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Risk Management of Gold Mine Operations in South Carolina

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RISK MANAGEMENT OF GOLD MINE OPERATIONS IN SOUTH CAROLINA

A Master Thesis

Submitted to the Faculty

of

American Military University

by

Kendra Rembold

In Partial Fulfillment of the

Requirements for the Degree

of

Master of Science in

Environmental Policy and Management

December 2016

American Public University System

Charles Town, WV
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DEDICATION

I dedicate this thesis to my husband whose support has made my college education possible and to my four children for showing great patience during this process.
ABSTRACT OF THE THESIS

RISK MANAGEMENT OF GOLD MINE OPERATIONS IN SOUTH CAROLINA

by

Kendra Rembold

American Military University, December 2016

Charles Town, West Virginia

Dr. Elizabeth D’andrea, Thesis Professor

The Slate Belt Region of South Carolina has been the subject of gold exploration and mining activity for nearly two centuries. Renewed interest occurred in the 1980s but abandonment by mine owners and the subsequent listing of two mine sites on the National Priorities List reveals a breakdown in environmentally responsible mining practices. A compilation of data and reports on those sites was examined to identify trends and provide a foundation for a risk analysis that can be used to assess risks of future mining operations. Throughout this process, it was discovered that water contamination by metals and acid mine drainage are the most common issues South Carolina faces. Inputting this information into a risk analysis can provide the state with the necessary information needed to mitigate and plan for future impacts.
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I. Introduction

Gold mining has played a key role in South Carolina’s history. Its discovery in the early 1800s proliferated settlement and facilitated economic growth. In total, four gold mine sites have become well-established, operating intermittently for over two centuries. This is largely based on a cycle of supply and demand where periods of renewed interest and feasibility have driven exploration, production, and eventually closure of the mines. This cycle continues today with the Haile Gold Mine project which has been labelled the largest gold mine operation in the eastern United States. However, there is a great deal of risk and uncertainty associated with gold mining. Historic data proves this industry has significantly impacted the environment and even today states are left to make tough regulatory decisions regarding the presence, operation, and rehabilitation of mine sites.

Problem Statement

Two abandoned open-pit gold mines in South Carolina have been added to the National Priorities List (NPL). This designation as a Superfund site with the Environmental Protection Agency (EPA) requires state and federal officials to work together to create long-term remediation plans. Although the solution is one that will ultimately reduce damage to human and environmental health, these sites continue to present challenges. The Brewer Gold Mine was added to the NPL in 2005, seven years after the Brewer Gold Company abandoned the site (Environmental Protection Agency, 2016). Treatment for acid rock drainage is ongoing and may continue indefinitely to mitigate toxic impacts to local tributaries and streams. The Barite Hill Gold Mine was added to the NPL in 2009 due to the contamination of groundwater, surface water, and sediments (Environmental Protection Agency, 2016). At this time, a final long-term remediation plan is still in progress.
Reducing or eliminating hazardous materials at Superfund sites is also extremely costly. In accordance with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), states may be liable to pay up to 50% for long-term remedial actions and 100% of operation and maintenance costs (SC Department of Health and Environmental Control, 2015). Facing already tight budgets, the outcome proposed by states is often one that merely meets rather than exceeds federal environmental regulations and standards. At the Brewer mine alone, an existing groundwater treatment system, deemed both outdated and inadequate, costs nearly $75,000 per year to operate and maintain and costs for a new treatment system required by the EPA is estimated at $800,000 per year (SC Department of Health and Environmental Control, 2015).

Due to the extent of contamination and costly actions already associated with clean-up of the Brewer and Barite Hill sites, the Haile Gold Mine project is of significant concern. The mine has witnessed intermittent mining activity for nearly two centuries but it is believed that two million troy ounces in gold reserves still lies within the site of which 1,682,000 ounces of gold is recoverable (U.S. Army Corps of Engineers, 2014). OceanaGold, the company taking on the vast mining operation, was issued permits in late 2014 to begin mining. The company has touted technological advancement as a commodity of environmental and human health protection but the magnitude of the mining operation, the largest ever conducted in South Carolina, warrants a thorough investigation to determine the likelihood that this mine will see the same fate as the Brewer and Barite Hill mines.

**Purpose Statement**

In response, there has been little research compiled on the environmental consequences and trends associated with gold mine operations in South Carolina. This paper is a first step
toward identifying those trends and incorporating them into a risk analysis. Actions taken at the Brewer and Barite Hill mines to mitigate or eliminate sources of contamination or actions taken that prevented a contamination event will be examined. It will also explore impacts of general mining processes that is commonly considered unavoidable. This information will be recovered from historic data and reports. Using these events to create a risk analysis will demonstrate whether the Haile Gold Mine owners or the state has acted to prevent or mitigate similar contamination events. Applying this type of analysis to current and future mining operations could allow permitting officials to mitigate repeat violations and anticipate potential risks unique to the state, thereby preventing designation as a Superfund site.

II. Literature Review

Gold Mines of South Carolina

Gold deposits were first discovered within the Carolina Slate Belt in the 1800s. This unique geologic feature runs in a southwest to northeast direction from Georgia to Virginia. In South Carolina, it runs through the central region of the state (Figure 1). The Slate Belt has historically proven to be prospective for many types of gold ore hosted within quartz-sericite-pyrite rocks and juvenile metasedimentary rocks deposited on or near the surface through volcanic activity (Foley & Ayuso, 2012). Major advancements in geologic thought, mapping, and
exploration techniques throughout the 1900s has led to redevelopment of some of the largest
gold deposits found within the Slate Belt in South Carolina. These occur at the Brewer, Barite
Hill, Haile, and Ridgeway mines. To date, deposits have produced gold ranging from
approximately one metric ton to well over 50 metric tons although the Haile Mine is thought to
still contain more than double what has already been produced (Foley & Ayuso, 2012). This
entire region remains a high interest for potential mining companies.

The Brewer Mine is located just west of Jefferson, South Carolina in Chesterfield
County. The mine site lies between the Lynches River and Little Fork Creek on over 200 acres
of privately owned land (U.S. Environmental Protection Agency, 1991). It is the northernmost
gold mine site in the state, approximately 15 miles from the North Carolina border. A long
history of mining has occurred at this location, mostly small-scale operations until advancements
in exploration and mining technology paved way for new opportunities. In the 1970s,
exploration at the mine began once again as a result of rising gold prices (U.S. Environmental
Protection Agency, 1991). Under ownership of the Brewer Gold Company, the site was used as
an open-pit heap leach mine. Over 18,000 ounces of gold and small amounts of silver were
activities lasted until 1999 when the company abandoned the mine. It was then turned over to
the state.

Roughly 150 miles away lies the Barite Hill Mine. This mine is located approximately
three miles southwest of McCormick, South Carolina in McCormick County. The site is situated
along a ridge near two un-named tributaries that drain into Hawe Creek and just east of the
Gold was discovered in the mid-1800s and mining has occurred intermittently since that time.
From 1991 through 1994, Nevada Goldfields, Inc. recovered an estimated 65,000 ounces of gold and 120,000 ounces of silver from oxide and sulfide ore from the open-pit mine (Black and Veatch Special Projects Corp., 2015). The company led reclamation activities until 1999 when Nevada Goldfields declared bankruptcy and abandoned the site. Reclamation activities are ongoing today under the state’s control.

