Improving the underground pump scheduling of a dewatering system for a hydropowered gold mine

SDL van Niekerk
22894543

Dissertation submitted in fulfilment of the requirements for the degree Master of Engineering in Mechanical Engineering at the Potchefstroom Campus of the North-West University

Supervisor: Dr. WC Kukard

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Abstract

Title: Improving the underground pump scheduling of a dewatering system for a hydropower gold mine
Author S.D.L. van Niekerk
Supervisor Mr. W Kukard
Keywords Water Reticulation, Demand Side Management, Pump Scheduling, Dewatering Pumps, Eskom, Cost Saving, Hydropower, Gold Mine
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The objective of this study was to reduce underground water pumping costs at a marginal hydropower gold mine located close to the town of Orkney, in the North West Province of South Africa, which has in recent years decreased its production by 50% as well as stopping all new development.

A marginal mine is a mine with high production costs and low grades of ore, where profit will only be viable if the commodity prices are high. A hydropower mine is a mine which uses high pressurised water for scraping, better known as cleaning, and drilling.

The underground water reticulation system at the mine currently pumps water on demand to several underground levels and includes manually operated dewatering pumps. An opportunity existed in investigating their dewatering pumping schedule. The results obtained from this investigation showed that the mine was pumping during Standard Time of Eskom (the national energy utility), which is not necessary.

A newly developed simulation model to improve the pumping schedule was implemented at this gold mine. An annual saving of approximately R935 000 was achieved by implementing the simulation model. The model contains the inflow from the settlers to the underground dams and the flow from the dewatering pumps to surface. This gives the underground dam levels which can then be used to create a new pumping schedule.

With the increase in the price of gold since the end of 2015, the production of the mine has been steadily increasing. The simulation model can be adapted if there is any increase or decrease in the production rate.

Opsomming

Titel:	Die verbetering van ‘n ontwaterings sisteem se pomp skedule vir ‘n hidrokrag goudmyn.
Outeur	S.D.L. van Niekerk
Promotor	Mr. W. Kukard
Sleutelwoorde	Water retikulasie, Aanvraag besturing, Pomp Skedule, Ontwaterings pomp, Eskom, Koste besparing, Hidrokrag, Goudmyn
Degree	Meester van ingenieurswese in meganiese ingenieurswese

Die doel van hierdie studie is om die ondergrondse water pompstelsel se kostes te verminder. Die myn wat ge-ondersoek word is ‘n marginale hidrokrag goudmyn naby Orkney, wat onlangs produksie met 50% verminder het. Alle nuwe ontwikkeling is ook gestaak op die myn.

‘n Marginale myn is ‘n myn met hoë produksie kostes en ‘n lae graad erts, waar wins net moontlik is as die prys van goud hoog is. ‘n Hidrokrag myn is ‘n myn wat gebruik maak van water wat onder hoë druk is om die toerusting ondergrond te dryf: soos die bore en skrapers.

Die water retikulasiesisteem op die myn voer water outomaties na die ondergrondse vlakke, soos die aanvraag na water is en die water word dan deur handbeheerde ontwaterings pompstelsels weer terug oppervlakte toe gepomp. Daar was ‘n geleentheid om die ondergrondse ontwatering stelsel te ondersoek. Die ondersoek het getoon dat die myn huidiglik tydens die standaard tyd van Eskom (nasionale energie verskaffer) se tariewe water pomp, wat onnodig is.

‘n Nuut ontwerpte simulasie model was op die goudmyn ge-ïmplimenteer en dit was bevind dat R935 000 deur die projek per jaar gespaar kan word. Die ontwerpte model bevat die vloei van die setlaars na die ondergrondse damme en die vloei van die ontwaterings pompe na grondvlak. Hierdie informasie maak dit moontlik om die damvlakke te simuleer en om sodoende die nuwe pomp skedule te ontwerp.

Met die huidige groei van die goudprys vanaf die begin van 2015, het die produksie van die myn toegeneem. Die simulasie model is ontwerp om aanpasbaar te wees indien die waterverbruik van die myn toeneem of afneem, as gevolg van produksie wat styg of daal.

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Nomenclature

DEFINITIONS

Terminology	Definition
Load Shift	Load shift, also known as peak clipping, involves moving load capacity from peak periods to low demand periods.
Operating reserve	Safe reserve kept by Eskom between the available capacity and consumed capacity.
Unplanned outage assumption	This is the capacity that may be lost due to unforeseen circumstances by Eskom.
Demand Side Management	To change the demand of the consumer's energy usage through various methods, such as behavioural changes or education.
Hydropower	It is a term used in the mining industry to describe the method used to power the underground equipment (high pressurised water).

ACRONYMS AND ABBREVIATIONS

Abbreviation or Acronym	Definition
BAC	Bulk air cooler
DSM	Demand side management
EES	Engineering equation solver
ESCO	Energy service company
GEI	Global electricity initiative
h	Hours
kl	Kilolitre
kW	Kilowatt
kWh	Kilowatt hour
l/s	Litres per second
m	Metre
Ml	Megalitre
MW	Megawatt
MWh	Megawatt hour

Abbreviation or Acronym	Definition
NERSA	National Energy Regulator of South Africa
OR	Operating reserve
PLC	Programmable logic controller
SCADA	Supervisory control and data acquisition
TOU	Time of Use
UA	Unplanned outage assumption
ZAR	South African Rand

Chapter 1

Introduction

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1. Introduction

1.1 Problem Statement

South African gold mines are vital to the growth and development of the country; however, due to the fluctuation and weakness of commodity prices and fluctuation in the gold price, more mines are becoming marginal.

Electricity is one of the larger utility expenses of a mine. Since the increase of electricity tariffs in 2008, electricity costs have become a concern as they have doubled. Due to the increasing demand for electricity, the supply cannot be met. Thus, Demand Side Management (DSM) projects have been implemented on large industries to decrease the demand during peak periods.

DSM projects have been successfully implemented on dewatering systems for the past couple of years. However, the dewatering system of the mine being investigated has not been improved as yet, as a result, DSM has not been implemented. Thus, there is an opportunity to investigate the opportunity of implementing DSM on the mine's dewatering system and test if it is feasible. This cost saving initiative will become important when the continuing viability of the mining operations is being considered.

1.2 Previous research completed

Studies conducted by Vosloo (2012) and Schoeman (2014) are similar in nature to this study. However, their focus was limited to load shifting during Peak periods to Standard Time periods for their dewatering systems.

Peak, Standard Time and Off-peak periods are terminologies used in Eskom's Megaflex tariff structure to describe the time period in which electricity is used, where the rates are highest at Peak and Standard Time rates, and lowest at Off-peak.

This study will focus on shifting Peak and Standard Time periods to Off-peak periods to save the maximum amount of costs on underground water pumping. The mine being investigated is a hydropower mine, this means that the mine uses high pressurised water to operate the equipment underground. Thus, this study is unique as it is the only study to-date that has been completed in this field.

1.3 Purpose of this study

The purpose of this study is to improve the dewatering system of the mine being investigated by applying DSM initiatives.

This study will be completed from a cost savings point of view, thus, load shifting will be implemented to improve the pumping schedule of the mine. This means that the pumps will not run during Peak and Standard Time periods (where the tariff is high) but only during Off-peak periods.

Based on the above, the study's main goals are mentioned below:

- Research on DSM methods for the dewatering system of a hydropower gold mine
- A simulation model of the mine's dewatering system
- A pump scheduling algorithm
- Implementation of the pump schedule on the simulation model
- Cost calculations of the improved system

1.4 Methods of investigation

The following methods of investigation will be used to address the study's main goals listed above:

- Conducting extensive research on modern DSM techniques in South Africa
- Based on the requirements, a simulation model must be created simulating the dewatering system of the mine under investigation
- Verification of the simulation model

- Creating an algorithm to apply to any hydropower mine to improve the pumping schedule of the mine
- With load shifting applied to the simulation model, potential cost savings must therefore be calculated

Chapter 2

Literature Survey

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2. Literature Survey

2.1 Introduction

This section discusses DSM and the current state of electricity, with specific reference to South Africa, which will determine if there is an opportunity for DSM initiatives in South Africa. A deeper investigation to illustrate which industry has the most potential for DSM initiatives will follow.

The industry with the most potential will then be selected and a thorough investigation will be completed in that industry.

2.2 Current status of energy in the world

According to the Global Electricity Initiative (GEI), global electricity consumption has increased from 6,100TWh in 1973 to 13,200TWh in 1995. This is an increase of 46% in 22 years. From 1995 the electricity usage increased to 22,000TWh in 2011, this is roughly 60% over 16 years (World Energy Council, 2014).

One of the main concerns is that the generation facilities in developing countries are aging and need to be replaced. The projected figure, according to the World Energy Council (2014), for this is 1000 GWh.

Research conducted by GEI indicated that 97% of consumers globally are not willing to pay more for alternative energy, thus rely on fossil fuels for electricity generation.

The same statistics can be assumed for South Africa which mainly relies on fossil fuels for electricity generation. Eskom has conducted research and implemented alternative energy methods for South African households. For these alternative energy methods to be successful, Eskom needs to install smart meters and convince consumers to install alternative electricity generation systems in their homes. However, as this is expensive, not all households can afford these upgrades.

2.3 Current status of energy in South Africa

Although Eskom works on a demand and supply basis in South Africa, the demand is more than what the supply can meet, this has resulted in load shedding for South Africa (Mulder, 2012; Prinsloo, 2004).

In 2008 South Africa experienced an electricity crisis, resulting in electricity shortages, where all industrial and domestic consumers experienced power outages, hereinafter referred to as blackouts. According to the National Energy Regulator South Africa (NERSA) the economy suffered damages of up to R 50 billion (Inglesi, 2009). To address this shortage, Eskom embarked on building new power stations. Pouris (2008) argues that the electricity shortage was due to a lack of research in this area.

South Africa also experienced a 1.1% shortage in electricity supply during the 2013 winter. Eskom has since been able to satisfy the electricity demand to the low growth of the economy, but the gap between supply and demand has been steadily closing. As a result, Eskom can no longer perform proper maintenance on its generating units, in turn causing the performance of the power stations to deteriorate (Eskom, 2013).

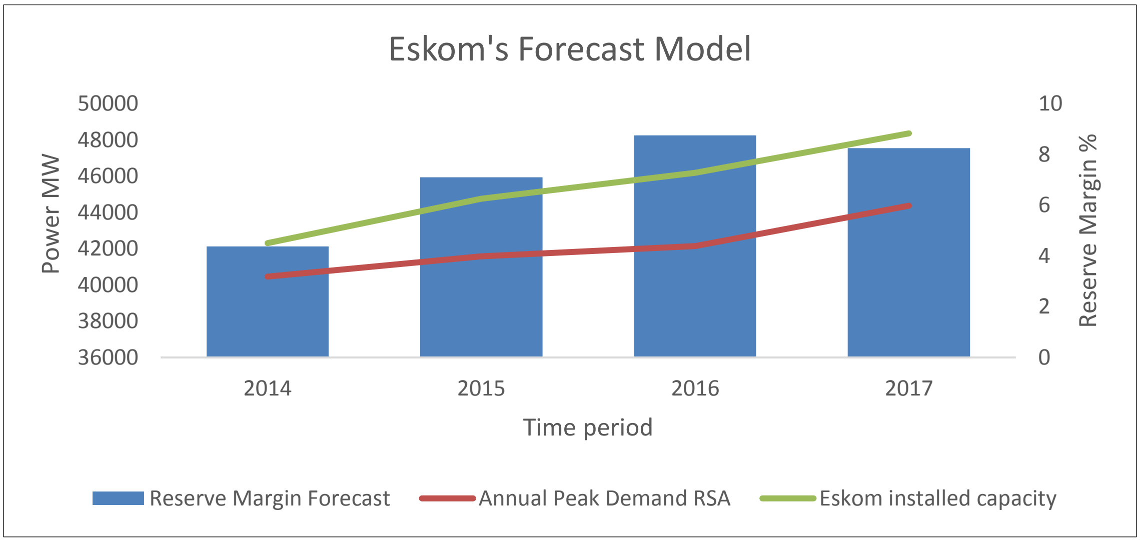


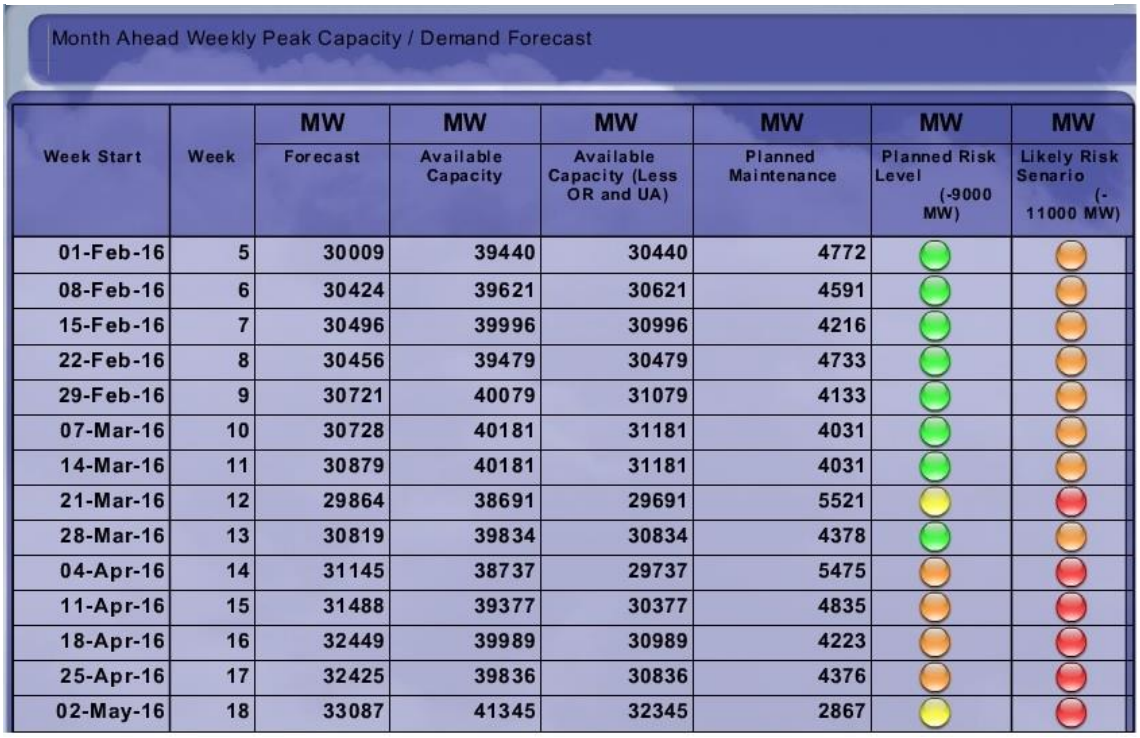
Figure 1: Eskom’s Forecast Model for Annual Peak demands for South Africa, Eskom installed capacity and Reserve Margin Forecast (Eskom, 2016)

Figure 1 depicts Eskom's forecast model for South Africa. It is evident that the Reserve Margin does not reach 10%; in order for maintenance to be conducted on the generating units, an amount of at least 15% is required.

It can therefore be concluded that there will be difficulty with maintenance. From Table 1 the available capacity minus the operating reserve (OR) and the unplanned outage assumption (UA) gives the available capacity less UA and OR.

When comparing the available capacity less UA and OR with the forecast value, it is clear that there is a very small reserve margin which increases the risk for load shedding.

Table 1: Weekly Peak Capacity / Demand Forecast (Eskom, 2016)



Month Ahead Weekly Peak Capacity / Demand Forecast

Week Start	Week	MW	MW	MW	MW	MW	MW
		Forecast	Available Capacity	Available Capacity (Less OR and UA)	Planned Maintenance	Planned Risk Level (-9000 MW)	Likely Risk Senario (-11000 MW)
01-Feb-16	5	30009	39440	30440	4772	🟢	🟠
08-Feb-16	6	30424	39621	30621	4591	🟢	🟠
15-Feb-16	7	30496	39996	30996	4216	🟢	🟠
22-Feb-16	8	30456	39479	30479	4733	🟢	🟠
29-Feb-16	9	30721	40079	31079	4133	🟢	🟠
07-Mar-16	10	30728	40181	31181	4031	🟢	🟠
14-Mar-16	11	30879	40181	31181	4031	🟢	🟠
21-Mar-16	12	29864	38691	29691	5521	🟡	🔴
28-Mar-16	13	30819	39834	30834	4378	🟢	🟠
04-Apr-16	14	31145	38737	29737	5475	🟠	🔴
11-Apr-16	15	31488	39377	30377	4835	🟠	🔴
18-Apr-16	16	32449	39989	30989	4223	🟠	🔴
25-Apr-16	17	32425	39836	30836	4376	🟠	🔴
02-May-16	18	33087	41345	32345	2867	🟡	🔴

Given the risk of load shedding increasing, Eskom has initiated quick fix solutions. Figure 2 shows a decline in the Actual Peak Demand of South Africa, thus indicating that these solutions are working. However, the decline in demand is not only due to

Eskom's solutions; there are three additional main factors that influence the demand of electricity:

- Increases in electricity tariffs
- Economic growth
- DSM

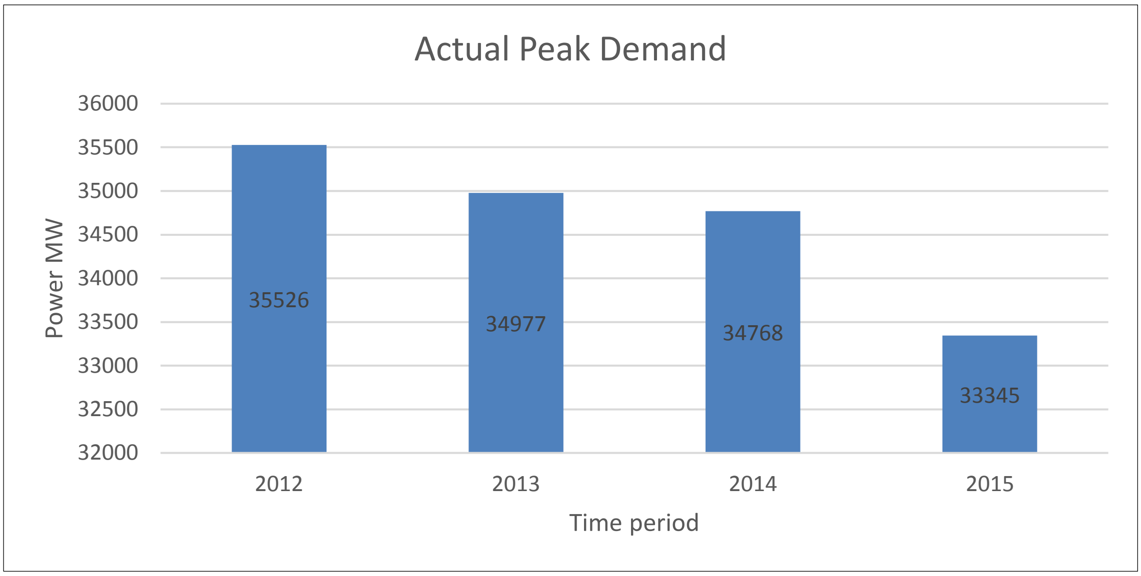


Figure 2: Actual Peak Demand for South Africa (Eskom, 2016)

Figure 3 reveals the increase of electricity tariffs from 1987 to 2015, with projected costs for 2016 and 2017.

As mentioned above, there are three additional main factors that influence the demand of electricity.

