MECH 4860

FINAL DESIGN REPORT

# Design of a Mine Dewatering Filtration System

## VALE CANADA LIMITED


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Dr. Labossiere,

Please find attached the final design report, "Design of a Solid Particle Removal System", sponsored on behalf of Vale Canada Limited, and submitted on the 7th of December 2015 by Swift Consulting.

Swift Consulting is proud to present the final design of a solid particle removal system that will integrate with the Vale Birchtree Mine's current dewatering system to more effectively remove solid particles from the water stream and reduce wear on the dewatering pumps. This report presents the details of the design along with engineering drawings and a cost analysis, as agreed upon by Vale and Swift Consulting. This report will allow Vale to make an informed decision about how to improve the current dewatering system in the Birchtree mine.

On behalf of Swift Consulting, I would like to thank you for your time and invite you to contact me if you have any questions or concerns regarding the project.

Sincerely,

Corbin Johnston
Team 22 Project Manager
Swift Consulting

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# EXECUTIVE SUMMARY

Vale requires an additional filtration component to be added to the dewatering system in the Birchtree mine to reduce wear of the dewatering pumps. The water used throughout each level in the mine drains down through a series of settling reservoirs to the 4040 level, where it is pumped to an intermediate sump on the 2340 level, and then subsequently pumped to the surface and removed from the mine.

The settling reservoirs, or sumps, are useful for filtering out larger particles, but the smaller particles often remain in the water stream. During high flow times, the water does not always remain in the settling reservoirs long enough to sufficiently filter out even the larger particles. These solid particles cause excessive wear on the dewatering pumps, resulting in maintenance costs of approximately $312 000 a year. Vale has requested a design that will eliminate all solid particles greater than 800 microns from the water stream before it enters the dewatering pumps.

Swift Consulting has designed a system that will successfully remove all particles greater than 84 microns from the water stream. The system involves draining Sump 3 and installing the Elgin Hyper-G Dual-Deck Shaker, an apparatus that consists of a set of vibrating coarse and fine screens that removes solid particles and allows the water to continue on through the discharge pipe. Sump 2 will remain operational for use in case of overflow or shaker maintenance. A teed joint with control valves will allow control of the flow direction to either the shaker or Sump 2. The water discharged from the shaker will exit through a pipe that leads directly into the clear water reservoir, from which the water enters the dewatering pumps. The solids simply fall into a pile off the end of the shaker

screen, and, once the pile grows sufficiently large, can be moved to another area within Sump 3 or another solid storage location selected by Vale.

This system will be able to handle up to 700 gpm, and the total capital cost of the system, including parts and the labour cost of installation, is $61 950, with yearly maintenance costs of approximately $188 133. This is the cost of maintenance for the entire dewatering system, and includes the cost to maintain the shaker as well as the reduced maintenance cost of the dewatering pumps. Implementing this system will result in $124 084 of annual savings in pump maintenance costs, and the payback period is 6 months.

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# GLOSSARY

**Basket**

The upper portion of the shaker assembly. It contains the screens and vibrating motors.

**Cage**

The elevator lift that delivers people to various levels within the mine.

**Carriage**

The bottom of the shaker assembly. It contains the trough that the water filters into before draining out of the bottom of the assembly.

**Centrifuge**

A machine that spins a solid-liquid mixture of various densities to remove more dense particles. In the case of this project, a centrifuge could be used to separate the solid particles from the water stream. Because of their higher densities, solid particles move to the outer edge of a spinning cylinder and the water is displaced toward the center.

**Cut Point**

The minimum solid particle size that would be removed from a slurry using a filtration device.

**Dewatering**

A process in place to bring all of the water used throughout the mine to the surface. Water drains down to the bottom of the mine, and then is pumped in stages to the surface.

**Drift**

The tunnels that run throughout the mine.

**Duty Pump**

In a pumping system containing more than one pump in parallel, the duty pump is the pump that is configured to run and pump liquid when required. The other pumps in the system typically do not run and are used as backups.

**Level**

This refers to a location or depth within the mine. For example, the 4040 level is 4040 feet below the surface.

**P & ID**

This is an acronym for Piping and Instrumentation Diagram. These are used to show piping arrangements, valves and other controls that the water in the mine flows through.

**Pipe Reducer**

A pipe fitting used to connect and provide a transition between two pipes of different diameters. Regardless of whether the fitting is providing a transition from a smaller pipe to a larger one, or a larger pipe to a smaller one, it is always referred to as a reducer.

**Screen Shaker**

A machine consisting of vibrating screens that stop solid particles from proceeding but allow water to filter through.

**Slurry**

A mixture of liquid (usually water) and solid particles.

**Standby Pump**

In a pumping system containing more than one pump in parallel, the standby pumps are used as backups for the duty pump in case the duty pump fails, or additional pumping capacity is required.

**Sump**

A reservoir that collects water and allows larger solid particles to settle out before the water travels to its next location in the dewatering system.

**Weir**

A type of dam that the water flows over before it can move on to the next location in the dewatering system. Its purpose is to control the flow of water and only allow suspended solids to move on through the system. There are two configurations used in the Birchtree mine; a rectangular weir and circular weir. The rectangular weir is essentially a horizontal edge the water must flow over, similar to a dam. The circular weir is essentially an open, vertically-oriented pipe whose edges the water must flow over to reach the next location.

# 1. INTRODUCTION

This report focuses on the final design recommended by Swift Consulting to improve the **dewatering** system in Vale's Birchtree Mine. Included in these design changes are:

1. The removal of redundant **sumps**.
2. The addition of a water filtration device.
3. Piping changes to incorporate the water filtration device.
4. Control system changes to incorporate the water filtration device.

The purpose of these changes is to reduce overall maintenance costs and labour requirements of the dewatering system, as well as to increase revenue by increasing ore recovery.

This report will begin by providing background information about Vale, the design problem, and the objectives of the design project. The next section will describe the final design in detail, and the report will conclude with an economic analysis to demonstrate the feasibility of the design.

## 1.1 Background

Vale is a multinational metals, mining, and logistics corporation with headquarters in Rio de Janeiro, Brazil. Vale's primary business is mining; it is the world's largest producer of iron ore, and the world's second largest producer of nickel. Additionally, Vale produces manganese, ferro-alloys, coal, copper, bauxite, potash, kaolin, and aluminum. Vale's operations in Thompson, Manitoba consist of three mines, as well as a mill, smelter and refinery. The Thompson operations accounts for 1.5% of Vale's total production [1].

Thompson's Birchtree Mine has **drifts** that span 4100 feet below ground. The mine produces nickel, copper, and cobalt ores, which are then refined and sold. To prevent the mine from flooding, it has been outfitted with a dewatering system that consists of a series of sumps and pumps to remove drain water from the mine. The drain water contains more than 500 mg/L of solid particles of silt, rock, and metal ores [2]. Data relevant to the exact amount of solid particle volume in the drain water was not available to the team, so 500 mg/L was used as a minimum assumed solid volume throughout the design process. To remove these solids, drain water is collected in two main settling reservoirs, named Sumps 2 and 3, which are located 3950 feet below the surface. Two additional smaller reservoirs, named Sumps 1 and 4, provide the capacity to store overflow drain water during peak flow seasons. Once the drain water enters the sumps, solid particles from the water settle out and accumulate at the bottom of the sump. The solids that accumulate at the bottom of the sump sometimes contain ore. The sumps are cleaned, and accumulated solids are removed once every three weeks to once every three months. The length of time in between each sump cleaning depends on the season and the amount of blasting and mining work that is taking place.

When the sumps are full, water flows over a **weir** at the back of the sump and is piped down to a clear water reservoir 4040 feet below ground level, where it enters the dewatering pump system. The pump configuration on the 4040 **Level** sends the water through a booster pump, and then on to one of three dewatering pumps. The booster pump is used to increase water pressure, which assists the dewatering pumps in pumping water to the 2340 Level. The booster pump may or may not be activated, depending on the performance of the dewatering pumps. The three dewatering pumps are connected in a parallel configuration. Under normal operation, one dewatering pump acts as a **duty pump**, while the other two pumps act as **standby pumps**. The pumps are activated when a high level switch in the clear water reservoir is triggered, and deactivated when a low level switch is triggered. The dewatering pumps send the water to a sump on the 2340 level, from which it enters a second system of pumps that brings the water to the surface where it can be removed from the mine.

Figure 1 shows a simplified diagram of the existing dewatering system in the Birchtree Mine [3]. The diagram includes the two settling reservoirs, the clear water reservoir, a strainer, the booster pump and the three dewatering pumps.

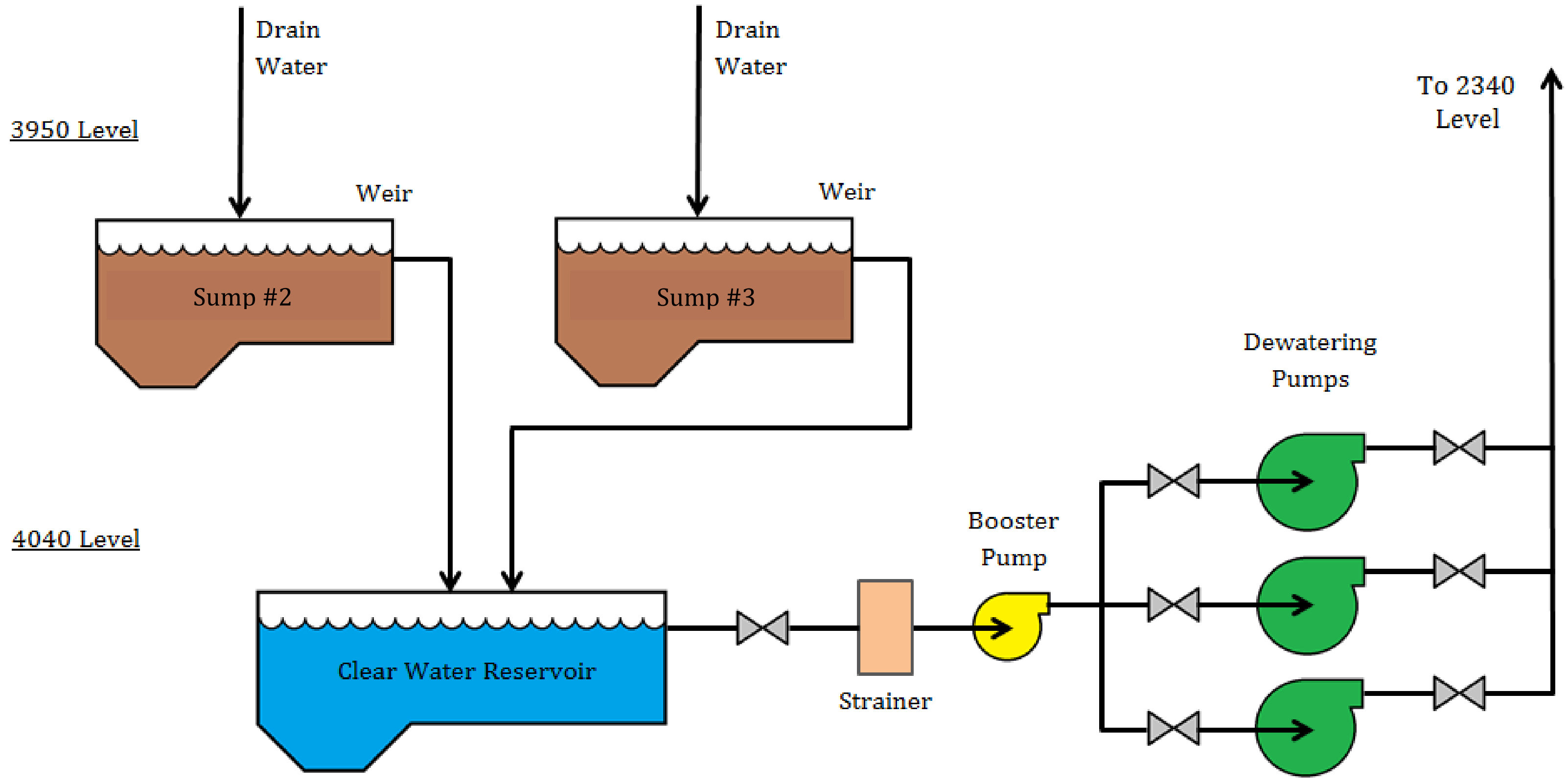


Figure 1: Birchtree Mine existing dewatering system diagram [3].

## 1.2 Problem Statement

The sumps in Birchtree Mine's dewatering system are intended to separate the solid particles from the clear water. The main problem is that many solid particles are not separated and travel through the system into the clear water reservoir. The solid particles are then pumped through the booster pump and dewatering pumps. The dewatering pumps are not designed to handle large quantities of solids, and as a result, the pumps experience excessive wear, damage, and a reduced service life. The dewatering pumps have each been failing approximately once a year, and the cost to rebuild each pump is approximately $115 000. An additional problem is that solids containing ore are pumped to the surface and discarded instead of being recovered, resulting in lost revenue for Vale. The final problem is that currently, sumps must be cleaned by hand, which is labour-intensive and time-consuming.

## 1.3 Project Objectives

Vale has requested design changes to the dewatering system, which include the incorporation of a filtration device to remove solid particles suspended in the drain water. The purpose of this project is to reduce wear of the Birchtree Mine dewatering pumps and increase the pump service lives. This will save Vale money by reducing the cost of maintaining the Birchtree Mine dewatering pumps, and increase revenue by allowing ore to be recovered from the removed solids. To ensure that the project's purpose is met, Swift Consulting has outlined a number of design objectives.

The design should:

**1.** Increase solid particle removal from drain water in Birchtree Mine.

2. Reduce pump maintenance costs.
3. Reduce labour associated with cleaning sumps.
4. Collect removed solids to improve ore recovery.
5. Have a low initial capital cost, and low additional maintenance costs to ensure a net reduction in costs when considering the cost of pump maintenance.

In addition to the design objectives, there are also a number of deliverables Swift Consulting agreed to present to Vale. These deliverables have helped to ensure the success of the project by justifying design decisions and providing relevant documentation to move forward and implement the design.

The final deliverables for this project are included in this report and are as follows:

1. Final design including final design specifications, engineering drawings or system diagrams, CAD models and any other relevant design information
2. A cost analysis to demonstrate potential cost savings
3. Final report outlining detailed design process used to come up with final design

Ultimately, it will be up to Vale's engineering staff to decide whether or not they would like implement our team's final design, and the success of the project will be dependent on that decision; however, by successfully completing the objectives and providing the deliverables outlined above, Vale should have enough evidence to support the implementation of the design. Additionally, Vale should have the required information to move forward with implementing the proposed final design.

## 1.4 Customer Needs

To create a successful final design, a clear understanding of the customer needs was required. To ensure all customer needs were identified, Swift Consulting met with Vale's Mechanical Engineering Supervisor and visited the Birchtree Mine to determine a list of needs. The needs are listed in TABLE I in order of importance, where a 5 is assigned to the most important needs and a 1 is assigned to the least important needs.