The Ridgeway Mine is located in Fairfield County east of Ridgeway, South Carolina. Most recent operations under ownership of Kennecott Ridgeway Mining Company completed in 1999 after 11 years of operation. During this time, approximately 1.5 million ounces of gold was collectively produced from two open pits (Crowl, Hulse, Lane, & Moritz, 2009). Mining operations produced an estimated 60 million tons of tailings, 40 million tons of waste rock and disturbed over 900 acres of land (Rio Tinto, 2013). Today, the mine site appears completely different. Freshwater lakes, wetlands, and a tall grass prairie dominate the land and the site continues to be a model for other mining companies in terms of sustainable reclamation (Rio Tinto, 2013). Reclamation is complete and the site is undergoing post-closure care.

The Haile Gold mine, under ownership of OceanaGold, is the only mine permitted to recover gold ore at this time. It is located northeast of Kershaw in Lancaster County, South Carolina. Like the Barite Hill and Brewer mines, the Haile site has a long history of mining activity but the latest project reveals that it will become the largest gold mining site in the history of South Carolina. The total project area is a reported 4,552 acres with eight open-pits and the capability to process over 7,000 tons of ore per day (U.S. Army Corps of Engineers, 2014). The mining phase is estimated to last 15 years which includes one year of development and pre-production, 12 years of active mining, and two years of active ore processing although these phases may be extended (U.S. Army Corps of Engineers, 2014). This operation is expected to
become a major revenue source for the life cycle of the mine. Aside from the creation of hundreds of jobs, it is anticipated to generate an estimated $70 million in direct and indirect revenue annually for Lancaster County and the state (White, 2016).

**Climate of South Carolina**

South Carolina has a humid subtropical climate, with hot summers and mild to cool winters. The state’s annual average temperature ranges from the mid-50s to low-60’s depending on the region (South Carolina State Climatology Office, n.d.). Average annual precipitation also varies but can range from 42 inches in the middle of the state to 80 inches in the northwest mountainous region, although no month typically averages less than two inches of precipitation in any region of South Carolina (South Carolina State Climatology Office, n.d.). The state may be affected by one or more tropical storms or hurricanes each year. Those that travel inland typically decrease in intensity but are be accompanied by flooding. As a result, overcoming climate barriers in South Carolina is of importance for a mining operation. Many large-scale gold mines in the United States operate in arid or semi-arid climates. South Carolina is unique in that overall precipitation is relatively high and the chances of experiencing extreme weather events related to hurricanes or tropical storms increase. This can lead to a wide range of operational and structural impacts from equipment failure to flooding; therefore, owners must take this into account during mine development and construction of facilities.

**Mining Cycle and Methods**

The modern gold mining industry has developed an intricate operational system. Large-scale mining operations can cost billions of dollars and a number of geologists, engineers, scientists, and regulatory agencies are involved. Reliance on scientific and technological
research is vital in understanding the underlying geologic processes that led to the formation of the ore, which minerals are associated with the ore, and best practices for extraction and site reclamation. The life cycle of a mine can be broken down into four stages: exploration, mine development, extraction, and closure (Figure 2) (McLemore, Smith, & Russell, 2014). Each stage of a mine’s life cycle presents unique challenges, impacted by both uncertainty and adaption to regulatory interventions. This paper briefly describes each stage.

The first step in the life cycle of a mine is exploration. This involves finding a large area of land to support a mining
operation and identifying an ore reserve. A feasibility assessment is also completed during this stage to evaluate whether mining the given area is economically feasible. Modern mapping and remote sensing surveys have made this process somewhat easier but it still requires the collection of huge amounts of data and literature regarding geology, topography, hydrology, climate, resources and reserves, and potential risks associated with mining the site (McLemore, Smith, & Russell, 2014). Exploration for minerals typically occur over many years and several feasibility studies may be conducted to re-evaluate ore reserves as economics change over time (McLemore, Smith, & Russell, 2014).

Once it is deemed feasible for a company to mine, development of the site can begin. Permitting, construction of infrastructure, operational plans, and preliminary closure plans are the primary activities associated with this phase (McLemore, Smith, & Russell, 2014). However, it also builds upon the data collected during the exploration process. If not completed already, baseline conditions at the site are documented and all other data is updated as development and further studies take place. Changes may also be required prior to issuance of a permit in order to meet commercial and industry standards as well as environmental standards.

The operational phase, consisting of ore extraction and processing, can begin once all permits are obtained. Mines in South Carolina use the conventional open-pit method which consists of drilling into and blasting ore. The ore is removed and hauled to a crusher that breaks it into smaller particles. Gold is then beneficiated, or separated from the ore, through a technique known as heap leaching. This involves placing the crushed ore into large piles and spraying cyanide over it, a chemical which bonds with gold. The gold-cyanide solution collects at the bottom of the heap where further processing takes place to separate the gold from the cyanide. This phase can last well over a decade.
Once the mine owner deems that the gold has been depleted to the point of unprofitability or the owner has reached their economic limit, mine closure takes place. Closure of a mine is a critical step which consists of removing mining facilities and reclaiming the land. This takes place over many years and any long-term monitoring of the site can extend this even longer. The post-closure monitoring period for the Haile Mine, for example, is estimated to last 30 years once ore processing is complete (U.S. Army Corps of Engineers, 2014).

**Environmental and Economic Impacts of Gold Mining**

Historically, gold mining has degraded landscapes, contaminated water supplies, and contributed to the destruction of habitat. Although environmental regulations have become more stringent and modern technology is helping move the industry forward, gold mining is still a complex process and challenges are often unique to the location of the mine. This section will provide a brief overview for some of the common environmental concerns related to gold mining activities, referencing specifics from the Brewer, Barite Hill, and Haile Gold mines.

Physical disturbances are often the most noticeable impacts of a mining operation. Large areas of land are rendered unsuitable for agricultural, recreational, industrial, and commercial use for long periods of time due to the relatively long life cycle of a mine. Large waste rock piles and open pits dominate the landscape. Not only are they visually unappealing but it also contributes to destruction and disturbance of habitat, pollution, loss of vegetation and cover, and erosion. At the Haile Gold Mine, for example, excavation of pits and placement of fill material is estimated to have a direct impact on 120 acres of wetlands and open waters and over 26,000 linear feet of streams (U.S. Army Corps of Engineers, 2014). Given this information, it is evident the landscape at the Haile Mine will be impacted and changed permanently even if reclamation activities are successful.
Handling of waste rock is typically the most concerning aspect of gold mining operations. Not only does gold mining produce more waste rock than other mineral mines but gold is often found in rock that contains acid-generating sulfides. For this reason, management of waste rock is of vital importance to the health of the environment. Runoff of acid rock drainage into waterways pose a serious threat to aquatic organisms and migration into groundwater could contaminate drinking water supplies or water used for agricultural purposes (Hudson, Fox, & Plumlee, 1999). In addition, erosion of mineralized waste may result in high metals concentrations in stream sediments and soil. Treating and monitoring this acid mine drainage and metal-bearing water is a challenge. This typically involves reducing acidic conditions by adding a neutralizing agent such as lime but in many cases construction and maintenance of a water treatment facility is required.

Water treatment facilities can present another concern. Treatment plants generate large amounts of chemical precipitates rich in metal hydroxides known as sludge. Options for handling and disposal of the sludge typically include enveloping the sludge in heat-sealed plastic liners or geochemical immobilization in cement (Environmental Protection Agency, 2014). Other times, there may be a market for metal-rich sludge in which it may be dried and sold to an external company. At the Brewer Gold Mine, sludge is dried and moved to a storage pile. However, it has also been subjected to wind erosion increasing contamination of the site by metal-laden fine-grained particulates (Environmental Protection Agency, 2014).