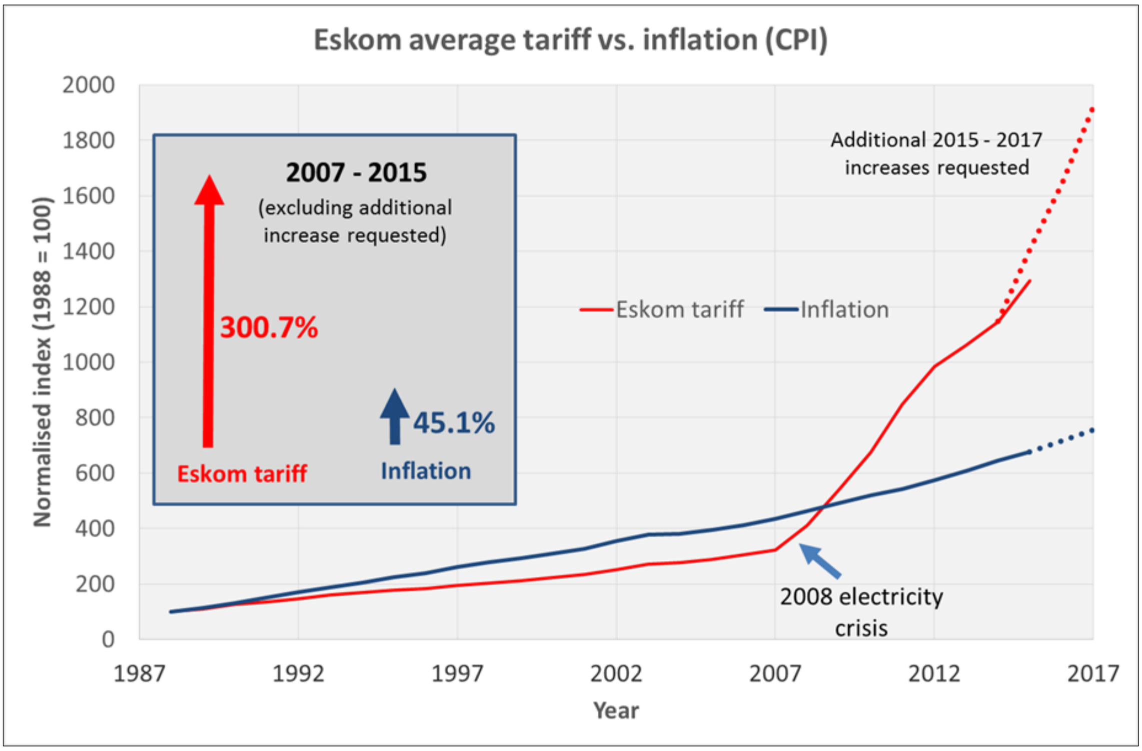


Figure 3: Cost Reflective Prices and Inflation c/kWh (Moolman, 2016)

Based on figure 3, an assumption may be made that the increase in the tariff had an influence in demand of electricity. Thus, the increase in electricity tariffs may force some consumers to consume less energy in order to avoid high electricity bills.

Economic growth is another factor identified. Figure 4 depicts a remarkable decline in South Africa’s rate of economic growth since 2012. This decline indicates that there is less industrial and commercial activity, which contributes to the decrease in electricity demand as revealed in figure 1.

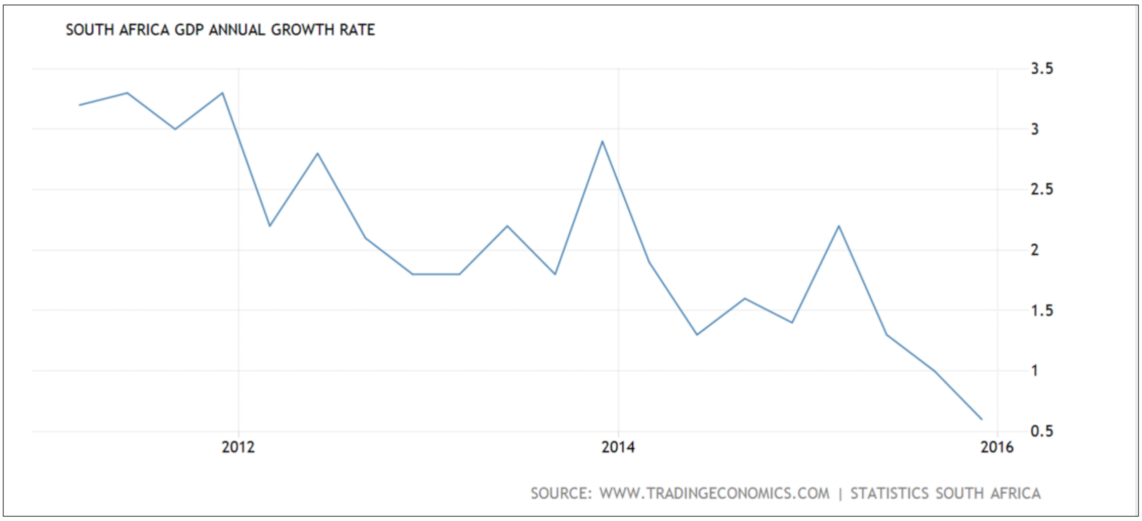


Figure 4: Economic Growth of South Africa (Trading Economics, 2016)

The third factor that influences the actual electricity demand is DSM projects. These projects involve the reduction in electricity usage from the demand side of the grid (Kreith & Goswami, 2007).

DSM projects prove most effective in reducing electricity consumption in a short period of time. In the next chapter the industries where DSM projects prove most effective will be discussed.

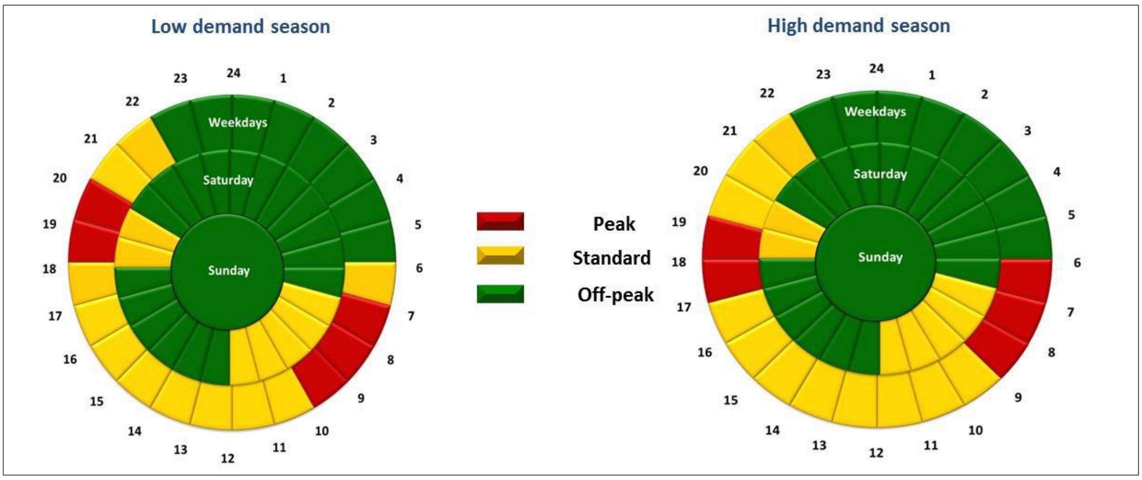


Figure 5: Megaflex Variable Pricing Chart (Eskom, 2016)

2.4 Energy consumption of the industries in South Africa

Eskom generates approximately 95% of the electricity used in South Africa and approximately 45% of the electricity used in Africa (Eskom, 2016). Consumers of electricity can be divided into different groups, as illustrated in Figure 6 which reveals that the mining industry consumes approximately 14.5% of South Africa's electricity and is the third largest consumer of electricity in South Africa.

The mining industry is more commonly selected for DSM projects due to the heavy equipment and machinery used. Operating this machinery consumes a large amount of power, thus making DSM projects on mines more viable.

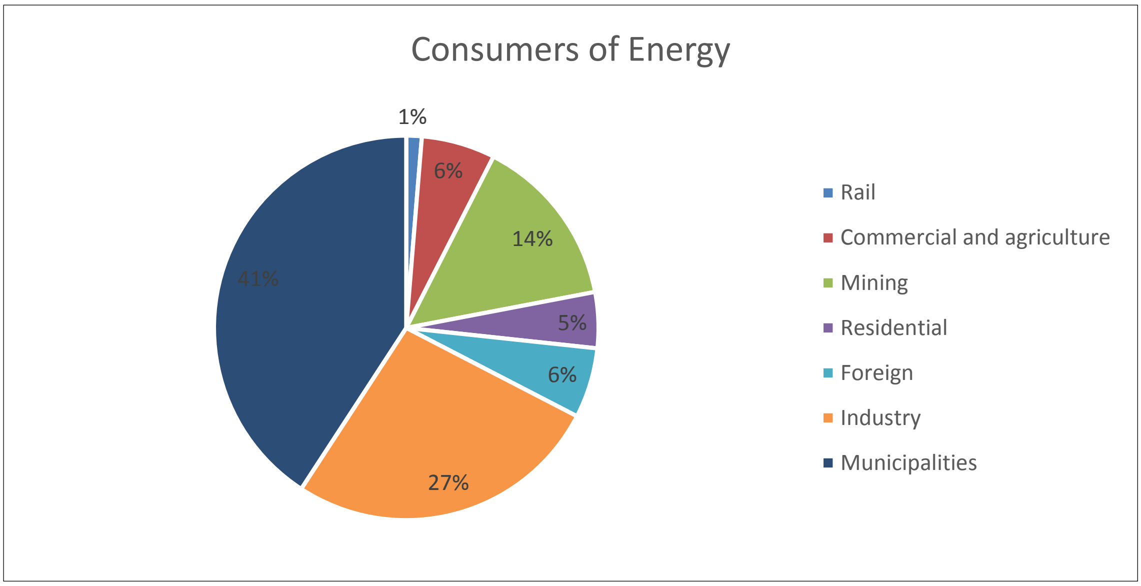


Figure 6: Consumers of the Energy Supplied by Eskom (Eskom, 2016)

Boef (2006) conducted research to investigate the potential for DSM in South African business industries. The findings indicate that the benefits of implementing DSM activities in all South African mines is a possible saving of 650MW per day.

The different types of mines and the electricity usage of each mine will be discussed in Chapter 3.

2.5 Energy consumption of mines in South Africa

South Africa has a mineral based economy and is one of the largest gold producers in the world. According to the South African Chamber of Mines, South Africa produces 21% of the world’s gold.

Within the mining industry, the gold mining sector is the largest electricity consumer; consuming 47% of the industry’s total usage. Where platinum mines are using 33% and all the other mining industries 20% (The energy efficiency series towards an energy efficient mining sector, 2016).

The gold mining sector is the largest electricity consumer within the mining industry; consuming 47% of the industry’s total usage. Conversely, platinum mines consume 33% and all the other mining sectors consume 20%.

In comparison with other mining sectors, gold mines consume more energy thus, the focus of this dissertation is on gold mines. In the next chapter, Eskom’s Megaflex tariff and the gold mine systems are discussed.

2.6 Analysis of Megaflex tariff

The Megaflex structure tariff is mainly used by large industries due to the increase in electricity usage. This tariff bills consumers according to their Time of Use (TOU), Off-peak, Standard Time and Peak time usage. This means that tariff costs change, depending on the time of day as well as the season.

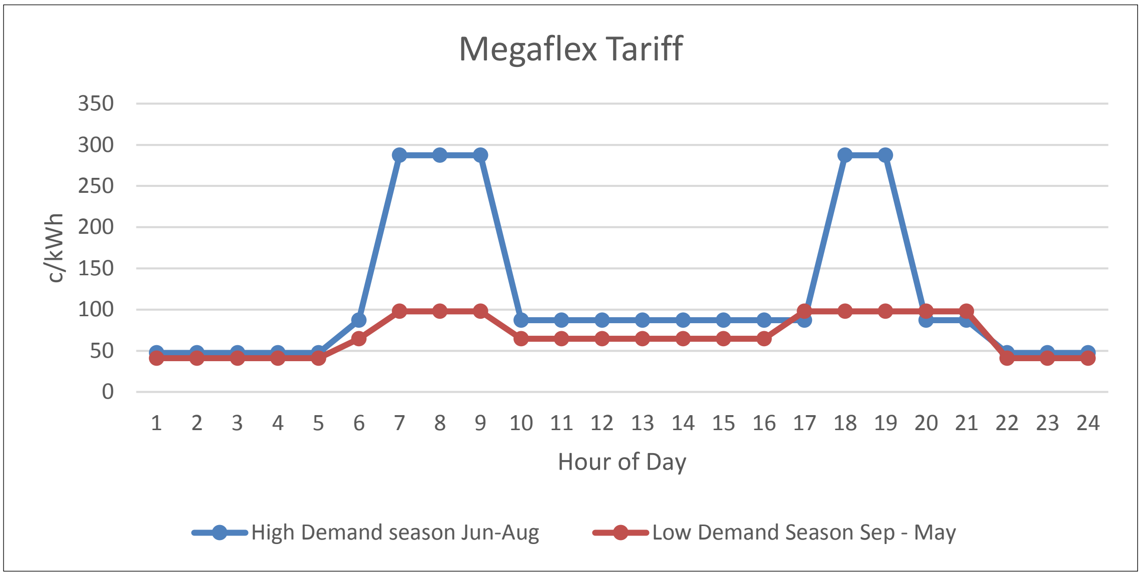


Figure 7: Megaflex Tariff ZAR c/ kWh (Eskom, 2016)

Figure 7 represents the TOU tariff and the seasonal base charge of the Megaflex tariff. Furthermore, peak time is between 6am and 9am, and 5pm to 7pm in high demand seasons. In low demand seasons, peak time is between 7am and 10am, and 6pm and 8pm during weekdays. There are no peak times on weekends. Charges during peak time in low demand seasons are 97.5 cents and 274.6 cents in high demand seasons.

Additionally, in high demand seasons, Standard Time is between 9am and 5pm, and 7pm and 10pm. In low demand seasons, peak time is between 6am and 7am, 10am and 6pm, and 8pm and 10pm during weekdays. On Saturdays, Standard Time is between 7am and 12pm, and 6pm and 8pm in high demand seasons and in low demand seasons. There is no Standard Time rate on Sundays. The rate of Standard Time in low demand seasons is 72.65 cents and in high demand season it is 103.8 cents.

Off-peak times in both high and low demand seasons are between 10pm and 6am during weekdays. For Saturdays, Off-peak rates are between 12pm and 6pm, and 8pm and 6am for both high and low demand seasons. On Sundays, Off-peak rates apply all day.

2.7 Systems in a gold mine

Figure 8 is an illustration of the main electricity consumers in a mine.

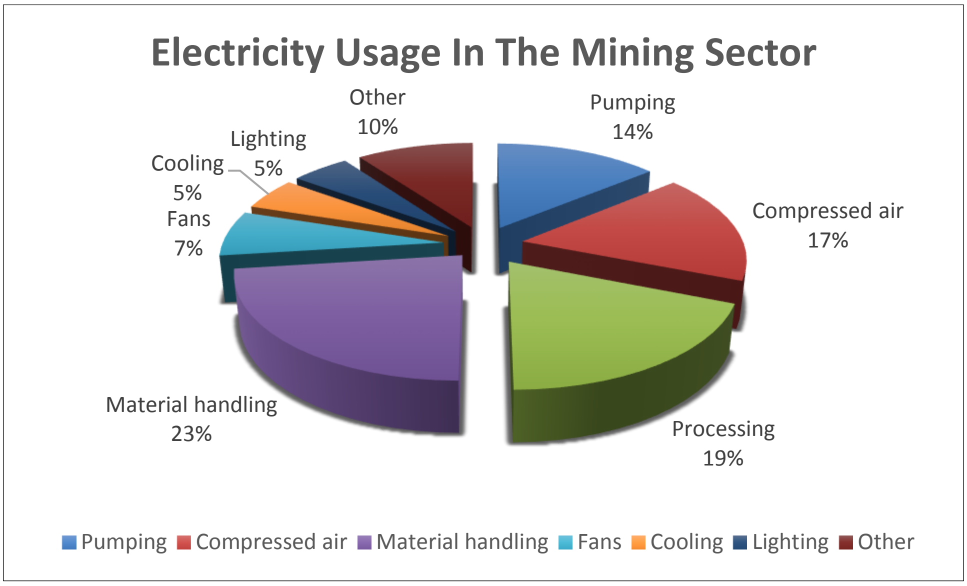


Figure 8: Electricity Usage in the Mining Sector (Eskom, 2016)

2.7.1 Compressed air

Compressed air systems in a mine consume about 17% of the mine’s total energy demand, thus making compressed air one of the biggest energy consumers in a mine. Research conducted in this field focussed mainly on the control philosophy of compressors and other DSM initiatives.

This has been proven to be quite effective where Booysen’s (2010) research mainly covered the control philosophy of a compressor by automating the compressor. This method delivered a saving of 19MW daily. The same line of work has been conducted by Du Plessis (2010) who implemented Energy Management systems (EMS) on compressors.

Research conducted by Neser (2008) focussed on DSM controlling methods and the automation of compressor systems. This research indicated that if underground control methods were practised by installing underground control valves, the pressure to each level could be controlled and thus reduced. This reduction in pressure reduces the energy consumption of the compressor. The energy saved on these three projects could reach 102MWh per day (Neser, 2008).

Van Heerden's (2014) study on mines with ring feed compressed air systems indicated that these mines selected static priorities for the compressors, which means that the system delivers a constant air pressure and volume flow rate. This method is acceptable on some days but it is not always ideal. The opportunity Van Heerden (2014) highlighted was to use the Dynamic Compressor Selector for mines with ring feed systems. This system is computer based and calculates the set-point pressure needed, as well as the optimal number of compressors operating. This system achieved an energy saving of 1.8MW.

Studies with topics focussing on compressed air have been covered extensively over the past 10 years, ranging from compressor control philosophies to air pressure valve control underground. Both these methods are being implemented on the mine being investigated in this study and no further research is required.

2.7.2 Processing

Processing has been identified as the second largest energy consumer within the mining industry, consuming 19% of the industry's energy.

From an operational perspective, processing can arguably be considered one of the most important systems of a mine as this is where the ore is milled and grinded. The fine powder then flows through a series of systems before the gold can be extracted. The milling process and the carbon heating process consume the most energy; thus, resulting in potential areas for DSM projects.

Research conducted by Jordaan (2007) on DSM projects in gold plants suggested that gold plants had the most potential for DSM projects. In Jordaan's (2007) research, load shifting opportunities were identified in the milling circuit and the elution boilers. A further finding was that Jordaan's (2007) research could be used for both mining plants and industrial facilities.

Based on the above, there is a shortage of research conducted in the processing of plants. The reasons for this shortage is that clients are sensitive about the investigations being conducted on their facilities and will not allow any changes to be made to their working systems. Although DSM research projects have been completed for many plants, the implementation rate is low. For this reason, research on processing plants is not considered viable.

2.7.3 Material Handling

Material handling in mines includes the transportation of the ore to the underground banks and hoisting the ore to surface. The two main energy consumers in this area are locomotives and winders.

Buthelezi (2009) researched the implementation of load shifting on underground rock winders. The system was automated according to his research and a peak shift of 2.1MW was achieved.

Load shifting on rock winders was also researched by Vosloo (2006). He used a real-time energy management system as a tool to predict and control load management on rock winders. His research indicated that the load shifting project can be implemented on both platinum and gold mines, where a peak shift of up to 9.5MW is possible.

Loco battery chargers were also mentioned as a consumer of electricity on the mine. In support of this, research conducted by Bosman (2006) suggests that load shifting is possible on this system by replacing the currently installed chargers with new technology. This new technology enables load shifting on the system that can result in good electricity savings for the mine.

Material handling methods between hydropower mines and conventional mines are the same. The research conducted by Vosloo (2006) and Buthelezi (2009) focuses on DSM projects on a mine’s material handling process. Moreover, both these researchers’ methods have already been implemented on the mine being investigated.

2.7.4 Fans

Fans are mainly used in gold mines for ventilation and getting air to flow down to the working areas. This system consumes about 7% of the mine’s total energy.

There are two possible energy savings opportunities with ventilation:

- Auxiliary fans
- Main Fans

Kukard (2006) investigated the current design of the installed auxiliary fans and the operational characteristics of the main fans. His research indicated that an improved design for auxiliary fans can deliver an 11kW saving per 45kW fan. His research further indicated that load shifting was possible on main fans with the help of real-time energy management systems and a variable speed drive. Another finding of Kukard’s (2006) research was that the main fan’s efficiency can be improved by replacing the propeller.

The research conducted by Kukard (2009) focussed on DSM projects regarding fans on conventional and hydropower mines. The main fans at the mine being investigated run at optimal efficiency with the guide vanes set at an optimal angle. Kukard’s (2009) method is currently being implemented on the auxiliary fans in the gold mine under investigation.

2.7.5 Cooling

Cooling consumes approximately 5% of the mine’s total energy. This energy is used to chill the water and air flowing down the mine to cool the working places.

This is necessary due to the Virgin Rock Temperatures (VRTs) reaching over 60 degrees Celsius underground. To counter these high temperatures, refrigeration systems are used to cool the air and water underground.

