Mining Company (Gulf Resources) and Landusky Mining Company (Wharf Resources). In 1981 Pegasus Gold Corporation became the operator of both mines following the merger of Pegasus Limited and Arco Gold Corp.

Mining continued from 1981 through 1998 with several expansions until 1998 when Pegasus declared bankruptcy (Williams, *et. al*. 2009).

Gold and silver produced over the life-of-mine were approximately 47 million grams and 200 million grams respectively. Approximately 195million tonnes of waste and ore were mined at the site and over 500 hectares were disturbed by the mining operations.

Following a complex legal history the various mine features were reclaimed between 2002 and 2005 and involved resloping, pit backfilling, surface water control and revegetation of reclaimed areas. In part due to the lack of sufficient funding in the reclamation bond ($45 million) and the limited availability of suitable construction material some reclamation was probably less than optimal (Williams, *et. al.* 2009).

Reclamation efforts were focused on reducing infiltration and therefore contaminant loading from the various waste facilities, while relying on and optimizing water management, collection and treatment. In 2010 a water treatment plant was constructed in Swift Gulch, which drains north onto the Fort Belknap Indian Reservation. Collectively the Z-L site included previous water treatment plants treating ARD at Zortman (built in 1994) and Landusky, (1997) and a bioreactor pant at Landusky (2002) which treated leach pad solutions to remove nitrates, cyanide and selenium. All these plants involved complex water collection infrastructure to collect the water to be treated.

In late May of 2011 the Z-L site received over 30 cm of rain in approximately 30 hours. The National Weather Service, Great Falls, Montana estimated the total May precipitation events in north central Montana to represent a 270 year recurrence interval event. The specific recurrence interval for the Z –L event was not calculated, but may well have been an even larger storm. Over the past several years average annual precipitation at the Z-L site is slightly less than 50 cm. The Swift Gulch treatment plant, pictured below, was designed to treat a maximum of 1900 L/min. Due to a heavy snow pack prior to the late May storm, the flow being treated before the storm was approximately 9500 L/min. Nordstrom (2009) has previously discussed the "first flush" and related sudden increases in metals and acid concentrations related to climate change and mine sites. His discussion focused principally on the need for more robust treatment facilities to account for more extreme climatic fluctuations and related "first flushes", but did not address in detail the potential catastrophic impacts to water treatment infrastructure a major storm could have. The Z-L case serves as an example of what such impacts might look like.The associated additional cost for the excess water needing treatment at Z-L was approximately $250,000.

Figure 9.During the storm water flowed through the building housing the treatment plant, to the right (Figure 11, below), an elevation difference of approximately 3.5 meters from the flow pictured above.

Figure 10.Swift gulch ARD treatment building, showing evidence of flow through the building.

The resulting downcutting, disruption and destruction of the installed collection infrastructure resulted in repair cost of approximately $252,500 at the Swift Gulch treatment plant.

The Carter Gulch waste dump (Figure 11-13, below) was originally reclaimed in 1998. It was an acidic material which would have been removed had mining continued, but following the bankruptcy it was reclaimed as a 2h:1v slope with a collection system in place below the slope. As is common in many engineered reclaimed waste rock dumps diversion channels were constructed at approximately 30 meter vertical intervals to control water on the reclaimed dump face. It was a failure of the midslope diversion channel which triggered the dump failure. Repair of this slope is estimated to range from $ 300,000 for short term stabilization to removal at approximately $ 14.5 million.Roads and erosion control infrastructure throughout the site were heavily impacted as shown in figure 14 below. Costs for these various repairs to the road infrastructure are in the range of $ 100,000. Total costs for all repairs range from approximately $ 3 million to $14.5 million depending on how the now dramatically oversteepened and unstable Carter Gulch dump is handled.

Because this mine and site went through a bankruptcy, any funds for repair will be public monies, either from the state of Montana or from the Federal government or some combination, thus making costs extremely sensitive in an austerity era.

Figure 11.Carter Gulch waste dump washout. Approximately 43,000M^3 were washed down Carter Gulch.

Figure 12.Carter Gulch below the washed out dump showing debris from various collection infrastructure destroyed by the washout.

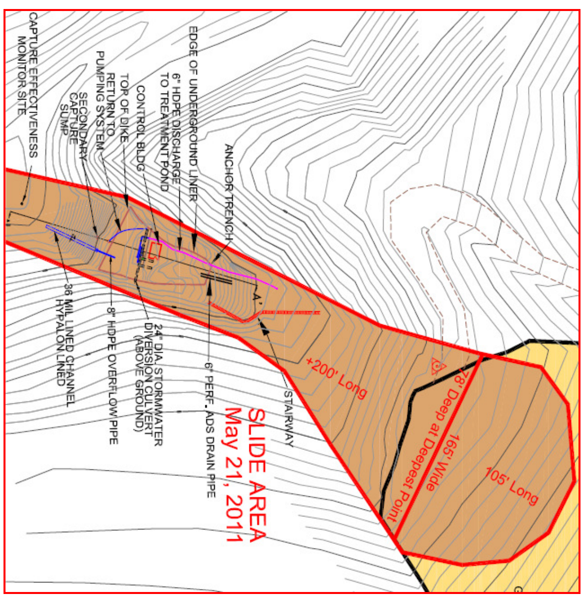


Figure 13. Detail of Carter Gulch failure, showing the specific water collection features destroyed or damaged.

Figure 14. Numerous roads and erosion control infrastructure features throughout the minesite were heavily damaged.

Conclusion

It will be important for mining companies to plan for extreme weather events as a contingency throughout the mine lifeand design their closure plans to survive them. The level of detail and commitment required will vary throughout the mine life depending on the nature of the disturbance, the facilities at risk, the availability of staff and equipment at hand and the relevant time window for potential extreme events. The highest level of risk is likely to be the extended time period following closure of the mine principally because the time window is essentially indefinite, there may be limited staff and equipment available to deal with a multifaceted extreme weather event and funds may be limited. The uncertainty of what a 25 year storm or recurrence interval means in a time of changing climate suggests that mine planners should be extremely conservative in developing erosion control and water treatment infrastructure to account for the uncertainties. The uncertainties associated with and changing temperatures and precipitation patterns are also relevant for cover design for waste facilities and should encourage operators to evaluate geomorphic based alternatives to more conventional engineered waste dump reclamation.

Regulatory agencies will be faced with the complexity of developing adequate financial guarantee mechanisms that can realistically account for the myriad uncertainties a changing climate presents.

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