Ore stored on heap leach pads present similar concerns to those of waste rock but with the additional concerns associated with the use of chemicals, primarily cyanide. Cyanide naturally degrades rapidly but acute effects can be lethal should an accidental release occur (Hudson, Fox, & Plumlee, 1999). It is highly toxic to aquatic life and ponds containing cyanide
is a risk for birds or other wildlife that use the contaminated water for drinking or swimming. In addition, as dilute cyanide is dispersed throughout the leach pile it leaves metal-depleted material that must be thoroughly rinsed to ensure removal of chemicals. To prevent leakage of cyanide and other metal-laden fluids into the ground, an impermeable barrier is used, typically consisting of a synthetic or natural clay liner (Hudson, Fox, & Plumlee, 1999).

Mining operators often attempt to mitigate contamination by constructing dams and placing toxic waste inside. Not only does the toxic waste have the potential to seep into soil and groundwater but it can also be accidentally released into the environment causing a catastrophic spill similar to the dam failure at the Brewer Gold Mine in 1990. This spill was a result of heavy rains associated with a tropical storm. Approximately 10 to 12 million gallons of cyanide leach solution flowed into a tributary of Little Fork Creek and eventually the Lynches River (Environmental Protection Agency, 2016). The spill poisoned water supplies, impacted recreational activities, and reportedly killed fish for at least 49 miles downstream (Environmental Protection Agency, 2016).

Gold mining also impacts air quality. In 2010, the EPA recognized gold processing and production facilities as a contributor to mercury air emissions and established emissions limits under the National Emissions Standards for Hazardous Air Pollutants (Environmental Protection Agency, 2010). Bioaccumulation of mercury and mercury compounds are the primary concern. Once mercury deposits into water, it transforms into methylmercury which is a highly toxic form that builds up in fish (Environmental Protection Agency, 2010). It then enters the food chain. In addition, particulate matter is often released in surface mining operations when overburden and vegetation is removed from the site. Exposed soil can become airborne through wind erosion.
Finding ways to effectively mitigate these impacts to the environment is vital. Historically, reclamation plans were largely non-existent. Today, they have become just as important as the operational plans themselves. At a minimum, reclamation plans should include activities such as neutralizing acidic conditions, backfilling pits, treatment of contaminated water, cover of growth medium to support vegetation, and modifying slopes. However, environmental health monitoring is a recurring process and should be thoroughly re-evaluated throughout each stage of the mine cycle. Any issues that arise should be addressed and corrected immediately to prevent further harm.

Federal Policy Governing Mines

Beginning in the 1960s, the Environmental Movement became a landmark moment for policy change in the United States. Congress recognized the impact pollution was having on human health and the environment and the result was revolutionary change in natural resource protection and management. Mining operations have certainly not been excluded. A number of federal laws and regulations have been put into place to ensure mine owners comply with environmental standards and procedures. This regulatory system governs active mining operations as well as the remediation of historic mine sites. The following federal laws directly impact mining operations:

- The Clean Water Act (CWA) establishes water quality standards and regulates discharges of pollutants into surface waters (Environmental Protection Agency, 2016). National Pollutant Discharge Elimination System (NPDES) permits fall under this act which regulates the disposal of water associated with mining activities, storm water runoff, and pumping groundwater to the surface.
- The National Environmental Policy Act (NEPA) establishes rudimentary environmental policies and requires federal agencies to take protection of the environment into consideration during the decision-making process. When federal approval is required for mine operations and permits, NEPA requirements must be met.

- The Clean Air Act (CAA) regulates airborne pollution. Pertaining to the mining industry, efforts to regulate emissions from processing facilities and dust emissions fall under this regulation.

- The Resource Conservation and Recovery Act (RCRA) focuses on preventing the release of hazardous wastes into the environment by management of waste through the “cradle to grave” approach (Environmental Protection Agency, 2016).

- Toxic Substances Control Act (TSCA) focuses on regulating new and existing chemical substances. For the mining industry, any chemical that presents an unreasonable risk to human health and the environment through manufacture, processing, or disposal are regulated under the TSCA (Toxic Substances Control Act, 2011). This includes cyanide used during the leaching process.

- The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), commonly referred to as Superfund, enables the government to clean up hazardous waste sites. CERCLA authorizes the use of special funds, emergency actions and responses, and holding responsible parties accountable for costs associated with clean-up.

**State Policy Governing Mines**

Oversight and enforcement of many environmental regulations have been delegated to the states. States may develop their own set of environmental regulations either equivalent to or
more stringent than federal standards regarding mining activities, hazardous waste management, pollution control, protection of water resources, among many others. Additional requirements are thought to be in the best interest of the state and better fit any unique circumstances such as localized natural resources, geography, or climate.

In 1974, South Carolina passed the South Carolina Mining Act to ensure mined lands protect human health and the environment and that reclamation activities returns the land to a useful purpose. The Act outlines South Carolina’s application process, how to conduct mine operations, and reclamation and bond requirements (South Carolina Legislature, 1990). Permits must be obtained before mining activities take place. This falls under jurisdiction of South Carolina Department of Health and Environmental Control’s (SCDHEC) Division of Mining and Solid Waste Management, Mining and Reclamation Department.

There are two types of mining permits and an exploration certificate issued by the state. An exploration certificate is limited to sites two acres or less but does not apply to an area already covered under a mine permit or for exploration by drilling or geophysical/geochemical sampling (South Carolina Legislature, 1990). A $2500 bond is required before a permit is issued to cover damages that take place during explorative activities (South Carolina Legislature, 1990). Only one permit type applies to gold mining operations in the state. These are known as individual mine permits. Issued for the life of the mine, they are required for sites over five acres and where material processing may occur (South Carolina Legislature, 1990). Reclamation bonds for large-scale gold mines such as the Haile Mine are highly dependent upon projected environmental degradation that may occur at the site.

SCDHEC is authorized to enforce standards through periodic inspections. If deficiencies or concerns are noted, the operator has 30 days to begin corrective actions and complete upon
within a reasonable timeframe established by the state (South Carolina Legislature, 1990). Should corrective actions not meet criteria, the mine owner faces suspension or revocation of the permit as well as legal actions where standards are not met.

The South Carolina Pollution Control Act (PCA), enacted in 1972, is also important in enforcement of mining operations within the state. Most the requirements in the statute are covered in the CWA or CAA, but South Carolina may have additional requirements such as requiring a permit for wastewater treatment plant construction. SCDHEC Bureau of Water Pollution Control issues NPDES permits and enforces CWA standards and SCDHEC Bureau of Air Quality enforces CAA standards.

Managing risks

From the initial stage of exploration through the post-closure period, there are risks associated with operating a gold mine. These may be economic, technological, geological, or even social (McLemore, Smith, & Russell, 2014). Any risk, however, can adversely impact the objectives and outcomes of a mining operation. Today, many tools exist that aid in the process of identifying and measuring risk but finding ways to effectively manage these risks in an industry compounded by uncertainty remains a challenge. The question for a mine owner is how they plan to mitigate, track, and report these risks in a way that supports the operation while maintaining compliance with permit requirements among all other aspects of operating a gold mine.