The following research was conducted in this field:

- Bulk Air Cooling (BAC) systems – the purpose of this research was to develop a system that will dynamically adapt to the changes in their environment (Van Jaarsveld, 2015).

- Designing a new control philosophy for a refrigeration system and executing successful load shifting during Eskom's evening peak period – an average load shift annually of 2.9MW was achieved (Calitz, 2006).

- Impact of reducing chilled water flow to underground sections on two shafts – the aim of this research was to investigate whether the reduction in chilled water affects other components negatively. The results of this research concluded that there is a possibility of achieving electrical cost savings without impacting other components negatively (Schoeman, 2014).

- DSM projects on underground refrigeration systems – a simulation model of the system where this was applied with various control strategies was created. These strategies will be implemented to shift the load out of peak periods. The results obtained from the model indicated that load shift was possible with 6.6MW (Strydom-Bouwer, 2008).

- Air Cooling Unit (ACU) that acts as a spot cooler – this cooler is different from a refrigeration system because it is modular with a smaller cooling capacity and it is mobile. The purpose of the study was to establish a suitable working area and to determine the techno-economic impact if this had to be spread throughout gold mines. A study in DSM initiatives was also investigated by reducing the total load of refrigeration plants on surface by using the ACU unit (Van Eldik, 2006).

DSM methods in refrigeration cycles have been researched by various scholars as indicated above, however, very little research has been conducted on the refrigeration cycle of a hydropower mine. The method is exactly the same as for conventional mining methods, however, the difference is that the water being used for drilling and working machines is chilled by the fridge plants and not the ventilation. Findings from Schoeman's (2014) research can be used for hydropower mines in order to reduce chilled water consumption.

2.7.6 Lighting

Lighting in a mine, although considered a low priority, consumes approximately 5% of a mine's total energy.

Research has been conducted in the technology of lighting by lowering the load each light consumes. This new technology was implemented on several mines through ESCO initiatives.

Masopoga, Van der Merwe and Grobler (2007) conducted research in the measurement and verification (M&V) of load reduction in lighting systems to measure the energy saved from these systems. They projected a saving of 157kW and pre-implementation metering was done to obtain a baseline. The results indicated that their method was 99% accurate with a saving of 157kW (Masopoga, Van der Merwe & Grobler, 2007).

The research completed by Masopoga, Van der Merwe and Grobler (2007) focussed on the problems encountered when conducting M&V with lighting projects. However, the mine being investigated has already installed energy efficient lights.

2.7.7 Pumping

From the 14.5% electricity used by the mining sector, 14% of that is used for pumping water in mines. This means that approximately 2% of Eskom's total electricity supplied to mines is used for pumping water in the mines.

The pumping system in gold mines can be divided into two categories, namely; distribution pumping and dewatering pumping.

Distribution pumps are the pumps that feed water down into the shaft, this system is more common in hydropower mines where high pressurised water is used for drilling and cleaning.

Dewatering pumps are used to pump clear water from shaft bottom to surface. It is common to find multiple underground pumping stations on different levels in one shaft. This allows underground water to be pumped in stages to the surface, thus reducing the size of pumps and motors required.

The following research has already been conducted on DSM for dewatering systems:

- Water reticulation system of two mines; Kopanang and Tshepong – a model for these two mines was developed to control their entire water reticulation system optimally. The uniqueness of this research was the inclusion of the refrigeration system into the model. The results concluded that there was a possibility for DSM and possible cost savings for the two mines (Vosloo, Liebenberg & Velleman, 2012).

- Two case studies on the dewatering systems were undertaken – the findings delivered desired results where load shifting was possible on the dewatering pumps. Cilliers (2014) technique included dynamic control ranges of the underground.

- Impact of load shifting projects on clear water pumping systems of South African mines – De Kock (2006) developed a generic model by investigating existing DSM projects and then suggested applying this model to future DSM projects. The results obtained from this model concluded that cost savings of electricity could be obtained.

- Investigation of the root problem regarding failure of automated pumps – Oberholzer (2015) applied a revised system with control parameters to the system, and the results gave a system with less failures and an additional energy savings to the system.

- Load shifting opportunities on multiple shaft dewatering systems – this study included the investigation of five different shafts, each with their own reticulation system and then an investigation on the shafts with a combined reticulation system. The systems were automated and optimized while adhering to the shaft's protocols (Oosthuizen, 2012).

- The possibility of automating pumps on thirteen shafts – the study included developing a tool that will simulate, control and optimize the reticulation system of the shafts. It concluded that it was possible to load shift 39MW out of evening peak (Rautenbach, 2007).

- Comparing automated pumping systems with manually controlled pumping systems – the conclusion was that it is beneficial for a pumping system to be automated. Electricity cost savings of up to 40% are possible by automating a system (Richter, 2008).

- Manual and automated pumping schedules, similar to Richter (2008) – this research concluded that the electrical cost savings of manually scheduled pumping systems are higher than those of automated pumping systems, however, there are failures to the infrastructure of the system due to over exhausting the system. In conclusion, an automated pumping system is more beneficial in the longer term due to lower maintenance costs and fewer infrastructure failures (Smith, 2014).

- DSM possibilities on an intricate multi-shaft pumping system controlled from one control room – the researcher also investigated the efficiency improvements of all the pump stations. The results obtained indicate that the improved efficiency of the pump stations resulted in a load reduction and with the load shift project greater cost savings were achieved. A load shift of 6MW was achieved by the project (Thein, 2007).

- Possible DSM interventions for marginal mines – the focus of this research was on the dewatering, refrigeration and water distribution systems. Van Niekerk (2014) used data from a previous DSM project to create a tool which was used to investigate the payback periods of each DSM intervention. The decision to focus on a specific DSM project was then made. The conclusion was that financial savings were possible.

2.8 Summary

Based on the literature reviewed it is suggested that the mining industry is ideal for applying DSM methods, with specific reference to the gold mines. The literature survey further revealed that no research had been conducted to date on DSM projects for pumping systems on hydropower mines thus, this study and topic are significant. Furthermore, this dissertation will indicate how to approach a hydropower mine’s dewatering system and the key areas for developing a pumping schedule for such a mine. To create the pumping schedule, it is important to understand how a hydropower mine operates.

In chapter 3 the operation of a hydropower mine will be discussed.

Chapter 3

Analysis of a hydropower mine

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3. Analysis of a hydropower mine

3.1 Cycle of a hydropower mine

Figure 9 illustrates the water reticulation system of a hydropower mine. Beginning with the surface reservoirs, the water flows from the surface reservoirs to the cooling towers, which cools down the water. From the cooling towers the water gets chilled in the fridge plant. The chilled water is then stored in the chilled water dam.

The water in the chilled water dams feeds the hydropower banks which gives high pressurised water to the users of hydro power, these systems will be explained in section 3.1.5 and 3.1.6.

The discharged water flows to the prepared drainage system into the settlers. The settlers separate the clear water and stores it in the underground clear water dams. The dewatering pumps will then pump the clear water back to the surface reservoirs where the cycle will be repeated.

The following sub sections in this chapter will explain each component's function in the system in more detail.

3.1.1 Surface Reservoir

The surface reservoir in a hydropower mine usually contains 10Ml of machine water, machine water is a term used for water that is not safe to drink. The reservoir's measuring equipment must be connected to the supervisory control and data acquisition (SCADA) system; this allows the mine to monitor the dam levels and water available for hydro power.

Figure 9, below, illustrates where the surface reservoirs fit in the system.

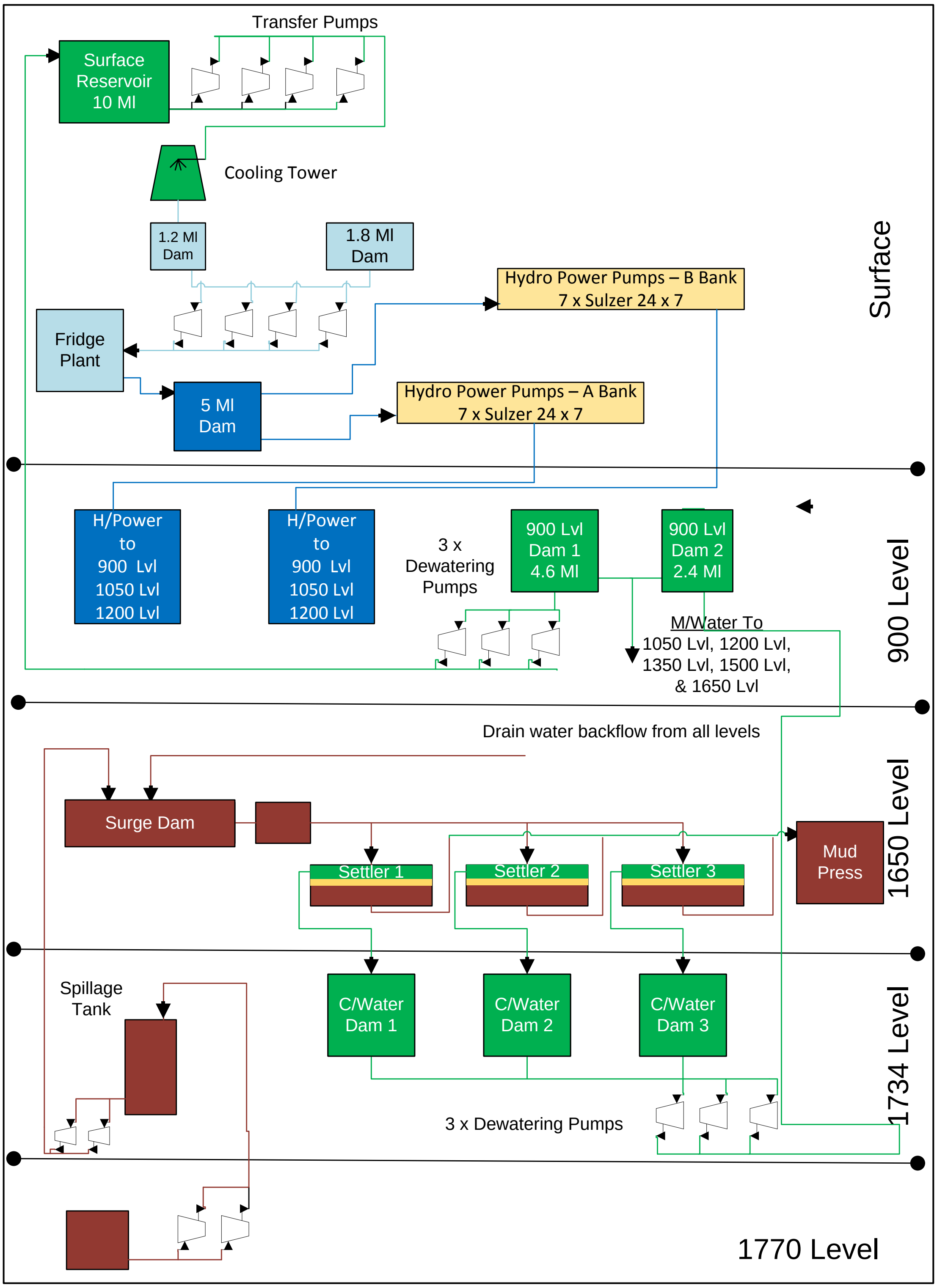

Figure 9: Hydropower water reticulation system

The surface reservoir also contains a pipeline that feeds the system potable water, commonly known as make up water. If the control room detects low water levels in the water reticulation system, potable water will be added to the system via the surface reservoir. There is no need to add chemicals to the water as the quality of potable water supplied by the local municipality is adequate to use in hydropower mines.

The water inside the surface reservoir is usually warm, ranging from 35 degrees Celsius to 40 degrees Celsius. To cool down the water for it to be reused by the system, the water flows to the cooling towers. This process is explained in the following section.

3.1.2 Cooling Towers

Cooling towers, also known as BAC are typically used to cool down air in the underground ventilation system (Stanton, 2003). It is placed in strategic underground areas to control air temperatures going to working areas.

An underground BAC usually cool downs air by transferring the thermal energy of the hot air to the chilled water, thus, producing cold air. BAC's in hydropower mines are used to cool down hot water by exchanging heat with the colder ambient air. This system usually has a delta T of 7 degrees Celsius.

The warm water which has been cooled then flows to the fridge plant.

The following section explains this system.

3.1.3 Fridge Plant

The fridge plant is used to cool down the warm water received from the BAC towers (Groenewald, 2015). Moreover, the fridge plant's reticulation looks different from the fridge plant of a conventional mine.

In a conventional mine the chilled water from the chilled water dam can be recirculated through the fridge plant, however, with hydropower mines the water are not recirculated. The hydropower mine's system is designed such that the chilled water is used as soon as possible after chilling the water. The system is designed with this method to avoid heat transfer between the chilled water and the surface ambient temperature.

In addition, with minimal heat exchange the chilled water can be distributed underground to the working areas where drilling and scraping takes place. Since no additional cooling systems is installed underground, it is very important that minimal heat exchange occurs.

The following section explains the importance of chilled water dams.

3.1.4 Chilled water dam

Chilled water, at a desired temperature, is obtained from the fridge plants where it is stored in the chilled water dam (Maré, 2015). The chilled water dam must be insulated to ensure minimal heat exchange between the dam and the ambient temperature.

In section 3.1.3 it is mentioned that the chilled water is used immediately, but it is important that the dam level does not reach its minimum level. This is due to impurities in the water system that settle in the chilled water dam. If the impurities get transferred to the next phase the pumps will be damaged. This is explained in the next section.

With hydropower mines the desired water temperature must be 6 degrees Celsius when leaving the chilled water dams, this ensures ideal working conditions underground. To distribute the water to the working areas underground, the water is pumped via the hydropower banks.

The pumping process is discussed in the following section.

3.1.5 Hydropower banks

Hydropower mines usually consist of one or more hydropower banks, where each hydropower bank contains a certain amount of hydropower pumps which is connected in parallel. The pumps add pressure to the water distribution system for drilling and scraping.

The machines that use the hydropower operate at a certain pressure, thus, there is more than one hydropower bank on surface. Each hydropower bank delivers a set pressure to the working areas underground. One bank may consist of seven hydropower pumps; where each delivers the desired pressure, and are connected in parallel to satisfy the demand of water.

The pumps in this system are usually automated to switch on as the demand for hydro power increases and automatically switch off as the demand decreases.

The following section will discuss the equipment that require hydro power.

3.1.6 Uses of hydro power

There are 40 types of hydropower equipment available for mining underground (Fraser, 2008). For this study's three main uses and additional main users are provided.

The three main uses are:

- Drills
- Water jets
- Watering down guns

The three additional main uses are:

- Loaders

- Box front chutes
- Roof support rigs

This equipment replaced conventional mining equipment that used compressed air as its power source. Since the compressed air was replaced with high pressurised water, the water usage of the mine increased. A typical conventional mine using 0.17kl of water per ton of reef will use 0.31kl of water per ton of reef on a hydropower system, according to Fraser (2008). It is clear that a hydropower mine uses more water.

The water emitted by the hydropower equipment will flow into underground drainage systems. This will be explained in the next section.

3.1.7 Water drainage system

The discharged water by the hydropower equipment and fissure water will flow from the arranged drainage systems into entrance exit (NX) holes. These NX holes are found on each level near the shaft.

From the NX holes the water flows into a surge dam. Due to the high water pressure caused by gravitational pressure, the surge dams' purpose is to absorb the impact of the water flowing from the NX holes.

From the surge dam the water flows to the settlers. The purpose of settlers in a hydropower mine will be discussed in the following section.

3.1.8 Underground Settlers

Figure 10: Underground settlers (Schutte, 2014)

The image in figure 10 is a photograph taken of an underground settler by Schutte (2014). The water received by this system flows from the surge dam.

Settlers are used to separate the mud from the water, flocculent is added to the system to help with this separation. The clear water overflow flows to underground clear water dams (which will be explained in the next section) and the mud underflow gets pumped by centrifugal pumps to a mud press. The mud press separates the remaining water from the mud and the mud gets transferred via conveyor belts to the reef dump. The remaining clear water is pumped to the settlers and the process is repeated.

3.1.9 Underground Clear Water Dams

There are multiple underground clear water dams in a shaft to collect water from the underground settlers as mentioned above (Van der Bijl, 2005). To prevent catastrophic failures and floods, the mine usually installs a dam capacity for a shaft that is well over designed. This will allow time for the mine to evacuate or implement a plan of action if the dewatering pumps fail.

Clear water dams in hydropower mines have the same function as clear water dams in conventional mines. The dams receive clear water from the settlers which is pumped to multiple shafts or to surface, depending on the design of the water reticulation system.

The following section explains the function of dewatering pumps in a hydropower mine.

3.1.10 Dewatering Pumps

Dewatering pumps are multi-staged pumps that pump hot water from underground clear water dams to surface dams (Botha, 2010). This equipment is very important to a deep level mine as it prevents flooding in the mine and it supplies the surface systems with water (Deysel, 2014). Hydropower mines and conventional mines dewatering pumps will be the same design, however, the operation of the pumps will be different.

Conventional mines will experience slight fluctuations in the water usage on a working day, whereas hydropower mines will experience large fluctuations of water usage on a working day. This appearance is explained in section 3.1.6, where all the uses of hydro power are mentioned.

These multi-stage centrifugal pumps’ power consumption ranges from 500kW to 3MW. Thus, the operation of these machines is very crucial to the mine, especially if the pumps operate in between peak and Standard Time tariffs, the mine will be spending more on the electricity bill.

With the knowledge on how a hydropower mine operates and what separates a hydropower mine from a conventional mine, a mine was selected to do a Case Study.

The selected mine is discussed in the following section.

3.2 Case Study

3.2.1 History of the hydropower mine being investigated

The hydropower mine selected for this Case Study is a deep level gold mine located close to the town of Orkney, in the North West Province of South Africa. The shaft sinking operations at this mine commenced in 1985 with the first gold being poured in 1991.

The mine was originally designed with a capacity to hoist 2.2 million ton of reef per year, however production reached its peak in 2007, with 1.4 million ton of reef per year. Moreover, as commodity prices decreased, production at the mine decreased too. That explains why the mine currently hoists 800 thousand ton of reef per year. This means that the production has decreased with 40% since 2007. The mine's system is still operating as if it is at a 100% production rate. Thus, there is an opportunity to implement DSM on the mine's system.

A further study conducted on the mine, indicated that there is no algorithm or method available to create a pumping schedule for hydropower mines, thus, there is no pumping schedule for the dewatering system of the mine. This reasoning was previously indicated in chapter 2.

The following section provides and explains the system layout of the chosen mine.

3.2.2 System Layout

Figure 11 is an illustration of the mine's dewatering system and indicates where the hydropower water, potable water and machine water flows to.

The following section will provide the system design of the mine.

