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Fall 2016

# A Protocol for Reclaiming In-Pit Tailings Ponds to Exceed Federal and State Regulations

John Seifert  
*Montana Tech*

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# A Protocol for Reclaiming In-Pit Tailings Ponds to Exceed Federal and State Regulations

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John Seifert, Montana Tech, Butte, MT

Paul W. Conrad, Montana Tech, Butte, MT

Charles Smith, Premier Silica, Voca, TX

Scott Rosenthal, Montana Tech, Butte, MT

Larry Hunter, Montana Tech, Butte, MT

## Abstract

*The goal of the protocol for reclaiming in-pit tailings ponds to exceed federal and state regulations was to develop a series of steps that can be followed to design, operate, and reclaim a tailings disposal pond that will develop into grazing land with a wetland for open pit sand mines in warm dry climates. By incorporating a wetland into the reclamation design, the post mining land use gives back to both the wildlife as a source of water as well as providing for a diverse range of post mining land use including but not limited to livestock grazing and ranch land use. An example design was completed using this protocol to demonstrate how the protocol can result in a well-designed, reclaimed tailings disposal pond.*

**Keywords:** In-pit Tailings Pond, Wetland, Tailings Deposition, Highwall Shaping

## List of Acronyms

The following acronyms are used through-out this paper:

Cubic Yards	yd <sup>3</sup>
Micrometers	μm
Horse Power	HP
Gallons Per Minute	GPM
Feet	ft
Square Feet	yd <sup>3</sup>
Mean Sea Level	MSL
Surface Mining Control and Reclamation Act of 1977	SMCRA

## Background

In an industry plagued with decaying historic mine sites, the public's perception of mining appears to be poor. While modern mines are closely monitored and generally managed by ethical professionals, history still influences how the public perceives the mining industry. From collapsing abandoned underground workings to historic tailings dam failures, the failure to account for the environment in the past seems to affect public perspective on mining today. In a 2013 "Opinion Former Survey," a survey conducted through interviews with a diverse range of stakeholders in various gold companies, it was noted that the most serious challenges facing the mining industry were environmental concerns and the permitting challenges associated with them (Council). In another article, this time focusing on Australian citizens and their perspectives of the mining industry, it was found that the majority of those surveyed had a big concern over the environmental impacts of mining especially when it comes to water quality and quantity (Scan). The statistics portrayed in these articles illustrate that today's mining engineers needs to make more of an effort to change the public's perspective of mining by being more environmentally aware. These engineers should be continuously asking themselves what they could be doing better from an environmental perspective to ensure that history is not repeated and that natural resources are used as efficiently as possible.

## Introduction

While there are many specific areas that mining engineers could focus on, this paper focuses on a protocol for the design, operation, and reclamation of in-pit tailings ponds for open pit sand mines in warm dry climates. This protocol is designed to help meet or exceed federal and state regulations. The Surface Mining Reclamation and Control Act of 1977 is the federal governing legislature; however, this act does not cover surface metal/non-metal mines. Many states have additional regulations that must be adhered to. These additional regulations will vary from state to state and are often enforced by a state's Department of Environmental Quality. This type of tailings pond has many advantages including but not limited to, abandoned pits being filled at a fraction of the cost of traditional backfilling, reducing reclamation costs, and the risks sometimes associated with tailings dam embankment instability are eliminated. Some disadvantages of this approach include tailings levels rising faster than anticipated leading to poor sediment deposition in the beginning stages of the pond, poor deposition resulting in surface deformation after the pit has been filled, and losses in water due to in-situ rock absorption and evaporation to the atmosphere (Tailings Info).

The protocol discussed in this paper will present the steps to design, implement, and reclaim an in-pit tailings disposal pond that includes a wetland with the following conditions:

- Sand and Gravel Deposit is composed primarily of quartz-silica
- Climatic conditions considered to be hot and have an annual precipitation of less than 30 inches (WeatherDB)
- Mine operations located in the South Central United States
- Processing plant discharge is a slurry
- Processing plant discharge does not contain chemicals
- Primary proposed post-mining land use is ranch land
- Reclamation plan includes construction of a wetland
- Use of a nearby freshwater holding pond

Using this protocol, an engineer can design, operate, and reclaim an in-pit tailings pond in a way that is environmentally conscientious. By incorporating a wetland into the reclamation design, the post mining land use gives back to both wildlife as a source of water as well as providing a diverse range of post mining land use including, but not limited to, livestock grazing and ranch land use. While this may seem like a narrow scope, the map shown in Figure 1 depicts every Frac Sand Mine in the United States. While the mines encompassed in the red outline meet the majority of the previously stated conditions, all of these mines may benefit from this protocol (Ted Auch).