The answer lies in an integrated approach. Identifying and measuring risks is a recurring process and re-assessment on a periodic basis is needed because hazards can and will likely change. What may be considered an uncertainty in the initial mining stages can quickly turn into a risk in the next stage. These fluctuations can occur at any time throughout a mine’s lifecycle.
Risk assessments measure what can go wrong, the likelihood of it going wrong, and measure the severity of adverse effects (McLemore, Smith, & Russell, 2014). A successful risk assessment is one that either eliminates or reduces a risk to the point the severity level and/or occurrence decreases after monitoring for effectiveness.

There are many types of risk analysis available but one commonly accepted for use by the mining industry is Failure Mode and Effects Analysis (FMEA). This tool was first developed by the US Armed Forces in 1949 to classify failures based upon their mission success and in consideration of personnel and equipment safety (Carlson, 2014). Since then, a wide variety of government and private organizations have adopted FMEA as a standard for determining risk impacts. This analytical tool helps officials identify and rank potential failures of specific processes. Essentially, it works proactively to identify where and how a process may fail so that preventative actions can be taken. The FMEA process can be tailored for additional inputs and has taken on many other forms since its development by the US Armed Forces. The steps according to Giannetti, et al. (2014) follows one of the most basic formats and is as follows:

1. Review process
2. Identify potential failure modes
3. List potential effects
4. Assign severity ranking
5. Assign occurrence ranking
6. Assign detection ranking
7. Calculate RPN
8. Prioritize failure mode for action
9. Take action
10. Recalculate RPN

A risk assessment such as FMEA, however, only provides the foundation. Risk management builds upon the assessment results to determine what options are available based on cost, benefits, and trade-offs (McLemore, Smith, & Russell, 2014). It also helps prioritize management actions. Various strategies to manage risk include avoidance, reducing negative impacts of the risk, transferring the risk to an external party, and even accepting consequences of a risk (McLemore, Smith, & Russell, 2014). Using this integrated approach allows mine owners to reduce liabilities and protect environmental resources (McLemore, Smith, & Russell, 2014). However, risk management is only as good as the information input into the assessment and time and effort of those involved in the process (McLemore, Smith, & Russell, 2014).

It is also necessary to consider outsider’s perceptions of risk. People’s views and reactions to risks and uncertainties is an ongoing process of learning and adapting. Therefore, consistent communication with government agencies and the public is important. This creates a sense of safety and health that is more desirable to citizens, employees, stakeholders, and permitting agencies. The result is a commitment to corporate social responsibility and improved decision-making processes associated with the protection of environmental resources.

III. Research Design

Research Questions

This paper will attempt to answer the following questions:

1. Can the development of a risk analysis based on historic gold mine processes or events mitigate risks for an active or future mine operation?

2. Are there trends associated with historic gold mines operations in South Carolina?
3. Does the Environmental Impact Statement (EIS) of the Haile Mine address necessary precautions to prevent or reduce the risk of environmental contamination that has historically occurred in the state?

**Study locations and timeframe limitations**

To answer the research questions, this paper will focus on the Brewer, Barite Hill, and Haile Gold Mines. The Haile Mine has recently acquired permits that allow mining to take place while the Brewer and Barite Hill sites are currently listed on the NPL Superfund list due to ongoing cleanup and maintenance efforts. Although each mine has been in operation on and off throughout the past two centuries, only the most recent mining operations will be evaluated. The primary reason is that environmental regulations and policies governing mining operations were virtually non-existent until the 1960s. Data prior to this is also lacking and inconsistent with little to no available literature on the environmental impacts of gold mine operations at these specific sites.

**Data Sources**

Documented contamination events, actions that were taken at historic mine sites to prevent or mitigate a potential contamination event, and general gold mining impacts are investigated in this paper. They are assessed through a compilation of historical/archived government reports, official memos, and permit applications for the Brewer and Barite Hill sites. The data collected is of prime importance in determining if there are trends between the mine sites and to create the foundation for the risk analysis. Information regarding the Haile site, on the other hand, is primarily derived from the Final EIS and any associated attachments. These documents provide the most up-to-date information regarding the status of the site.
**Variables**

A risk is the probability of an adverse effect occurring from a process, event, or activity. It measures the likelihood that it will cause an adverse effect and its potential severity. A risk factor is a variable associated with an increased risk of, for purposes of this paper, environmental contamination from a mining operation. This can be any change related to a process or mine-related activity that also causes a change in the probability of risk exposure. Although they are sometimes considered unavoidable, risks are economic and environmental uncertainties that require careful management. For a mine owner, managing risks and determining impacts of changes not only protects company assets but also provides assurance to outside stakeholders, agencies, and the public that systems or plans are in place to reduce risks.

**Software**

To gather and organize data more efficiently, Minitab Inc.’s Quality Companion process improvement software will be used. The built-in FMEA form provides a general template to assist in identifying potential failures and automatically calculates Risk Priority Number (RPN) rates to eliminate error (Minitab, Inc., n.d.). The FMEA form will also provide a visual representation that aids in data organization and easy identification of trends.
Failure Mode Effects Analysis

For purposes of this paper, the FMEA will be formatted as follows:

<table>
<thead>
<tr>
<th>FMEA: Mine Site</th>
<th>Haile Gold Mine</th>
<th>Revised metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process</td>
<td>Failure Mode</td>
<td>Failure Effects</td>
</tr>
<tr>
<td>-----------</td>
<td>---------------</td>
<td>-----------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1. FMEA format

1. Identify the Process or an activity associated with the mining operation.

2. Failure Mode will address specific events that occurred at the Brewer and Barite Hill mines that either caused or had the potential to cause a contamination event.

3. Failure Effects will list the impacts of the failure.

4. Severity Rating (SEV) will be based on the following criteria:

<table>
<thead>
<tr>
<th>Impact of failure mode on the environment and ability to meet environmental standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
</tr>
<tr>
<td>3-4</td>
</tr>
<tr>
<td>5-6</td>
</tr>
<tr>
<td>7-8</td>
</tr>
<tr>
<td>9-10</td>
</tr>
</tbody>
</table>

Table 2. Severity rating criteria

5. Identify Cause or source of failure.

6. Occurrence Rating (OCC) will be based on the following criteria:
Probability of occurrence for failure based on mining technology or methods

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>Impossible violation or failure is projected to never occur</td>
</tr>
<tr>
<td>3-4</td>
<td>Occurrence of failure is rare</td>
</tr>
<tr>
<td>5-6</td>
<td>Occurrence of failure is probable and occurs sometimes</td>
</tr>
<tr>
<td>7-8</td>
<td>Occurrence of failure is highly probable; failure occurs often</td>
</tr>
<tr>
<td>9-10</td>
<td>Occurrence of failure is extremely probable/expected to occur; failure is an ongoing problem</td>
</tr>
</tbody>
</table>

Table 3. Occurrence rating criteria

7. Controls are the corrective actions taken by the Brewer and Barite Hill owners.

8. Detection Rating (DET) will be based on the following criteria:

Detection of source contributing to failure

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>Extremely high detection/control system; detection of source causing failure always identified immediately</td>
</tr>
<tr>
<td>3-4</td>
<td>High detection/control system; detection of source causing failure almost always identified</td>
</tr>
<tr>
<td>5-6</td>
<td>Moderate detection/control system; detection of source causing failure sometimes identified or only identified after violations occurred</td>
</tr>
<tr>
<td>7-8</td>
<td>Poor detection; control measures available but detection of source was rare</td>
</tr>
<tr>
<td>9-10</td>
<td>Extremely poor detection; control measures either non-existent or not followed; source remains unidentified</td>
</tr>
</tbody>
</table>

Table 4. Detection rating criteria

9. The Risk Priority Number (RPN) is calculated as the product of the severity, occurrence, and detection scores. A high RPN indicates that a problem is severe, occurs frequently, and/or has minimal controls in place which calls for immediate attention (Martz, 2015).

\[
RPN = \text{Severity} \times \text{Occurrence} \times \text{Detection}
\]

10. Actions taken at the Haile Gold Mine or projected to take place that addresses the failure mode at the Brewer and Barite Hill sites.