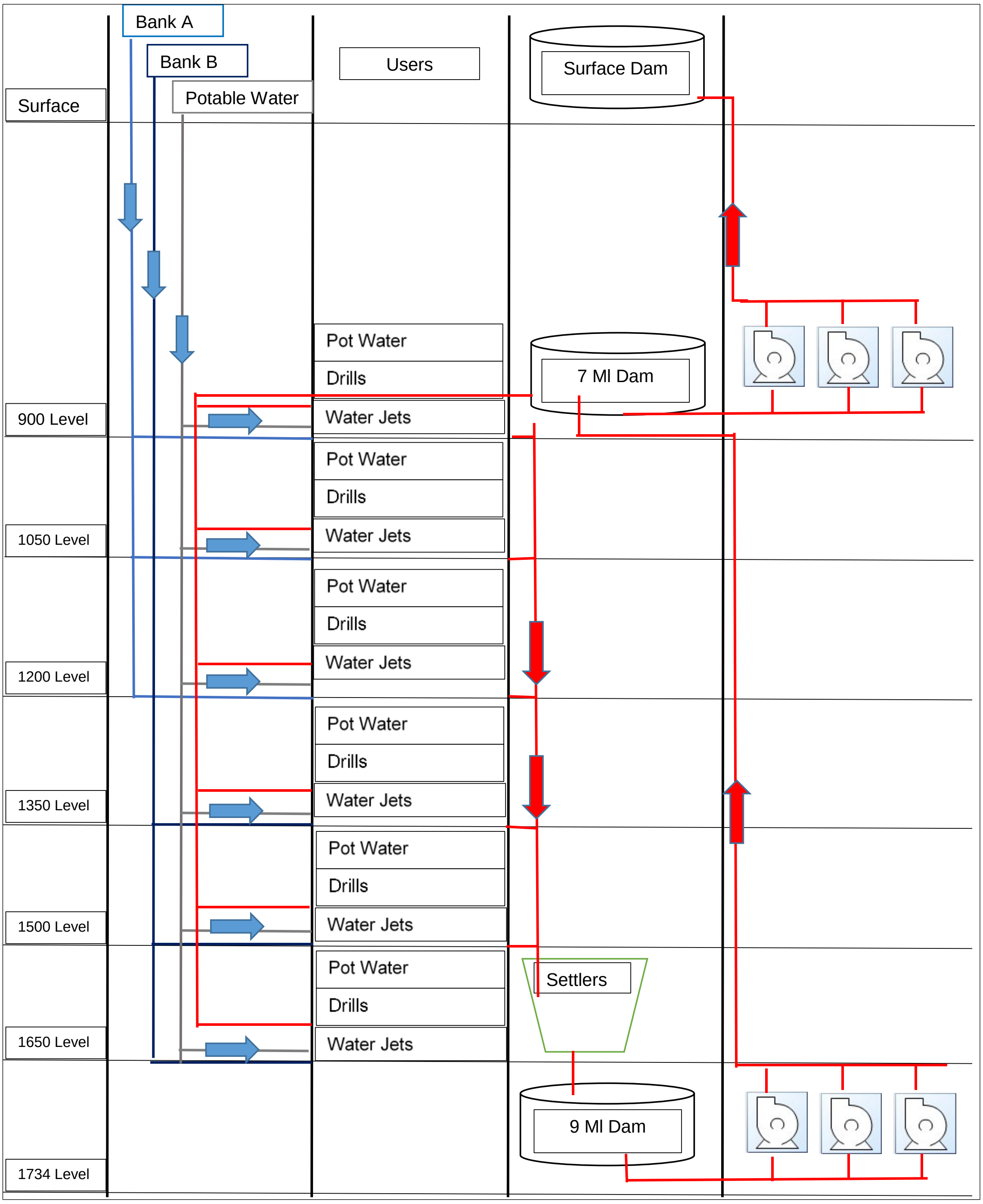

Figure 11: System Layout

3.2.3 System Design

- Shaft levels

There are seven shaft levels on the mine investigated; where six are working levels:

  - 900 Level
  - 1050 Level
  - 1200 Level
  - 1350 Level
  - 1500 Level
  - 1650 Level

And one shaft bottom:

  - 1734 Level

- Hydropower banks

There are two hydropower banks on surface; bank A and bank B. Bank A adds 10 MPa hydro pressure to level 900, 1050 and 1200. Bank B adds 5 MPa hydro pressure to level 1350, 1500 and 1650.

The hydropower is mainly used by drills and waterjets. Where drills use 1l/s hydro powered water and waterjets 3l/s. The emitted water finds its way through the prepared drainage system and then into the underground dams.

- Underground shaft bottom dam

There is a 9Ml dam underground at shaft bottom, the discharged water from the equipment is stored in this dam. The dam has equipment that measures dam levels and then sends the data to the control room where they monitor it on the SCADA. If the dam level exceeds the design value, the control room operator starts the pumps on level 1734

- Level 1734 Pump station

Level 1734 has three Sulzer HPH 58–25: 8 stage 2.8MW dewatering pumps. One of the pumps can deliver a flow of 280l/s, but the efficiency of the pumps has decreased and can only deliver a flow of 256l/s.

The machine water is then pumped from shaft bottom to level 900.

- Level 900 Underground dams

There are two underground dams on level 900. A 500Kl and a 1Ml dam that are interconnected. The dams serve two purposes; as an interconnection point between shaft bottom and surface and, as a reservoir for the machine water. Machine water is used to clean the working areas underground.

The levels of the dams are monitored in the control room. If the level of the dams exceeds the design criteria, the water gets pumped to surface.

- Level 900 Pump station

There are three Sulzer HPH 58–25: 8 stage 2.8MW dewatering pumps in level 900's pump station. Each can deliver a flow of 280l/s, however, since the efficiency of each pump has decreased, the pumps can only deliver 225l/s water to surface.

Thus, the control room operator must start the pumps effectively to avoid underground floods and to compensate for the difference in flows for each level's pumps. The current daily operation of the dewatering pumps is explained in the following section.

3.2.4 Current daily operation

Figure 12 represents the running profile of the dewatering pumps for level 900. The data was captured over a period of one year and an average profile was drawn.

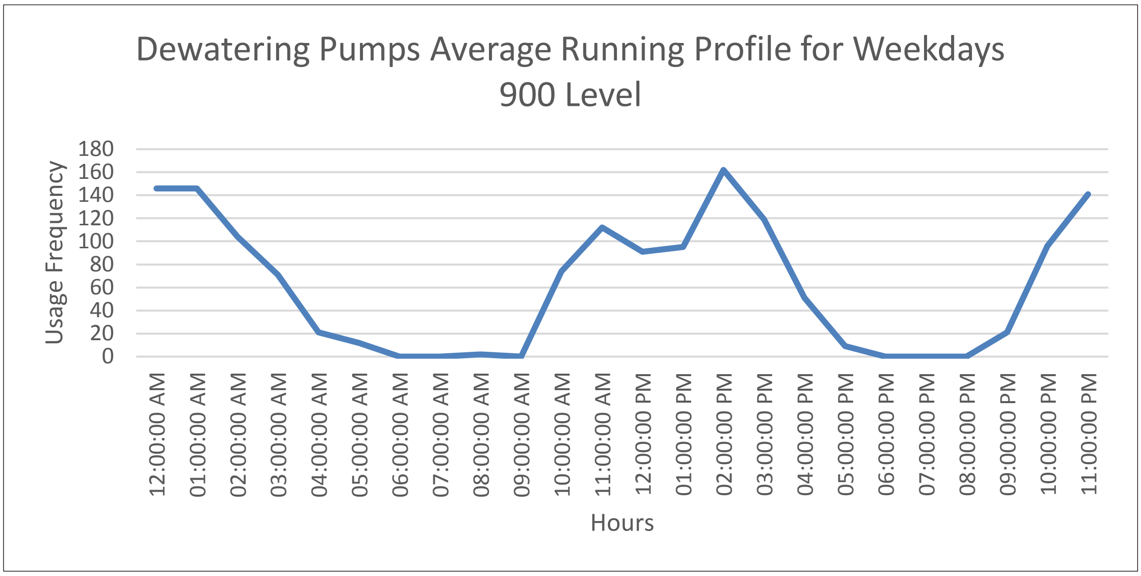

Figure 12: Current daily operation for 900 level on Weekdays

Considering the Megaflex structure on page 13 (Figure 5), the following information is obtained from figure 12. It is deduced that the pumps were running 21% of a 24-hour day, about 5 hours a day. In this period, the pumps run the following profile indicated in table 2 below.

Table 2: Pumps running profile 900 Level Weekdays

900 Level Weekdays	Peak period	Standard Time period	Off-peak period
% Runtime of pumps during Megaflex period	1	54	45

Table 2 indicates that the dewatering pumps operate 1% of the working time during peak time, 54% during Standard Time and 45% during Off-peak. This is for 900 level from Monday to Friday. For Saturdays, the following graph was obtained.

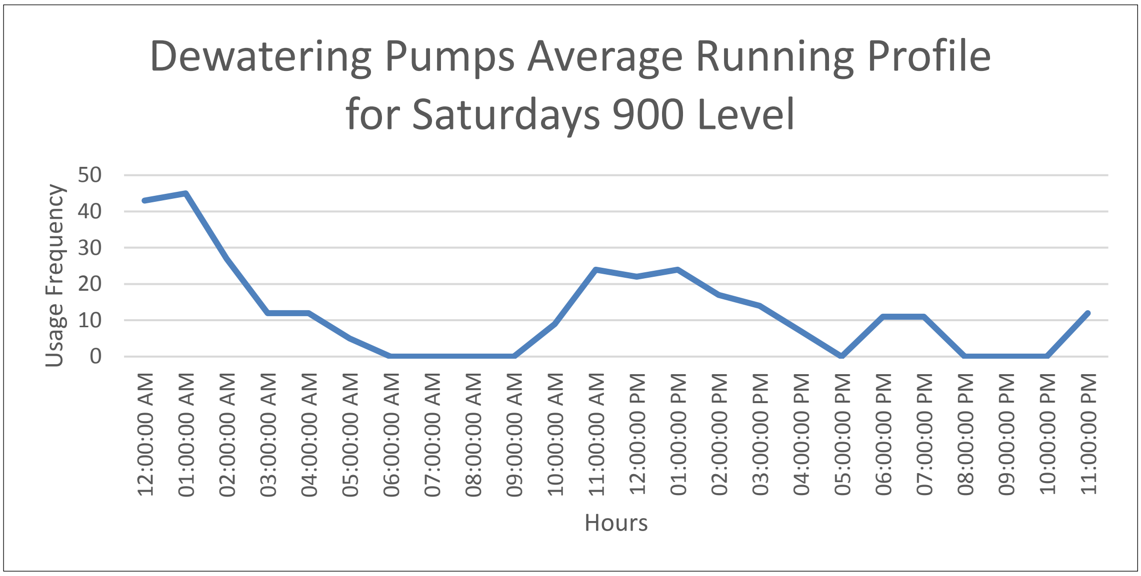

Figure 13: Current daily operation for 900 level on Saturdays

Figure 13 represents the running profile of the dewatering pumps for level 900 on Saturdays. The data was captured over a period of one year and an average profile was graphically represented.

Considering the Megaflex structure on page 13 (Figure 5), the following information is obtained from figure 13. It was deduced that the pumps were running 16% of a 24-hour day, about 3 hours a day. In this period the pumps run the following profile indicated in Table 3 below.

Table 3: Pumps running profile 900 Level Saturdays

900 Level Saturdays	Standard Time period	Off-peak period
% Runtime of pumps during Megaflex period	14	86

Table 3 indicates that the dewatering pumps operate 14% during Standard Time and 86% during Off-peak. This is for 900 level on Saturdays. For 1734 level the following data was captured:

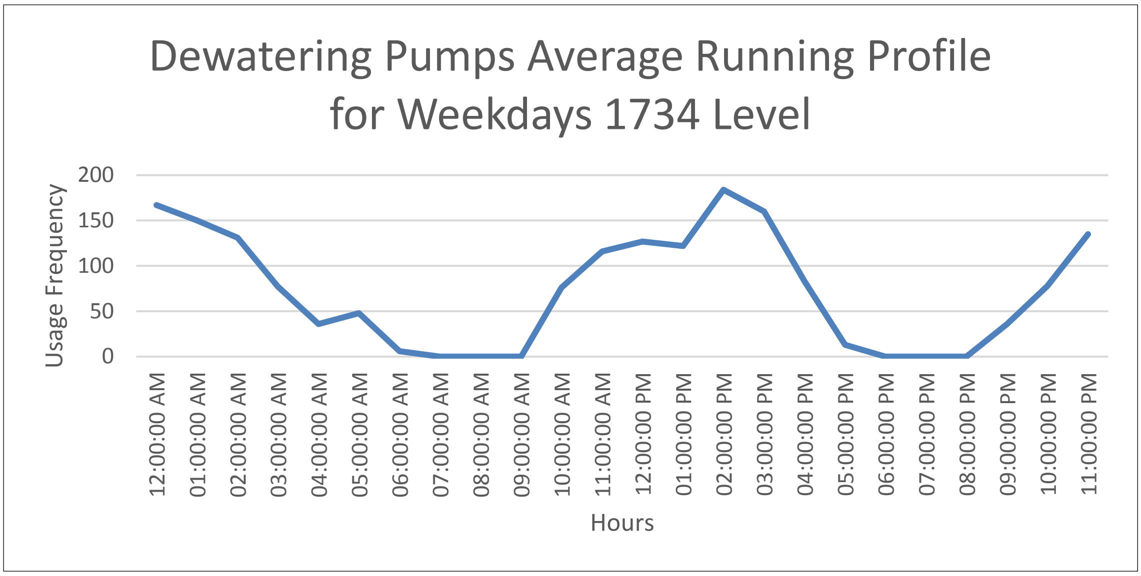

Figure 14: Current daily operation for 1734 level on Weekdays

Figure 14 represents the running profile of the dewatering pumps for level 1734 on Weekdays. The data was captured over a period of one year and an average profile was created.

Considering the Megaflex structure on page 13 (Figure 5), the following information is obtained from Figure 14. It was deduced that the pumps were running 25% of a 24-hour day, about 6 hours a day. In this period, the pumps run the following profile indicated in table 4 below.

Table 4: Pumps running profile 1734 level Weekdays

1734 Level Weekdays	Peak period	Standard Time period	Off-peak period
% Runtime of pumps during Megaflex period	1	56	43

Table 4 indicates that the dewatering pumps operate 1% of the working time during peak time, 56% during Standard Time and 43% during Off-peak. This is for 1734 level Monday to Friday. For Saturdays, the following graph was obtained.

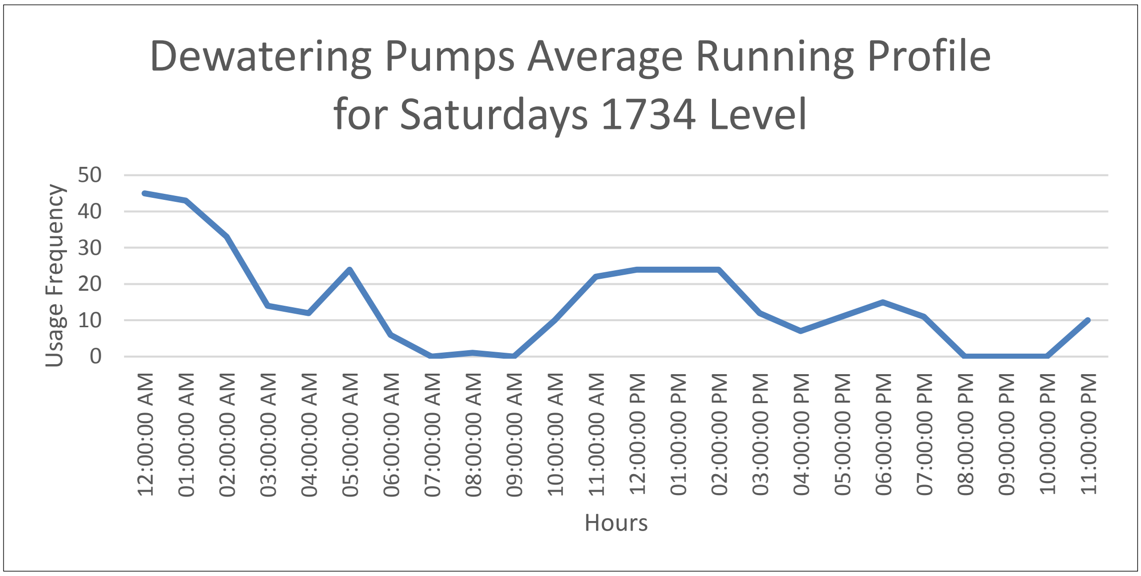

Figure 15: Current daily operation for 1734 level on Saturdays

Figure 15 represents the running profile of the dewatering pumps for level 1734 on Saturdays. The data was captured over a period of one year and an average profile was created

Considering the Megaflex structure on page 13 (Figure 5), the following information is obtained from figure 15. It was obtained that the pumps were running 20% of a 24-hour day, about five hours a day. In this period, the pumps run the following profile indicated in table 5 below.

Table 5: Pumps running profile 1734 level Saturdays

1734 Level Saturdays	Standard Time period	Off- peak period
% Runtime of pumps during Megaflex period	13	87

Table 5 indicates that the dewatering pumps operates 13% during Standard Time and 87% during Off-peak. This is for 1734 level on Saturdays.

The information gathered from the running profiles of the dewatering pumps indicate that there is no pumping schedule used by the mine. This is indicated by the blue coloured lines in the graph which represent random fluctuations in the graphs. The graphs further indicate that the mines do not pump during peak times. This provides mines with cost reduction opportunities, however, for maximum cost savings to be achieved, the system must be investigated. The current demand of the system will indicate whether the dewatering pumps are able to pump water to surface during Off-peak periods. Thus, in the next section the current demand for water will be discussed.

3.2.5 Current daily demand

Figure 16 represents the daily use of water underground, ranging from the water being pumped by the hydropower banks to the water being pumped by the dewatering pumps. This figure will indicate whether the dewatering pumps would be able to pump all the water to surface during Off-peak periods. To see if this is possible, the pumps pumping specifications must be known.

An investigation on the pumps gave the following data:

Table 6: Pumps flow specifications

	900 Level	1734 Level
Pump flow (l/s)	225	256

This means that each pump on 900 level can deliver a flow of 225l/s and each pump on 1734 level can deliver a flow of 256l/s.

This indicates that if only one pump on 900 level runs during Off-peak (eight hours), the pump can deliver 6.48 Ml of water to surface. Referring back to figure 16 it can be deduced that the total water that flows down the shaft adds up to 4.396Ml.

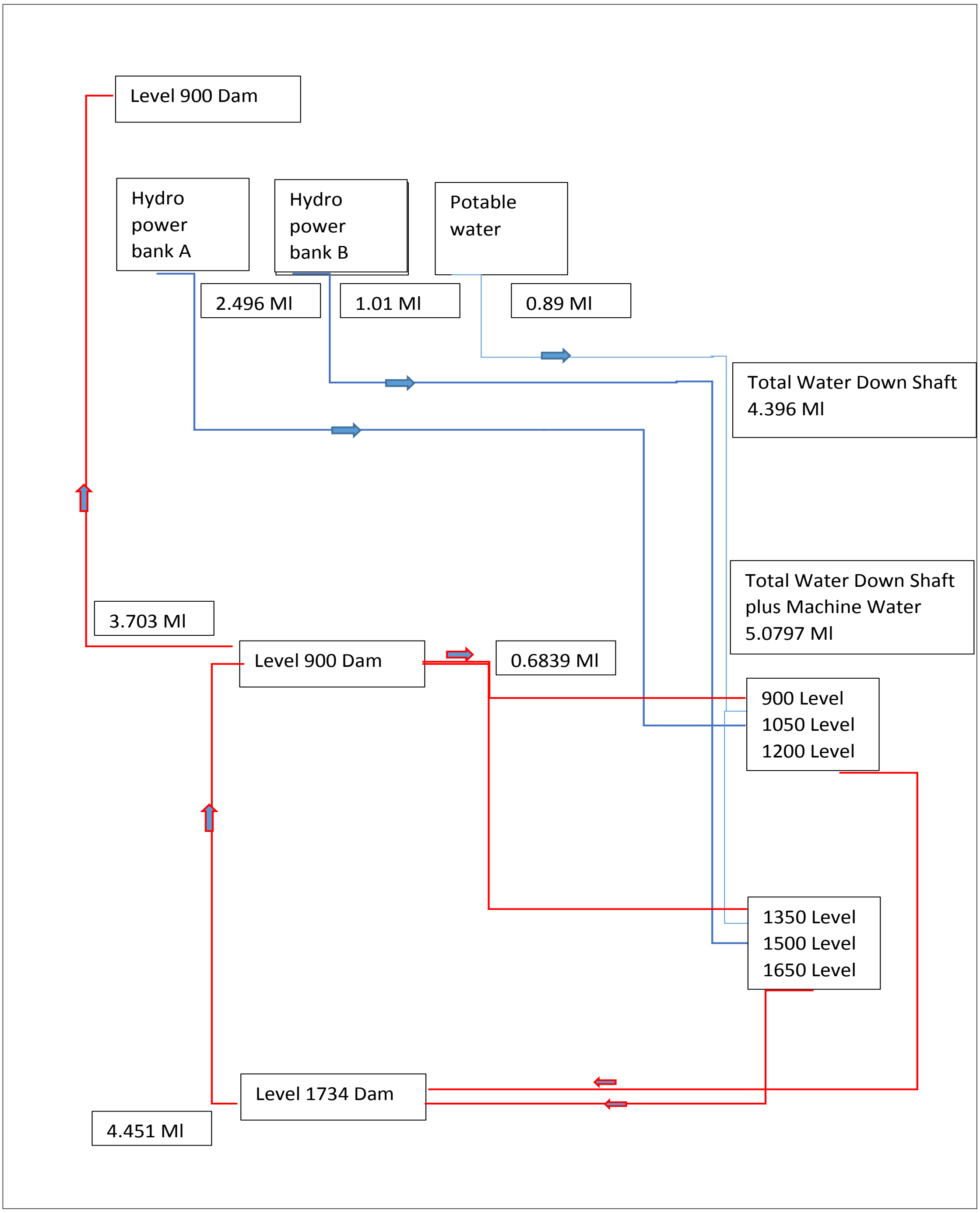

Figure 16: Current daily demand of the mine investigated

Thus, it is possible for the amount of water to be pumped to surface during Off-peak. Another parameter that influences the pumping schedule is dam capacity. The underground dams must be able to store the water being used during peak periods and Standard Time periods till it can be pumped to surface. To assess if the capacity of the dams is sufficient, a simulation model must be created. Existing models have been created by Schoeman (2014) and Vosloo (2012) and Cilliers (2014).