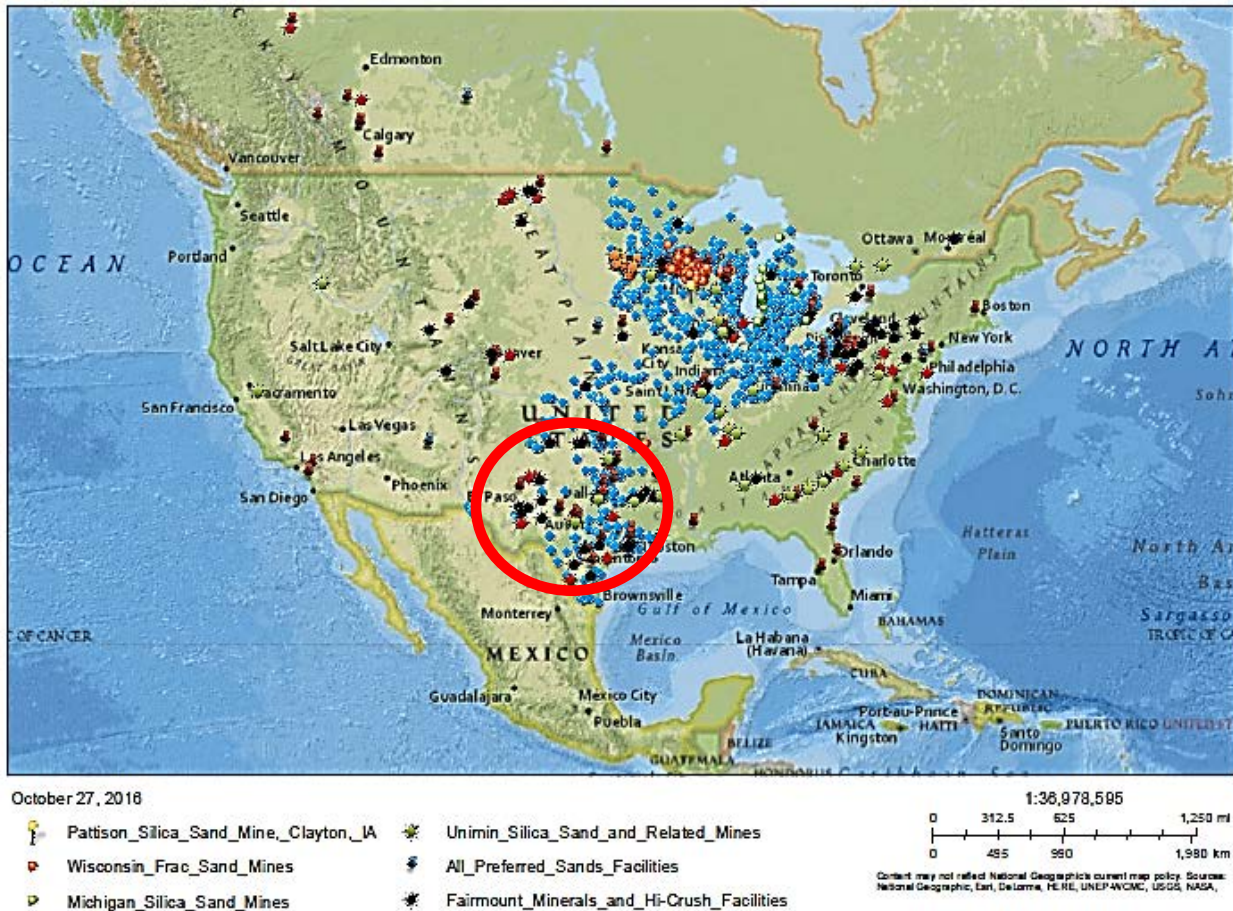


Figure 1 - North America Frac Sand Mines

## Methodology

The proposed protocol for creating a reclamation plan that can be used to design, operate, and reclaim an in-pit tailings disposal pond that includes a wetland consists of the following stages:

- Data Collection
- Tailings Deposition
- Highwall Shaping
- Freshwater Management
- Top Soil Placement
- Seeding
- Associated Costs

### Data Collection

The first step of tailings pond design is data collection. For an in-pit tailings pond, the data that needs collected includes mine parameters, tailings specifications, and pump specifications. The parameters needed include:

- Type of Mine
- Location of Mine
- Annual Mine Production
- Mine Permit Constraints
- Composition of Gravel Deposit
- Composition of Waste
- Empty Pit Dimensions and Drawings
- Processing Plant Recovery
- Chemicals Used in Processing the Deposit
- Top Soil Availability
- Post-Mining Land Use

The tailings specification parameters needed when designing an in-pit tailings pond include:

- Tailings Composition
- Slurry Percent Solids
- Slurry Particle Size Distribution

Two types of pumps are required: a slurry pump and a standard water pump. For the example design discussed in this paper, two slurry pumps and three freshwater pumps are used. Pump manufacturer's specifications dictate pumping limitations (i.e. flow rates) as well as pumping costs.

### Tailings Deposition

Once all of the required background information has been collected, the next step in developing a design for an in-pit tailings pond is to prepare a tailings deposition-staging plan. This staging plan should reflect the steps used to determine the best possible tailings deposition design to meet the goals for the

pond. The empty pit dimensions, properties of the tailings, and in-situ water level will dictate the number of stages required for each specific pit. Regardless of the number of stages required, the first stage will always be to determine the final grade.

The final grade will guide the engineer in developing the stages to fill the pit to meet that final grade. The following factors need to be considered when determining the final grade:

- A. Location of the wetland pond
- B. Surface grade of the deposited tails
- C. Final grade of filled in pit

To determine the location of the wetland pond, two main factors must be considered: the empty pit dimensions and the ground water level. The engineer must first identify the high spots and low spots along the top of the empty pit's highwalls as well as throughout the bottom of the pit. Low spots along the highwall help the designer identify choke points that will limit the amount of tailings that can be deposited in specific areas of the pit. The low spots throughout the bottom of the pit will dictate where water will initially pool. The designer can use this information to determine the location of the wetland pond. The goal for determining this location is to remove as many choke points as possible, limiting water pooling in as few places as possible during the tailings deposition process. A good rule of thumb is to start with the pond in the section of the highwall that is at the lowest in elevation.

The next step is to determine the surface grade of the deposited tailings once decanted. Tailings composition is the key component to determining this. The tailings composition determines if a liner is needed to prevent toxic substances from permeating into ground water and how the solids will settle out of the slurry. Slurry percent solids determines the amount of water to be pumped from the tailings pond as it fills with solids. Pumping also impacts particle settling in the tailings pond. The faster the tailings are flowing, the longer the solids within the slurry will take to settle out. While particle size distribution affects the surface slope of the deposited solids and the rate at which the solids settle out of the slurry, the slope can also be determined from a nearby tailings pond that uses the same tailings slurry. If a nearby tailings pond that utilizes the same slurry as what is to be used in this pond is not available, testing will be needed to determine how the tails distribution.

Once the final grade of the deposited tailings has been determined, the remaining stages can be developed. Each stage will represent one tailings discharge point. From each discharge point, the tailings will deposit in a conical manner at the previously determined slope. To limit the amount of iterations, it is recommended that the first discharge point be located on a section of the highwall that has one of the highest elevations and is furthest away from the deepest point which will become the wetland pond. This allows for the maximum amount of tailings to be deposited from the first discharge location. The highest possible elevation of the tailings at this location will be dictated by the final grade. Using this, the grade of the deposited tailings can be determined and the amount of tailings that can be deposited can be calculated. The remaining stages are determined in the same manner with each stage representing a tailings discharge location. Placing the discharge locations of each stage at the highest highwall elevation nearest the previous discharge point will maximize the capacity of the tailings pond.

Developing these stages can be an iterative process to determine the appropriate sequencing of discharge locations to construct the designed final grade.