**TABLE I: PRIORITIZED CUSTOMER NEEDS FOR FINAL DESIGN**

| # | Customer Needs | Importance |
|---|---|---|
| **1** | The design separates solid particles from water. | 5 |
| **2** | The design is capable of handling the maximum flow rate. | 5 |
| **3** | The design is capable of being manufactured through external sourcing or in-house manufacturing of components. | 5 |
| **4** | The design fits within the selected area. | 5 |
| **5** | The design is able to be transported to the selected area. | 5 |
| **6** | The design can operate in an underground environment. | 5 |
| **7** | The design is reliable. | 4 |
| **8** | The design maintains functionality for extended period of time | 4 |
| **9** | The design is safe to operate. | 4 |
| **10** | The design is compatible with water **slurry**. | 4 |
| **11** | The design transports solids to the designated area. | 4 |
| **12** | The design is easily maintainable. | 4 |
| **13** | The design is affordable. | 4 |
| **14** | The design can be integrated into the system's existing control circuitry. | 2 |
| **15** | The design is compatible with current piping. | 1 |
| **16** | The design is compatible with the power supply connections in the designated area. | 1 |

## 1.5 Design Specifications

Once Vale approved the set of design needs specified in TABLE I, Swift Consulting determined a set of metrics that were used to analyze each need. These metrics are given in TABLE II and ranked in order of importance in accordance with the ranking system used in TABLE I. Each metric is linked to one or more customer need in the second column. Marginal and ideal values have also been established for each metric, where the marginal values establish an acceptable range for the design parameters to fall within, and the ideal values  represent what the team is striving to achieve with the final design.

TABLE II: PRIORITIZED METRICS FOR CUSTOMER NEEDS ANALYSIS

| Metric # | Needs #'s | Metric | Importance | Units | Marginal Value | Ideal Value |
|---|---|---|---|---|---|---|
| **1** | 1,11 | Quantity of solids present in clear water [2] | 5 | mg/L | <5 | 0 |
| **2** | 1,11 | **Cut point** [2] | 5 | microns | <800 | 0 |
| **3** | 2 | Water flow rate [2] | 5 | gpm | 300 | >300 |
| **4** | 3,12,13 | Design/replacement cost [2] | 5 | $ | 225K–345K | <225K |
| **5** | 3,12 | Total annual downtime due to maintenance/repair | 5 | days | <14 | <7 |
| **6** | 4,5 | Maximum size of components | 5 | ft | <5'-2"x 30' | <5'x12' |
| **7** | 6 | Operating temperature of design | 5 | ℃ | 10 - 30 | 5 - 40 |
| **8** | 3,12,13 | Annual maintenance cost | 4 | % initial cost | 10-20 | < 10 |
| **9** | 9 | Time required to shut down design | 4 | s | 15-30 | <15 |
| **10** | 7,8,10,12 | Life expectancy of design (time until first rebuild) | 4 | years | 5 | >5 |
| **11** | 1,4,11 | Distance from filtration component to solids holding reservoir | 4 | ft | <30 | 5 |
| **12** | 7,8 | Cycles until failure [2] | 4 | cycles | $4.73 \times 10^9$ | $>4.73 \times 10^9$ |
| **13** | 7 | Strength of components [4] | 4 | ksi | 60.2 | >60.2 |
| **14** | 7,12 | Required maintenance interval | 4 | months | .5 - 1 | >1 |
| **15** | 9 | Noise level [5] | 4 | dB | 80-88 | <80 |
| **16** | 7,8,9, 12 | Vibration velocity [6] | 4 | ips | .2 - .3 | <.2 |
| **17** | 13 | Annual energy usage [2] | 4 | kW | <1629K | <814K |
| **18** | | Power required [2] | 3 | HP | 100-300 | < 100 |
| **19** | 14 | Clear water reservoir level | 2 | % | 27-100 | 27-60 |
| **20** | 2,15 | Pipe inlet/outlet size [7] | 1 | in | 4-10 | 6-8 |
| **21** | 2,16 | Electrical power input | 1 | V | 120, 600, 4160 | 4160 |
| **22** | 5 | Design weight | 1 | lbs | 20,000 | < 10,000 |

Swift Consulting focused on providing a design that will remove solids from the water in the most cost effective manner, as indicated by the importance rankings of the parameters outlined in TABLE I and II. This design also needs to be small enough to be transported to the bottom of the shaft and capable of operating in underground conditions. A tertiary focus includes ensuring the design is safe, durable, and easy to maintain. The last three needs and metrics are ranked fairly low as the mine has experienced personnel, such as mechanics and electricians, who can modify the existing system to incorporate the selected design into the existing dewatering system. Determining the priorities of the project and quantifying design objectives established a strong foundation for the physical design.

# 2. DETAILED DESIGN

Swift Consulting conducted extensive research to generate several different design concepts. A thorough concept selection process was used to refine the concepts to one final design that will effectively and economically solve the design problem Vale presented. The details of the concepts considered, as well as the selection techniques used, can be found in Appendix A. This section begins by describing the dewatering system currently used in the Birchtree Mine, and then proceeds with an overview of the new system as well as detailed descriptions of the components of the final design.

## 2.1 Current System Overview

The current dewatering system begins at a sump located on the 3800 Level of the mine, where a slurry mixture of water and rock, dirt, and nickel particles from the mine's upper levels collects. As this slurry collects, the sump level increases until it reaches a circular weir. By this time, the heavier solids have settled out of the slurry so that only suspended solids remain. The slurry then cascades over the circular weir and down a 6 inch diameter borehole angled at 75° below the horizontal for a total head change of 122 ft to the 3950 Level.

The 3950 Level consists of four sumps. Sumps 1 and 4 are for overflow purposes only and are connected to the dewatering system by external, portable pumps. Sumps 2 and 3 are connected to the borehole from the 3800 Level sump at a tee connection, with valves on both discharge pipes that regulate which sump the incoming slurry is directed to. Following each of these valves is 100 feet of 6-inch diameter pipe containing six long radius elbows over the entire pipe length. The slurry is then discharged at atmospheric pressure into either Sump 2 or 3. Sumps 2 and 3 have a series of rectangular and circular weirs that assist in settling the larger solids from the slurry, as shown in Figure 2.

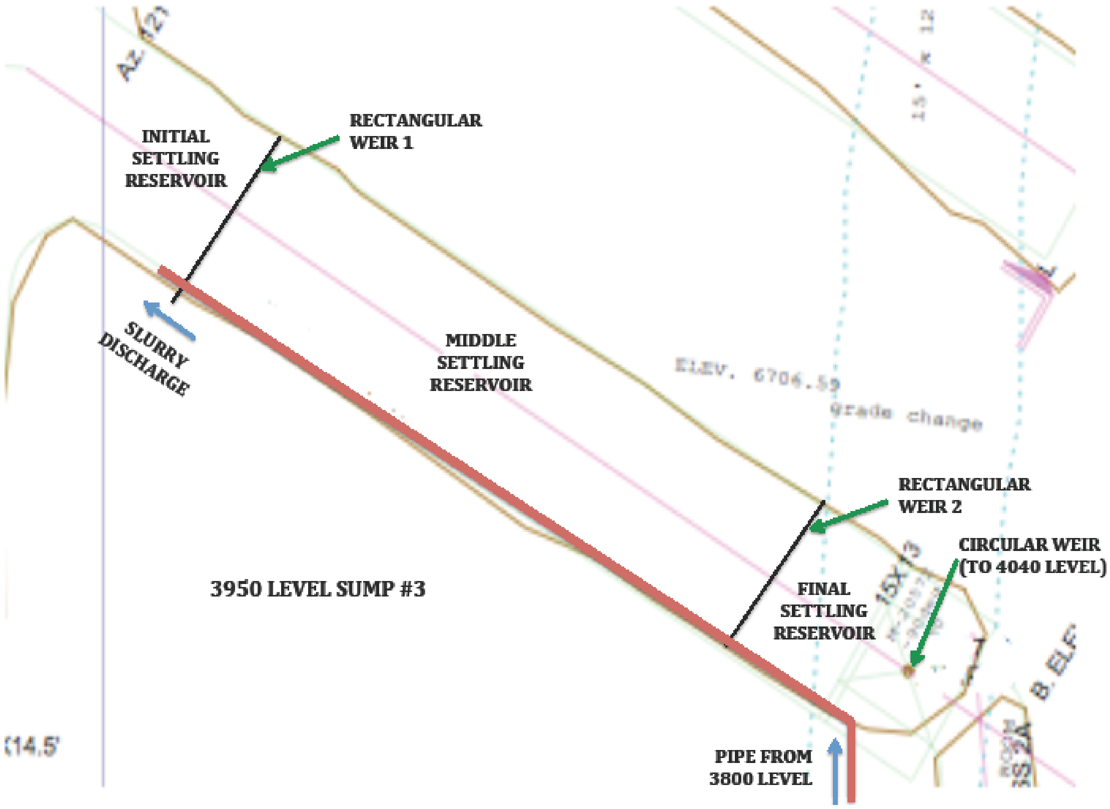


**Figure 2: Layout of Sumps 2 and 3 on the 3950 Level [8], [9].**

The background of Figure 2 is taken from a Vale engineering drawing of the 3950 and 4040 Level sump layout, and the labels show the approximate locations of the weirs that split Sump 3 into three separate reservoirs. The original engineering drawing of the sump layout is shown in Appendix B.

The slurry discharges into an initial settling reservoir near the opening of the sump. This initial settling reservoir is separated from the middle reservoir by rectangular weir 1, which is shown in Figure 3.

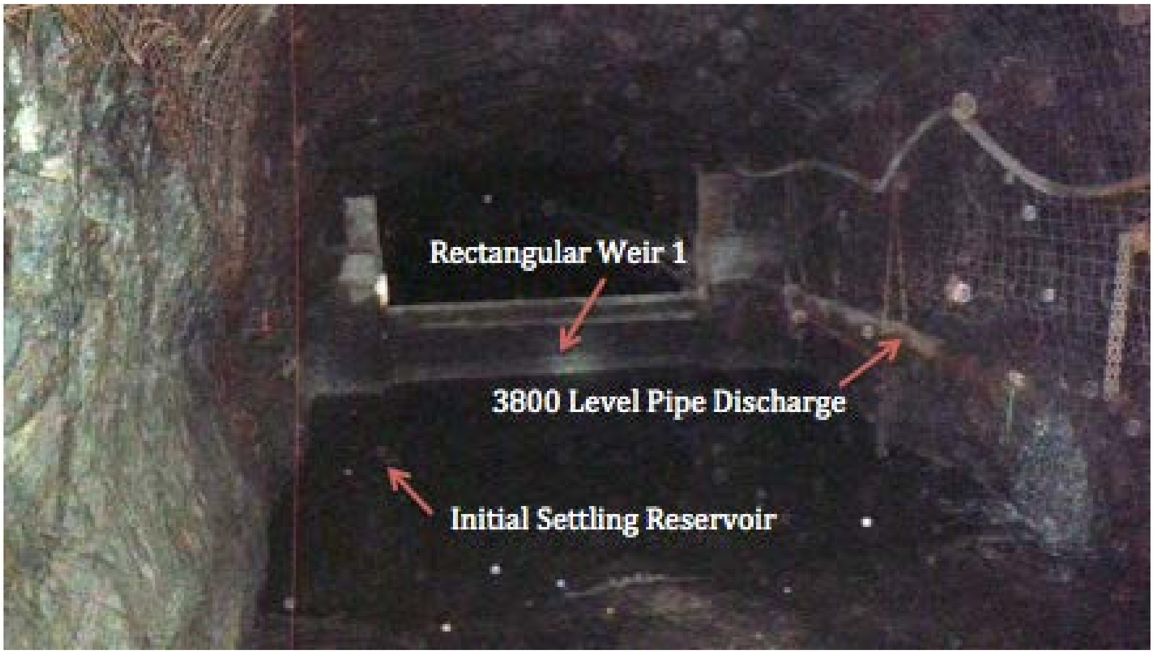


**Figure 3: Layout of the initial settling reservoir in Sump 3 [10].**

Once the slurry flows over this first rectangular weir, it enters the middle settling reservoir, where the slurry continues to settle out the solids until the level of the slurry reaches the height of rectangular weir 2. The water flows over this second rectangular weir into the final settling reservoir where the slurry will eventually cascade over a circular weir down to the clear water reservoir on the 4040 Level. A picture of the final settling reservoir in Sump 3 is shown in Figure 4.


**Figure 4: Layout of the final settling reservoir in Sump 3 [11].**

The clear water reservoir on the 4040 Level has three level sensors that regulate the operation of the three dewatering pumps. These pumps are activated separately based on the level of the clear water reservoir.

This dewatering system, up to but excluding these dewatering pumps, is illustrated in Figure 5 [12].

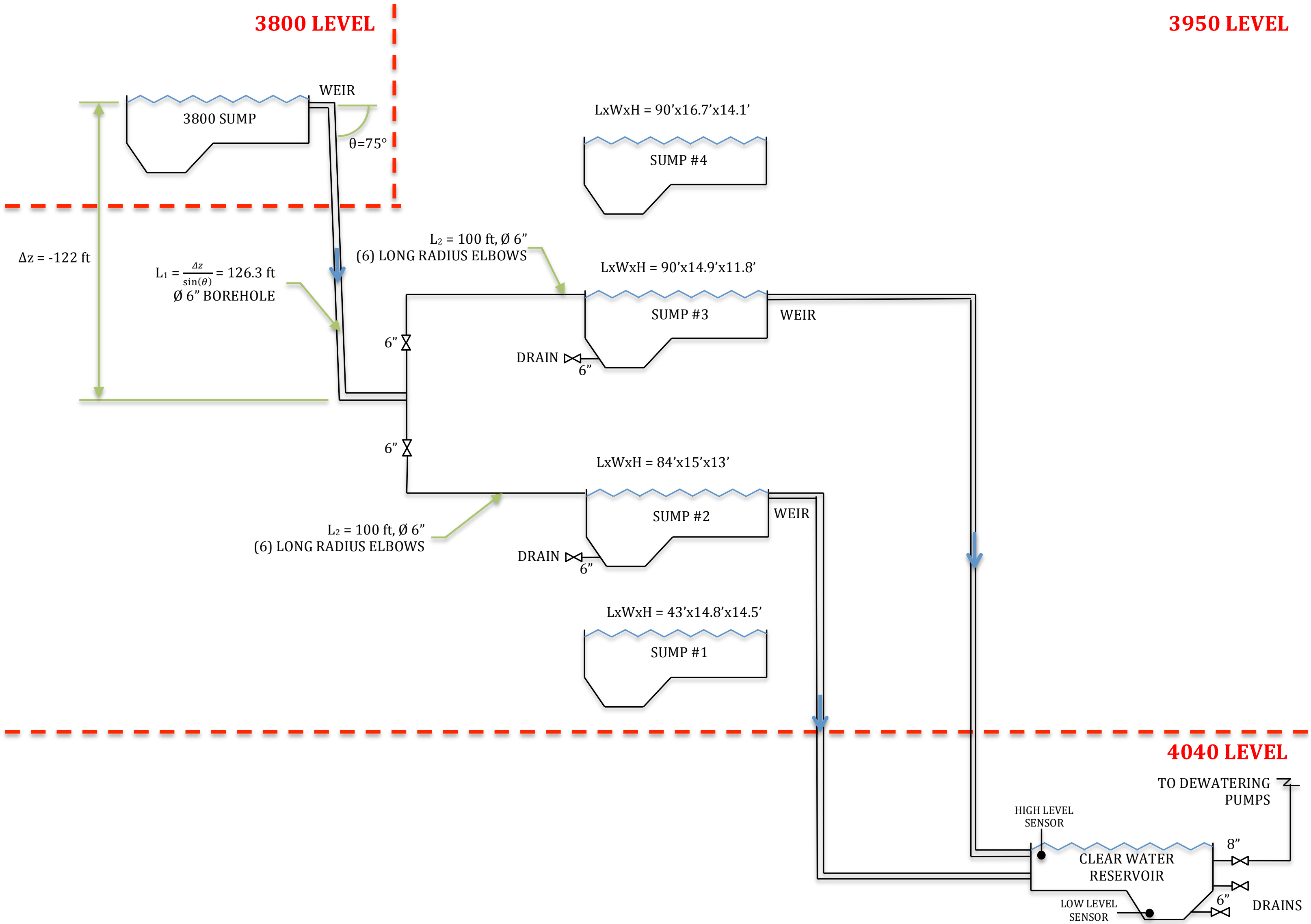


**Figure 5: Current dewatering system schematic excluding dewatering pumps [12].**

## 2.2 New Dewatering System Overview

The new proposed dewatering system design outlined in this report contains modifications to the current piping and layout of Sump 3 so that the filtration device can be installed within this area. These modifications include draining Sump 3, removing both of its rectangular weirs, installing the filtration device, connecting the pipeline coming from the 3800 Level sump directly to the inlet of the filtration device, and connecting the pipeline from the outlet of the shaker directly to the 4040 Level clear water reservoir. These changes are discussed in more detail in Sections 2.3 through 2.7.