11. Revise Metrics associated with Haile’s actions.
## IV. Risk Analysis

### FMEA: Brewer and Barite Hill

<table>
<thead>
<tr>
<th>Process</th>
<th>Failure Mode</th>
<th>Failure Effects</th>
<th>SEV</th>
<th>Causes</th>
<th>OCC</th>
<th>Controls</th>
<th>DET</th>
<th>RPN</th>
<th>Actions</th>
<th>SEV</th>
<th>OCC</th>
<th>DET</th>
<th>RPN</th>
</tr>
</thead>
</table>
| Mine closure and reclamation | Reclamation of site incomplete or inadequate | Long-term contamination of environment  
Impacts to water quality through acid mine drainage  
Economic constraints associated with clean-up efforts | 10 | Abandonment of mine by owner  
Insufficient bond | 10 | Add to NPL list for clean-up efforts | 1 | 100 | Involvement with local community and government agencies  
Post bond sufficient to cover clean-up costs  
Perform concurrent reclamation | 1 | 1 | 1 | 1 |

Table 5. FMEA for incomplete reclamation
Mine abandonment occurs when an owner leaves the site before acceptable closure and reclamation is complete. There are many factors that contribute to the abandonment of a mine but in South Carolina, it has been associated with a decrease in the price of minerals or other unforeseen circumstances that led to bankruptcy of the mining companies and the subsequent inability to properly close the mine and complete reclamation plans. Furthermore, in the case of the Brewer and Barite sites, financial assurances in the form of environmental bonds were insufficient to cover costs associated with closure and reclamation. This is very unpredictable and mining plans do not typically include measures that address abandonment other than posting a bond. Rather, it is up to state officials to thoroughly review operation and reclamation plans to ensure the bond will cover these costs. Abandonment of the Brewer and Barite Hill mines and their subsequent Superfund site listings have placed severe economic constraints on the state. The longevity of this issue combined with subsequent Superfund listings and economic impacts resulted in a high SEV and OCC rating.

Based on public comments during the Scoping Period, opinions of the gold mine operation widely vary. However, the Haile Mine website states that “working together with local communities and regulatory entities, OceanaGold and the Haile Gold Mine are driving economic growth in the region to an entirely new level while maximizing production and setting new standards for environmental protection” (Haile Gold Mine Incorporated, 2015). They also hold frequent town hall meetings to address the public’s concern. Maintaining involvement with the local community and government agencies will establish a partnership of trust but it still does not guarantee abandonment will not occur. Regarding financial assurances, Haile estimated these costs to be $34,764,979 (U.S. Army Corps of Engineers, 2014). Final bond requirements since the publication, however, is set at $65 million. In addition, the mine owners transferred three
parcels of land totaling 4,374 acres to the S.C. Department of Natural Resources to create and add to wildlife preserves in surrounding counties (S.C. Department of Natural Resources, 2015).

Furthermore, Haile intends to reclaim pits concurrently with mining activities. This practice is not currently required by current regulations. If this is completed, it will decrease the number of pits needing reclaimed should the owners ever abandon the site. Based on the three actions taken by the Haile Mine to ensure site reclamation will occur, the RPN is rated 1 at this time. Re-evaluation throughout the mining stages would be required to determine if changes occur.
<table>
<thead>
<tr>
<th>Process</th>
<th>Failure Mode</th>
<th>Failure Effects</th>
<th>SEV</th>
<th>Causes</th>
<th>OCC</th>
<th>Controls</th>
<th>DETRPN</th>
<th>Actions</th>
<th>Revised metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reclamation</td>
<td>Future use of land restricted</td>
<td>Loss of habitat</td>
<td>8</td>
<td>Designation of Superfund sites/long-term remediation of land required</td>
<td>10</td>
<td>Follow reclamation plan to extent necessary so that future land use is possible</td>
<td>1</td>
<td>80</td>
<td>Future land use is expected upon completion of the reclamation plan for much of the site</td>
</tr>
</tbody>
</table>

Table 6. FMEA for land use
Mining operations can have long-term effects on future land use. Designation as Superfund sites has prevented the Brewer and Barite Hill sites from being re-purposed for other uses that will benefit the local community and the state. Long-term maintenance is required unless the state can successfully find another willing owner to take over maintenance and operation of water treatment plants and the additional rehabilitation of the land. At this time, reuse opportunities available for these sites remain have not been addressed.

According to the EIS, future land use at the Haile site is expected upon successful completion of the reclamation plan for a majority of the land. Future land use is anticipated for agriculture, forestry, commercial, industrial or residential development, or restricted recreational use (U.S. Army Corps of Engineers, 2014). However, two areas within the project area have been identified as having no future purposes due to expected poor quality requiring long-term intervention. These two areas are known as Johnny’s PAG, an area named for potentially acid-generating wastes, and the Duckwood Tailing Storage Facility area which will need to be sustained in a permanent undisturbed condition (U.S. Army Corps of Engineers, 2014). Overburden storage areas may also have limited suitability for future use due to steep slopes after reclamation. At this time, the extent of land use in the future is unknown and largely depends upon successful reclamation with no long-term issues. Goals for re-use of most of the areas, however, slightly lowers RPN.
### FMEA: Brewer and Barite Hill

<table>
<thead>
<tr>
<th>Process</th>
<th>Failure Mode</th>
<th>Failure Effects</th>
<th>SEV</th>
<th>Causes</th>
<th>OCC</th>
<th>Controls</th>
<th>DET</th>
<th>RPN</th>
<th>Actions</th>
<th>Revised metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pit Dewatering</td>
<td>Change of hydrological balance of the water table</td>
<td>Reduction of base flows impacting wetlands  Streams/streamflow alterations</td>
<td>5</td>
<td>Dewatering of pit</td>
<td>10</td>
<td>Monitoring only; pit dewatering considered a necessary action</td>
<td>1</td>
<td>50</td>
<td>Monitoring only; pit dewatering considered a necessary action</td>
<td>10 10 1 100</td>
</tr>
</tbody>
</table>

Table 7. FMEA for hydrological changes
Dewatering is necessary to keep a pit dry enough to mine and is necessary for operation of an open-pit surface mine. As groundwater is pumped out of the pits, groundwater levels often decline. This technique can dry up land, affect well yields of groundwater users and even impact surface waters used for recreational purposes. In theory, this is considered a temporary trade-off. Once pumping stops, the aquifers are projected to recover naturally in the future. There are no mention of long-term impacts from dewatering activities that occurred at the Brewer and Barite Hill sites, resulting in a SEV rating of 5.