## **Highwall Shaping**

In situations where the deposited tailings do not reach the top of the highwalls, shaping will be necessary to keep both animals and people from falling off the edges of the highwall. The shaping should be done at a slope of 3 horizontal feet to 1 vertical foot to reduce the vertical drop along the highwalls. Waste material is recommended to be used for this process; however, any material may be used. Using waste material for this shaping will reduce the need for waste material stockpiles throughout the mine site. The shaping can also be broken down into stages. Staging the shaping eliminates highwalls in areas of the pit as they are filled to their respective capacities.

## **Water Plan**

To save and recycle as much water as possible, a water management plan needs to be developed. The first step in developing this plan is to determine the pump set-up. This can vary from having one pump to having multiple pumps within the tailings pond. Pump set-up must be able to handle, at a minimum, the water being pumped into the tailings pond as slurry. Due to the wetland pond being a low spot within the area, water accumulated during storm events will collect in the pond. The second step of the plan is to determine where the final freshwater location. As previously discussed, a freshwater pond should be located nearby. This pond will most likely be the final destination of the nearly sediment free water removed from the tailings pond. By pumping the water right away to the pond, the rate at which the water is lost in the tailings disposal process will be decreased. Pumping reduces the exposed surface area of water to the atmosphere, reducing evaporation losses. The final step of the water plan is to determine the location of the pump set-up and the associated utilities. The location may vary throughout the life of the tailings pond, especially in beginning of the tailings deposition process. If the pumping location varies, it will be dictated by the topography of the bottom of the pit as well as the tailings deposition plan.

## **Top Soil Placement**

The process of capping the deposited tailings is relatively simple. A minimum of 6 inches of top soil is recommended to be spread across the entire surface area of the final tails surface (Congress). Using the depth of the top soil and the surface area of the final tailings surface including highwall shaping, the amount of top soil needed can be obtained. The next step is to determine the source of this material. It is expected that the topsoil from mining the pit will have been stockpiled nearby and that there will be enough material to meet the amount needed for the capping process. If this is not the case, top soil will need to be brought in from on site or from an outside source. Federal regulations do not require dust control however some states do. If dust control is required, the top soil is to be spread as soon as each stage of the highwall grading process has been completed.

## **Seeding**

Seeding the area can be divided into two parts: the wetland area and the non-wetland area. If there are wetland areas nearby, seeding of the wetland area may not be necessary. Seeds of wetland species of

vegetation may travel through natural causes to the newly created wetland. If there are no wetland areas nearby, seeding of the wetland will need to be completed and must meet both federal and state regulations. For the non-wetland area of the reclaimed tailings pond, the seeding will need to be compatible with the post-mining proposed land use as well as what is required by federal and state regulations. For example, if the post-mining land use is livestock grazing, a perennial pasture seed mixture is recommended. Many different seed mixtures can be considered, therefore, choosing the correct seed mix will depend on regulations, climate conditions, and the animal species that will be grazing. It is important to take note of recommended seed maintenance strategies to ensure optimal growth. Not only will the vegetative cover provide for future land use, the vegetation will also prevent erosion during peak runoff periods. If dust control is required, the seeding will be conducted in conjunction with the top soil spreading.

### Costs

Each section of the design has an associated cost. The tailings deposition process’s cost includes the cost associated with pumping the slurry from the processing plant to the tailings pond. If slurry pumps are not already in use on site, the cost will need to include acquisition and installation of the pumps, necessary piping, and diesel or electrical related costs. The fresh water pumping costs will include the cost of pumping the nearly sediment free water from the tailings pond to the fresh water pond. If those pumps are not already in use on site, their costs will need to include acquisition and installation of the pumps, necessary piping, and diesel or electrical related costs. The costs associated with the highwall shaping as well as the top soil grading will include the cost of operating the equipment, including labor. Seeding costs will be obtained from a seed supplier.

### Example Design

The following design was developed using the proposed protocol. It is for an open-pit frac sand mine located in the South Central United States.

### Data Collection

The following mine parameters were collected for this design:

Mine Type	Sand
Mine Location	South Central United States
Mine Production	1,100 Tons per Hour
Mine Permit Constraints	None
Deposit Composition	Quartz-Silica
Waste Composition	Quartz-Silica
Recovery	43%
Chemicals Used	None
Top Soil Availability	Nearby Stockpiles
Post-Mining Land Use	Ranch Land (Grazing)
Tailings Discharge	1,657,000 yd <sup>3</sup> of solids per year



The following tailings specifications were collected for this design:

Tailings Composition:	Quartz-Silica Sand
Slurry Percent Solids:	<10%
Slurry Particle Size Distribution:	149 $\mu\text{m}$ to 2380 $\mu\text{m}$

The following pump specifications were collected for this design:

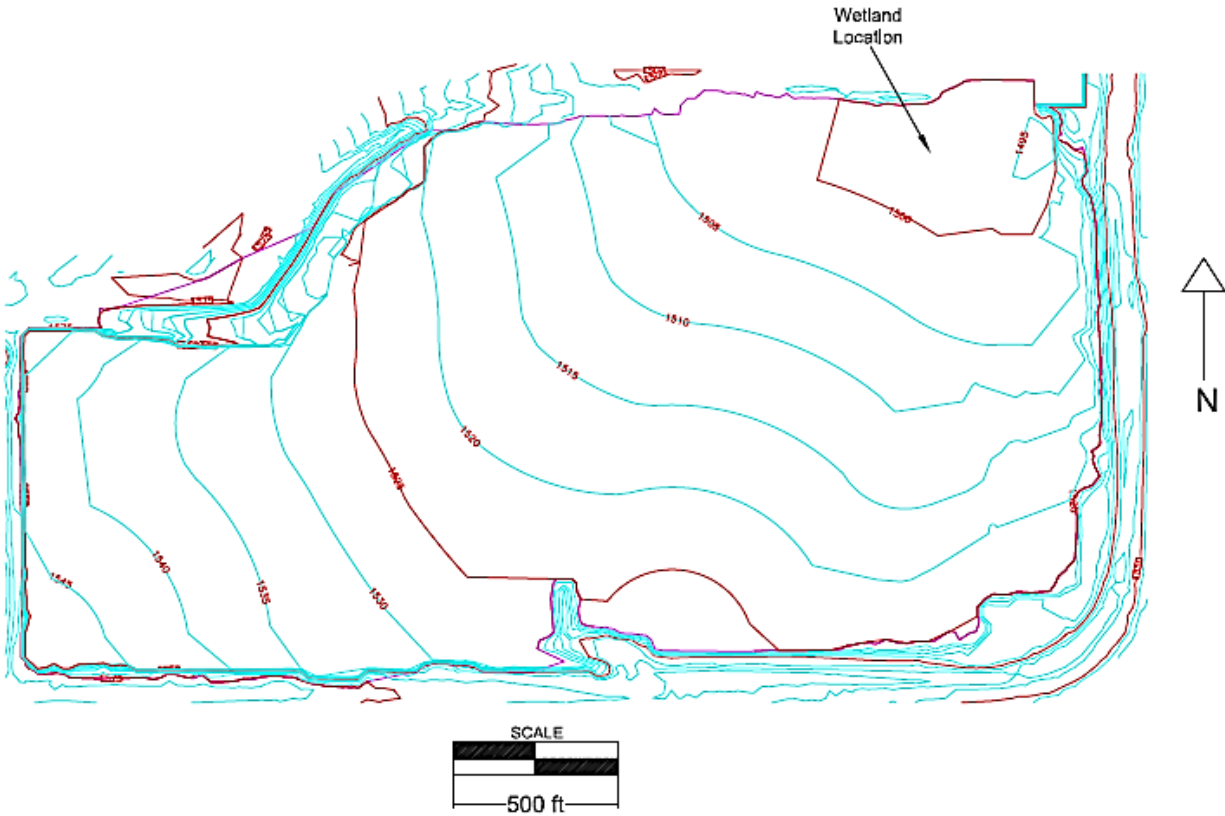
Tailings Pump	300 HP 6760 GPM
Tailings Booster Pump	300 HP 6760 GPM
Freshwater Pump 1	125 HP 1950 GPM
Freshwater Pump 2	125 HP 2150 GPM
Freshwater Pump 3	125 HP 2350 GPM