The flow path of the new system still runs from the 3800 Level through the tee connection. The valves on each discharge pipe will be used to control whether the water goes to the filtration device in Sump 3, or is directed to Sump 2, which provides a bypass of the filtration system when the filtration device is undergoing maintenance. If the water is directed to Sump 2, it will proceed through the system in the same way it currently does. If the water is directed to Sump 3, it will be piped directly into the filtration device, which will remove solids and then discharge the filtered water into a pipe that feeds into the 4040 Level clear water reservoir. From this reservoir, the water will be pumped to the 2340 Level.

Sumps 1, 2, and 4 remain unchanged in the new system design. A schematic diagram of the newly proposed dewatering system is shown in Figure 6 [13].

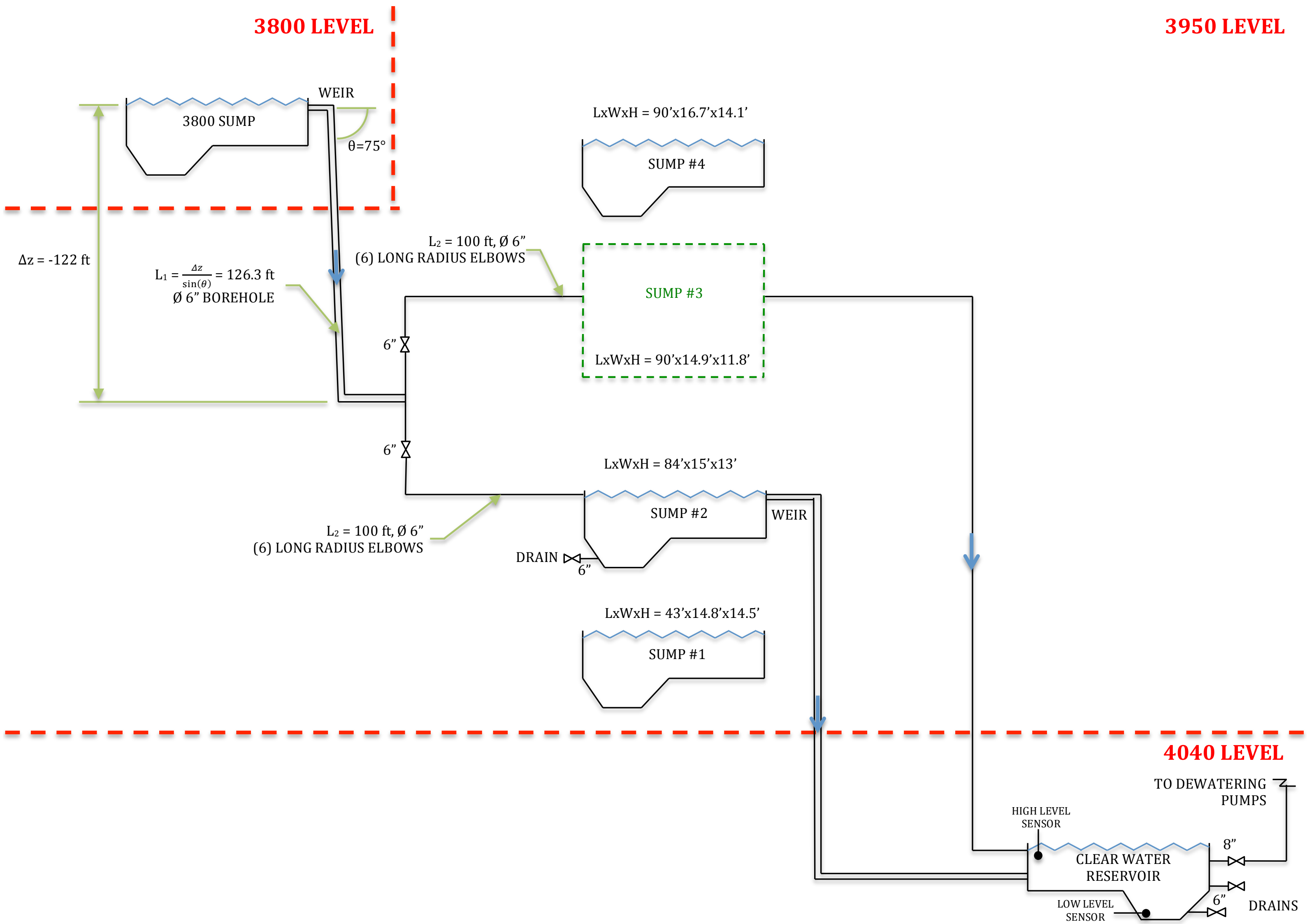


**Figure 6: New proposed dewatering system schematic excluding dewatering pumps [13].**

## 2.3 Filtration Device

Through the concept development and evaluation phase of this project, a wide variety of potential filtration methods were considered. These methods included decanter **centrifuges**, screen-scroll centrifuges, pusher centrifuges, **screen shakers**, belt filters, self-cleaning filters, flocculation, and a series of screens. Initially, Swift Consulting selected the decanter centrifuge as the filtration device for the final design; however, further research showed that a screen shaker is more suitable to the application in the Birchtree Mine dewatering system. The team collected quotes from suppliers for both types of device, and scored each on its performance pertaining to various metrics including initial cost, maintenance cost, flow rate, cut point, power requirement, size, and weight. Ultimately, the team proceeded with the screen shaker for the final design filtration device. The details of the selection process can be found in Appendix A.

The Elgin Hyper-G Dual-Deck Shaker received the highest score in the filtration device selection process, and thus was selected as the filtration device for the final design. It is a rectangular screen shaker supplied by Elgin Separation Solutions with an upper coarse-mesh screen to filter out larger particles, and a bottom, fine-mesh screen to filter out smaller particles. It has a flow rate capacity of up to 700 GPM , and can filter out solids with a cut point down to 84 microns [14]. The shaker is powered by a 2.5 horsepower motor which comes with the assembly. The shaker is 9.81 feet long, 5.76 feet wide, and 5.81 feet high with a weight of 4,673 pounds. General dimension drawings of the shaker can be found in Appendix A. Figure 7 shows a model of the Hyper-G Shaker.

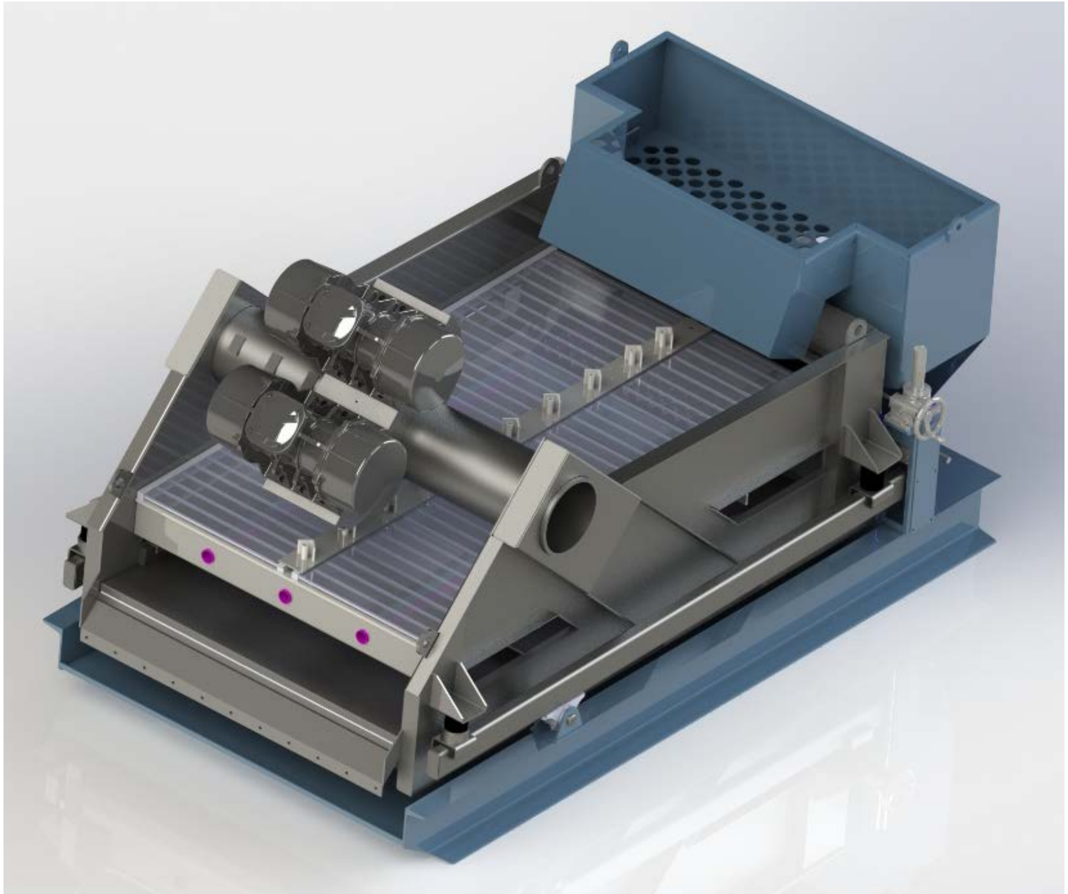

Figure 7: Elgin Hyper-G Dual-Deck Shaker [14].

Once the Elgin Hyper-G Dual-Deck Shaker was selected as the final filtration device, we worked with Elgin Separation Solutions to determine the final specifications of the Hyper-G Shaker. The Hyper-G Shaker is made to order by Elgin and has many options for customization that do not incur extra cost.

One of the customization options that was included in the original quote was the material used for construction of the shaker, and a 304 stainless steel with a strength of 30.2 ksi was selected because of its high corrosion resistance [14]. Another customization option was the type of screens used on each of the two decks. Based on the application and the desired degree of solid removal, Elgin recommended a coarse, WedgeWire mesh for the upper screen deck. This mesh is capable of removing all solid particles over 1000 microns in size [15]. For the lower screen deck, Elgin recommended a stainless steel 200 x 200 mesh. This essentially means there are 200 strands of stainless steel per linear inch in both the horizontal and vertical directions. This mesh is capable of removing all solid particles over 84 microns in size. The upper deck consists of two coarse screens that should be replaced twice a year, and lower deck requires three fine screens that should be replaced six times a year. The cost of screens for the upper deck is $600 USD ($804 CAD) each, for a total annual replacement cost of $2 400 USD ($3 216 CAD). The cost of screens for the lower deck is $250 USD ($335 CAD) each for a total annual replacement cost of $4 500 USD ($6 030 CAD). Combined with an estimated 5% annual part maintenance cost of $1 977 CAD, the total annual maintenance cost of replacing screens and repairing the unit would be $11 223 CAD which is approximately 26% of the initial cost of the shaker.

Elgin has quoted the Hyper-G shaker at $29 500 USD ($39 530 CAD) with taxes not included [14]. Additionally, Elgin recommended the purchase of a replacement parts kit with the shaker to minimize downtime. This parts kit is available for $2 886 USD ($3 867 CAD), bringing the initial cost of the shaker to $43 397 CAD.

Another customization option that Elgin offered was to replace the standard 460 Volt motor with a 575 Volt motor [15], which would be compatible with electrical connections in the Birchtree Mine. For the inlet of the shaker, a “possum belly” was also added to the shaker to diffuse the pressure of the incoming water and reduce splashing [14]. This possum belly includes 10 inch flanged connections for connecting to an inlet pipe. Finally, a 10 inch flanged connection was added to the shaker’s drain pan for direct connection to the clear water reservoir. Through working with Elgin to determine the final specifications of the recommended shaker, we were able to ensure as many target specifications were met as possible. TABLE III summarizes the final specifications of the recommended Hyper-G Dual-Deck Shaker and compares them to the target specifications.

TABLE III: FINAL FILTRATION DEVICE SPECIFICATIONS

| Metric | Design Spec | Marginal Spec | Ideal Spec | Marginal Spec Met? |
|---|---|---|---|---|
| Material | 304 Stainless Steel | N/A | N/A | N/A |
| Material Strength | 30.2 Ksi [4] | 60.2 Ksi | > 60.2 Ksi | No |
| Max Flow Rate | 700 GPM | 300 GPM | > 300 GPM | Yes |
| Upper Deck Cut Point | 1000 microns | N/A | N/A | N/A |
| Lower Deck/ Final Cut Point | 84 microns | 800 microns | 0 microns | Yes |
| Power | 2.5 HP | 300 HP | < 100 HP | Yes |
| Electrical Power Input | 575 V -600 V | 120 V, 600 V, 4160 V | 4160 V | Yes |
| Weight | 4,673 lbs | 20,000 lbs | < 10,000 lbs | Yes |
| Size | 9.81 ft X 5.76 ft | 30 ft X 5.17 ft | < 12 ft X 5 ft | No |
| Shutdown Time | 6 seconds [15] | 15-30 seconds | <15 Seconds | Yes |
| Pipe Inlet/Outlet | 10 inch | 4-10 inch | 6-8 inch | Yes |
| Coarse Screen Replacement Interval | 6 months | N/A | N/A | N/A |
| Fine Screen Replacement Interval | 2 months | N/A | N/A | N/A |
| Design Cost | $39 530 | $225K-$345K | < $225K | Yes |
| Spare Parts Kit Cost | $3 867 | N/A | N/A | N/A |
| Annual Maintenance Cost | 26% ($11 223) | 10%-20% | < 10% | No |

TABLE III shows that most of the target specifications are met or exceeded by the Hyper-G shaker. However, three target specifications were not met, including the material strength, the size, and the annual maintenance cost. Although the material strength target is not met, the design strength is likely still adequate, since Elgin specified 304 stainless steel for this application and has extensive experience in providing designs for applications in the mining industry. The shaker also does not meet the target size requirement. The main reason for this size requirement was due to the size limitations of the **cage**, which will be used to transport the equipment down into the mine; however, the Hyper-G shaker can easily be disassembled into two components that will meet this requirement, so although it does not meet the target size requirement, it will still be able to be transported into the mine. Finally, the annual maintenance cost is higher than desired at 26% of the initial equipment cost; however, the target specifications were initially determined assuming a much higher equipment cost, so the marginally higher maintenance cost is acceptable, considering the relatively low initial cost of the shaker.

## 2.4 Modified Piping Design and Layout

The pipe system modifications required to accommodate the inlet and outlet connections of the shaker in Sump 3 are outlined in the following sections. This includes an overview of the modified pipe system layout, pressure and system head calculations to determine pipe specifications, and a detailed pipe system layout with appropriate calculations.

### 2.4.1 Pipe System Overview

As described in Section 2.1, a 6-inch pipe currently runs along the sidewall of Sump 3, discharging into the sump's initial settling reservoir. This pipe will need to be re-routed so that it connects directly to the shaker inlet. To reduce wear of the new piping system, long radius elbows have been utilized in the design when re-routing the piping path. Since the solid particles in the slurry have a larger mass, and thus a larger magnitude of momentum, they take a longer period of time to change direction than smaller particles, and will collide with the interior pipe walls when there is a sudden direction change. These repeated collisions cause excessive wear on the pipes, so long radius elbows are used to help mitigate this effect. To prevent blockage, the pipe system has been designed with no valleys, as the solids in the water will settle when the water is left stationary in the pipe for extended periods of time [16].