However, the created models will not work for the mine being investigated. The model created by Schoeman (2014) and Vosloo (2012) is designed to load shift from peak period and distribute the load between Standard Time and Off-peak (Schoeman, van Rensburg & Bolt, 2014) (Vosloo, Liebenberg & Velleman, 2012). Based on this, Cilliers (2014) created a model that will load shift an added load to Off-peak periods by investigating preparation loads and comeback loads. Moreover, due to the peak periods in water this model will not work for a hydropower mine. This model also does not include complete load shifting to Off-peak periods as hydropower mines have two shifts. A drilling shift with blasting and a cleaning shift with waterjets. Figure 17 indicates two shifts; an afternoon and a midnight/morning shift. Thus, Cilliers' (2014) model is not prepared for these peak periods with very low demand periods included as well.

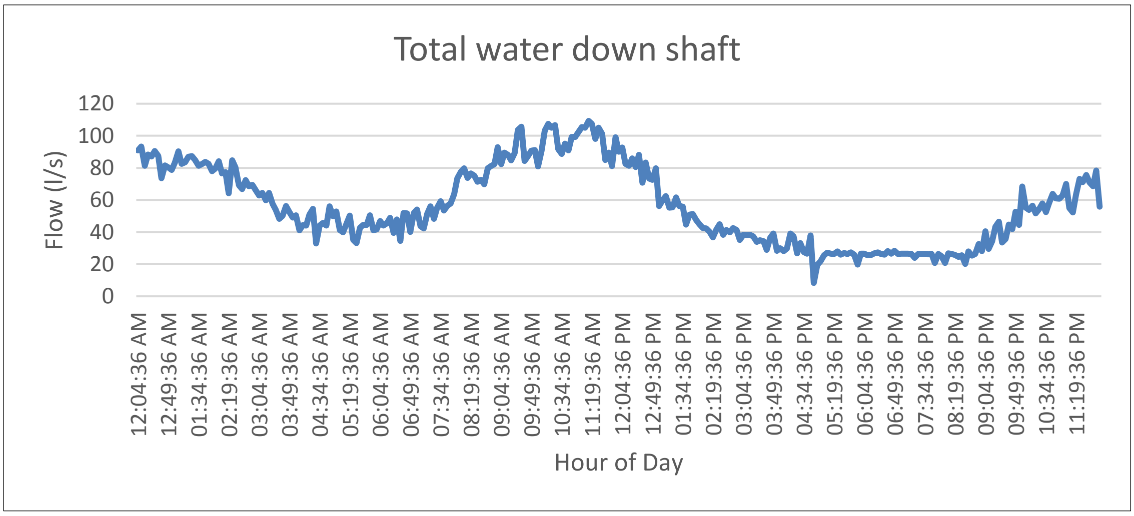

Figure 17: Water consumption on an average day

Thus, a simulation model must be created to simulate underground dam levels to obtain if pumping during Off-peak periods is possible. The next chapter will discuss the simulation model for a hydropower mine.

3.3 Summary

The knowledge obtained from investigating the water reticulation system of a hydropower mine was used to select a hydropower mine and create a Case Study. In this Case Study, a hydropower mine was selected and the investigation proposed that no pumping schedule was being used for the dewatering pumps. The mine currently avoids peak period tariffs, however, only by means of guessing pumping times. This indicates that a method to create dewatering pumping schedules for a hydropower mine is in fact required.

Chapter 4 will discuss the method to create a simulation model for a hydropower mine.

Chapter 4

Simulation Methodology

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4. Simulation Methodology

The previous chapter discussed the importance of developing a simulation model. This chapter will provide the methodology and technique for creating a simulation model for a hydropower mine which allows load shifting on the dewatering pumps. This model will allow for complete load shifting from peak periods and Standard Time periods to Off-peak periods.

4.1 Procedure to create a model for load shifting purposes.

Figure 18 summarises the procedures that will be followed to create s new pumping schedule or adjust an existing one.

Step 1: select the type of mine. The type of mine selected is important as it affects the steps taken for approaching the simulation model. Typical types to select from include; conventional and hydropower mines. Chapter 3 indicated key areas to identifying a hydropower mine.

Step 2: identify potential for load shifting on the hydropower mine. To identify if there are load shifting possibilities on the dewatering system of a hydropower mine, without running simulations, there are some quick calculations that can be made, but these calculations may only be used as guess values. This will be discussed in more detail.

Step 3: obtain the system design of the dewatering system. Pumps specifications, dam sizes and the inflow of mining water needs to be obtained. The amount of fissure water needs to be known as well.

Step 4: locate the preferred control range by the mine. It is important to use the preferred boundaries and specifications of the mine.

Step 5: once the required has been gathered, a model can then be created. The model must be verified by comparing the results of the model with real life values gathered from the mine. Once verified, it can be used to design an improved model with new boundaries.

Step 6: new boundaries are set to create a new schedule that will allow complete load shifting from peak periods and Standard Time periods to Off-peak periods.

Step 7: once new boundary conditions are obtained, the boundary conditions can be added to the verified model, thus creating a new pumping schedule. If the dam levels are in between the preferred ranges, the schedule may be implemented on the mine’s systems.

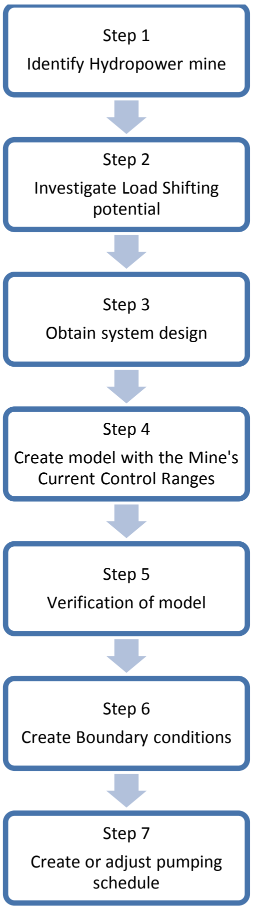

Figure 18: Flow chart, steps for creating a pumping schedule

The following sections will discuss each step in detail and further explain the method used for creating a pumping schedule for a hydropower mine to obtain complete load shifting to Off-peak periods.

4.2 Step 1 Identifying a hydropower mine

The analysis of a hydropower mine has been discussed in chapter 3. This provided a better understanding on how to identify a hydropower mine. One of the major characteristics of a hydropower mine is that it uses high pressurised water for its equipment. Thus, there are no water leaks in the pipeline leading to very little water usage in blasting times and in between shift changes. This gives the opportunity to load shift the TOU period from 6am and 10pm to Off-peak periods 10pm to 6am.

4.3 Step 2 Investigating load shift potential

Power usage is a critical factor to observe in load shifting projects. It gives a baseline to work with when energy savings are being calculated. To deduce if any load shifting is present on the system, the following method can be followed;

Obtain the average power consumption during TOU periods, the method of obtaining this value may differ from mine to mine, but the generic method is as follows.

$$AvePowerTOU = \frac{\sum PowerTOU}{DataCapTOU} \tag{1}$$

where

AvePowerTOU = The average power usage during the specific TOU

PowerTOU = The power value captured at each DataCap

DataCapTOU = The number of data points at which data was captured during the TOU

Equation (1) will be implemented for Off-peak, Standard Time and peak periods according to the Megaflex structure (Figure 5).

$$AvePower = \frac{\sum TotalPower}{DataCap} \tag{2}$$

Where

AvePower = The average power usage for a normal 24-hour day

TotalPower = The power value captured at each Datacap for a 24-hour day

Datacap = The number of data points captured in a 24-hour day

With Equation (2) the average power consumption of a day can be calculated. The values required to know if load shifting is already implemented are now available. It is important to know where load shifting has already been implemented, thus the (3) to (5) equations will give an indication of where it has already been implemented.

$$Off - PeakRatio = \frac{AvePowerTOU(OffPeak)}{AvePower} \tag{3}$$

Where

Off-PeakRatio = Gives a value that indicates if load shift is present during Off-peak

Equation (3) gives the ratio between power consumed in Off-peak period and the average power consumed in a 24-hour day. If the value is lower than one, it means that load shifting has already been implemented in this phase. If the value is greater than one, it means that there is no load shifting being implemented during this phase. In the Off-peak period, it rarely occurs that the ratio is lower than one, because this will indicate that the most energy is consumed during higher tariff periods.

$$StandardTimeRatio = \frac{AvePowerTOU(Standard\ Time)}{AvePower} \tag{4}$$

Where

StandardTimeRatio = Gives a value that indicates if load shift is present during Standard Time

Equation (4) delivers the ratio between power consumed in the Standard Time and the average power consumed in a 24-hour day. If the value is lower than 1, it means that load shifting has already been implemented in this phase. If the value is greater than 1, it means that there is no load shifting being implemented on this phase.

$$PeakRatio = \frac{AvePowerTOU(Peak)}{AvePower} \tag{5}$$

Where

PeakRatio = A value that indicates if load shift is present during Peak period

Equation (5) delivers the ratio between power consumed in peak period and the average power consumed in a 24-hour day. If the value is lower than 1, it means that load shifting has already been implemented in this phase. If the value is greater than 1, it means that no load shifting will be being implemented during this phase. The ratio in this period is very important, because the tariff in this period is high. The purpose of this study is to reduce costs and reduce pumping between these periods.

This method ranging from equation (1) to (5) proves most effective if more than one pump is operating at any given time period, if the mine has only one pump operating through the day, the following method can be implemented.

Obtain the operation time for a dewatering pump in a 24-hour weekday.

$$\%OfDayRuntime = \frac{PumpsOperationTime}{24\ hours} \times 100 \qquad (6)$$

Where

%OfDayRuntime = The percentage the pump was running in one day

PumpsOperationTime = The minutes the pump is used in one day

Equation (6) provides an indication of how frequently the pump the pump is used daily. With this value known, it is also important to know when the pump was used in this period. To calculate in which TOU period the pump was used, equation (7) to (9) must be followed.

$$\%OffPeakRuntime = \frac{PumpOperationTimeOffPeak}{(\%OfDayRuntime \times \frac{1}{100} \times 24)} \times 100 \qquad (7)$$

Where

%Off-PeakRuntime = The % value in which the pumps were operating duringOff-peak

PumpsOperationTimeOff-Peak = The minutes the pumps operated in Off-peak

Equation (7) will indicate the percentage in which the pump was operated during Off-peak period. To obtain the percentage value in which the pump was operated during Standard Time, the following equation was used.

$$\%StandardTimeRuntime = \frac{PumpOperationTimeStandardTime}{(\%OfDayRuntime \times \frac{1}{100} \times 24)} \times 100 \qquad (8)$$

Where

%StandardTimeRuntime = Gives the % value in which the pumps were operating during Standard Time

PumpsOperatingStandardTime = The minutes the pumps operated in Standard Time

Equation (8) will indicate the percentage in which the pump was operated during Standard Time period. To obtain the percentage value in which the pump was operated during peak, the following equation was used.

$$\%PeakRuntime = \frac{PumpOperationTimePeak}{(\%OfDayRuntime \times \frac{1}{100} \times 24)} \times 100 \qquad (9)$$

Where

%PeakRuntime = The % value in which the pumps were operating during peak

PumpsOperatingPeak = The minutes the pumps operated in Peak

Equation (9) will indicate the percentage in which the pump was operated during peak period.

When the percentage values are obtained, it can be graphically represented, the recommended graph is a pie chart. The graph will indicate in which time period the pumps are running more frequently. To obtain if the percentages indicated in peak and Standard Time periods could be load shifted to Off-peak periods, equation (10) and (11)

If the pumps available can pump the water being used in between 6am and 10pm in the time slot of 10pm to 6 am, it is estimated that that the system will allow complete load shift to off peak.

$$TotWaterUsedTest = TotalWaterUsedPeak + TotalWaterUsedStandardTime \qquad (10)$$

Where

TotalWaterUsedTest = The water used during Standard Time and Peak (litres)

TotalWaterUsedPeak = The water used during peak period (litres)

TotalWaterUsedStandardTime = The water used during Standard Time (litres)

$$PumpMaxCap = PumpFlow \times OffpeakPeriod \times 60 \times 60 \quad (11)$$

Where

PumpMaxCap = The amount of water the pumps can displace during Off-peak (litres)

PumpFlow = The flow the pump van deliver (l/s)

Off-PeakPeriod = The number of hours in Off-peak

If PumpMaxCap is greater than TotalWaterUsedTest it indicates that the water used during peak and Standard Time periods can be load shifted to Off-peak periods. This is a good indication however, to ascertain if the system will allow complete load shifting to Off-peak; steps three to six must be followed.

4.4 Step 3 System design

The design of the system needs to be known, therefore the following specifications are required:

- Number of pump stations
- Number of pumps per station
- Pump size
- Pump flow
- Dam sizes
- Inter dam connection must be known
- Maximum dam levels
- Minimum dam levels
- Number of hydropower banks and their inflow
- Potable water inflow
- Fissure water
- Machine water flow

Once these values are known, a model can be created on how the mine is currently operating. In Step 4 these values are going to be used to create a model with the current control ranges.

4.5 Step 4 Creating a model with the mine's current control ranges

With the design of the dewatering system known, a model can be created. The design of this model is important, as it the same model that is also going to improve the system.

Inflow into the dams and dam levels

The inflow into the dams can be calculated by using the following equations:

$$DamLevel\% = \frac{\left(\frac{PreviousDamLevel}{100}\times DamCapacity + DamInflow - DamOut\right)\times 100}{DamCapacity} \quad (12)$$

Where

DamInflow = *The water flowing into the dam (Potable water, hydro power water, Machine water and fissure water) (l/s)*

DamCapacity = *The amount of water the dam can contain (l)*

DamOut = *Water flow out of the dam*

DamLevel% = *The level of the dam*

It is important to note that the discharged water from the hydropower equipment, potable water, machine water and fissure water will not reach the dam immediately; it will take from 30 minutes to 180 minutes depending on the drainage system of the mine. Including this key factor into a calculation resulted with figure 19 below:

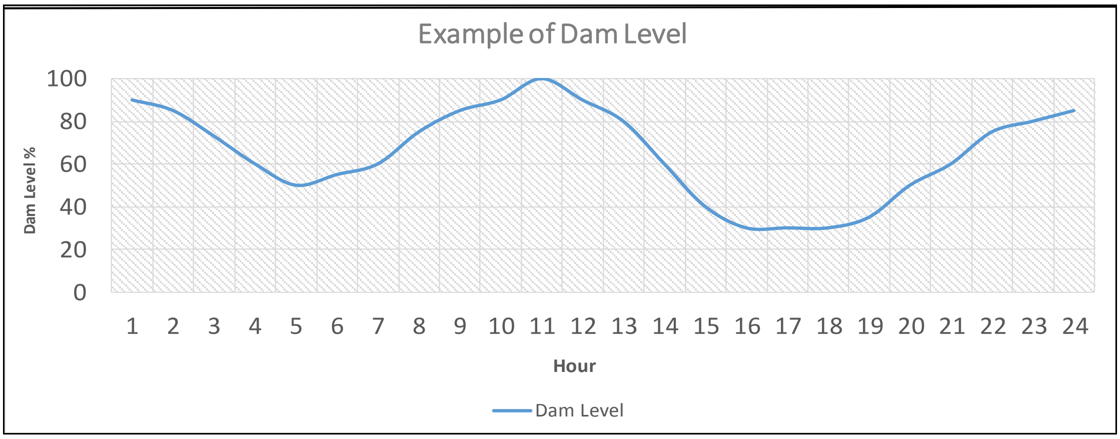

Figure 19: Example of dam inflow illustrated in dam % levels

Interpretation of the graph’s gradient:

- A strong incline means that a large amount of water is being used
- A Strong decline means that water is being pumped out of the dam
- A weak decline means that there is machine water being re-used out of the dam
- A very weak decline means that there may be leaks in the dam
- A near horizontal line means that no water or little water is being used in the mine

Indicating maximum and minimum dam levels

The maximum and minimum dam levels have already been obtained in a previous step. As such, they have been added to the model.

In the example provided the minimum dam level was selected to be at 20%, this is illustrated in figure 20. The reason why the minimum will never be chosen to be 0%, is because of mud lying in the bottom of the dam. If mud gets sucked into the pumps it will damage the pumps. The maximum dam levels are usually selected to ensure that there is still capacity left in case of emergencies where pumps have broken down or power outages.

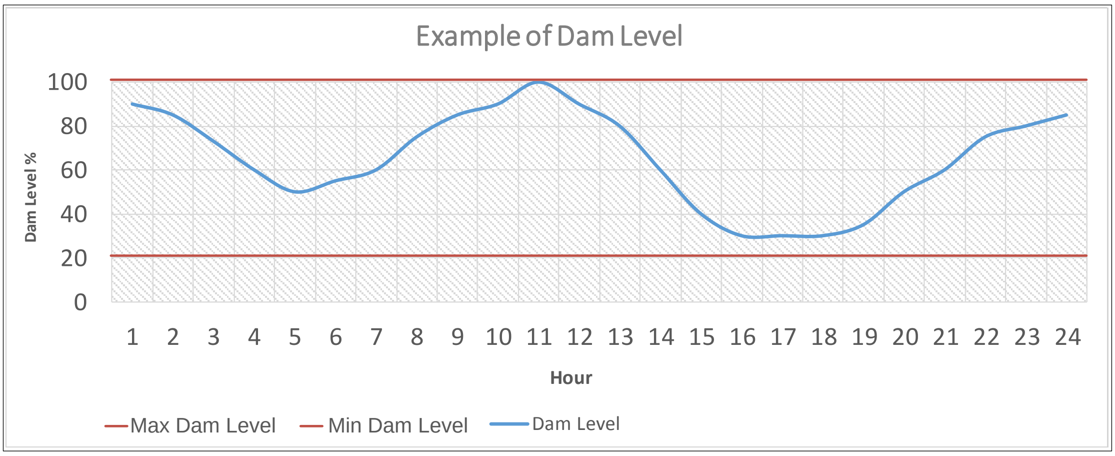

Figure 20: Example of Minimum and Maximum dam levels added

Adding the mine’s current control ranges to the model

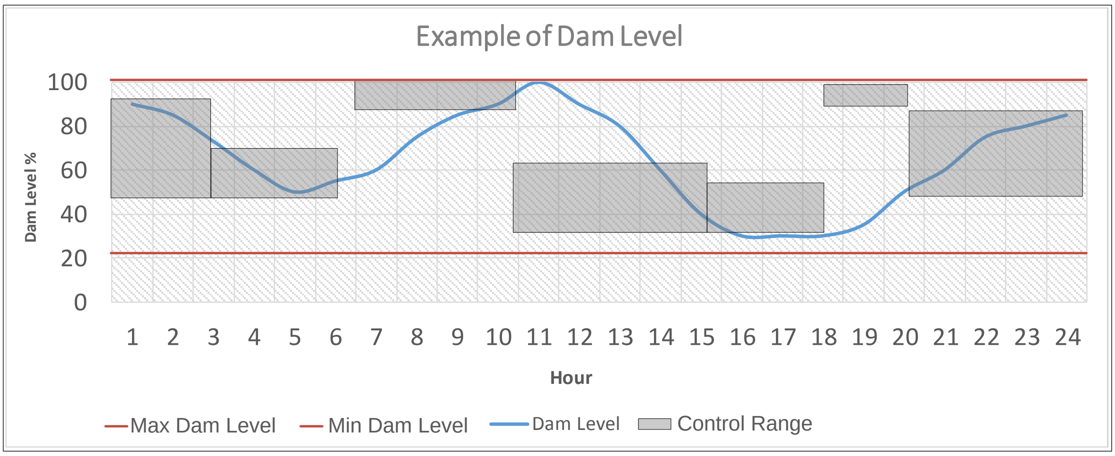

Figure 21: Adding Control ranges to example model

Figure 21 indicates the control areas of a mine that has already implemented load shifting on its dewatering system. It is important to note that each control area has a maximum boundary and a minimum boundary. These boundaries indicate when the pumps must start and stop. These control ranges are added before verification to understand the control philosophy of the mine. The next step will be to verify the created model with real life values obtained from the mine.