### **Tailings Deposition Staging**

Six stages were developed to achieve the desired final placement of the deposited tailings. The stages are discussed below:

#### **Stage 1**

Stage 1 determines the final grade of the deposited tailings surface and the location of the constructed wetland. The in-situ water level in the pit is approximately at 1500 ft mean sea level (MSL). For the constructed pond and its surrounding land to become a wetland, the surface of the pond was designed to be at the in-situ water level during normal climatic conditions. The lowest elevation of the tailings pond was designed to be at elevation 1495 ft MSL. The wetland pond was designed for the Northeast corner of the pit. This location allowed for the greatest use of the pit's available disposal capacity with a limited amount of restrictions created by other pit edges. The final surface of the of the tailings will slope at approximately 1.8% towards the constructed wetland. Figure 2 shows the wetland location and final grade of the tailings surface.



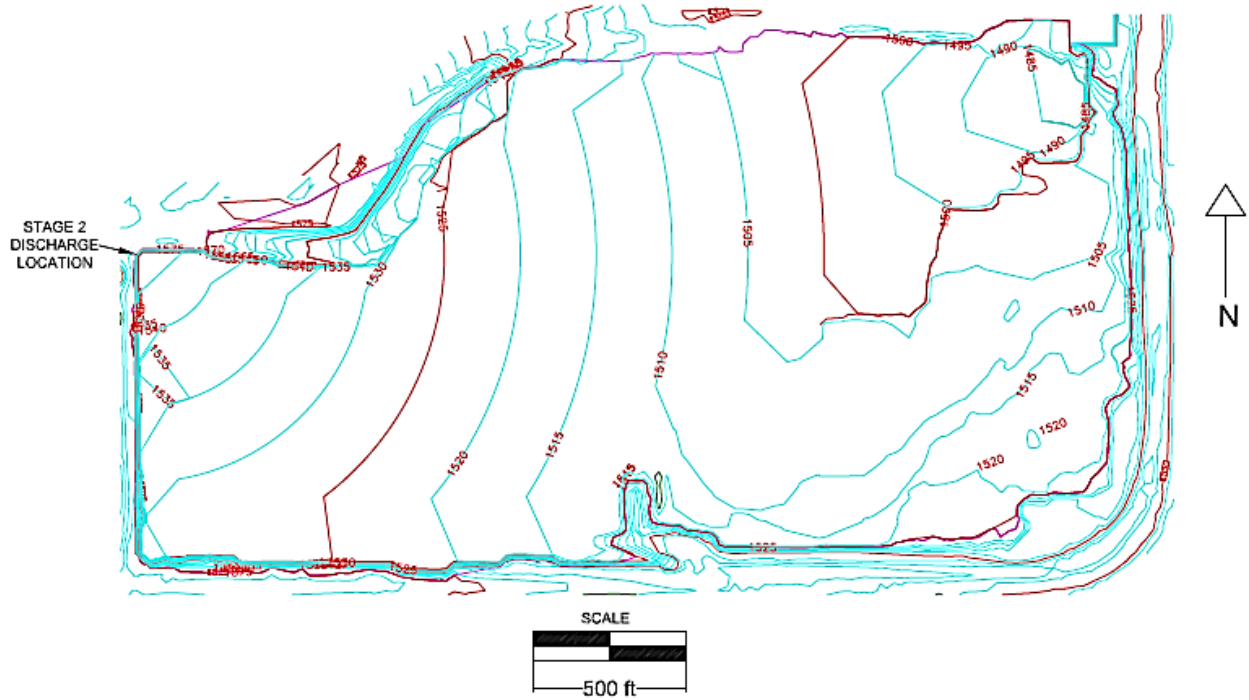
**Figure 2- Final Tails Surface Grade**

This final grade design provides the following:

Tailings Pond Capacity:	4,200,000 yd <sup>3</sup>
Wetland Pond Surface Elevation:	1500 ft MSL
Wetland Pond Bottom Elevation:	1495 ft MSL
Wetland Pond Surface Area:	257,000 ft <sup>2</sup>
Total Time	31 Months

### Stage 2

Stage 2 of the design is for the first tailings discharge location. The discharge point is located at the Northwest corner of the pit as shown on Figure 3. This location allows for the maximum tailings possible to be deposited into the pit without moving the discharge pipe.