An isolation valve needs to be installed in the inlet pipe section of the shaker so the filtration device can be isolated from the dewatering system when maintenance is required. Since the shaker discharges the filtered water out of the bottom of the assembly, only an isolation valve is needed at the outlet, instead of both check and isolation valves, as gravity will prevent any backflow from the piping system.

Finally, the inlet and outlet connections to the shaker are a 10-inch weld neck flange, while the piping used in the mine is 6-inch pipe. Due to the discrepancy in size between the inlet and outlet flanges and the mine piping, **pipe reducer** fittings will need to be installed before the shaker's inlet and after its outlet. The fittings will provide a transition from the 6 inch diameter pipe to the 10 inch diameter flanges [17].

### 2.4.2 Pipe System Specifications

To determine the required pipe specifications that will be used in the new piping design, the current pressure at the discharge of the pipe into Sump 3 was calculated. For the purpose of these calculations, the properties of the slurry were assumed to be for water at a temperature of T = 20°C. Once this discharge pressure was determined, it was assumed that the new piping system would operate under a similar pressure.

To begin, the velocity of the water through the pipe was calculated using Eq. 1 with the specified maximum flow rate of water through the dewatering system and the pipe's area.

$$\mathbf{v} = \frac{\mathbf{q}}{\left(\frac{\pi}{4} d^2\right)} \qquad \text{Eq. 1}$$

Next, using this calculated velocity and pipe diameter with the density and absolute dynamic viscosity of the water, the Reynolds Number of the flow was calculated using the relation given in Eq. 2 [18].

$$\mathbf{Re} = \frac{\mathbf{v} \cdot \mathbf{d} \cdot \boldsymbol{\rho}}{\boldsymbol{\mu}} \qquad \text{Eq. 2}$$

Assuming that the pipes operate with turbulent flow, the flow can be characterized by a Reynolds Number of greater than 4000. Consequently, the friction head loss coefficient of the piping system was computed using the empirical correlation given by the Colebrook equation, as shown in Eq. 3 [19].

$$\frac{1}{\sqrt{f}} = -2\log\left[\left(\frac{2.51}{(\mathbf{Re} \cdot \sqrt{f})}\right) + \left(\frac{\left(\frac{e}{d}\right)}{3.72}\right)\right] \qquad \text{Eq. 3}$$

For the remainder of the calculations, the current pipe system characteristics specified in Figure 5 were used. To start, the major frictional head losses throughout the entire pipe length, from the 3800 Level sump to the discharge in Sump 3 on the 3950 Level, were calculated with the computed friction head loss coefficient using Eq. 4 [20].

$$\mathbf{h_{loss,maj}} = \mathbf{f} \cdot \frac{\mathbf{L_{tot}}}{\mathbf{d}} \cdot \frac{\mathbf{v^2}}{\mathbf{2g}} \qquad \text{Eq. 4}$$

For the same pipe section, the minor friction head losses were calculated for all of the pipe fittings along this total pipe length using Eq. 5 [21].

$$\mathbf{h_{loss,min}} = \sum \xi \frac{\mathbf{v^2}}{\mathbf{2g}} \qquad \text{Eq. 5}$$

Finally, using the major and minor friction head losses, the overall change in elevation of the system, and the velocity of the water in the pipe, the pressure at the discharge into Sump 3 was calculated using Eq. 6 [22].

$$\mathbf{p_2} = -\frac{\gamma\left(\Delta \mathbf{z} + \frac{\mathbf{v^2}}{\mathbf{2g}} + \mathbf{h_{loss,maj}} + \mathbf{h_{loss,min}}\right)}{\left(\mathbf{144}\,\frac{\mathbf{in^2}}{\mathbf{ft^2}}\right)} \qquad \text{Eq. 6}$$

A detailed analysis of these pressure calculations for the current pipe system is provided in Appendix B. Values and units for the input variables used in these equations along with the calculated results are highlighted in TABLE IV.

**TABLE IV: CURRENT PIPE SYSTEM PRESSURE CALCULATION INPUT VARIABLES AND CALCULATED RESULTS**

| Variable | Definition | Value | Units |
|---|---|---|---|
| | Inputs | | |
| **q** | Maximum flow rate | 300 | $gpm$ |
| | | 0.668 | $ft^3/s$ |
| **d** | Pipe diameter | 0.5 | $ft$ |
| $\boldsymbol{\rho}$ | Density of water | 62.3 [22] | $lbm/ft^3$ |
| $\boldsymbol{\mu}$ | Dynamic viscosity of water [24] | 6.796 x $10^{-4}$ | $\frac{lbm}{s*ft}$ |
| $\mathbf{L_{tot}}$ | Total pipe length | 226.3 | $ft$ |

| Variable | Definition | Value | Units |
|---|---|---|---|
| **g** | Gravitational Force | 32.2 | $ft/s^2$ |
| **e** | Absolute roughness coefficient (steel commercial pipe) [25] | 0.0003 | $ft$ |
| $\xi_{elb,90}$ | Minor loss coefficient [26] (6 Long Radius Elbows, Welded, 90°) | 0.7 | - |
| $\gamma$ | Specific weight of water | 62.3 [22] | $lbf/ft^3$ |
| **Δz** | Change in elevation | -122 | $ft$ |
| Outputs | | | |
| **v** | Pipe water velocity | 3.404 | $ft/s$ |
| **Re** | Reynold's Number | 156 025 | - |
| **f** | Friction head loss coefficient | 0.0197 | - |
| $h_{loss,maj}$ | Major head loss | 1.604 | $ft$ |
| $h_{loss,min}$ | Minor head loss | 0.756 | $ft$ |
| $p_2$ | Outlet Pipe Pressure (Discharge to 3950 Level Dirty Water Reservoir) | 56.875 | $PSIG$ |

Based on this discharge pressure, $p2 = 56.875\ PSIG$, the Engineering Standard Specification Number SPEC-35004 from Vale Manitoba Operations was used. This standard has a pipe pressure rating of 150 PSIG at 149°F and is valid for operating conditions of 100 PSIG at ambient temperatures ranging from 1℃ to 40℃ [27].

### 2.4.3 New Pipe System Layout

A general overview of the modified pipe system layout is illustrated in Figure 8.

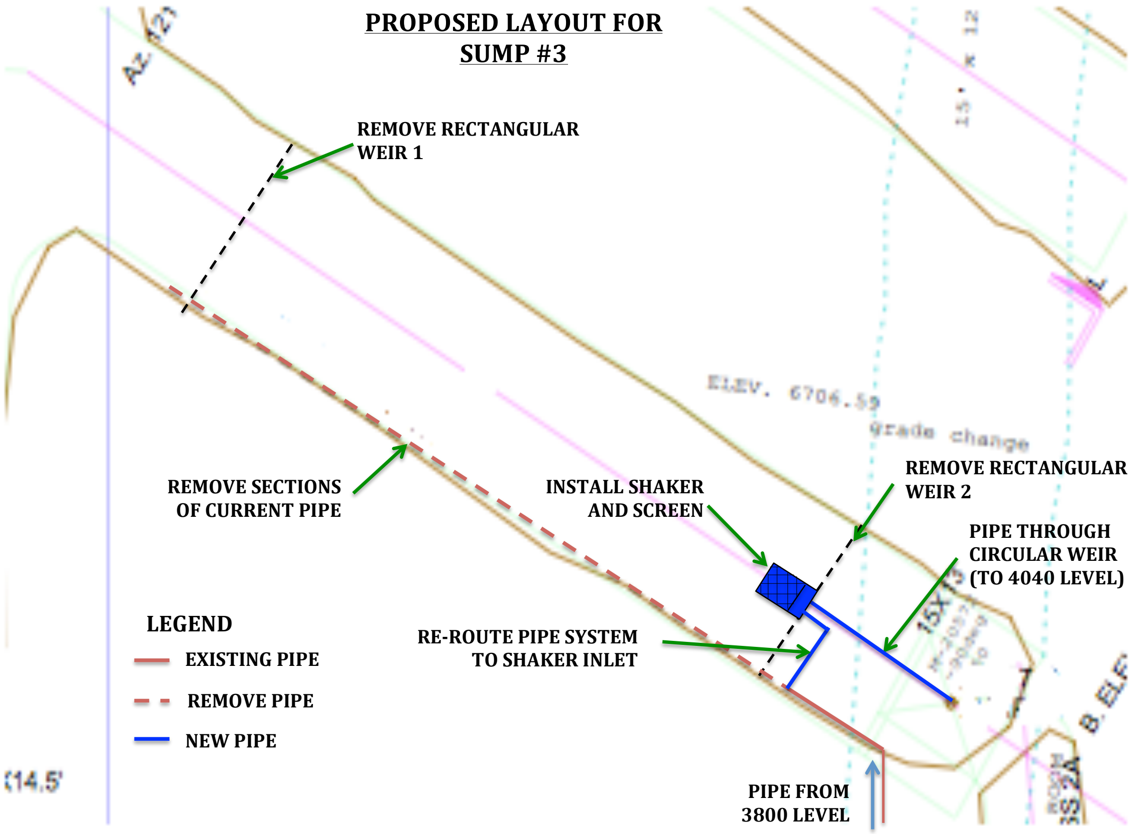


**Figure 8: General piping layout of new Sump 3 pipe system [28].**

Using the scale on the original drawing, the team calculated that approximately 65 feet of the current pipe system will need to be removed to accommodate the new pipe system, as shown in Figure 8. A more detailed representation of the new piping layout, with required pipe and fitting sizes, is provided in Figure 9 and Figure 10.

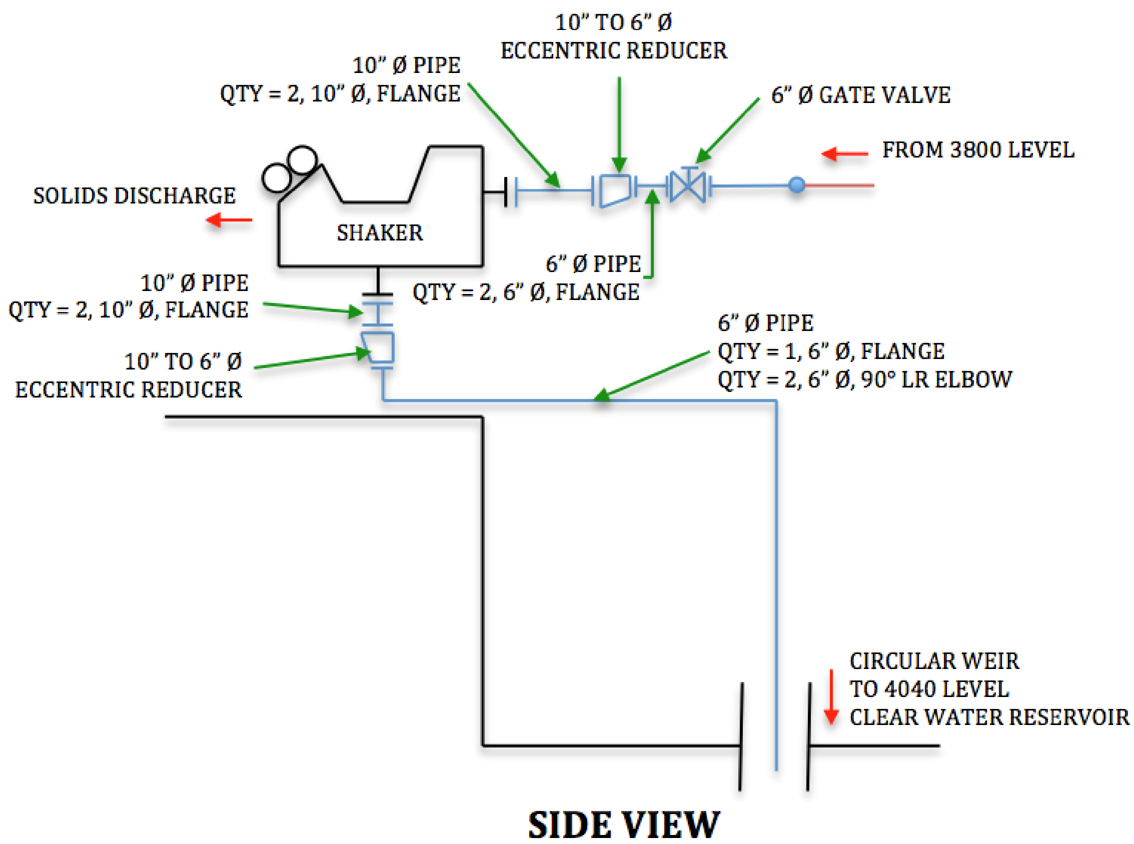


**Figure 9: Detailed side view outlining required components for pipe modifications [29].**

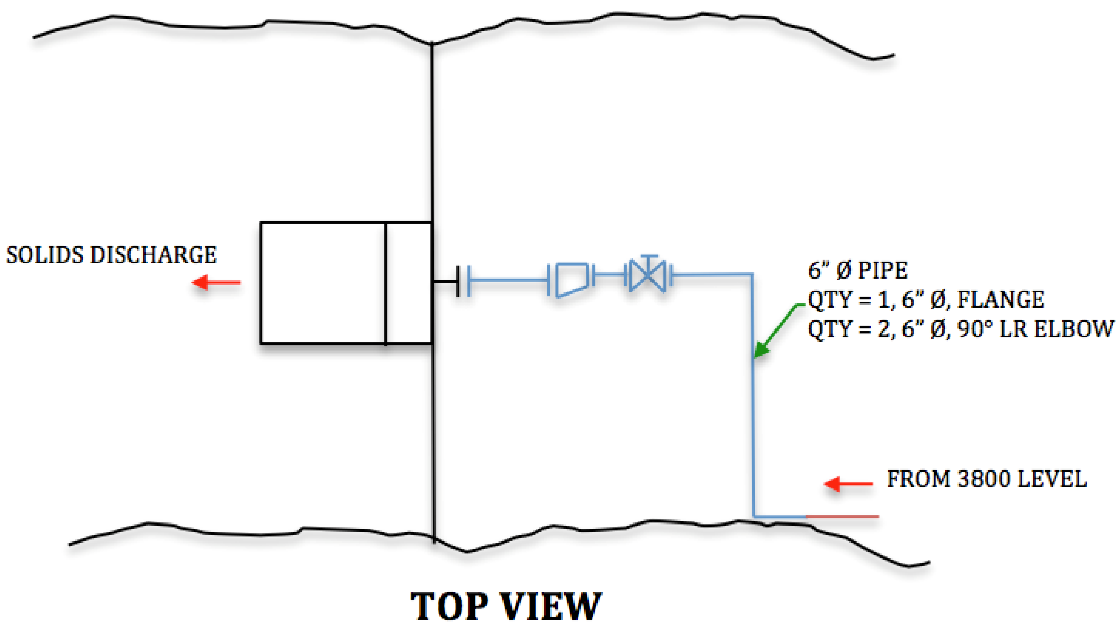


**Figure 10: Detailed top view outlining remaining inlet components for pipe modification [30].**

Since the dimensions and elevation of the current pipe system in Sump 3 are unknown, accurate pipe lengths for the new piping system cannot be determined. Therefore, the following considerations should be taken when determining the location to install the shaker. The inlet must be installed at an equal or lower elevation than the current piping to ensure that the slurry has sufficient head to feed the shaker. To reduce turbulence and mixing in the slurry at the inlet of the shaker, the pipe system needs a straight pipe section with a length of four to ten pipe diameters before connecting to the inlet flange. This means a pipe length of 40 to 100 inches for the shaker's 10 inch input flange [17]. Finally, to allow for adequate drainage in the horizontal component of the discharge pipe, the pipe needs to be sloped at an angle of 1/8 inch per foot. This will prevent any water from remaining stagnant in the pipe section when the shaker is not operating [31].