4.6 Step 5 Verification of the model created

The model created needs to be verified by comparing the simulated dam levels with real life dam level values. Depending on how many models have been created till this point determines the number of models that need to be verified.

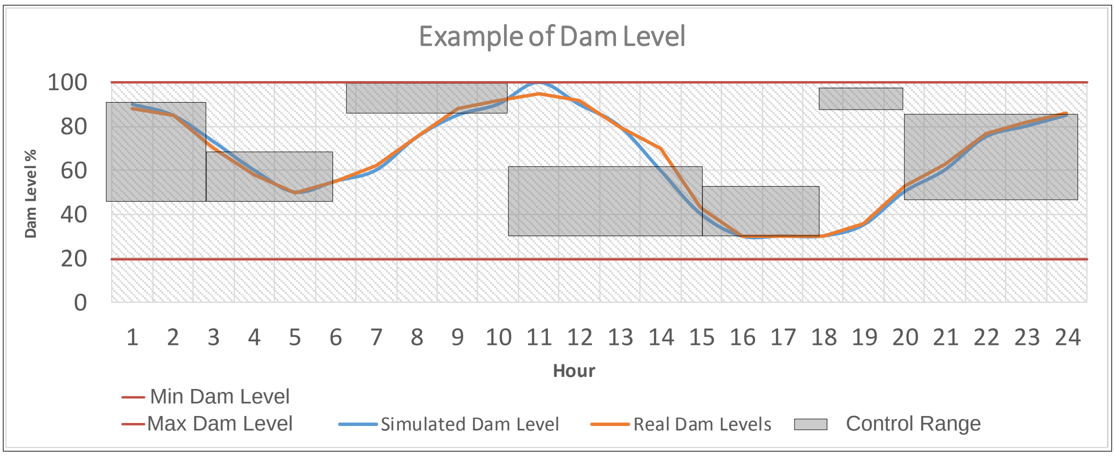

Figure 22: Verification example of mine model

Figure 22 is an example of how the model is verified. With 10% as the largest error the model may be verified to use as a model to create new boundaries for the control ranges. In step 6, these new boundary areas will be created.

4.7 Step 6 Improving the boundary areas

Prior to improving the boundary areas, figure 21 is going to be represented with a letter for each boundary area. Thus making it easier to reference each area as illustrated in figure 23.

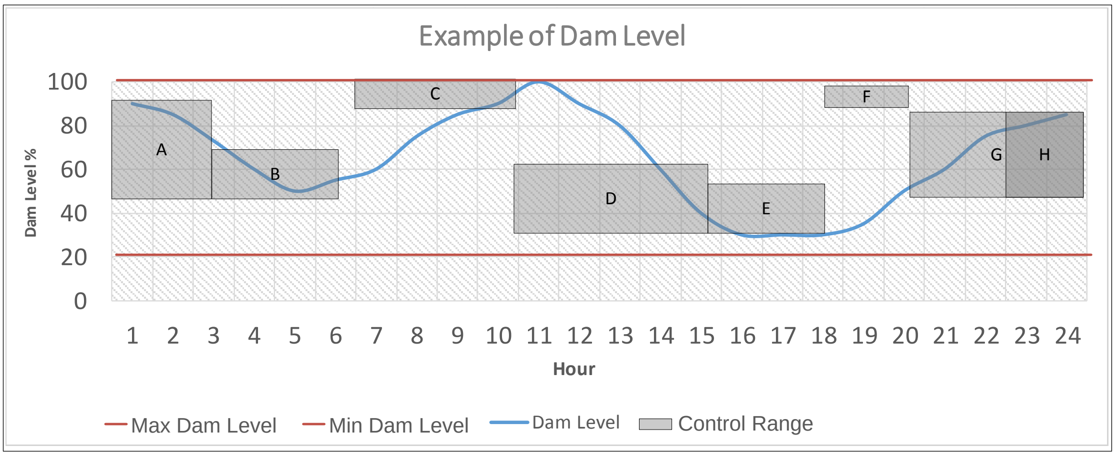

Figure 23: Example model with symbols to each control range

The key control ranges that will enable complete load shift to Off-peak periods will be area A, B and H. As observed, these mentioned areas are positioned in the Off-peak period. The rest of the areas are found in peak and Standard Time periods. To calculate the maximum boundary for area B, the following equation is used:

$$MaxBoundary_B = MaxDamLevel - \left(\frac{InflowTOU}{DamCapacity} \times 100\right) \tag{13}$$

Where

MaxBoundary_ B = The maximum boundary of area B (%)

MaxDamLevel = The maximum level the dam may reach (%)

InflowTOU = The total volume of water used in Peak and Standard Time (%) period

DamCapacity = The size of the dam in the simulated model (litres)

If MaxBoundary_B is smaller than the minimum control range preferred by the mine, MaxBoundary_B must be set to be equal to the preferred control range. As explained in the previous section, it is important to use the mine's preferred control ranges.

To obtain the minimum boundary for area B the following equation is used:

$$MinBoundary_B = MinDamLevel \tag{14}$$

Where

MinBoundary_B = The minimum boundary of area B (%)

MinDamLevel = The minimum level of the dam used in the model (%)

Boundary level C and F are during peak period. These boundaries must be calculated to only start the pumps if necessary. This is why these boundary levels must be calculated as follow:

$$MaxBoundary_{C,G\&F} = MaxDamLevel \tag{15}$$

Where

MaxBoundary_C,G&F = The maximum boundary of area C, G and F (%)

MaxDamLevel = The maximum level of the dam used in the model (%)

$$MinBoundary_{C,G\&F} = MaxDamLevel - PreferredControlRangeTOU \tag{16}$$

Where

MinBoundary_C,G&F = The minimum boundary of area C, G and F (%)

PreferredControlRangeTOU = The preferred control range specified by the mine for peak periods (%)

Boundary area D and E are in the same period and Standard Time. Thus, the same boundary conditions will be set for these areas. The calculations for these boundaries are as follows:

$$MaxBoundary_{D\&E} = MaxDamLevel \tag{17}$$

Where

MaxBoundary_D&E = The maximum boundary of area D&E (%)

$$MinBoundary_{D\&E} = MinDamLevel \tag{18}$$

Where

MinBoundary_D&E = The minimum boundary of area D and E (%)

The maximum boundary level for area C and D will allow the system to only pump when necessary. The minimum boundary area has been set to avoid the peak area if pumping is needed in these areas.

The boundary conditions for area A and H are as follows:

$$MaxBoundary_{A\&H} = MinDamLevel + PreferredControlRangeTOU \tag{19}$$

Where

MaxBoundary_A&H = The maximum boundary of area A and H (%)
PreferredControlRangeTOU = The preferred control range of the mine during Off-peak periods (%)

If MaxBoundary_A&H is smaller than MaxBoundary_B then
MaxBoundary_A&H = MaxBoundary_B

$$MinBoundary_{A\&H} = MinDamLevel \tag{20}$$

Where

MinBoundary_A&H = The minimum boundary level for area A, and H (%)

With all the boundary areas set for each area, an improved pumping schedule can be created. In the final step (step 7) the improved pumping schedule will be created.

4.8 Step 7 Create an improved pumping schedule

With the new boundary levels calculated in Step 6, the improved pumping schedule can be created. The boundary conditions can be graphically represented as follows:

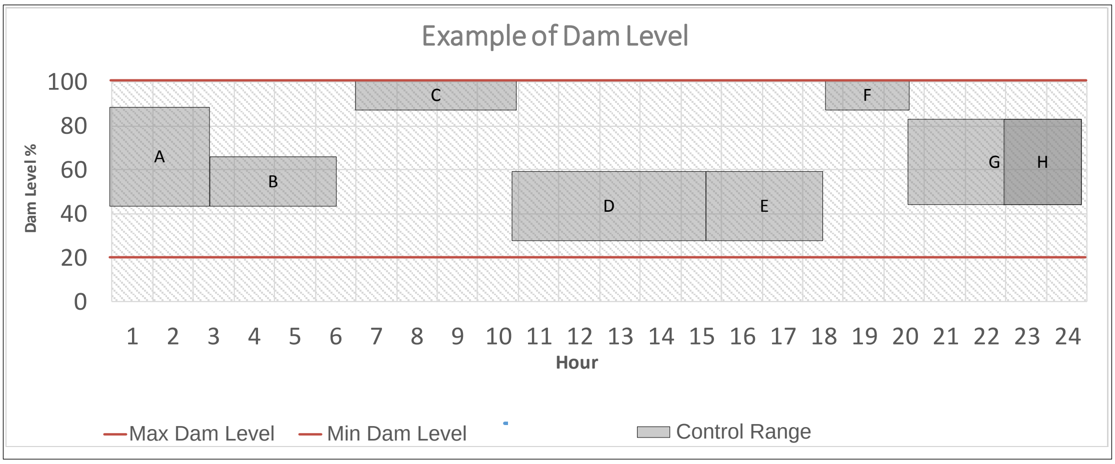

Figure 24: Improved schedule representation

Figure 24 is an example of the improved schedule. The simulation model can now be simulated using the schedule created. If the schedule is setup correctly the system will enable complete load shifting from peak and Standard Time periods to Off-peak periods. The simulated model will look like the following figure, figure 25:

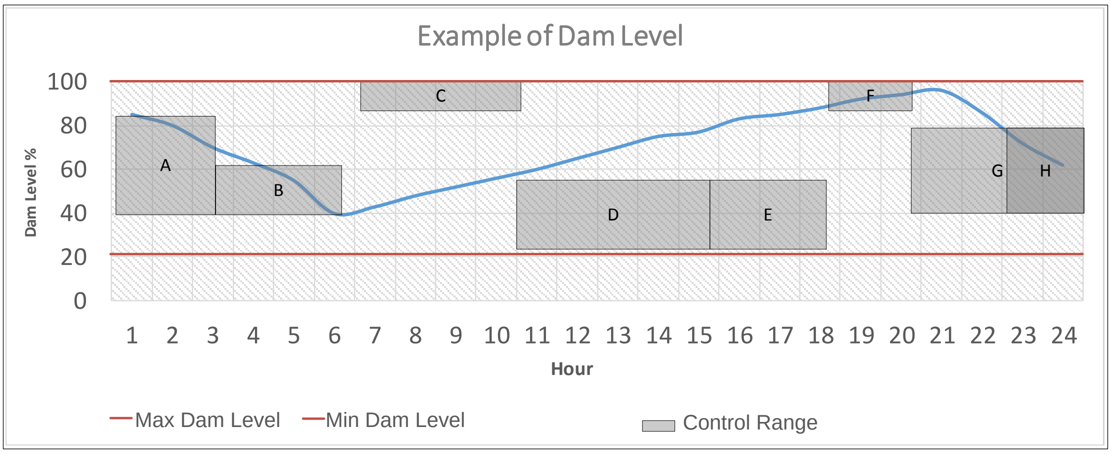

Figure 25 Improved schedule simulated

The methodology is specifically setup for a hydropower mine. The next chapter will discuss the results obtained from the mine chosen in the Case Study.

4.9 Summary

The methodology created proposed a 7-step guide to creating a pumping schedule for a hydropower mine. It is important to obtain the minimum and maximum boundary levels specified by the mine for the underground dams. The control range preferred by the mine is important as well as it indicates the runtime frequency the pumps are allowed to run.

The implementation of this method will be illustrated in Chapter 5.

Chapter 5

Results Obtained

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5. Results Obtained

This chapter presents the results of the study based on the methodology created in chapter 4. All the calculations were done in Engineering Equation Solver (EES) and Excel – these are available in Appendix A and B of this research.

5.1 Step 1 Identifying a Hydropower mine

The mine selected for this study is mentioned in Chapter 3 (section 3.2, Case Study). It is a hydropower gold mine located close to the town of Orkney, in the North West province of South Africa. The mine, as previously discussed, has no current pumping schedule, but they avoid pumping in power hour (peak time of use periods).

5.2 Step 2 Investigating the load shift potential of the mine

The potential for load shift on the dewatering pumps of the mine can be investigated by looking at the power profile.

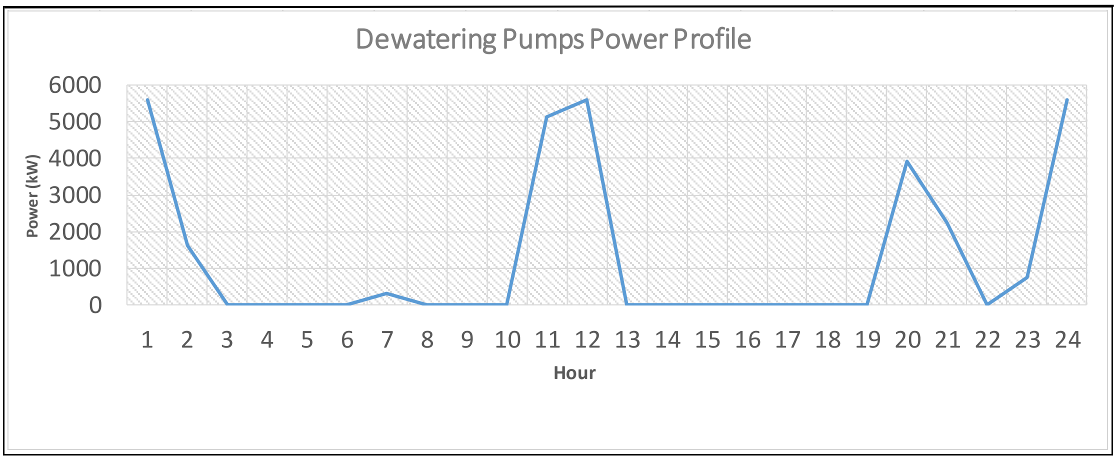

Figure 26: Combined Dewatering Pumps Power Profile of the Mine for an average day

The power profile above provides us with an indication of which time period the pumps are used. The energy usage of the pumps is as follow in Table 7:

Table 7: Combined Dewatering Pumps' Power, Working Hours and Energy

Megaflex time period	Power (kW)	Hours	Energy (kWh)
Off-peak	2800	4 hours 54 minutes	13720
Standard Time	2800	6 hours	16800
Peak	2800	6 minutes	308

The following process involves calculations which tariff period has the most load shift potential. Following equation 1 to 5, the following numbers was obtained:

Table 8: Load shift potential ratios

Megaflex time period	Ratio
Off-peak	1.3
Standard Time	1.2
Peak	0.04

Table 8 indicates that there is load shift potential for Off-peak periods and Standard Time periods with the ratios greater than 1. However, the purpose of this study is to load shift Standard Time and peak time to Off-peak.

The Case Study in section 3.2 indicated that the mine has two pumping stations and only runs one pump per station. To put the potential of load shift in perspective per pump station, equation 6 to equation 9 was used to obtain a graph that indicates in which time the pumps was used more frequently for weekdays and Saturdays.

For Level 900 Weekdays and Saturdays the following graphs were obtained:

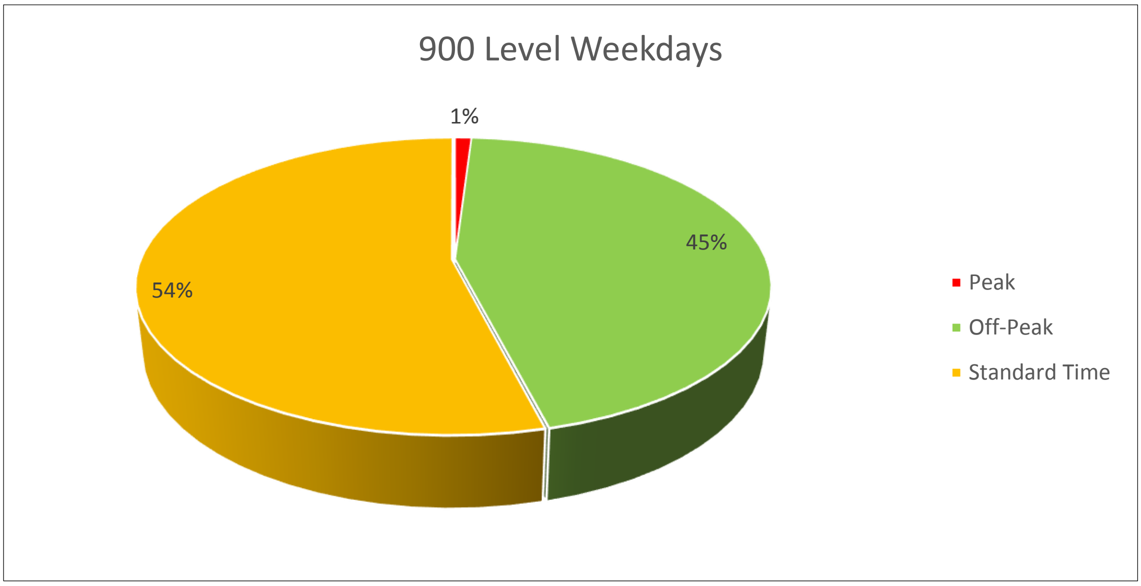

Figure 27: 900 Level weekdays pump distributed usage

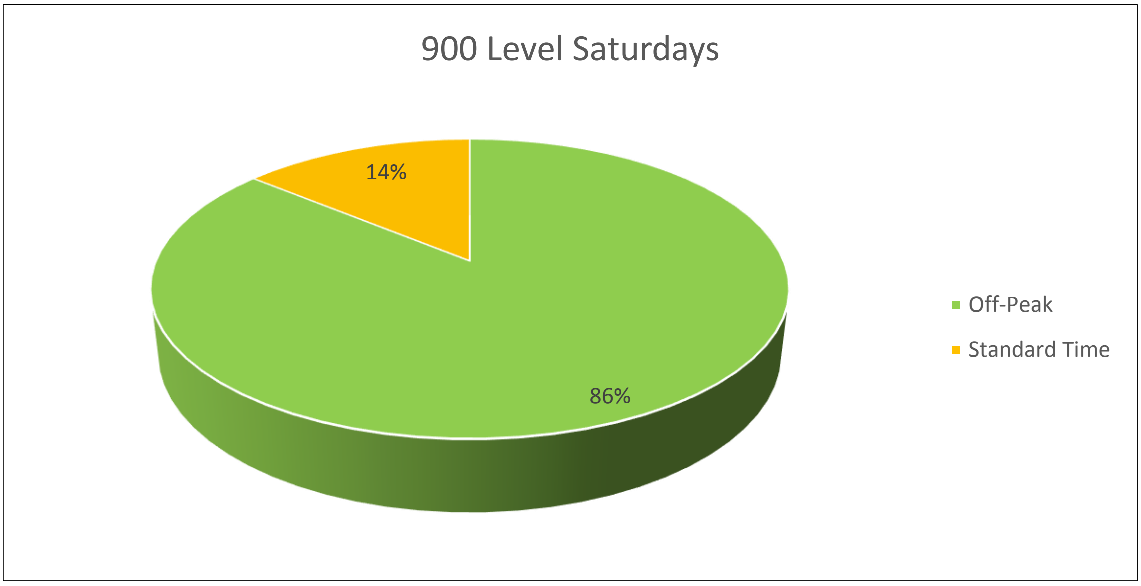

Figure 28: 900 Level Saturdays pump distributed usage

Figure 27 and 28 indicate the period at which the pumps were used most frequently. Figure 27 indicates that while the pump was running 54% of the time during Standard Time on Saturdays, figure 28 was running 14% of the time during Standard Time.