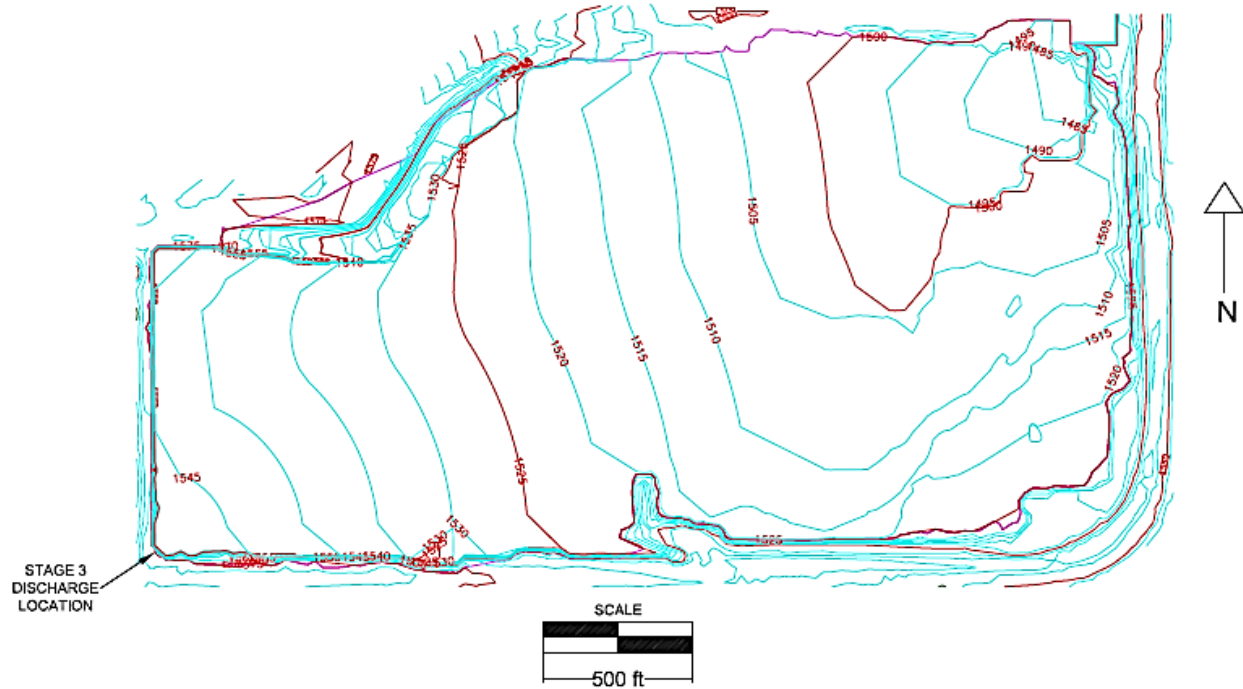
**Figure 3 - Stage 2 Discharge Location and Designed Surface**

Stage 2 design provides the following:

Stage Tailings	
Capacity:	3,300,000 yd <sup>3</sup>
Stage Timing:	24 Months

### Stage 3

Stage 3 of the design is for the second tailings discharge location. The discharge point is located at the Southwest corner of the pit as shown on Figure 4. This location allows for as much tailings as possible to be deposited into the pit without moving the discharge pipe.



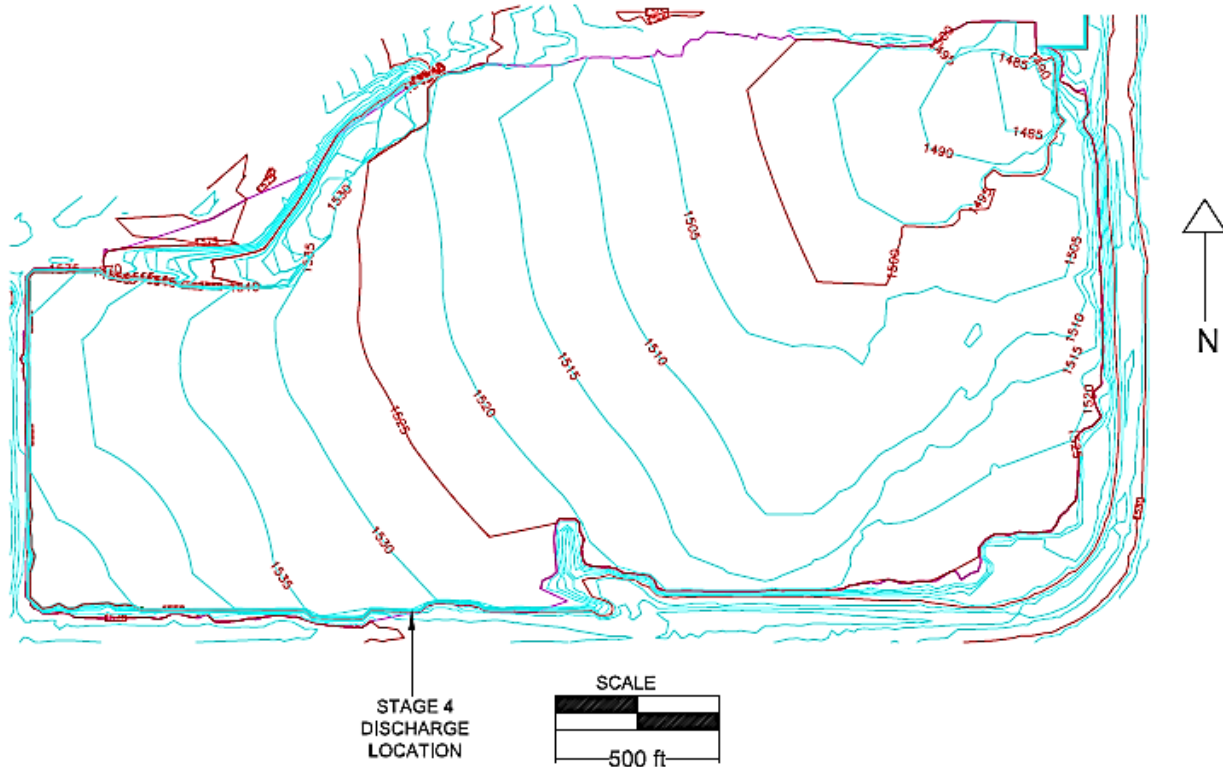
**Figure 4 - Stage 3 Discharge Location and Designed Surface**

Stage 3 design provides the following:

Stage Tailings	
Capacity:	404,900 yd <sup>3</sup>
Stage Timing:	3 Months

#### Stage 4

Stage 4 of the design is for the third tailings discharge location. The discharge point is located along the South highwall approximately 1/3 of the way across the pit from the West as shown on Figure 5. This location allows for as much tailings as possible to be deposited into the pit without moving the discharge pipe.