With the shaker located in the center of Sump 3, the amount of new pipe required to reach the inlet will be approximately 15 feet based on the overall dimensions of the reservoir. The pipe lengths and fittings required to modify the piping system are summarized in TABLE V, with their corresponding size, specification and quantity. The pipe lengths in this table are based on the standard order quantity of 21 feet per length provided by Comco [32], [33].

**TABLE V: REQUIRED PIPE LENGTHS AND FITTINGS FOR PIPE MODIFICATIONS WITH SPECIFICATIONS BASED ON SPEC-35004 [27]**

| Component | Size | Specification | QTY | Units |
|---|---|---|---|---|
| Pipe | 10” | Schedule 40 carbon steel ASTM A53 Gr. B Type E (ERW) or Type S (Seamless), beveled ends. | 21 | Ft |
| | 6” | | 42 | |
| 90° Elbow | 6” | Schedule 40 carbon steel per ASTM A234 Grade WPB, butt weld prep per ASME B16.9. | 4 | Ea |
| Eccentric Reducer | 10” to 6” | | 2 | Ea |
| Pipe Flange | 10” | Class 150 lb. slip-on or welding neck type, raised face, forged steel ASTM A105 , ANSI/ASME B16.5. Bore of welding neck flanges to suit pipe ID. | 4 | Ea |
| | 6” | | 4 | |
| Gate Valve | 6” | Class 125 lb. flanged, iron body, bronze mounted, wedge disc, outside stem and yoke, rising stem. Valves to be lockable. | 1 | Ea |

### 2.4.4 New Pipe System Operating Conditions

To verify that the selected pipe specification standard, SPEC-35004, is suitable for the pressures created in the new piping system, the calculations highlighted in Section 2.4.2 were re-calculated for the new pipe system. Since the system will experience a pressure drop expanding through the pipe reducer from 6 inches to 10 inches, the pressure at the opening of the reducer, $p_{2,new}$, was calculated, as this location will contain the highest pressures. The overall pipe length used for the major friction losses is shown in Eq. 7,

$$L_O = L_1 - L_R + L_N \qquad \text{Eq. 7}$$

where $L_O$ is the overall pipe length, $L_1$ is the original pipe length, $L_R$ is length of the pipe that was removed, and $L_N$ is the length of new pipe added. For the minor loss calculations, eight 90° long radius elbows and one gate valve were used.

Values and units for the input variables used in these equations along with the calculated results are highlighted in TABLE VI. A detailed analysis of these pressure calculations is shown in Appendix B.

**TABLE VI: NEW PIPE SYSTEM PRESSURE CALCULATION INPUT VARIABLES AND CALCULATED RESULTS**

| Variable | Definition | Value | Units |
|---|---|---|---|
| **Inputs** | | | |
| **q** | Maximum flow rate | 300 | $gpm$ |
| | | 0.668 | $ft^3/s$ |
| **d** | Pipe diameter | 0.5 | $ft$ |
| **ρ** | Density of water [23] | 62.3 | $lbm/ft^3$ |
| **μ** | Dynamic viscosity of water [24] | 6.796 x $10^{-4}$ | $\frac{lbm}{s * ft}$ |
| $L_{tot,new}$ | Total pipe length | 176.3 | $ft$ |
| **g** | Gravitational Force | 32.2 | $ft/s^2$ |
| **e** | Absolute roughness coefficient (steel commercial pipe) [25] | 0.0003 | $ft$ |

| Variable | Definition | Value | Units |
|---|---|---|---|
| $\xi_{elb,90}$ | Minor loss coefficient [26] (8 Long Radius Elbows, Welded, 90°) | 0.7 | - |
| $\xi_{gv}$ | Minor loss coefficient (Gate Valve, Fully Open) [26] | 0.15 | - |
| $\gamma$ | Specific weight of water [23] | 62.3 | $lbf/ft^3$ |
| $\Delta z$ | Change in elevation | -122 | $ft$ |
| **Outputs** | | | |
| v | Pipe water velocity | 3.404 | $ft/s$ |
| Re | Reynold's Number | 156 025 | - |
| f | Friction head loss coefficient | 0.0197 | - |
| $h_{loss,maj}$ | Major head loss | 1.25 | $ft$ |
| $h_{loss,min}$ | Minor head loss | 1.035 | $ft$ |
| $p_{2,new}$ | Shaker inlet pressure (Before eccentric reducer) | 51.716 | $PSIG$ |

Since the shaker inlet pressure, $p_{2,new} = 51.716\ PSIG,$ is less than the maximum operating pressure of 100 $PSIG$ specified by SPEC-35004, this pipe specification is valid for the new pipe system.

## 2.5 Control System Design

In order to effectively integrate the shaker and pipe layout outlined in Section 2.4.3 with the Birchtree mine's dewatering system, a control system is required. This control system will activate and deactivate the shaker in accordance with the activation of high and low level sensors in the 3800 Level sump and the clear water reservoir. Since the design of electrical sensors and controls is outside the scope of a mechanical engineering project, this section will focus on describing how commercially available sensors can be used to control the filtration system.

A flow sensor is to be installed a sufficient distance upstream from the shaker inlet, so that it will be activated before the slurry reaches the shaker. The early activation will allow the shaker enough time to reach full speed before the slurry enters the shaker inlet. The required distance between the flow sensor and the shaker inlet depends on the reaction time of the system and the maximum flow velocity within the pipe. A flow chart showing how various sensors are used to control the flow path of the water through the dewatering system is shown in Figure 11.

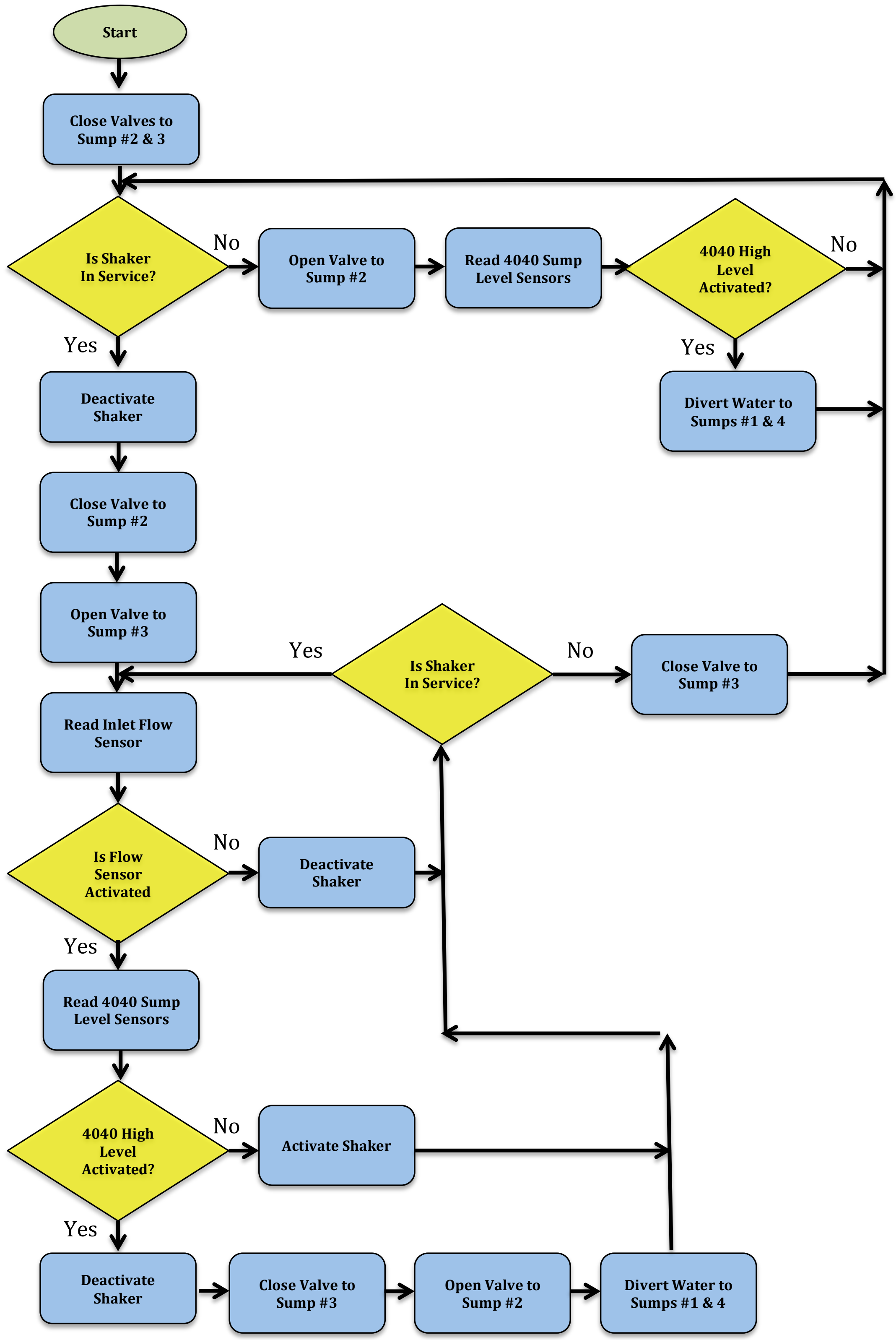


Figure 11: New dewatering system flow chart [34].

The flow control process begins by closing both valves to Sumps 2 and 3 and verifying whether the shaker is in service or removed for maintenance purposes. If the shaker is removed, the valve to Sump 2 will be opened and the slurry will proceed through the settling reservoirs in Sump 2, eventually reaching the 4040 Level clear water reservoir. If the high-level sensor in the 4040 Level reservoir is activated, the slurry will be diverted into Sumps 1 and 4 until the high level sensor is no longer activated. This process provides a sufficient bypass path for the water when the shaker is non-operational.

When the shaker is operational, it will initially be deactivated while the valve to Sump 2 closes, and the valve to Sump 3 opens. If the flow sensor installed in the shaker inlet piping is activated and the 4040 Level high-level sensor is not activated, the shaker will be started. If the 4040 Level high-level sensor is activated, the shaker will be shut down and the valve to Sump 3 will be closed. The valve to Sump 2 will then be opened and the slurry can be diverted to Sumps 1 and 4 until the 4040 Level high-level sensor is no longer activated. Finally, if the flow sensor is not activated, the shaker will be shut down. This process will continue until the shaker is disconnected for maintenance, at which point the flow process will loop back to the beginning.

**Piping and instrumentation diagrams (P & IDs)** are a tool that is often used in the design of piping systems and their control systems to communicate the piping layout and path as well as any instrumentation used to control the flow path. The flow path layout of the new dewatering system is given in the P & ID shown in Figure 12.

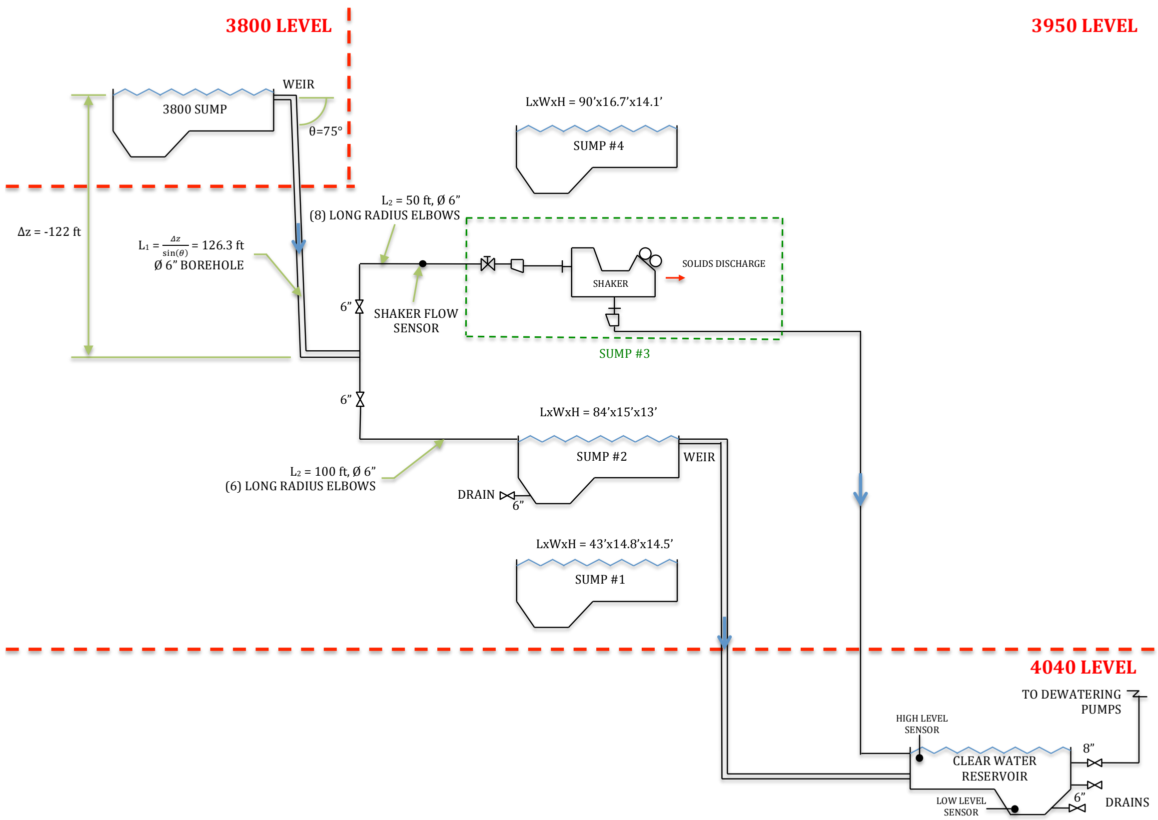


**Figure 12: P & ID diagram of the new dewatering flow process [35].**

The valves and sensors used to control the water flow path through the dewatering system are also shown in Figure 12. This should provide Vale with a foundation on which to base the control system for the filtration device.

## 2.6 Solid Discharge Method

The addition of a filtration device to the dewatering system will result in solid discharge from the system. A method of transporting these solids away from the shaker outlet to a temporary storage location was initially part of the project scope; however, there were no data available regarding the volume content of solids in the water flow. Without this information, Swift Consulting could not predict the volume of solids ejected from the shaker per minute during peak flow season, and an accurate solid transportation and storage system could not be included as part of the design. Therefore, this section focuses on describing how solid transportation and storage is currently managed in the mine, and suggests other solid transportation methods commonly used to perform this function in mining applications, and the steps Vale could take to add such a system to this design.

Currently, Sumps 1 through 4 are cleaned between every three weeks and every three months, depending on the amount of solid buildup. Solid material is removed from the sumps and stored in a designated space across the drift from the sumps. Machine-operated loaders are used in the cleaning process to scoop the solid material and transport it to the storage area.

If the volume of solids in the water is low, the solid material could simply be ejected off the end of the shaker's screens and be deposited onto a pile where they could be stored until the pile grew large enough that it required transportation to the designated storage space. The advantages to this method are that it is very simple and requires no extra equipment cost. The disadvantage is that the solids would be deposited at the back of the sump near the shaker location, which is much further from the designated solid storage space than the front of the sump is. The initial deposit location at the back of the sump may be accessible with a machine-operated loader; however, this will be limited by the 12 foot height of the Sump 3 area and any piping that would block the path to the deposit pile.

Alternatively, other methods, such as screw or belt conveyors, can be used to transport the solids to another location. A screw conveyor consists of a large auger rotating in a trough to move the solid material along the trough to a new location. Figure 13 shows the general assembly of an auger.

Figure 13: General assembly of screw conveyor for solid material transportation [36].