Pit dewatering will have significant impacts on wetlands in Haile’s project area. The EIS states that this process will lower the groundwater elevation and reduce baseflows in both the groundwater and surface streams (U.S. Army Corps of Engineers, 2014). Some of these changes, however, will be permanent, resulting in hydrologic changes in the form of loss of wetlands and stream and/or their functions (U.S. Army Corps of Engineers, 2014). Once pumping stops, groundwater will flow through backfilled pits and pit lakes although acidic conditions in disturbed areas will alter groundwater chemistry and water quality. Recovery of groundwater levels may take decades although some areas will never fully recover. Because of this the RPN is rated at a 10. This permanent loss of wetlands was a primary factor in the creation and protection of preserves and wetlands outside the project area as previously mentioned. This shows that Haile assumes full responsibility associated with this risk.
<table>
<thead>
<tr>
<th>Process</th>
<th>Failure Mode</th>
<th>Failure Effects</th>
<th>SEV</th>
<th>Causes</th>
<th>OCC</th>
<th>Controls</th>
<th>DET</th>
<th>RPN</th>
<th>Actions</th>
</tr>
</thead>
</table>
| Ore beneficiation and processing | Spills and leaks through open-air leach pad | Contamination of soils and groundwater by chemicals used in the leaching process  
Contamination by acidic water | 6   | Heap leach pad insufficient | 5   | Fix leaks by making repairs to leach pad | 4   | 120 | Conduct ore processing and beneficiation in large-above ground tanks housed in secondary containment areas |

Table 8. FMEA for leach pads
At the Barite Hill mine agglomerated ore was transported to an asphalt-lined reusable leach pad. The asphalt rested on 12 inches of compacted road base which was laid atop a woven geotextile and compacted soil base (Black and Veatch Special Projects Corp., 2015). Periodic leaks through the asphalt pad did occur (OCC rating of 6). This resulted in the contamination of soils and groundwater by chemicals used in the leaching process. Repairs were required under the direction of SCDHEC’s Water Quality Assessment and Enforcement Division (Black and Veatch Special Projects Corp., 2015). SEV rating of 5 was given due to the fact that repairs were made which prevented long-term degradation.

The Haile Mine, on the other hand, intends to isolate the leaching process. It will be conducted in large above-ground tanks housed in secondary containment areas to prevent spillage in the event of a tank failure (U.S. Army Corps of Engineers, 2014). Not only will this isolate chemicals such as cyanide used in the leaching process, but it will also be more compact which means less physical land disturbance and avoids wetlands and streams (U.S. Army Corps of Engineers, 2014). This process proposal is the first of its kind in South Carolina and eliminates any chances of contamination common to the open-air heap leach process. Based solely on the information and data available at this time, SEV, OCC, and DET rating are each 1.
<table>
<thead>
<tr>
<th>Process</th>
<th>Failure Mode</th>
<th>Failure Effects</th>
<th>SEV</th>
<th>Causes</th>
<th>OCC</th>
<th>Controls</th>
<th>DET</th>
<th>RPN</th>
<th>Actions</th>
<th>SEV</th>
<th>OCC</th>
<th>DET</th>
<th>RPN</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPDES permit compliance</td>
<td>Exceedance of standards resulting in effluent and metals violations</td>
<td>Contamination of surface waters, Reduction/elimination of aquatic life in surface waters</td>
<td>8</td>
<td>Effluent violations due to erosion</td>
<td>8</td>
<td>Identify and correct sources associated with violations</td>
<td>5</td>
<td>320</td>
<td>Meet NPDES permit requirements</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 9. FMEA for effluent and metals violations
Per a consent order, the Barite Hill Mine owners violated a NPDES permit that authorized the discharge of stormwater runoff and process wastewater into a tributary of Hawe Creek. In total, three Notice of Violations were issued by SCDHEC between 1995 and 1997 for failure to meet limits of total suspended solids, ammonia-nitrogen, pH, copper, zinc, and other heavy metals (South Carolina Department of Health and Environmental Control, 1998). Owners of the mine addressed each violation and identified potential sources. These include release of water via overflow due to a high precipitation event, seeps from a stormwater pond, agricultural lime used to inhibit the leaching of metals from soils by overland flow of rain water, erosion of access roads, leaching of metals from soils by precipitation, fertilizer applications used in the reclamation process and contamination of a haul road from truck traffic during reclamation of a process heap (South Carolina Department of Health and Environmental Control, 1998). These violations caused contamination of surface waters and a reduction of aquatic life in the impacted streams, resulting in SEV rating of 8. OCC rating of 8 was given due to the amount of violations. A higher rating was not given because sources or causes were not repeated.

It is of importance to also note that the lowest achievable background level for copper was higher than NPDES permit limits set at an average of 0.02035 mg/l and a daily maximum of 0.02871 mg/l (Filas & Wilkinson, 1988). It was suggested by mine personnel that higher background copper concentrations may be typical of the site where measurements were taken (Filas & Wilkinson, 1988). This violation could have been eliminated by collecting background data for storm water levels during the exploration and development phases.

The Haile Mine has provided several water quality assurances to permitting officials that ensure compliance with the water quality standards. Under normal operating conditions, the effluent would not exceed permit limits. However, the EIS also suggests that long-term
monitoring would be required to identify potential water quality violations during mining operations and especially during the post-mining period where cyanide will be treated and discharged (U.S. Army Corps of Engineers, 2014). The Haile Mine meets permit requirements at this time, resulting in a SEV rating of 1. An OCC rating of 5 was given because there is no guarantee outlined in the EIS that effluent violations will not occur during the post-mining stage.
<table>
<thead>
<tr>
<th>Process</th>
<th>Failure Mode</th>
<th>Failure Effects</th>
<th>SEV</th>
<th>Causes</th>
<th>OCC</th>
<th>Controls</th>
<th>DET</th>
<th>RPN</th>
<th>Actions</th>
<th>SEV</th>
<th>OCC</th>
<th>DET</th>
<th>RPN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sediment control</td>
<td>Contamination of sediments</td>
<td>Contributes to poor water quality</td>
<td>7</td>
<td>High metals concentrations in sediment associated with mining activity and storm water runoff</td>
<td>10</td>
<td>Identify source of sediment contamination; Meet state requirements for storm water management and sediment and erosion control measures</td>
<td>3</td>
<td>210</td>
<td>Meet state requirements for storm water management and sediment and erosion control measures</td>
<td>1</td>
<td>9</td>
<td>1</td>
<td>9</td>
</tr>
</tbody>
</table>

Table 10. FMEA for sediment contamination
Contaminated sediment is a common pollutant and may contribute to poor water quality in tributaries and streams at and near the Barite Hill Mine. Sediment samples collected in 2004 by SCDHEC tested at least three times greater than levels of metals that naturally occur in the area for arsenic, barium, cadmium, copper, lead, and zinc (Agency for Toxic Substances and Disease Registry, 2011). Sediments analyzed by the EPA in 2007 and 2011 showed similar metal contaminants but with varying concentrations (Black and Veatch Special Projects Corp., 2015). The source is believed to be storm water runoff. Controls included identifying sources and continuing to meet state requirements for storm water management and sediment and erosion control measures. SEV rating of 7 was assigned because contaminated sediment is a contributing factor to poor water quality in tributaries and streams and an OCC rating of 10 was assigned because it is an ongoing issue.