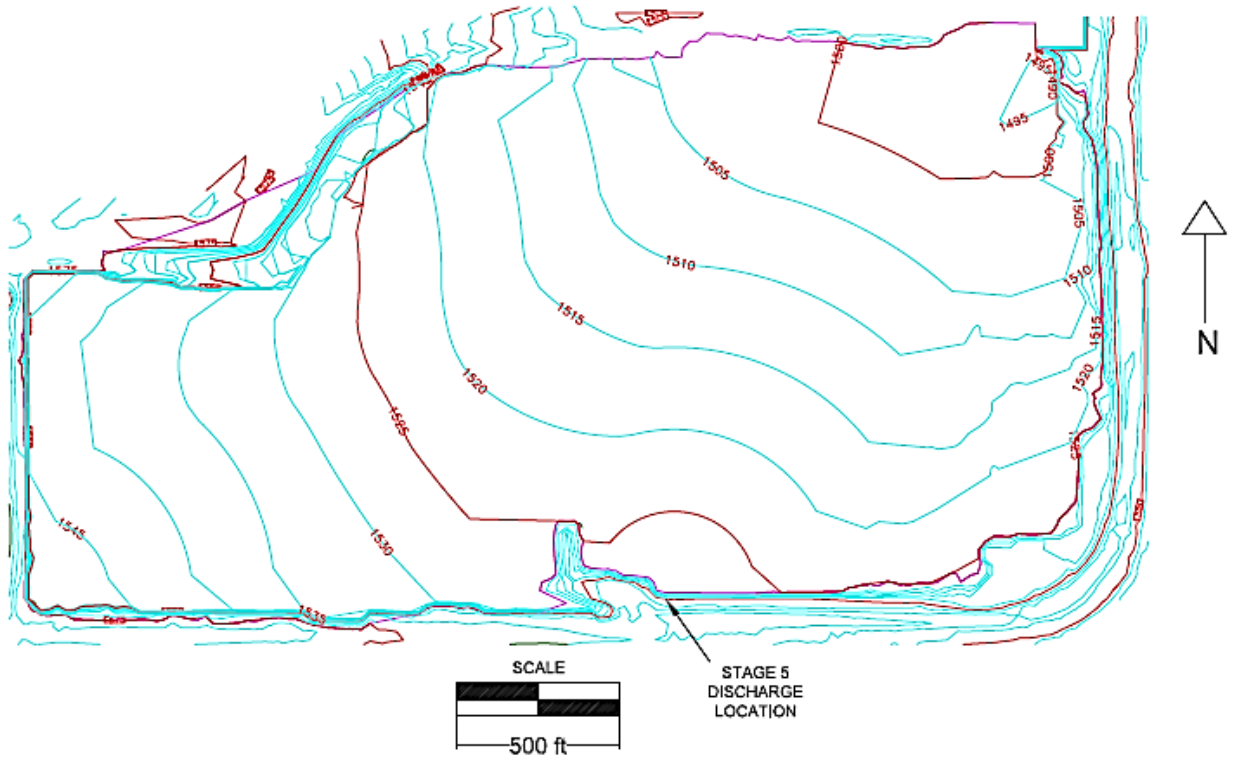
**Figure 5 - Stage 4 Discharge Location and Designed Surface**

Stage 4 design provides the following:

Stage Tailings Capacity:	91,000 yd <sup>3</sup>
Stage Timing:	2 Weeks

### Stage 5

Stage 5 of the design is for the fourth tailings discharge location. The discharge point is located along the South highwall approximately 1/3 of the way across the pit from the East as shown on Figure 6. This location allows for as much tailings as possible to be deposited into the pit without moving the discharge pipe.



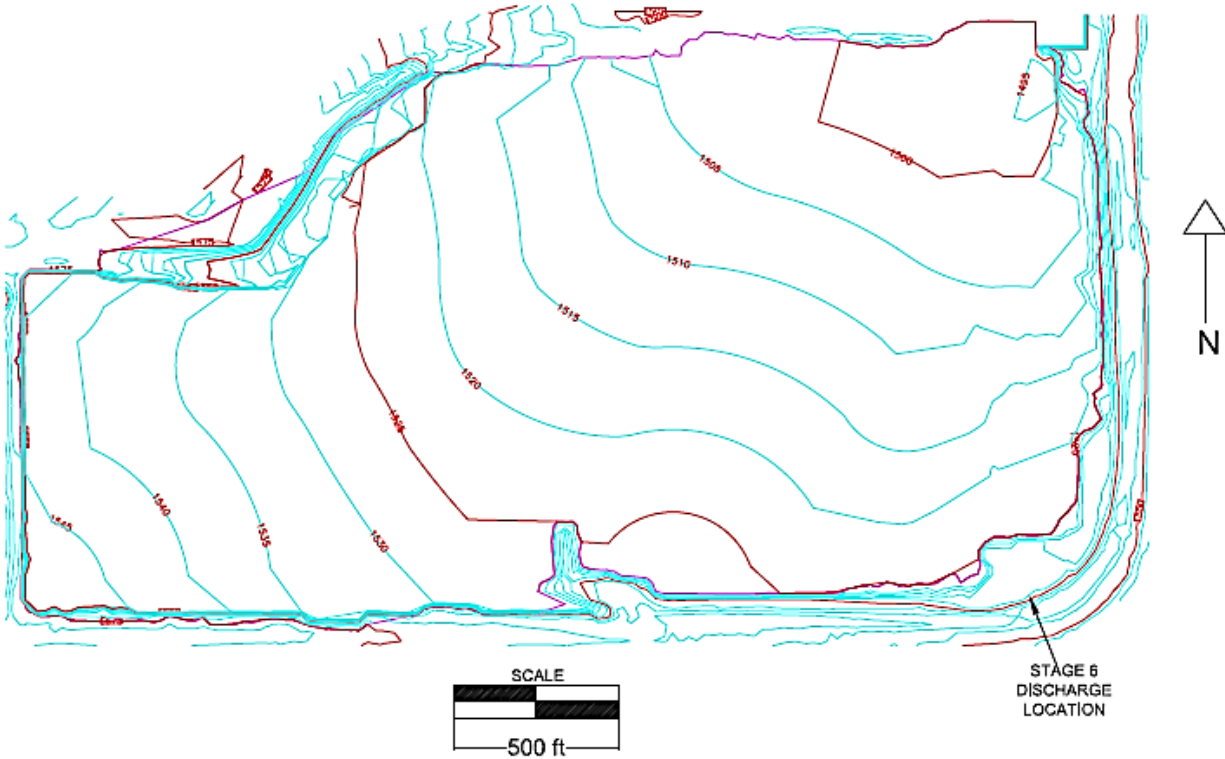
**Figure 6 - Stage 5 Discharge Location and Designed Surface**

Stage 5 design provides the following:

Stage Tailings Capacity:	417,540 yd <sup>3</sup>
Stage Timing:	3 Months

### Stage 6

Stage 6 of the design is for the fifth tailings discharge location. The discharge point is located in the Southeast corner of the pit as shown on Figure 7. This location allows for as much tailings as possible to be deposited into the pit without moving the discharge pipe.