For Level 1734 Weekdays and Saturdays the following graphs were obtained:

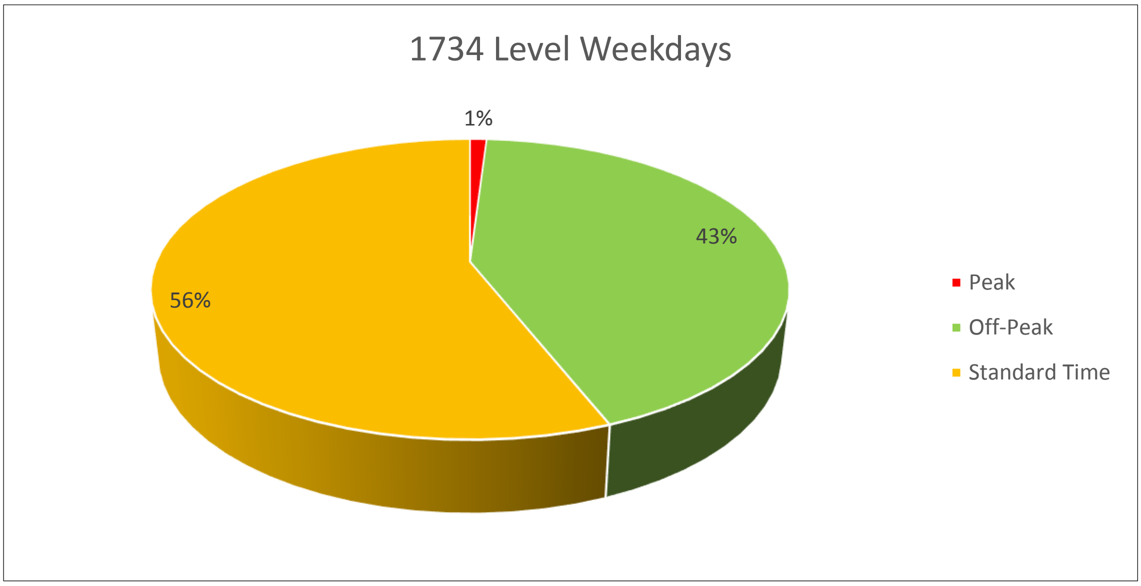

Figure 29: 1734 Level weekdays pump distributed usage

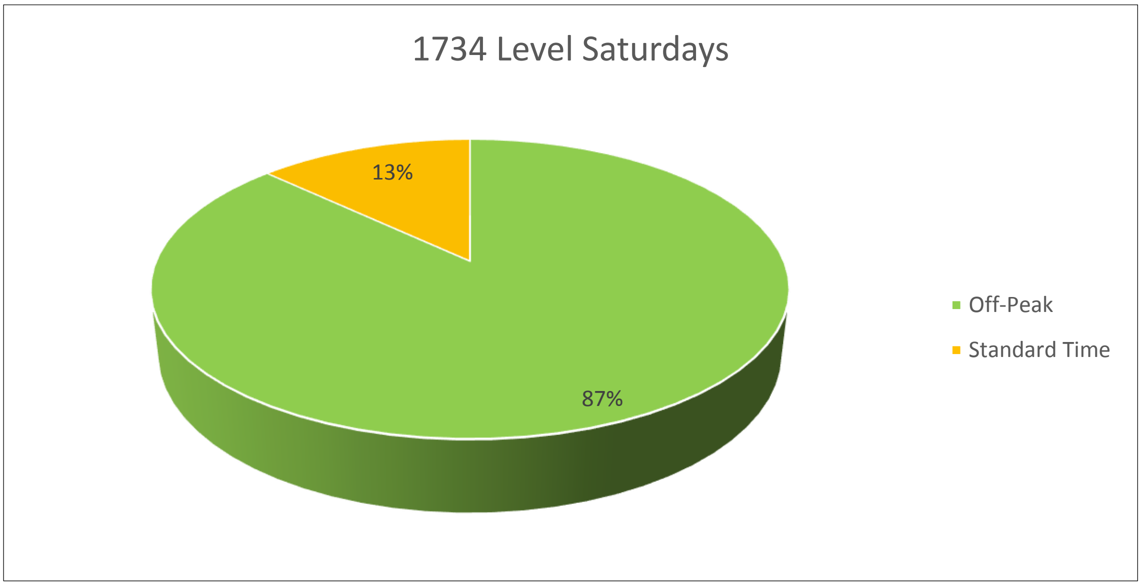

Figure 30: 1734 Level Saturdays pump distributed usage

Figure 29 and 30 indicate at which period of the day the pump was used the most. On weekdays, as illustrated in figure 29, the pump is used more frequently during Standard Time and on Saturdays as illustrated figure 30 the pump is used more during Off-peak. As highlighted in the pie charts on the previous pages, the pumps run more during Standard Time tariffs. The objective is to load shift these pumping periods to Off-peak.

Equation 10 and 11 are used to ascertain if the pumps are able to pump the water being used during peak and Standard Time periods on Off-peak periods. The results obtained from the calculation are as follows:

Table 9: Pumps max flow capacity during Off-peak and water usage during Standard Time and peak periods

Pump Capacity during Off-peak	6.7Ml
Total amount of water used per day	4.6Ml

Table 9 indicates that there is a surplus in capacity that can be delivered from the pumps when comparing the value to the total amount of water being used during the day. This indicate that the pumps can handle the load shift from Standard Time periods to Off-peak periods.

It is clear that the pumps can handle the capacity, however, to ascertain if the dams can handle the capacity, a model of the current mine must be created, verified and then improved.

The next step will be to gather all the relevant information required for the model.

5.3 Step 3 Obtaining the system design of the mine

The system layout is shown in section 3.2.2 and the system design is found in section 3.2.3. Thus, only the specifications needed to create the model will be obtained.

- Number of pump stations
  - 2 Pump station
    - 900 Level
    - 1734 Level
- Number of pumps per station
  - 900 Level
    - 3 x 2.8MW pumps

    - 1734 Level
        - 3 x 2.8MW pumps
- Dam sizes
    - 1734 Level shaft bottom dam
        - 9Ml
        - Maximum level 100%
        - Minimum level 50%
    - 900 Level dams
        - 1.5Ml interconnected dam
        - Maximum level 99%
        - Minimum Level 36%
- Number of hydropower banks
    - 2 x hydropower banks
        - Bank A
        - Bank B
- The following water flow was obtained:

Table 10: Water flows per hour going down the shaft

Hours of the day	Bank A+ Bank B + Potable water + Machine water inflow (kl)	Machine water outflow out of 900 level dam (kl)
1	246	18.8
2	252	19.2
3	238	21.6
4	207	18.3
5	159	18.4
6	136	19.1
7	130	20.4
8	136	29.9
9	180	33.6

10	245	51.2
11	321	60.8
12	369	61.8
13	368	52.7
14	289	40.5
15	199	32.6
16	150	24.5
17	131	22.8
18	126	20.4
19	108	19.9
20	105	19.1
21	103	20.5
22	109	21.9
23	147	20.2
24	219	170

It was revealed by the mine that they do not have fissure water; this value is set to zero. With the known design specification of the mine, the model can now be created.

5.4 Step 4 Creating a model for the mine

A model for the mine will be designed in this step

Inflow of the dams and dam levels

By implementing equation (12) on a 24-hour day, the following two models were obtained for the dam on level 1734 and the interconnected dam on 900 level. It was also determined that the discharged water takes two hours to move through the system and find its way into the dam at shaft bottom.

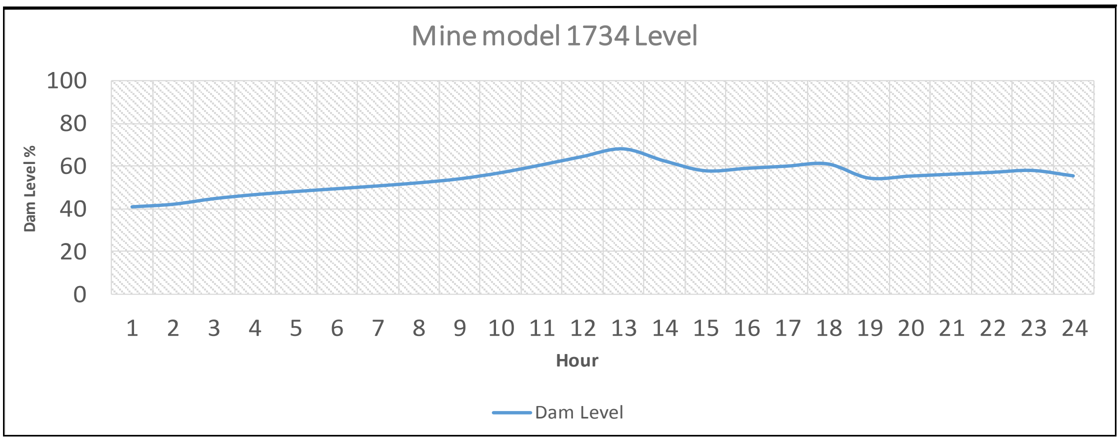

Figure 31: Mine Model 1734 Level Dam levels

When interpreting the gradient of figure 31 the system design can be observed. The strong incline indicates that the mine is using water and that the discharged water flows to the dam. The strong decline indicates that water is being pumped out of the dam.

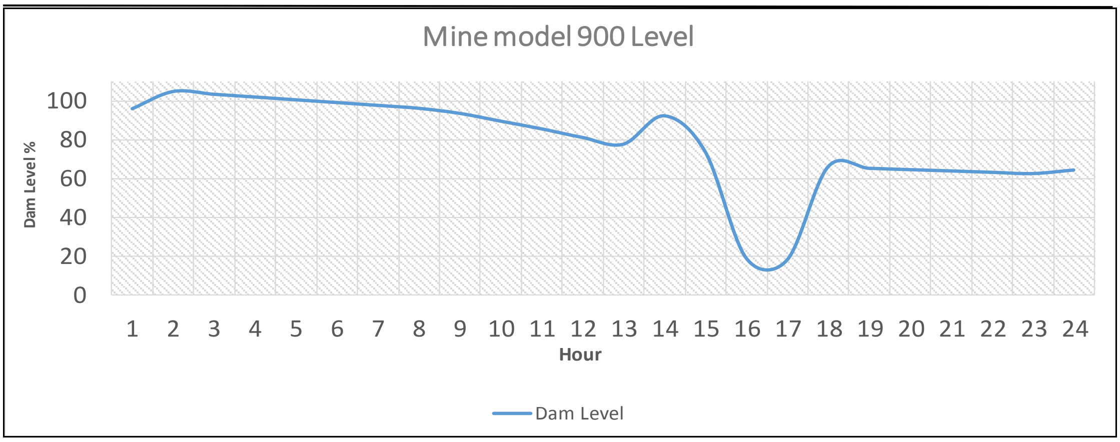

Figure 32: Mine Model 900 Level

When interpreting figure 32 a weak decline in the gradient is observed, this indicates that machine water is being used and that no discharged water flows into this dam. The figure also contains strong inclines, this indicates that water is being pumped into the dam and the strong declines indicate when water is being pumped out of the dam. The minimum and maximum dam levels will be added to the model to observe the range in which the model can operate.

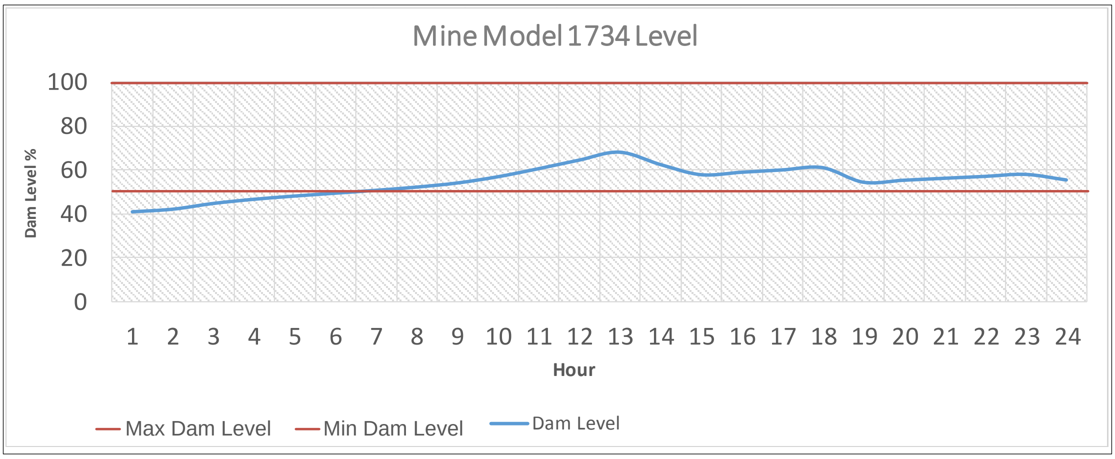

Figure 33: Mine model 1734 level minimum and maximum dam levels added

As observed in figure 33, the minimum dam level has been reached. On the day of capturing this data, the control room operator did not operate the pumps as instructed and as a result, the dams were pumped below the minimum level.

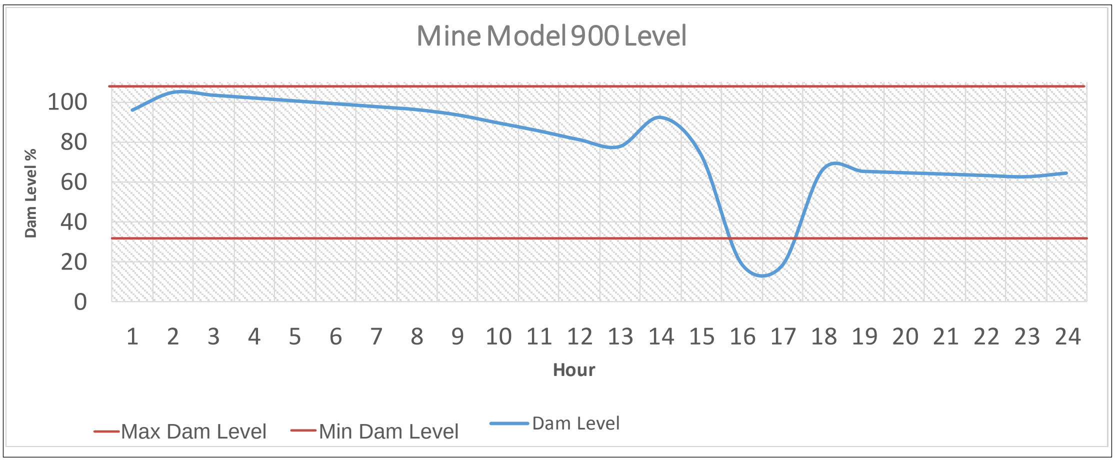

Figure 34: Mine model 900 level minimum and maximum dam levels added

As indicated in figure 34, it is clear that the dam reached its maximum and minimum dam levels. The minimum and maximum levels received from the mine are the levels at which the mine feels safe at. Therefore, an improved model will be designed to work between the limits.

Adding the mine's current control ranges to the model

This section is added to the methodology for a mine that has an existing schedule, the mine mentioned in the Case Study has no pumping schedule, and thus there are no control ranges. As directly quoted from the control room operator: "We pump via our gut feelings and try to stay out of power hour." The only control range implemented is on 900 level dam. To ensure there is enough water for the machine water pipeline, the dam should be at a minimum of at least 70% before 6am.

Before a pumping schedule for the mine can be created, the mine model must be verified. The next step will be to verify the model.

5.5 Step 5 Verification of the mine model

In order to verify the model, the model needs to be compared with real life values obtained from the mine's SCADA. The model created till step 4, was created using data obtained from a specific day. That same day's dam levels monitored by the installed metering will be used to verify the mine model. The following figure represents the verification of the two models.

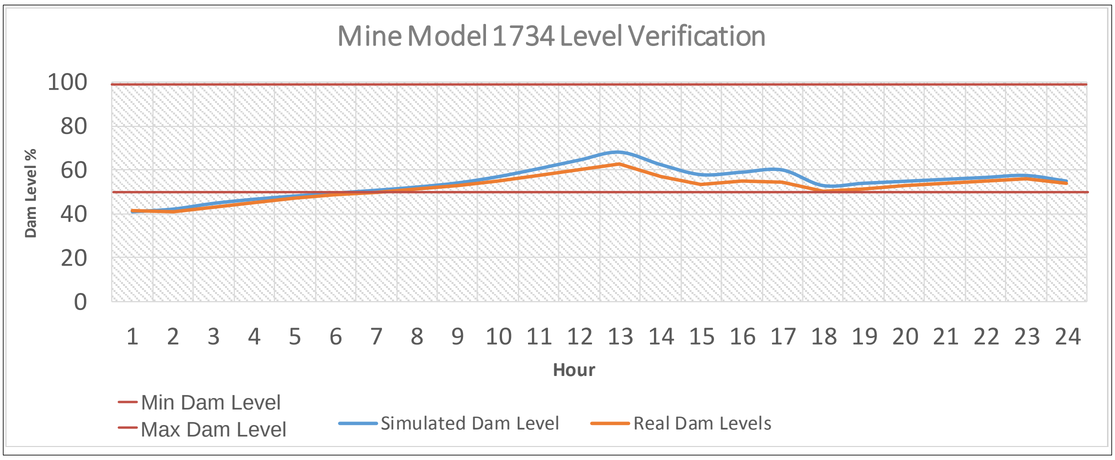

Figure 35: Mine model verification of 1734 level

It can be deduced from figure 35 that the model created may be used and is verified. The percentage error never exceeds 10 and the differences in the two graphs may be due to block drainages on that specific time of the day.

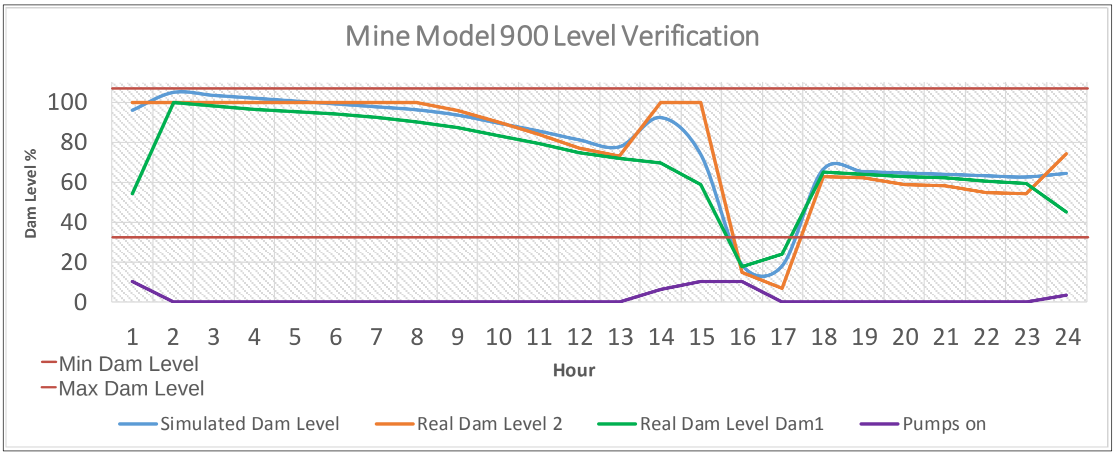

Figure 36: Mine model verification of 900 level

When scrutinizing figure 36, the following key observations are made:

- There is a large percentage error between 1am and 2am
- There is a large percentage error between 1pm and 4pm
- There is a large percentage error between 11pm and 12pm

This only happens when water is being pumped. The measuring instrumentation used to measure the dam levels give faulty readings due to swirling and splashing inside the dams when pumping occurs. In between the rest of the periods the percentage error never rises above 10%. With the knowledge obtained from the measuring equipment/instrument and why the models fluctuate during pumping, this model may be verified.

5.6 Step 6 Create new boundary areas for the models

A basic representation of possible control ranges will be indicated in the following graphs for both models.

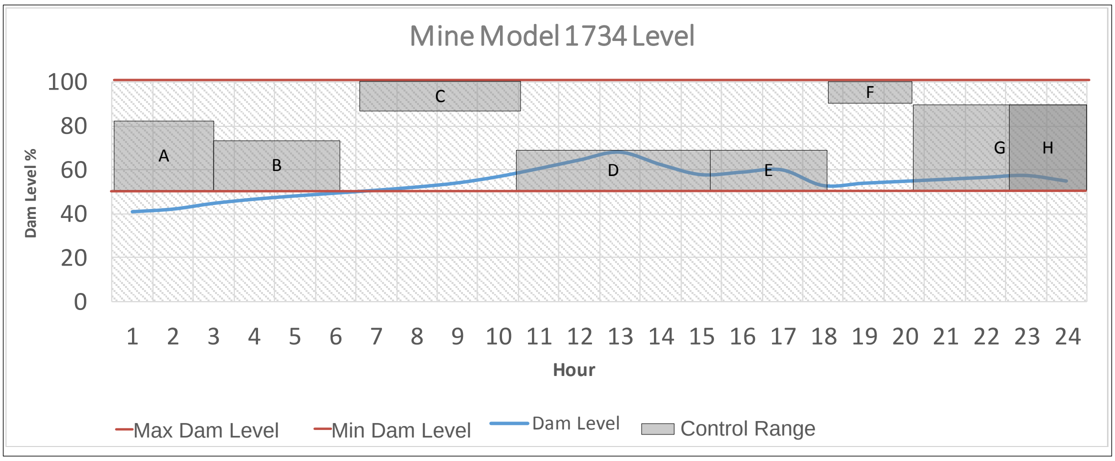

Figure 37: Mine model of 1734 level with example control ranges

Figure 37 represents an example of where control ranges should be. There is a morning period, two peak periods, a midday period and a night period.