Runoff related to construction and operation of facilities at the Haile Mine may increase sediment-associated pollutant loading to tributaries and streams (U.S. Army Corps of Engineers, 2014). This will be mitigated by use of a sediment detention pond and by following state-required storm water management and sediment and erosion control measures to minimize negative impacts. The biological condition of streams, however, are expected to decline due to sediment loading (U.S. Army Corps of Engineers, 2014). Due to requirements being met at this time, the SEV rating is low but the OCC is rated high due to the fact that sediment loading is expected to occur in the EIS.
### FMEA: Barite Hill

<table>
<thead>
<tr>
<th>Process</th>
<th>Failure Mode</th>
<th>Failure Effects</th>
<th>SEV</th>
<th>Causes</th>
<th>OCC</th>
<th>Controls</th>
<th>DET</th>
<th>RPN</th>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protect ecological resources</td>
<td>Mining activity negatively impact ecological resources</td>
<td>Decrease in fish, macroinvertebrates, and benthic organisms Mortality of biota</td>
<td>10</td>
<td>10</td>
<td></td>
<td>Determine source of seeps and catch and treat prior to discharging into surface waters Conduct regular biological monitoring of tributaries and streams</td>
<td>5</td>
<td>500</td>
<td>Minimize impacts to aquatic life Monitor biological conditions of tributaries and streams</td>
</tr>
</tbody>
</table>

Table 11. FMEA for ecological resource impacts
Poor quality of surface waters is a significant concern at the Barite Hill Mine. Seeps and storm water runoff consisting of contaminated and acidic water have led to a decrease in fish, macroinvertebrate, and benthic organisms. This issue continues to this day as a Superfund site. Controls have included determining source of seeps and treating them prior to discharge into surface waters as well as surveys to monitor biological conditions.

It is expected that similar occurrences will occur at the Haile site. According to the EIS, biological conditions of several streams and tributaries are expected to decline to a state of “fair” or “poor” (U.S. Army Corps of Engineers, 2014). In addition, it is expected that one stream will be completely cut off from the upper region of the stream disallowing fish to move back and forth (U.S. Army Corps of Engineers, 2014). At this time, the impacts are related to site excavation and construction of the mine which will reduce or dramatically alter existing habitat rather than acid mine drainage since active mining has not yet begun. Re-evaluation once ore processing takes place can provide more accurate results.
### Table 12. FMEA for dam failure

<table>
<thead>
<tr>
<th>Process</th>
<th>Failure Mode</th>
<th>Failure Effects</th>
<th>SEV</th>
<th>Causes</th>
<th>OCC</th>
<th>Controls</th>
<th>DET</th>
<th>RPN</th>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water treatment and processing</td>
<td>Dam failure</td>
<td>Contaminated water entered Little Fork Creek and Lynches River. Fish killed downstream</td>
<td>10</td>
<td>Overflow pond capacity insufficient for large rain event and storm water runoff</td>
<td>4</td>
<td>Re-design and reconstruct dam for additional capacity levels</td>
<td>1</td>
<td>40</td>
<td>100 year FEMA zone “A” floodplains indicates a low chance of inundation of the site/flow for 100 year flood event of Little Lynches River is 4 feet below surface elevation of mining activities in project area</td>
</tr>
</tbody>
</table>

Table 12. FMEA for dam failure
On October 28, 1990, a dam failure occurred at the Brewer Mine after heavy rains caused a buildup of water in an overflow pond (Sirrine Environmental Consultants, 1990). Approximately 10 million gallons of water contaminated with cyanide and copper was released into the Little Forks Creek (Sirrine Environmental Consultants, 1990). Contaminated waters eventually reached the Lynches River. Emergency actions were required to contain the embankment and prevent further release of water. A survey conducted by Fish and Wildlife officials determined that multiple fish species were killed up to 50 miles along the Lynches River with 200 – 300 fish observed dead as a result of the release (Smith, 1990). The mine resumed normal operations after reconstruction and design of the overflow pond and dam were complete.

Annual precipitation in the project area is relatively high and heavy rains due to a hurricane or tropical storm has historically occurred. The Haile Mine asserts the probability of facility failures, tailings dam failures, or flooding of facilities and pits from extreme precipitation events is very low (U.S. Army Corps of Engineers, 2014). Based on information provided in the EIS, all critical system components have been designed to withstand and accommodate maximum storm events (U.S. Army Corps of Engineers, 2014). In addition, it takes into account FEMA’s floodplains designations. The project area is located in the FEMA zone “A” which indicates a low chance of inundation of the site and flow for a 100-year flood event of Little Lynches River is four feet below the surface elevation of mining facilities (U.S. Army Corps of Engineers, 2014). Given the information available, risk for a dam failure associated with a high precipitation event is low; however, the SEV rating is not 1 because the EIS does not appear to address a contingency plan should a high rain event threaten dam performance.
<table>
<thead>
<tr>
<th>Process</th>
<th>Failure Mode</th>
<th>SEV</th>
<th>Causes</th>
<th>OCC</th>
<th>Controls</th>
<th>DET</th>
<th>RPN</th>
<th>Actions</th>
<th>SEV</th>
<th>OCC</th>
<th>DET</th>
<th>RPN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wastewater treatment</td>
<td>Long-term or indefinite treatment of water required beyond reclamation</td>
<td>8</td>
<td>Owner abandoned mine prior to reclamation being completed</td>
<td>10</td>
<td>Emergency action from EPA to take over maintenance and operation of the treatment plant</td>
<td>1</td>
<td>80</td>
<td>Plan to eventually eliminate need for a wastewater treatment plant upon closure and mine reclamation but will still require long-term monitoring</td>
<td>5</td>
<td>8</td>
<td>1</td>
<td>40</td>
</tr>
</tbody>
</table>

Table 13. FMEA for long-term water treatment
Upon mine abandonment, the Brewer Mine’s wastewater treatment plant was left with no monitoring or ongoing maintenance. Emergency action was required to ensure continued treatment of contaminated groundwater and surface waters. As a result, the state requested assistance from the EPA which took control of the plant under CERCLA removal authority (Environmental Protection Agency, 2016). It is now operated under EPA’s Remedial Program so that a permanent solution can be explored. At this point, remedial actions that have been taken prevent most impacts to Little Fork Creek although annual macroinvertebrate sampling was discontinued and weekly effluent sampling was reduced to monthly sampling in order to reduce costs (Environmental Protection Agency, 2016). Furthermore, the pump-and-treat wastewater system was constructed of salvaged parts and is not equipped to remain in operation. A new treatment system is required in which maintenance and operation costs will substantially rise. Other solutions are being explored but continued operation of a waste water plant is long-term.