**Figure 7 - Stage 6 Discharge Location and Designed Surface**

Stage 6 design provides the following:

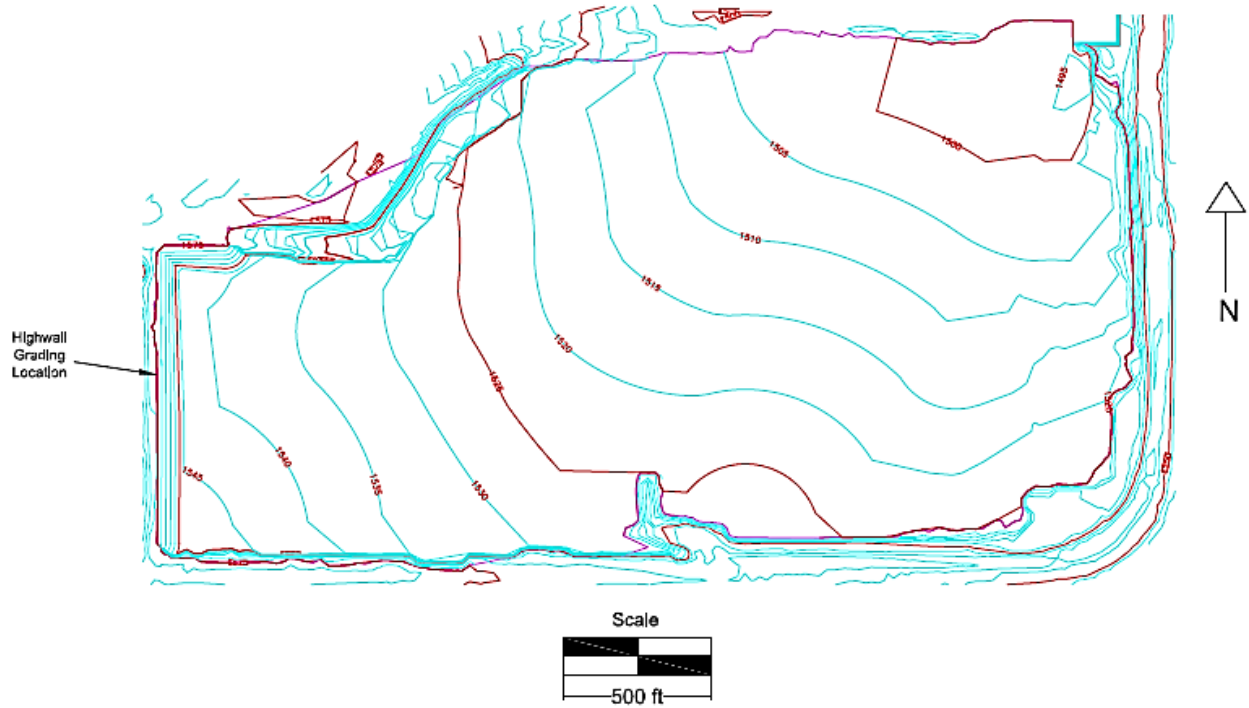
Stage Tailings Capacity:	13,357 yd <sup>3</sup>
Stage Timing:	3 Days

### Highwall Shaping Plan

Two stages were developed to achieve the desired final placement of the shaped highwalls. An estimated 163,000 yd<sup>3</sup> of material is needed for this shaping. This material will need to be brought in by truck from nearby waste stockpiles. The stages are discussed below:

#### Highwall Shaping Stage 1

Stage 1 of the highwall shaping will take place as soon as Stage 3 of the tailings deposal operations begin. Highwall shaping during Stage 1 is the shaping of the west highwall of the pit. The required shaping is estimated at 61,000 yd<sup>3</sup> of material. The Stage 1 highwall shaping plan is shown in Figure 8.



**Figure 8 - Highwall Shaping Stage 1**

### Highwall Shaping Stage 2

Stage 2 highwall shaping will begin as soon as Stage 4 tailings deposal operations begin. Highwall shaping during Stage 2 is the remaining highwalls that are above the surface of the deposited tailings. The required shaping is estimated at 102,000 yd<sup>3</sup> of material. The Stage 2 highwall shaping plan is shown in Figure 9.