In a belt conveyor system, solids are dropped onto a moving belt and transported to another location. There are often trough-like edges to ensure the solids remain on the belt. This method is currently used in other applications within the Vale Birchtree Mine. Figure 14 shows an example of this type of conveyor system.

Figure 14: Belt conveyor system for solid material transportation [37].

Either of these methods could be used to transport the solids ejected from the shaker to a location closer to the front of the sump, where they would be easily accessible to machine-operated scoops that could transport them across the drift to the designated solids storage area. The advantage to this system is that it would eliminate the labour involved with manually transporting solid material, and the disadvantages are that it would drive the cost of the new water filtration system up, and that it would require more specialized maintenance than manually transporting solids.

To determine what kind of solid transportation system best suits Vale's application, a clearer knowledge of the volume content of solids in the mine drain water is required. This can be done by taking a water sample during peak flow and having it analyzed for solid content. Many solid solutions companies will perform this analysis free of charge. Once the volume of solid content in the water is known, a solid transportation and storage system can be designed to meet the needs of the water filtration system.

## 2.7 Assembly and Installation

To implement the design of the dewatering filtration system outlined in this report, the following procedure was developed to install the shaker and its components.

The first step is to close the valve to Sump 3 and drain the remaining water in Sump 3 by pumping the water to Sump 2. Once the sump is dry, rectangular weirs 1 and 2 should then be removed to allow for easier access from both sides to the interior sections of the reservoir. Figure 2 can be referenced for the locations of the weirs within the sump. Once a clear path through the sump has been made, the next step is to determine the optimal location for the shaker within the sump. This location will depend on the elevation difference between the ground level of the middle settling reservoir of Sump 3 and the opening of the circular weir in the final settling reservoir of Sump 3. It will also depend on the distance from the Sump 3 entrance to the location of the second rectangular weir. As these measurements are not shown on the sump drawings provided by Vale, and could not be measured during Swift Consulting's visit to Birchtree Mine, we cannot identify the best location for the shaker. Our recommendation is that the shaker be placed near the back of the sump to reduce extra piping costs.

Once the shaker location is determined, the distance from the current pipe system to the sump floor can then be measured and used to fabricate a stand or base for the shaker such that the shaker's inlet flange is level or slightly below the elevation of the pipe. As this distance measurement was also not available to Swift Consulting, we could not accurately design a stand for Vale to manufacture and install. However, we recommend building a base composed of two concrete pads for the shaker to be mounted to. Elevating the shaker onto the concrete pads will allow for the discharge piping to be connected to the bottom of the shaker. The shaker can be mounted to the concrete pads using anchor bolts or threaded rod. Approximate dimensions and costs of the concrete pads are shown in TABLE VII.

**TABLE VII: APPROXIMATE DIMENSIONS AND COSTS OF SHAKER BASE**

| | Length [ft] | Width [ft] | Height [ft] | 15M Rebar [ft] | Concrete | |
|---|---|---|---|---|---|---|
| | | | | | [ft$^3$] | [yd$^3$] |
| **Pad 1** | 7 | 3 | 3 | 195 | 63 | 2.33 |
| **Pad 2** | 7 | 2 | 3 | 126.5 | 42 | 1.56 |
| **Total Required Quantity** | | | | 321.5 + 10% =353.65 | 105 | 3.89 + 10% =4.28 |
| **Unit Cost** | | | | $0.63/ft [38] | $123.28/yd$^3$ [39] | |
| **Total Cost** | | | | $222.80 | $527.64 | |
| | | | | $750.43 | | |

The space will then be ready for shaker installation. Due to the size limitations of the mine's cage, the shaker must be disassembled before being transported down the mine shaft. The required shaker disassembly is fairly simple; the set of bolts that attach the shaker's **basket** to the **carriage** must be removed, and these two components separated. Individually, these components are small enough to fit in the mine's cage. The basket can remain upright for transportation, and the carriage will need to be transported on its side to fit the width of the cage. Once the shaker and the manufactured stand have been transported to the 3950 Level, the shaker can be reassembled and placed on the stand in the selected location in Sump 3.

With the shaker in place, the necessary portion of the current piping must be removed, as discussed in the Section 2.4.3. The next step is to install the new pipe system with the corresponding fittings, valves and sensors.

Finally, the shaker's control panel must be wired into the 4000 Level Sump Electrical room and the necessary cables connected to the shaker unit.

Once the shaker has been installed, commission as per manufacturer, check all valves and connections, and sample water discharge for shaker quality. If the system passes these checks, it is ready for operation.

## 2.8 Cost

Swift Consulting has made it a priority during the selection of various design components to find high quality materials and apparatuses at economic prices. Swift Consulting worked with various suppliers to create a design that is of the highest value to Vale. We have also performed a full economic analysis to show the cost savings that Vale can expect to gain from the implementation of the dewatering filtration system design.

### 2.8.1 Bill of Materials

TABLE VIII shows a full bill of materials with each component's associated cost, with the total capital cost of the project displayed at the bottom of the table. It is important to note that this total is for materials only and does not include the cost of labour incurred by installation and maintenance of the design.

TABLE VIII: BILL OF MATERIALS

| **Item** | **Quantity** | **Unit Cost** | **Cost** |
|---|---|---|---|
| **<u>Shaker</u>** | | | |
| Hyper G™ Dual Deck 6-Panel Shaker with Single-Point Jacking System [14] | 1 piece | $36 180/ea | $36 180.00 |
| Hyper G™ Dual Deck 6-Panel Shaker Starter Panel | 1 piece | $3 350/ea | $3 350.00 |
| Concrete Shaker Base [38], [39] | 1 piece | Manufactured by Vale | $750.43 |
| **<u>Shaker Spare Parts Package</u>** | | | |
| Firestone Vibration Isolation Mounts [14] | 8 pieces | [redacted] | [redacted] |
| Crown Rubbers | 48 pieces | [redacted] | [redacted] |
| Screen Wedges – Left | 4 pieces | [redacted] | [redacted] |
| Screen Wedges – Right | 4 pieces | [redacted] | [redacted] |
| Grease Tube | 4 pieces | [redacted] | [redacted] |
| Grease Gun | 1 piece | [redacted] | [redacted] |
| **<u>Piping and Fittings</u>** | | [redacted] | [redacted] |
| Steel pipe, 6 inch diameter, ASTM A53 [32] | 42 feet | [redacted] | [redacted] |
| Galvanized steel pipe, 10 inch diameter, ASTM A53 | 21 feet | [redacted] | [redacted] |
| Long radius elbows, 90 deg | 4 pieces | [redacted] | [redacted] |
| Slip-on flanges, 6 inch diameter | 4 pieces | [redacted] | [redacted] |

| Item | Quantity | Unit Cost | Cost |
|---|---|---|---|
| Slip-on flanges, 10 inch diameter | 4 pieces | [redacted] | [redacted] |
| Eccentric reducer, 10 inch X 6 inch | 2 pieces | [redacted] | [redacted] |
| Isolation valve | 2 pieces | [redacted] | [redacted] |
| **<u>Power and Control System Requirements</u>** | | | |
| Electrical cable | At electrician's discretion | No cost available | No cost available |
| Flow sensor | 1 piece | No cost available | No cost available |
| **<u>Total</u>** | | | $45 970 |

As shown in TABLE VIII, the total capital cost of this design, excluding labour, is $45 970. It should be noted that this value is approximate; there were several items for which no pricing information was available, and the cost of these items was not included when calculating the total.

Most of the items listed were special order and could not be acquired off the shelf. Swift Consulting contacted several suppliers regarding each component, however, we did not receive a reply for each item. Those items for which we could not gain pricing information are marked as “no cost available” in the bill of materials. Additionally, the quantity of electrical cable required is marked as “at electrician’s discretion”. This quantity is dependent on the route from the power supply to the shaker that the electrician chooses to take. It should be noted that the shaker’s control panel includes 30 feet of electrical cable.

### 2.8.2 Economic Analysis Results

One of the main purposes of implementing the new design is to significantly reduce the current operating and maintenance costs of the dewatering pumps in Birchtree Mine. It is important to show in this study that implementing the proposed system will result in significant savings for Vale money in the upcoming years. The economic study was limited to the next [redacted] years of operation, as this was the estimated remaining Birchtree Mine lifetime provided by Vale. Vale also uses a rate of return of [redacted] in their economic analyses, so this was the rate of return used to analyze the implementation of the water filtration system designed by Swift Consulting. Some costs were quoted to the team by in $USD, and a conversion rate of $1.34 CAD to every $1 USD was used. This conversion rate was taken on November 28, 2015 [40]. In order to calculate labour costs involved with installation and maintenance of the new system, an average hourly rate of $85 was used, as this was the approximate value supplied to the team by Vale. To perform the economic study, the option of implementing Swift Consulting's recommended system was compared to the option of continuing to operate the system in its current state.

Three different methods have been used to show the feasibility of the proposed system. A payback period has been calculated to show how quickly the investment will be recovered. It is necessary that the payback period on the initial investment is short, considering the uncertainty in the remaining lifetime of the Birchtree Mine. The overall savings, in dollars, are also presented to show the total estimated amount of money Vale could save over the next [redacted] years. Along with the payback period and overall savings for [redacted] years of operation, a net present value (NPV) calculation has been included to show today's present value of the savings incurred over the next seven years, if the design is implemented.

The current dewatering system in the Birchtree Mine consists of three pumps that each require extensive repair approximately once per year. Currently, the maintenance and repair costs are too high to tolerate. Using maintenance data for the past 27 months provided by Vale, the average yearly cost of pump repair and maintenance for the dewatering system was calculated to be $[redacted] per year. If the water filtration system design is implemented, it is estimated that each of these three pumps will require repair once every two years, and the economic analysis has been prepared under this assumption. This is a conservative estimate, as many pumps are designed to last much longer than two years when pumping clear water. The results of the economic analysis show a revised yearly pump maintenance cost of $[redacted] per year. The repair and maintenance costs calculated for the current and new system include the cost of parts and labour.

The initial cost of the new system includes the Elgin High-G Dual-Deck Shaker as well as the piping and fittings required to install it, as listed in the bill of materials shown in TABLE VIII. Assuming an installation time of 188 hours, the initial investment is approximately [redacted], which includes the cost to purchase the system components as well as the cost of labour to install the system. As cost information was not available for various system components, this cost is approximate. The details of the installation time calculation can be found in Appendix C.

Implementing a new system incurs additional costs to maintain the components of the new system. The annual average maintenance cost for the new system is [redacted] per year on average. This maintenance cost covers parts and labour. Combining this maintenance cost with the revised pump maintenance cost results in a total average yearly maintenance cost of $[redacted] per year for the new system. TABLE IX summarizes the final calculated costs to implement and maintain the new system, and compares it to the yearly cost to maintain the current system.

**TABLE IX: COSTS OF IMPLEMENTING NEW DESIGN VERSUS KEEPING THE CURRENT SYSTEM**

| | **New System** | **Current System** |
|---|---|---|
| **Capital cost** | $[redacted] | --- |
| **Maintenance Cost** | $[redacted] | $[redacted] |

If the design is implemented, the total savings Vale can expect over the next [redacted] years is $[redacted]. The expected payback period is 6 months. The NPV of choosing to implement the new system is $[redacted] using a rate of return at [redacted] for [redacted] years.

These results show that there are significant savings for Vale to gain from implementing the new system. Maintenance costs will be lowered substantially, and the short payback period means Vale will quickly recover the initial investment required to implement the system. Details of this economic analysis can be found in Appendix C.

# 3. CONCLUSION

The main purpose of this project was to reduce pump maintenance costs in Vale's Birchtree Mine dewatering system. In order to achieve this purpose, Swift Consulting determined that changes should be made to the dewatering system, including the addition of a filtration component to the system. The addition of a filtration device will reduce the number of solid particles in the mine drain, which were identified as the main cause of pump damage. In addition to reducing pump maintenance costs, the addition of a filtration device will result in reduced labour associated with cleaning sumps, improved ore recovery by processing the solids removed from the water, and increased revenue for Vale. Swift Consulting strived to create a feasible design, so the equipment selected needed a low initial capital cost, as well as low additional maintenance costs to ensure a net reduction in costs.

After considering multiple filtration concepts, and equipment from several different suppliers, the Elgin Hyper-G Dual-Deck Shaker was selected as the best solution. The Hyper-G shaker is capable of processing slurry at 700 gpm to a cut point of approximately 84 microns. The shaker significantly exceeds Swift Consulting's goals of designing a system that would process slurry at 300 gpm to a cut point of 800 microns.

To accommodate the Hyper-G shaker, we recommend draining Sump 3 on the 3950 Level and placing the shaker in that location. With the addition of the Hyper-G shaker, Sumps 2 and 3 will no longer be required to settle out solid particles in the mine drain water, resulting in reduced labour involved with sump cleaning. Sump 3 is the optimal location because it provides a large space and is close in proximity to the current solids storage area. Sump 2 will be left in operation and act as a bypass path for the water to allow for shaker maintenance. Discharge piping from sumps on the 3800 Level will be connected directly to the inlet of the shaker. The discharge from the shaker will be piped directly to the clear water reservoir, where the filtered water will be pumped to as reservoir on the 2340 Level, from which it is pumped out of the mine.

The cost of purchasing and installing the water filtration system components is approximately $[redacted] CAD, which is significantly lower than the design goal of $225 000 set by Vale and Swift Consulting at the beginning of the project. The annual maintenance cost would be $[redacted] CAD per year, which is also significantly lower than the current maintenance cost of $[redacted]. Implementing this design would result in a reduction in pump maintenance costs that would save Vale approximately $[redacted] over the course of [redacted] years.

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# APPENDIX A:
# FILTRATION COMPONENT SELECTION

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## List of Tables

## A.1 Initial Concept Selection

The filtration device concepts initially considered in the concept selection phase of the project included decanter centrifuges, screen-scroll centrifuges, pusher centrifuges, screen shakers, belt filters, self-cleaning filters, flocculation. After evaluating these concepts with a scoring matrix, the decanter centrifuge concept scored the highest, due to its ability to remove a high volume of solids with very small particle sizes. Thus, the team initially pursued the decanter centrifuge for the filtration device in the final design.

## A.2 Further Concept Research

Decanter centrifuges are used in a wide range of industrial applications for solid-liquid separation, thus there is also a wide range of suppliers that would likely be able to provide a decanter centrifuge for the Birchtree Mine dewatering application. For this reason, Swift Consulting decided to source an existing centrifuge from a supplier rather than attempting to design a custom centrifuge. Additionally, a supplier sourced centrifuge also has the advantage of customer support, readily available replacement parts, maintenance manuals, and assurance that the centrifuge design has been tested and refined.

After deciding to pursue a supplier sourced centrifuge, eighteen different suppliers were contacted with details regarding the dewatering system application, and decanter centrifuge quotes were requested. Of the eighteen suppliers contacted, four provided centrifuge quotes for comparison. Two suppliers also recommended the use of a screen shaker instead of a centrifuge. Although the use of a screen shaker was eliminated during the initial concept selection process, specific details from suppliers revealed that screen shakers could be provided at a much lower cost than decanter centrifuges, and with greater solid removal capabilities than previously assumed. A screen shaker can be acquired for a tenth of the cost of a decanter centrifuge [1]. Therefore, after consulting with Vale, the team decided to also collect quotes and specifications for screen shakers to compare with the decanter centrifuges when considering a specific filtration device to recommend for the final design. In total, four decanter centrifuge quotes were collected, and two screen shaker quotes were collected. Many of the quotes were provided in United States dollar amounts and had to be converted to Canadian dollar amounts. The conversion rate, recorded on November 28, 2015, is $1.34 CAD to every $1 USD [2]. The makes and models of the specific decanter centrifuges and screen shakers that were considered for the final design are:

- Elgin ESS-1967HD2 Decanter Centrifuge
- Kubco KHV89SSFVD Decanter Centrifuge
- SWECO 414 Decanter Centrifuge and 509 Hydrocyclone
- Tomoe Engineering OFM25L Decanter Centrfiuge
- Elgin Hyper-G Dual-Deck Shaker
- SWECO MX60S158 Round Screen Shaker

The important parameters of each filtration device are summarized in TABLE I.