The Haile Mine will also operate a treatment plant during active mining operations to treat contaminated groundwater and surface waters. Reclamation plans indicate that flows from water treatment are expected to decline during post-mining period to the point that water could be treated passively in treatment cells (U.S. Army Corps of Engineers, 2014). Any water released through the treatment cells will meet water quality standards in accordance with a NPDES permit. This is expected to occur in year 20 of the mine cycle and long-term monitoring would persist up to 30 years later if necessary (U.S. Army Corps of Engineers, 2014). As a result, the revised metrics are based on the assumption that mine abandonment will not occur prior to the switch from the treatment plant to passive treatment cells. The fact that it is long-term treatment raises the SEV and OCC ratings.
<table>
<thead>
<tr>
<th>Process</th>
<th>Failure Mode</th>
<th>Failure Effects</th>
<th>SEV</th>
<th>Causes</th>
<th>OCC</th>
<th>Controls</th>
<th>DET</th>
<th>RPN</th>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water treatment and processing</td>
<td>Contaminated water reaching tributaries and streams</td>
<td>Impairment of surface waters</td>
<td>8</td>
<td>Acidic water reaching Little Fork Creek through seeps</td>
<td>10</td>
<td>Control contaminants released to surface water</td>
<td>5</td>
<td>400</td>
<td>Identify sources of contamination</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Exposure of contaminants to macroinvertebrates and fish</td>
<td></td>
<td>Reclamation not complete due to mine abandonment</td>
<td></td>
<td>Control contaminants released to surface water</td>
<td></td>
<td></td>
<td>Control contaminants released to surface water</td>
</tr>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td>Perform concurrent reclamation</td>
<td></td>
<td></td>
<td>Perform concurrent reclamation</td>
</tr>
</tbody>
</table>

Table 14. FMEA for contamination of surface waters
Occurrence of metal and acid-contaminated seeps prior to and during the reclamation phase were common to the Brewer Mine. A seep at the east end of a pit known as B-6 discharged poor quality water at a three-year average rate of 118.8 gallons per minute (Environmental Protection Agency, 2016). Another seep, termed the “upper seep”, flowed at 10 gallons per minute and began to flow after a drainage tunnel portal was plugged during backfilling of the main Brewer pit while the “lower seep” had reportedly been active prior to reclamation activities (Environmental Protection Agency, 2016). These seeps were contributing to poor water quality in Little Fork Creek. Upon the EPA taking control of the treatment plant, capturing and treating seeps became a priority.

While it is difficult to predict contamination associated with seeps at this time, the Haile Mine intends to conduct concurrent reclamation. This means that some areas will be reclaimed as soon as mining activity in that given area is complete but before completion of ore processing (U.S. Army Corps of Engineers, 2014). This will allow for better identification and treatment of seeps before reclamation plans for the site as a whole begins. It will also allow for a longer monitoring period to ensure contaminated seeps are captured and treated before reaching surface waters. The revised metrics are based on the assumption that mine abandonment will not occur during the reclamation phases and that the practice of concurrent reclamation is not a requirement set forth in any federal or state policies associated with gold mining operations.
V. Discussion

Trend Results

Gold mining in South Carolina has caused environmental legacy issues as suggested by the Superfund listing of the Brewer and Barite Hill Mine sites. Investigating causes and impacts of contamination events led to the conclusion that there are trends associated with environmental degradation in the state. These are apparent in the form of repeated standards violations, ongoing contamination concerns, or a commonality between the two Superfund sites. It omits any one-time events such as the dam failure at the Barite Hill Mine. Identified trends are as follows:

- Insufficient financial assurances posted by the owners of the Brewer and Barite Hill mines
- Mine abandonment of two out of the four total sites in the state based on most recent mining operations
- Long-term management of land required with no reuse opportunities
- Ongoing water quality issues require long-term operation of water treatment system
- Seeps causing impairments of local tributaries and streams
- Decreased abundance of aquatic life associated with poor water quality in tributaries and streams

FMEA Results

The FMEA for general mining activities that occurred at both the Brewer and Barite Hill sites puts the vastness of the Haile project into perspective. It shows that it can be a high-risk venture with many uncertainties. The Haile project is unique within the state and uses modern mining practices that were not used at the Brewer and Barite Hill sites. Based on information in
the EIS, the owners take full responsibility for issues such as loss of wetlands and streams from fill material, long-term impact of dewatering activities, and impacts on fish and other aquatic organisms. However, where it has taken, it has plans to give back by providing protection for other areas in the state and projecting re-use of the land upon successful reclamtion.

Results from the general analysis indicate that the greatest risk for long-term impact is associated with pit-dewatering. The RPN of 100 shows that permanent changes in the hydrology of the site is a high-risk “failure”. This is followed by land-use restrictions with an RPN of 63. Although slightly lower than the RPN for the Brewer and Barite Hill sites, it indicates that gold mining has long-term impacts associated with future land use and the Haile Mine could possibly repeat this “failure”. The RPN of 1 for incomplete reclamation, on the other hand, suggests that there is no concern or that it will likely not be repeated. However, this rating is based on the actions being taken at the Haile Mine to prevent inadequate or incomplete reclamation of the site at this time. More accurate risk results would require re-evaluation in later stages of the mine cycle.

The FMEA for the Barite Hill Mine reveals that Haile’s methods significantly decreases re-occurrence of similar contamination events. This is based solely on the RPN. Isolating the ore beneficiation process virtually eliminates leaks that would otherwise occur with an open-air heap leach pad. It is difficult to predict, however, if issues unique to this technique will arise later in the mine cycle as this is the first time a mine in South Carolina has proposed use of above-ground tanks. Compliance with water quality and sediment control standards are also extremely low risk at this time. Periodic re-evaluation once ore processing begins will provide more accurate results.
Ecological resource protection, however, is a concern. The RPN decreases from 500 at the Brewer and Barite Hill mines, assigned for the declined presence of macroinvertebrates and fish species in surrounding tributaries and streams, to 100 for the Haile Mine. While impacts have not yet occurred, it is expected that mine development and construction will result in the loss of wetlands and streams. Should acid-mine drainage become an additional concern, this RPN is likely to increase to a rating similar to the Brewer and Barite Hill mines.

Events at the Brewer Mine primarily focus on water treatment and processing. The risk analysis shows that the highest risk for a repeat event is related to the long-term or indefinite treatment of contaminated water. The Haile Mine acknowledges that long-term treatment of water will be required but the full extent will not be known until the ore processing stage and concurrent reclamation activities take place. Therefore, re-evaluation of this potential risk is required. In addition, the possibility of a high precipitation event occurring at the Haile Mine over the life cycle of the mine is high but the overall RPN for dam failure remains very low. This is attributed to Haile’s infrastructure, the low risk of flooding based on floodplains maps, and the Brewer dam failure being considered a one-time event. Ultimately, this analysis indicates that there is a low risk of a repeat dam failure occurring at the Haile Mine.

Limitations

Two primary limitations have been identified throughout the risk analysis process. The first is that facilities and critical functions at a mine site operate as a system. As a result, many events and trends identified during the FMEA process overlap with one another. This made it more challenging to assess each issue individually. In addition, the Haile EIS is written in a way that assumes mitigation plans aimed at minimizing environmental impacts will result in a successful outcome and will adequately address long-term maintenance and monitoring. The
Haile Mine anticipates post-monitoring to virtually end at year 50 per the mine’s timeline. Given the nature of the Brewer and Barite Hill sites, it is difficult to assume that a mine site with this scale of an operation will not experience unpredicted impacts that require additional remediation measures. For the most successful and informative outcome, re-evaluation of the “failures” are essential once the Haile Mine begins ore processing.

**Conclusion**

This paper has compiled and presented historical events and trends associated with gold mining in South Carolina. A key focus was placed on environmental impacts and to a lesser extent, economic-related issues of an abandoned mine. The risk analysis shows that the state has struggled to protect its water resources from gold mining activity and insufficient financial assurances significantly limited resources available for clean-up efforts. The NPL listing of the Brewer and Barite Hill sites, however, offered an opportunity to gain a better understanding of the environmental concerns associated with gold mining. The Haile Mine is using improved technology to mitigate environmental harm and state requirements appear to be more stringent. The challenge now is for South Carolina to continuously build upon their policies to promote environmentally sound mining techniques. This paper established a foundation to assist in that process. Recurring risk analyses and identification of trends will allow the state to better predict, plan for, and minimize risks as mining operations and technology move forward.
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