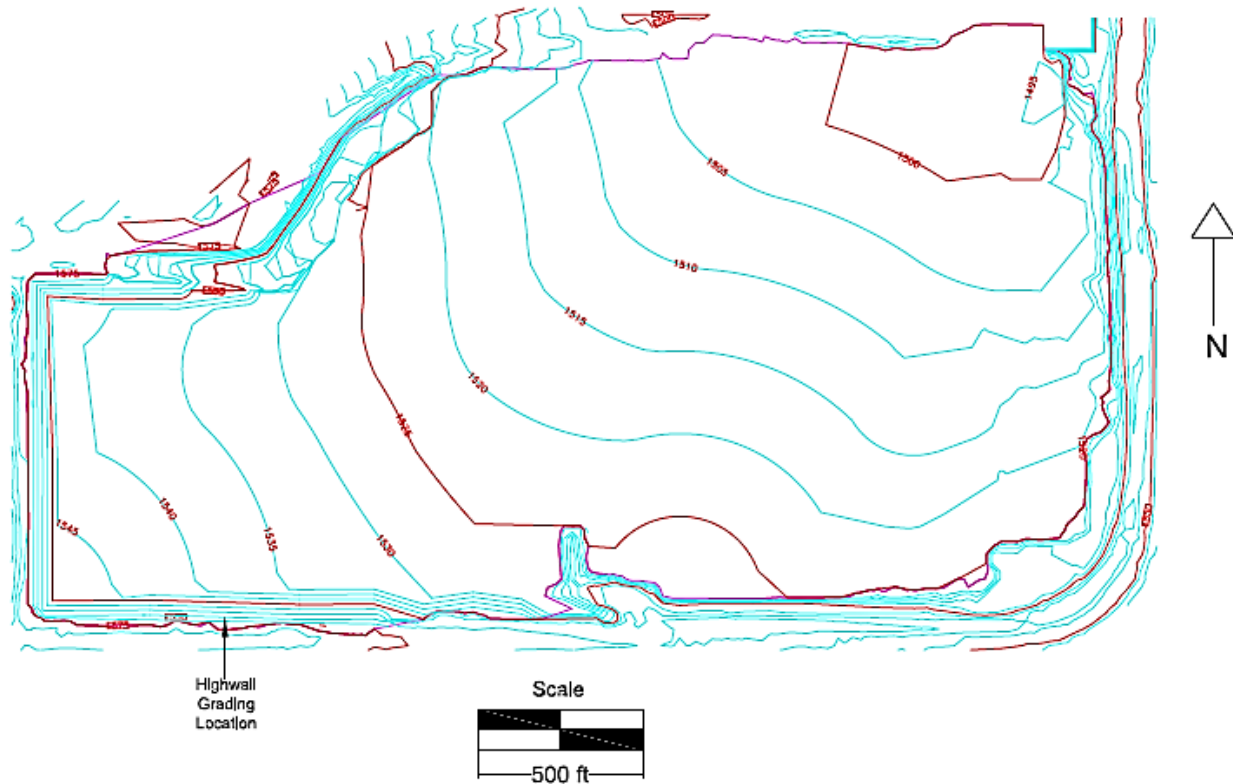


Figure 9 - Highwall Shaping Stage 2

## Water Plan

The existing water pumps have a combined capacity of 6,450 gpm. With a maximum tailings discharge rate of 6,760 gpm from the processing plant composed of a maximum of 10% solids, the existing pumps have the capacity to handle the proposed design pumping rates. The pumps will be placed in the area of the pit where the wetland pond is to be located.

## Top Soil Placement

Top soil will be placed at an average depth of 6 inches to cap the deposited tailings. An estimated 81,000 yd<sup>3</sup> of top soil will be needed to cap the nearly 100 acres of exposed surface. The top soil will come from a series of safety berms that surround the pit and will be spread with low pressure dozers. These berms contain an estimated 155,000 yd<sup>3</sup> of top soil available for reclamation. The location of this mine does not require dust control.

## Seeding

Seeding the entire reclaimed area has been divided into two parts: the wetland area and the non-wetland area. Once topsoil has been spread in the constructed wetland, the entire area will be flooded with fresh water to kill the roots and seeds of all non-wetland vegetation and invasive species. This will enhance the development of a healthy wetland. Cattails and other nearby wetland vegetative species should naturally spread to the constructed wetlands and thus seeding of the wetland area should not be necessary. For the non-wetland area of the reclaimed tailings pond, the seed planting mixture will be

compatible with the proposed post-mining land use as well as what is required by federal and state regulations (The Surface Mining Control and Reclamation Act [SMCRA]). With the post-mining land use being cattle grazing, it is recommended that a warm season pasture mix be used. This seed mix is composed of Bonanza Big Bluestem, Scout Indian Grass, and Trailway Sideoates Grama. The recommended planting rate is 10-12 pure live seed (PLS) pounds per acre. The chosen mix is suitable for warm dry seasons and is ideal for grazing (Farms). Suppliers of this seed mixture recommend using 50 pounds of fertilizer per acre annually to provide optimum growing conditions. The fertilizer recommendation is outside the scope of this project and it is up to the mine operator and landowner to determine if it is necessary to meet their post-mining land usage. Mulch or erosion control blankets may also be used; however, these should not be placed too thick. With this type of seed mixture, too thick of erosion control can block too much sunlight, which is needed for optimal growing conditions (Farms).

## Costs

A simplified cost estimate was developed to show the estimated cost for each stage of the proposed reclamation plan. The costs are designated at a prefeasibility level planning costs,  $\pm 25\%$ , and are presented in Table 1 (Minimum Engineering Study Requirements Update).

**Table 1 - Estimated Costs**

Slurry Pumping Costs	\$ 1,321,938
Fresh Water Pumping Costs	\$ 459,844
Highwall Shaping Costs	\$ 350,592
Top Soil Grading Costs	\$ 102,666
Seeding Costs	\$ 216,394
<b>Total Cost</b>	<b>\$ 2,451,433</b>

Slurry pumping costs includes pumping slurry from the processing plant to the tailings pond. Electrical costs are based on the 2015 yearly average for industrial consumers in Texas according to the U.S. Energy Information Administration. That same electricity rate was also used to develop the fresh water pumping costs for the life of the tailings pond disposal operations. The costs for highwall shaping and for top soil grading were developed using data from the USDOT FEMA equipment rates, the 2012 edition of the Cost-Mine Handbook, and the 41<sup>st</sup> Caterpillar Performance Handbook. The seeding costs were developed from information provided by various seed companies with their references being listed within the calculation spreadsheet as well as in the Reference section.

## Design Summary

The total amount of tailings that can be placed within the tailings pond using this design discussed in this paper is 4,200,000 yd<sup>3</sup>. The amount of waste material needed to shape the highwall is 163,000 yd<sup>3</sup>. Approximately 81,000 yd<sup>3</sup> of topsoil is needed to cap the disposed tailings at a depth of 6 inches. The recommended seeding mix was chosen to provide vegetative species most suitable for warm dry seasons and for grazing. The estimated cost for operating and reclaiming the tailings pond using this design is estimated to be approximately \$2.5 million.

## Conclusion

The protocol for reclaiming in-pit tailings ponds to exceed federal and state regulations developed in this study generated a series of stages to depict the steps to be taken in the design of an in-pit tailings disposal pond. The steps outline the basic process of designing, implementing, and reclaiming an in-pit tailings disposal pond that will develop into a grazing land and a wetland with the following conditions:

- Sand and Gravel Deposit is composed primarily of quartz-silica
- Climatic conditions considered to be hot and have an annual precipitation of less than 30 inches (WeatherDB)
- Mine operations located in the South Central United States
- Processing plant discharge is a slurry
- Processing plant discharge does not contain chemicals
- Primary proposed post-mining land use is ranch land
- Reclamation plan includes construction of a wetland
- Use of a nearby fresh water holding pond

## Acknowledgements

The authors would like to thank Premier Silica for the support provided during this project.

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