TABLE I: FILTRATION DEVICE SPECIFICATION SUMMARY

| | Elgin | Kubco | Process Equipment (SWECO) | Tomoe Engineering | Elgin | Process Equipment (SWECO) |
|---|---|---|---|---|---|---|
| **Model #** | ESS-1967HD2 | KHV89SSFVD | 414 Centrifuge +509 Hydrocyclone | OFM25L | Hyper-G Dual-Deck Shaker | MX60S158 |
| **Type** | Decanter Centrifuge | Decanter Centrifuge | Decanter Centrifuge & Hydrocyclone | Decanter Centrifuge | Screen Shaker | Round Screen Shaker |
| **Max Flow Rate** | 500 GPM [3] | 500 GPM [4] | 300 GPM [5] | 300 GPM [6] | 700 GPM [7] | 300 GPM [8] |
| **Minimum Cut Point** | NOT SPECIFIED | NOT SPECIFIED | 6 Microns [9] | NOT SPECIFIED | 43 Microns [10] | 37 Microns [11] |
| **Power** | 165 HP [3] | 190 HP [4] | 25 HP [9] | 175 HP [6] | 2.5 HP [7] | 2.5 HP [11] |
| **Max Speed** | 3,100 RPM [3] | 3,000 RPM [4] | 3,300 RPM [9] | 2,900 RPM [6] | N/A | N/A |
| **Weight** | 11,500 lbs [3] | NOT SPECIFIED | 4,040 lbs [9] | 19,900 lbs [6] | 4,673 lbs [7] | 900 lbs [11] |
| **Length** | 15.50 ft [3] | 15.83 ft [4] | 7.95 ft [9] [9] | 20.00 ft [6] | 9.81 ft [7] | 6.50 ft [11] |
| **Width** | 4.20 ft [3] | 4.83 ft [4] | 5.83 ft [9] | 5.42 ft [6] | 5.76 ft [7] | 4.90 ft [11] |
| **Height** | 5.20 ft [3] | 4.21 ft [4] | 3.41 ft [9] | 7.58 ft [6] | 5.81 ft [7] | 4.61 ft [11] |
| **Initial Cost** | $455 600 CAD [12] | $[redacted] CAD [13] | $[redacted] CAD [14] | $[redacted] CAD [15] | $39 530 CAD [7] | $[redacted] CAD [8] |
| **Annual Maintenance Cost** | 10% to 20% initial cost (assumed) | 10% to 20% initial cost (assumed) | 10% to 20% initial cost (assumed) | 10% to 20% initial cost (assumed) | 5% initial cost [1] | 10% to 20% initial cost (assumed) |

## A.3 Filtration Device Selection

To evaluate the different filtration devices, they needed to be compared to each other based on their specifications for each metric. However, not every metric should be weighted equally, since some metrics are more important than others. To rank metrics in order of importance and assign a weight prior to evaluation, the metrics are first compared to one another. The matrix used to compare and assign weight to the metrics used for evaluation is shown in TABLE II.

**TABLE II: METRIC WEIGHTING MATRIX**

| Criteria | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| A | | A | A | A | E | A | G |
| B | | | B | B | B | F | B |
| C | | | | C | C | F | G |
| D | | | | | E | F | G |
| E | | | | | | F | G |
| F | | | | | | | F |
| G | | | | | | | |
| Total Hits | 4 | 4 | 2 | 0 | 2 | 5 | 4 |
| Weightings | 0.19 | 0.19 | 0.10 | 0.00 | 0.10 | 0.24 | 0.19 |
| Rank | 2 | 2 | 5 | 7 | 5 | 1 | 2 |

| Legend |
|---|
| A = Flow Rate |
| B = Cut Point |
| C = Power |
| D = Weight |
| E = Size |
| F = Initial Cost |
| G = Maintenance Cost |

From this weighting matrix, the rank and assigned weights for each metric can be seen in the table below. It is notable that the filtration device weight was assigned a weighting of zero. This means it was not deemed more important than any other metrics and will not be considered in further evaluation. A summary of the metric ranks and weighting is listed in TABLE III.

TABLE III: FILTRATION DEVICE METRIC WEIGHTINGS AND RANKS

| Rank | Metric | Weighting |
|---|---|---|
| **1** | Initial Cost | 0.24 |
| **2** | Maintenance Cost | 0.19 |
| **2** | Flow Rate | 0.19 |
| **2** | Cut Point | 0.19 |
| **5** | Power | 0.10 |
| **5** | Size | 0.10 |
| **7** | Weight | 0.00 |

After assigning weights to each of the metrics to be used for evaluation, each of the potential filtration devices needs to be assigned a score for each metric. Scores are assigned out of 5 for each metric and are based on the specifications for each device listed in TABLE I. The scoring matrix used to rank the different filtration devices is shown in TABLE IV.

TABLE IV: FILTRATION DEVICE EVALUATION MATRIX

| Metric | Weighting | Elgin ESS-1967HD2 | Kubco HV89SSFVD | SWECO 414 Centrifuge + 509 Hydrocyclone | Tomoe Engineering OFM25L | Elgin Hyper-G Dual-Deck Shaker | SWECO MX60S158 |
|---|---|---|---|---|---|---|---|
| **Initial Cost** | **0.24** | 1.2 | 1.0 | 2.5 | 1.5 | 5.0 | 4.9 |
| **Maintenance Cost** | **0.19** | 1.2 | 1.0 | 2.5 | 1.5 | 5.0 | 4.9 |
| **Flow Rate** | **0.19** | 3.8 | 3.8 | 2.5 | 2.5 | 5.0 | 2.5 |
| **Cut Point** | **0.19** | 5.0 | 5.0 | 5.0 | 2.5 | 3.9 | 4.1 |
| **Power Required** | **0.10** | 1.3 | 1.0 | 4.3 | 1.2 | 5.0 | 5.0 |
| **Size** | **0.10** | 3.0 | 3.0 | 5.0 | 1.0 | 3.0 | 5.0 |
| **Weight** | **0.00** | 2.0 | 1.0 | 3.0 | 1.0 | 3.0 | 5.0 |
| | **Score** | **2.6** | **2.5** | **3.4** | **1.8** | **4.6** | **4.3** |
| | **Rank** | **4** | **5** | **3** | **6** | **1** | **2** |

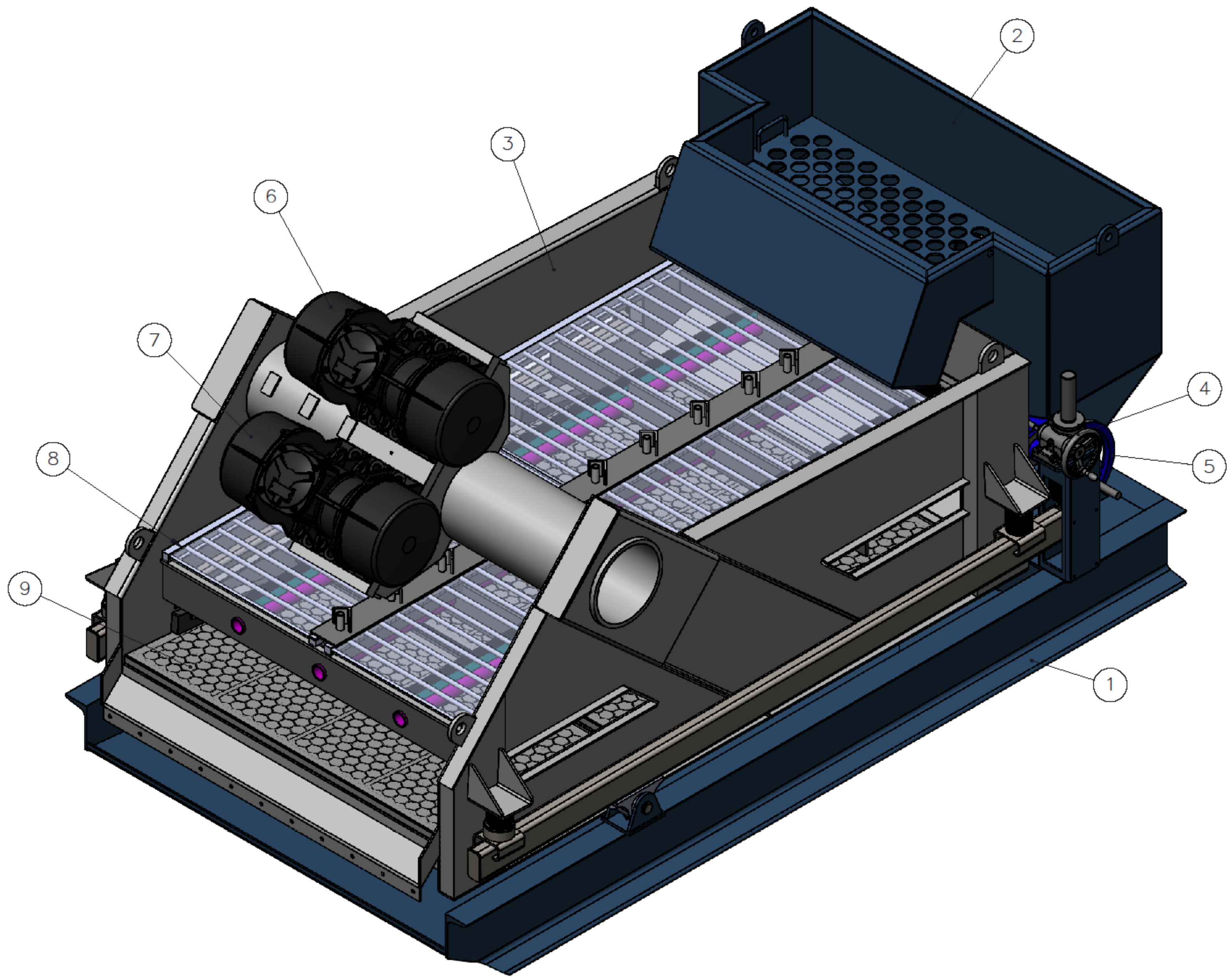
From TABLE IV it can be seen that the Elgin Hyper-G Dual-Deck Shaker scored the highest with a score of 4.6. This is the device Swift Consulting selected as part of the final design recommendation to Vale for the design of a water filtration system for the Birchtree Mine. The general dimension drawings of the shaker, provided by Elgin, are provided in Section A.4.

## A.4 General Dimension Shaker Drawings

This section contains the drawings showing general dimensions and features of the Hyper-G Dual-Deck Shaker. These drawings were supplied to Swift Consulting by Elgin Separation Solutions, the manufacturer of the Hyper-G Shaker.

| BILL OF MATERIALS | | |
|---|---|---|
| ITEM | DESCRIPTION | QTY |
| 1 | HYPER-G-6PN-W FLOW SHAKER CARRIAGE | 1 |
| 2 | HYPER-G 4P FLOW SHAKER BACKTANK WELDMENT | 1 |
| 3 | BASKET ASSY., HYPER-G 6PN FLOW VERSION | 1 |
| 4 | SINGLE POINT JACK ASSEMBLY | 2 |
| 5 | KNIFE GATE VALVE, ANSI 8" FLANGE | 1 |
| 6 | 2.5 HP MOTOR W/ 95% SWING WEIGHT | 1 |
| 7 | 2.5 HP MOTOR W/ 75% SWING WEIGHT | 1 |
| 8 | WEDGE WIRE SCREEN ASSY. | 4 |
| 9 | KPT-28 SCREEN ASSY. | 3 |

NOTE: ESTIMATED WEIGHT: 4477 LBS




WELDING NOTE (UNLESS OTHERWISE NOTED)

1) ALL WELDS SHALL BE CONTINUOUS.

2) ALL FILLET WELDS SHALL HAVE EQUAL LEGS.

3) FILLET WELD SIZE SHALL EQUAL BASE METAL WHEN BASE METAL IS LESS THAN OR EQUAL TO 3/16".

4) WHEN THE THINNEST METAL IS 1/4" OR GREATER THE FILLET WELD SIZE SHALL BE 1/16" LESS THAN THE THINNEST METAL.

| REV. | ECN NO. | DATE | DWN. | CHK'D |
|---|---|---|---|---|

UNLESS OTHERWISE SPECIFIED

MACHINING TOLERANCES
FRACTIONS – ±1/64"
.X – ±.030
.XX – ±.015
.XXX – ±.005
ANGLES – ±1/2°

SURFACE FINISH 125 RMS

INSIDE CORNER RADII .010min./.030max.
BREAK ALL EDGES .005min./.015max.
–ALL DIMENSIONS IN INCHES–

FABRICATION TOLERANCES
PREP ±1/16"
AS FORMED ±1/16"
LOCATIONAL FIT ±1/8"
CONSTRUCTION 0"–120" ±1/8"
CONSTRUCTION 120"–18' ±1/4"
CONSTRUCTION 18'> ±1/2"
ANGULAR ±1°
ANGULARARITY BOLT HC ±1/2°
DIMENSIONING INCHES < 144" FEET > 144"
–REMOVE ALL BURRS AND SHARP EDGES–

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PART NUMBER KEQM–21328

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TITLE HYPER–G–6PN–W FLOW SHAKER

| DWN. TYZ | DATE: 11/25/15 | SCALE: NONE | DRAWING NO. 1 OF 2 | REVISION |
|---|---|---|---|---|
| CHK'D. ETB | DATE: 11/25/15 | WEIGHT: 4486 | KEQM–21328 | 01 |
| APP'D. ETB | DATE: 11/25/15 | | | |

Figure 1: Elgin Hyper-G Dual-Deck Shaker Engineering Drawing Page 1 of 2 [7].

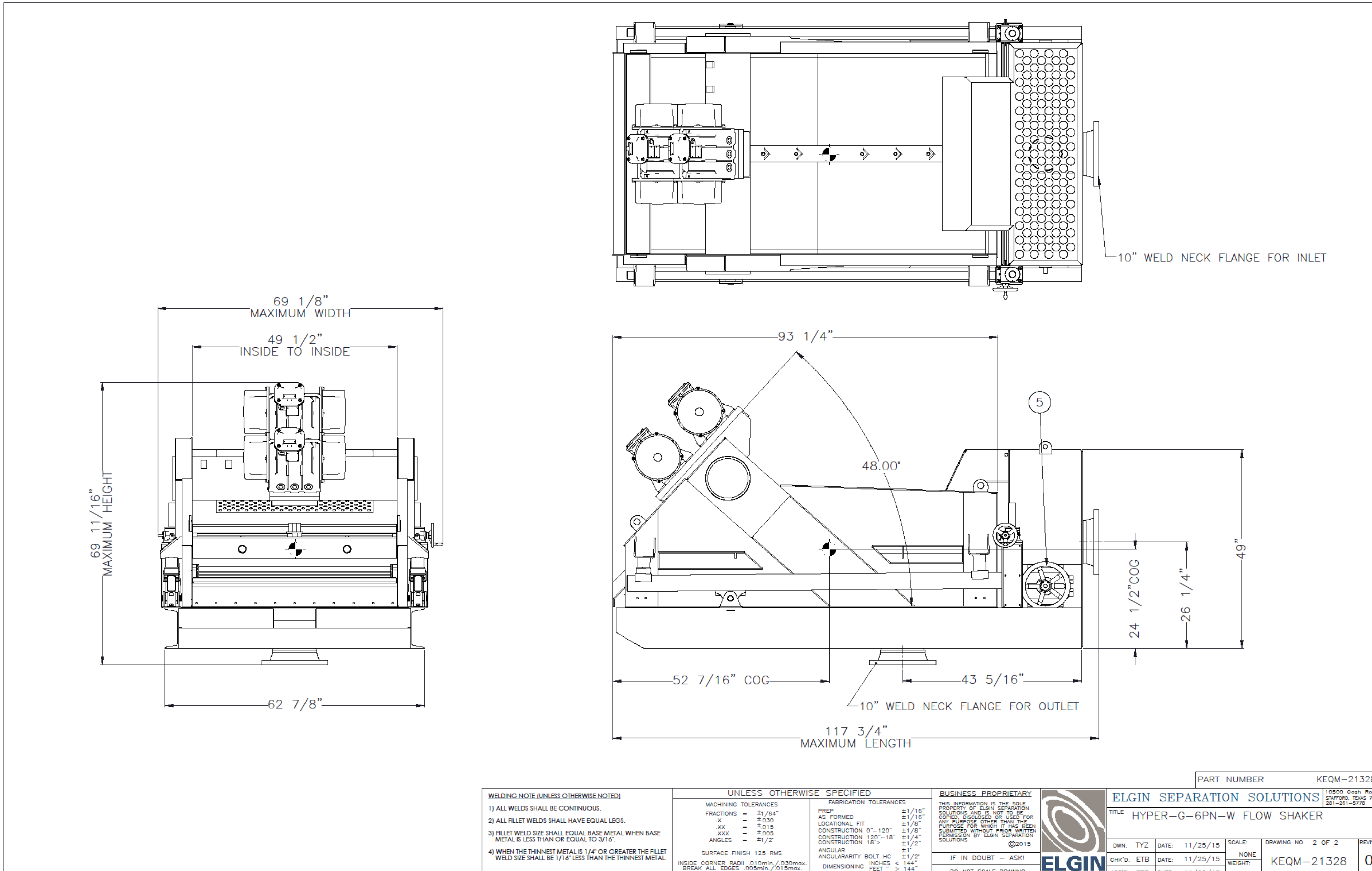


**Figure 2: Elgin Hyper-G Dual-Deck Shaker Engineering Drawing Page 2 of 2 [7].**

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# APPENDIX B:
# PIPING DETAILS

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## B.1 Pipe System Analysis

Calculations for the pressure values at the discharge into the 3950 Level sump of the current piping system and inlet to the filtration device of the modified piping system are outlined in the following subsections.

### B.1.1 Current Pipe System Pressure Calculations

The following calculations were performed using the input variables and equations outlined in Section 2.4.2.

Using Eq. 1 with the specified maximum flow rate of q = 300 gpm = 0.668 $\frac{ft^3}{s}$ and pipe diameter of d = 6 in = 0.5 ft, the velocity of the water was calculated.

$$v = \frac{q}{\left(\frac{\pi}{4} d^2\right)} \qquad \text{Eq. 1}$$

$$v = \frac{0.668 \frac{ft^3}{s}}{\left(\frac{\pi}{4} (0.5\ ft)^2\right)}$$

$$v = 3.404 \frac{ft}{s}$$

Next this velocity was used in Eq. 2 to calculate the Reynolds Number of the slurry flow [1]. As mentioned previously, values for the slurry properties were taken for water at a temperature of T = 20°C. This gives a water density of 62.3 $\frac{lbm}{ft^3}$ and absolute dynamic viscosity of 6.796 x $10^{-4}$ $\frac{lbm}{s \cdot ft}$.

$$Re = \frac{v \cdot d \cdot \rho}{\mu} \qquad \text{Eq. 2}$$

$$\mathrm{Re} = \frac{\left(3.404\,\frac{\mathrm{ft}}{\mathrm{s}}\right)\cdot(0.5\ \mathrm{ft})\cdot\left(62.3\ \frac{\mathrm{lbm}}{\mathrm{ft}^3}\right)}{6.796\ \mathrm{x}\ 10^{-4}\ \frac{\mathrm{lbm}}{\mathrm{s}\cdot\mathrm{ft}}.}$$

$$\mathrm{Re} = 156{,}025$$

Since the calculated Reynolds Number is greater than 4000 the flow will be turbulent, verifying the previous assumption. This means the empirical correlation given by the Colebrook equation, can be used to determine the friction head loss coefficient, f. Using Reynolds Number, the pipe diameter and the absolute pipe roughness coefficient, e = 0.0003 ft the friction head loss coefficient is computed to be f = 0.0197 using online software [2].

With this friction head loss coefficient, the major frictional losses over the entire length of the pipe system, $L_{tot}$ = 226.3 ft, was calculated using Eq.3 [3]. The gravitational force used in this equation is g = 32.2 $\frac{\mathrm{ft}}{\mathrm{s}^2}$.

$$h_{loss,maj} = f\cdot\frac{L_{tot}}{d}\cdot\frac{v^2}{2g} \qquad \text{Eq. 3}$$

$$h_{loss,maj} = 0.0197\cdot\frac{(226.3\ \mathrm{ft})}{(0.5\ \mathrm{ft})}\cdot\frac{\left(3.404\,\frac{\mathrm{ft}}{\mathrm{s}}\right)^2}{2\left(32.2\,\frac{\mathrm{ft}}{\mathrm{s}^2}\right)}$$

$$h_{loss,maj} = 1.604\ \mathrm{ft}$$

This same length of pipe contains a total of six long radius 90° elbows, which have a minor friction coefficient of $\xi_{elb,90}$ = 0.7. Using Eq. 4, the minor frictional losses was calculated [4].

$$h_{loss,min} = \sum \xi\,\frac{v^2}{2g} \qquad \text{Eq. 4}$$

$$h_{loss,min} = 6 \cdot 0.7 \cdot \frac{\left(3.404\,\frac{ft}{s}\right)^2}{2\left(32.2\,\frac{ft}{s^2}\right)}$$

$$h_{loss,min} = 0.756\ ft$$

Finally, the pressure at the outlet of the pipe discharging into Dirty Water Settling Reservoir 3 on the 3950 Level was calculated using Eq.5 [5]. The overall change in elevation from the 3800 Level reservoir to the 3950 Level dirty water reservoir number 3 is Δz = -122 ft. The specific weight of water at T = 20°C is $\gamma = 62.3\,\frac{lbf}{ft^3}$.

$$p_2 = -\frac{\gamma\left(\Delta z + \frac{v^2}{2g} + h_{loss,maj} + h_{loss,min}\right)}{(144\,\frac{in^2}{ft^2})} \qquad \text{Eq. 5}$$

$$p_2 = -\frac{\left(62.3\,\frac{lbm}{ft^3}\right)\left((-122\ ft) + \frac{\left(3.404\,\frac{ft}{s}\right)^2}{2\left(32.2\,\frac{ft}{s^2}\right)} + 1.604\ ft + 0.756\ ft\right)}{(144\,\frac{in^2}{ft^2})}$$

$$p_2 = 56.875\ PSIG$$

### B.1.2 Modified Pipe System Pressure Calculations

The location of the pipe pressure used in the new pipe system had the same diameter, surface roughness and fluid properties as the previous pressure calculations. As such the slurries velocity, Reynolds Number and friction head loss coefficient remained the same. These values are highlighted below.

$$v = 3.404\,\frac{ft}{s}$$

$$\mathrm{Re} = 156{,}025$$

$$f = 0.0197$$

Now using Eq. 3 with the new pipe system's overall pipe length, $L_{tot,new}$ = 176.3 ft the major frictional losses were calculated [3].

$$h_{loss,maj} = f \cdot \frac{L_{tot}}{d} \cdot \frac{v^2}{2g} \qquad \text{Eq. 3}$$

$$h_{loss,maj} = 0.0197 \cdot \frac{(176.3\ \mathrm{ft})}{(0.5\ \mathrm{ft})} \cdot \frac{\left(3.404\,\frac{\mathrm{ft}}{\mathrm{s}}\right)^2}{2\left(32.2\,\frac{\mathrm{ft}}{\mathrm{s}^2}\right)}$$

$$h_{loss,maj} = 1.25\ \mathrm{ft}$$

Next, the minor frictional losses were calculated using the eight long radius 90° elbows, $\xi_{elb,90}$ = 0.7, and the fully open gate valve, $\xi_{gv}$ = 0.15 with Eq. 4 [4].

$$h_{loss,min} = \sum \xi \frac{v^2}{2g} \qquad \text{Eq. 4}$$

$$h_{loss,min} = (8 \cdot 0.7 + .15)\frac{\left(3.404\,\frac{\mathrm{ft}}{\mathrm{s}}\right)^2}{2\left(32.2\,\frac{\mathrm{ft}}{\mathrm{s}^2}\right)}$$

$$h_{loss,min} = 1.035\ \mathrm{ft}$$

Finally, the pressure at the inlet of the shaker was calculated using Eq. 5 [5]. The overall change in elevation from the 3800 Level reservoir to the 3950 Level dirty water reservoir number 3 is $\Delta z$ = -122 ft. The specific weight of water at T = 20°C is $\gamma$ = 62.3 $\frac{\mathrm{lbf}}{\mathrm{ft}^3}$.

$$p_2 = -\frac{\gamma\left(\Delta z + \frac{v^2}{2g} + h_{loss,maj} + h_{loss,min}\right)}{(144\,\frac{in^2}{ft^2})} \qquad \text{Eq. 5}$$

$$p_2 = -\frac{\left(62.3\ \frac{lbm}{ft^3}\right)\left((-122\ ft) + \frac{\left(3.404\,\frac{ft}{s}\right)^2}{2\left(32.2\,\frac{ft}{s^2}\right)} + 1.25\ ft + 1.035\ ft\right)}{(144\,\frac{in^2}{ft^2})}$$

$$p_2 = 51.716\ PSIG$$

## B.2 Sump Layout and Piping

Figure 1 shows the layout of the 3950 Level and 4040 Level sumps and the existing piping to each sump.

[redacted]

**Figure 1: Layout of 3950 and 4040 Level Sumps in Vale Birchtree Mine [6].**

## References

[1] The Engineering Toolbox, "Reynolds Number," 2015. [Online]. Available: http://www.engineeringtoolbox.com/reynolds-number-d_237.html. [Accessed November 10, 2015].

[2] The Engineering Toolbox, "Colebrook Equation," 2015. [Online]. Available: http://www.engineeringtoolbox.com/colebrook-equation-d_1031.html. [Accessed November 10, 2015].

[3] The Engineering Toolbox, "Major Losses in Ducts, Tupes and Pipes," 2015. [Online]. Available: http://www.engineeringtoolbox.com/major-loss-ducts-tubes-d_459.html. [Accessed November 10, 2015].

[4] The Engineering Toolbox, "Minor Losses in Pipe or Duct Components," 2015. [Online]. Available: http://www.engineeringtoolbox.com/minor-pressure-loss-ducts-pipes-d_624.html. [Accessed November 10, 2015].

[5] R. Sellens, "Losses in Pipes," Queens University, 2015. [Online]. Available: http://me.queensu.ca/People/Sellens/LossesinPipes.html. [Accessed November 10, 2015].

[6] Vale Canada Limited, "BT Mine 3950-4040 Dirty and Clear Sumps," Vale, Thompson, 2015.

# APPENDIX C:
# ECONOMIC ANALYSIS

# Table of Contents

## List of Tables

## C.1 Introduction

The economic analysis studied the next [redacted] of mine operation with an [redacted] rate of return, and compares the scenario of implementing the design of the new dewatering filtration system with leaving the system in its current state.

## C.2 Maintenance Costs of Dewatering Pumps

To calculate the average yearly cost of maintaining the pumps, a value of $[redacted] was used, as this is the average dewatering pump rebuild cost including parts and labour [1]. The life of the pumps between rebuild was approximated as two years if the new filtration design is implemented.

$[redacted] • 3 pumps / 2 years = [redacted]/year

For the current dewatering system, the maintenance costs were calculated using Vale's maintenance records over the past 26.5 months [2]. In 26.5 months, [redacted] were performed.

[redacted]

## C.3 Additional Costs of the New System

Annual maintenance for the Elgin Screen Shaker is quoted to be approximately $11 383 with parts [3]. The team assumed 50 hours of labour per year would be sufficient to maintain the shaker. At [redacted], yearly labour costs are:

[redacted]

This results in a total additional maintenance cost of:

[redacted]

Combining this with the cost of maintaining the pumps if the new system is implemented, we have:

[redacted]

The cost of parts to implement the system, as shown in Section 2.8.1, is $45 970.

To approximate the number of labour hours required to install the new filtration system, the installation process was broken down into various tasks. The estimated number of hours required for each task is documented in TABLE 1.

**TABLE I: APPROXIMATE TIME REQUIRED FOR INSTALLATION TASKS**

| Installation Task | Time Allocated | Number of Workers | Total time |
|---|---|---|---|
| Prepping sump for shaker installation | 24 hrs. | 1 | 24 hrs. |
| Transporting equipment to site | 8 hrs. | 3 | 24 hrs. |
| Forming/placement of shaker and foundation | 15 hrs. | 2 | 30 hrs. |
| Install required piping for new system | 20 hrs. | 2 | 40 hrs. |
| Wiring/control system/power hook up | 15 hrs. | 2 | 30 hrs. |
| Trouble shooting and testing | 20 hrs. | 1 | 20 hrs. |
| Unforeseen action items | 20 hrs. | N/A | 20 hrs. |
| | | **TOTAL** | 188 hrs. |

If we assume that 188 hours of labour is required to install the system at [redacted], the cost of labour to install the equipment is:

[redacted]

Therefore the total cost of installation including labour and components is:

[redacted]

## C.4 Summary of Total Costs for Both Scenarios

The following table summarizes the costs of implementing the new filtration system and of leaving the system as is.

**TABLE II: SUMMARY OF COSTS**

| | New System | Current System |
|---|---|---|
| **Initial cost** | [redacted] | --- |
| **Maintenance Cost** | [redacted] | [redacted] |

## C.5 Calculated Savings

Over the next seven years of operation, the savings resulting from implementing the new design would be:

Savings = [redacted]

Savings = [redacted]

Assuming that the operation and maintenance costs would increase at the same rate over time for each scenario, the interest and inflation rates were ignored in the above calculation.

## C.6 Payback Period

The following formula can be used to determine the payback period for the implementation of the new filtration system [4].

$$Payback\ Period = \frac{Initial\ Investment\ [\$]}{Annual\ Savings\ [\frac{\$}{year}]}$$

Taking the annual maintenance costs for each scenario, the total savings per year for implementing the new system can be calculated:

Annual savings = [redacted]

The payback period can be calculated using the initial investment and annual savings:

Payback period = [redacted] = 6 months

## C.7 NPV Calculation

The following is a calculation of the net present value of implementing the new system with respect to leaving the dewatering system in its current state.

Rate of return: [redacted] [3]

Number of years included in economic study: [redacted]

NPV = - Initial investment + annual savings (P/A, I, n) [5]

NPV = - [redacted]

NPV = - [redacted]

NPV = [redacted]

## References

[1] Vale, "ER13310-01 - Birchtree 4040L Dewatering Pumps FEL1 Study," Vale, Thompson, 2014.

[2] Vale, "Pump Maintenance Records," Vale, Thompson, 2015.

[3] M. Anderson and B. Sebastiao, Interviewees, *Meeting with Elgin Separation Solutions.* [Interview]. November 25, 2015.

[4] Accounting Explained, "Payback Period," 2015. [Online]. Available: http://accountingexplained.com/managerial/capital-budgeting/payback-period. [Accessed December 4, 2015].

[5] Finance Formulas, "Net Present Value," 2015. [Online]. Available: http://www.financeformulas.net/Net_Present_Value.html. [Accessed December 4, 2015].