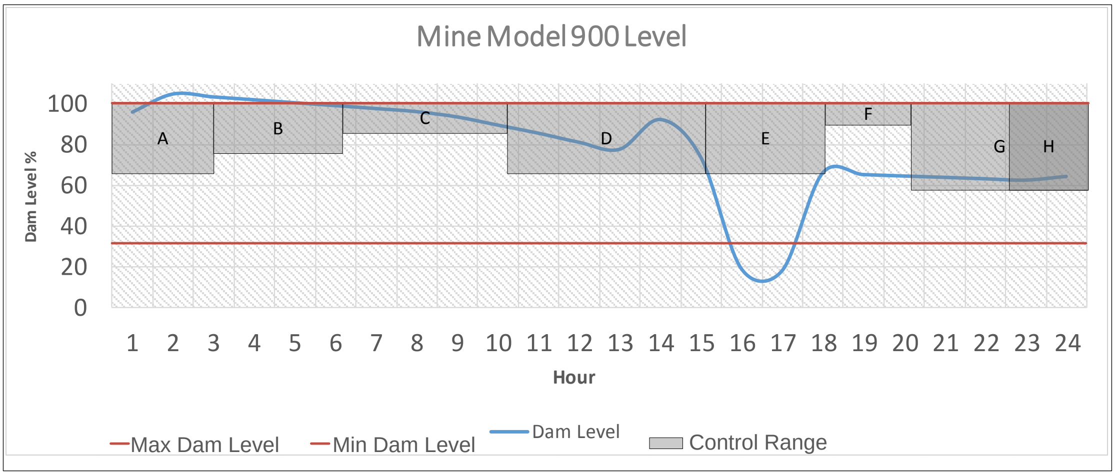

Figure 38: Mine model of 900 level with example control ranges

Figure 38 represents an example of what the control range should look like. The improved boundaries will be calculated using equation 13 to 20. The mine has also given a preferred control range of 10%.

Boundary conditions for level 1734 control range B

Maximum = 65% Pump start

Minimum = 50% Pump stop

Boundary conditions for level 1734 control ranges C, G and F

Maximum = 100% Pump start
Minimum = 90% Pump stop

Boundary conditions for level 1734 control ranges D and E

Maximum = 100% Pump start
Minimum = 50% Pump stop

Boundary conditions for level 1734 control ranges A and H

Maximum = 65% Pump start
Minimum = 50% Pump stop

The boundary conditions for 900 level dam will now be calculated using equation 13 to 20 as well, keeping in mind the control ranges set by the mine for 900 level dams.

Boundary conditions for level 900 control range B, as set by mine

Maximum = 80%Pump Start
Minimum = 75% Pump Stop

Boundary conditions for level 900 control ranges C, G and F, as set by mine

Maximum = 85% Pump Start
Minimum = 75% Pump Stop

Boundary conditions for level 900 control ranges D and E, as set by mine

Maximum = 85% Pump Start
Minimum = 75% Pump Stop

Boundary conditions for level 900 control ranges A and H, as set by mine

Maximum = 80% Pump Start

Minimum = 75% Pump Stop

Boundary I

If the dam level on 900 level is below 36% (absolute minimum), a 1734 level pump should pump water to level 900 until the boundary condition in that area is met.

Equation 13 to 20 have been implemented on both models, but 900 level dam had to be designed to fit the mine’s control range.

The new pumping schedule can now be created with the new boundary conditions known. This will be created in Step 7.

5.7 Step 7 Create the improved pumping schedule

With all the boundary conditions calculated in step 6, the pumping schedule can be created for both models.

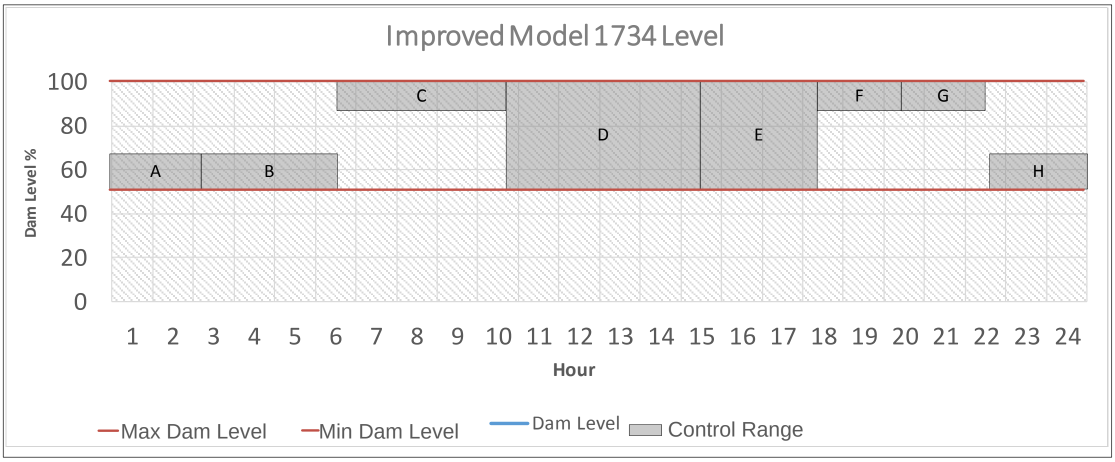

Figure 39: Improved model of 1734 level with new boundaries

Figure 39 represents the new boundaries calculated in step 6, when these boundaries are implemented on the verified model the following graph is obtained:

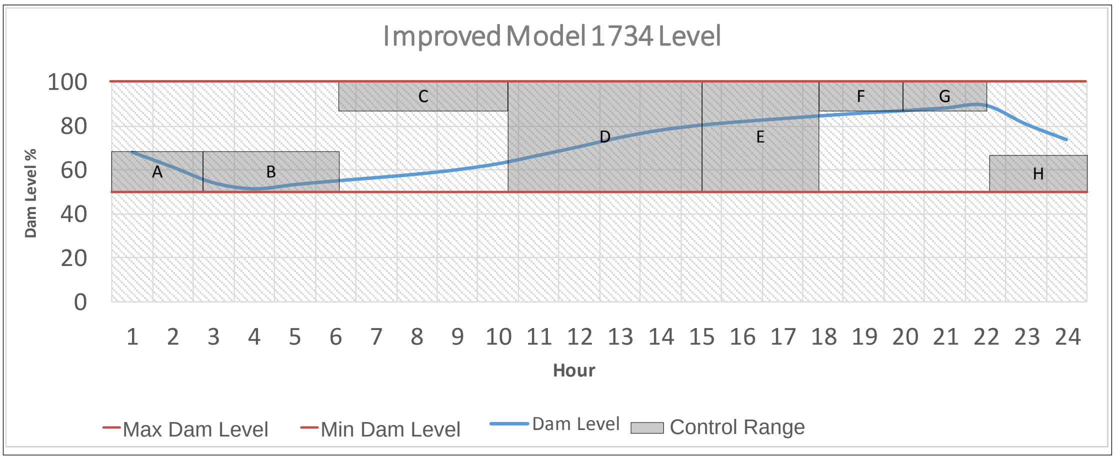

Figure 40: Improved model of 1734 level

Figure Graph 40 indicates that the schedule created is successful. The dam levels stay between minimum and maximum dam levels and 100% load shift is successful using this schedule.

The following figure represents the calculated boundaries with the mine’s boundaries for 900 level.

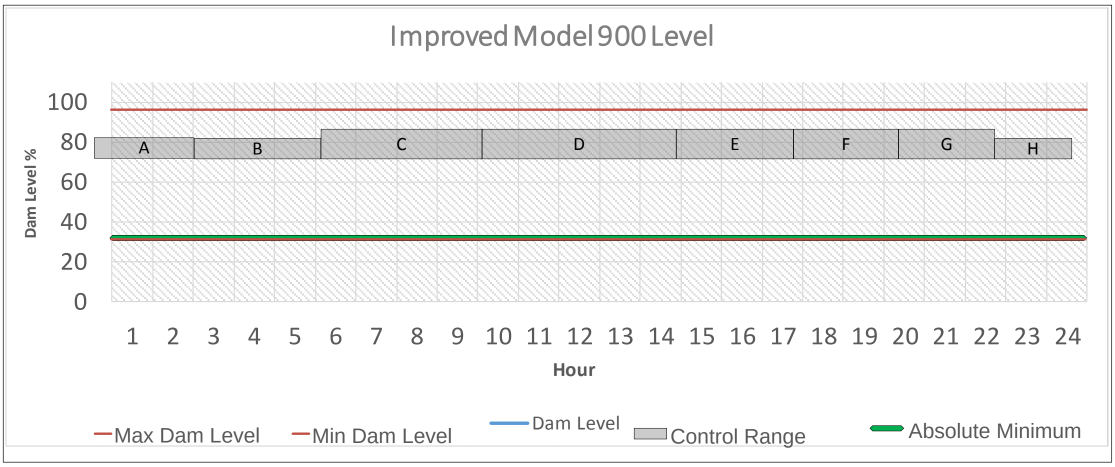

Figure 41: Improved model of 900 level with new boundaries

The following graph was obtained for implementing the schedule with the verified model:

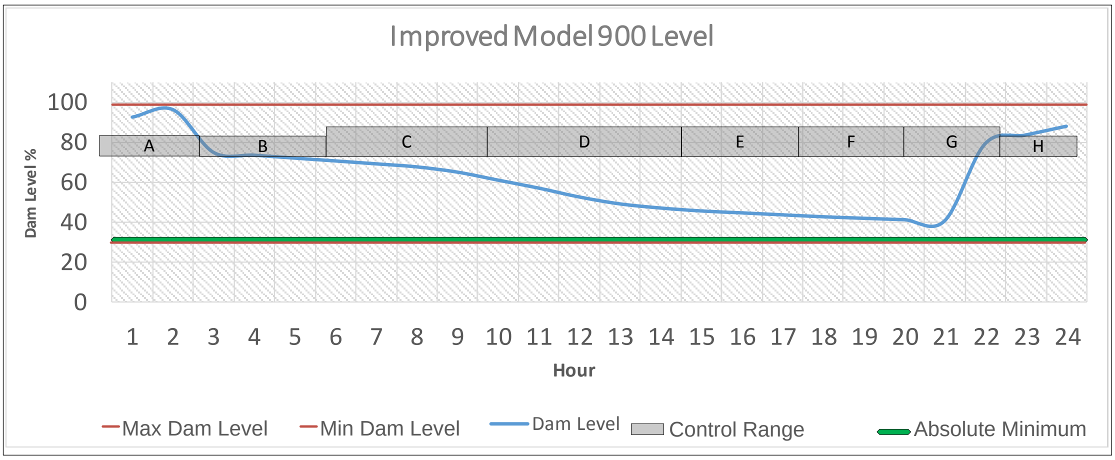

Figure 42: Improved model of 900 level

Figure 42 indicates that the schedule created for 900 level's dam is successful in load shifting 100% of the load to Off-peak.

5.8 Summary

The seven steps mentioned in chapter 4 were implemented on the mine chosen in the Case Study; a hydropower mine located close to the town of Orkney, in the North West Province of South Africa. Step 2 delivered a potential of 16,800Kwh per day that could be load shifted to Off-peak periods. To complete step 3, the system design of the mine was investigated. This information was required to create a model of the mine as in step 4. In step 5, the created model was verified and the outcome was successful. The verified model was then used to create new boundary areas for the new model, this was in step 6. Step 7 was implemented to create the new pumping schedule for the mine that would allow 100% load shift from Standard Time and peak periods to Off-peak periods.

When an average day's water usage was simulated, with the verified model and the new pumping schedule, it was found that the complete load shifting was possible on the hydropower mine.

With the potential of load shifting known and the simulation model to prove that complete load shifting is possible by following the new pumping schedule, the costs saved by implementing the pumping schedule can be calculated.

The cost analysis will be discussed in the next chapter.

Chapter 6

Cost Analysis

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6. Cost Analysis

The cost analysis section of a project is important; it determines if the client will accept the proposal to implement the project. Thus, it is important to work accurately in this section, with at least six month's data. The cost savings that can be achieved by implementing the proposed pumping schedule and method used to calculate the costs saved will be discussed in this section.

6.1 Quantifying the cost savings

As previously mentioned, at least six month's data is required to accurately calculate the costs. For this dissertation, 11 months' data was gathered. In section 3.2 a method was used to obtain information regarding the hours the pumps run during a day. The same method was used to obtain the hours each pump on 900 level and 1734 level during the month on Standard Time tariffs for weekdays and Saturdays. The following data was obtained during low demand season for the pump station on 900 level Weekdays:

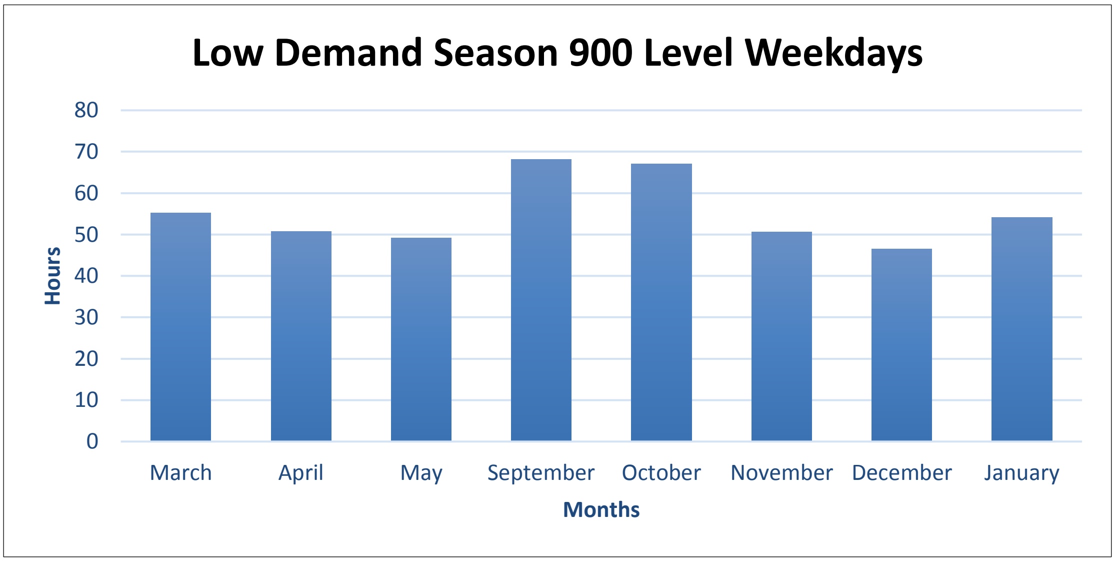

Figure 43: Pumps running profile for 900 level weekdays low demand season in Standard Time TOU

Figure 43 shows consistency in the hours that the pumps ran during the low demand season for weekdays, except for September and October. Between these two months the mine experienced rain which is a natural cause that may be experienced each year.

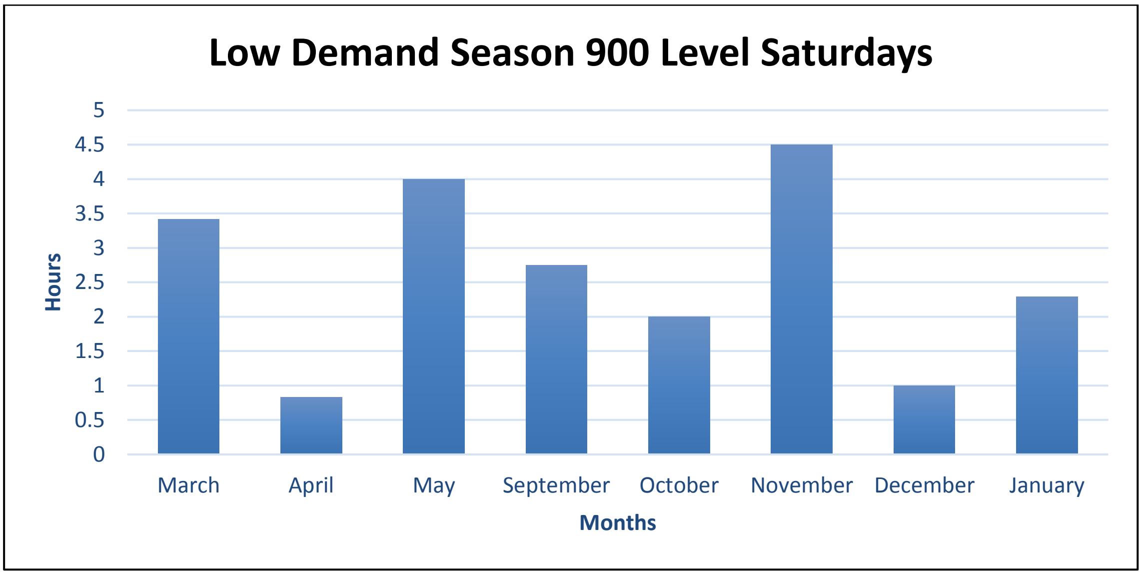

Figure 44: Pumps running profile for 900 level Saturdays low demand season in Standard Time TOU

Figure 44 shows inconsistencies in the hours that the pumps were running during Saturdays. This is due to the fact that some Saturdays are working Saturdays and some Saturdays are off days (i.e., no work on this day), and other Saturdays they work in days of the summer holiday. This profile will be used to calculate cost savings as well, because even if there are fluctuations in the profile, the number of non-working Saturdays will be constant.

The next profiles represent high demand season for 900 level weekdays and Saturdays.

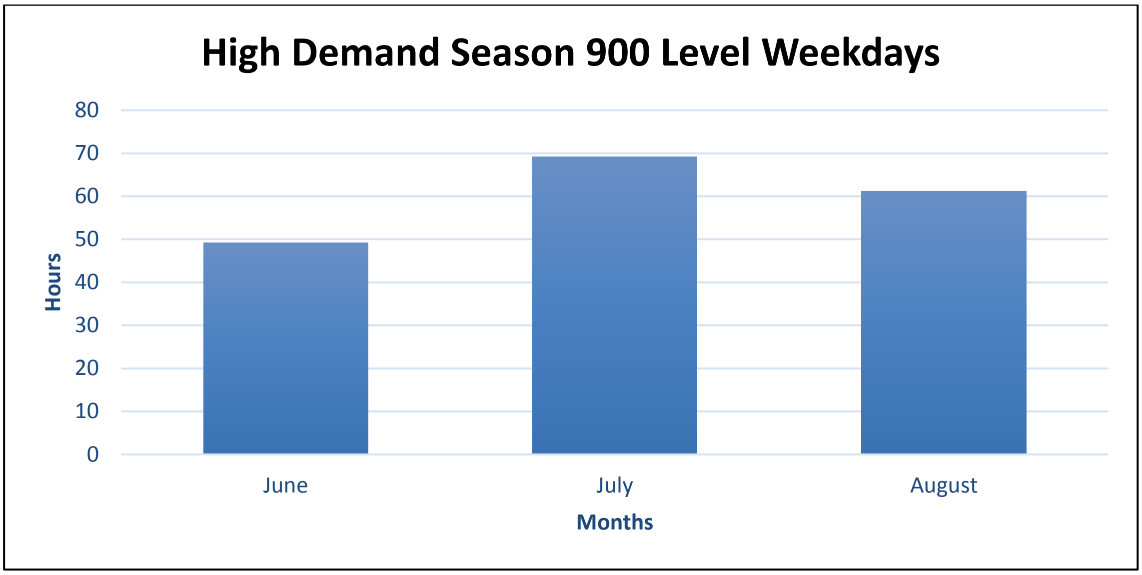

Figure 45: Pumps running profile for 900 level Weekdays high demand season in Standard Time TOU

The increase seen in Figure 45 for July and August is a result of the two extra days in July and August according to the calendar.

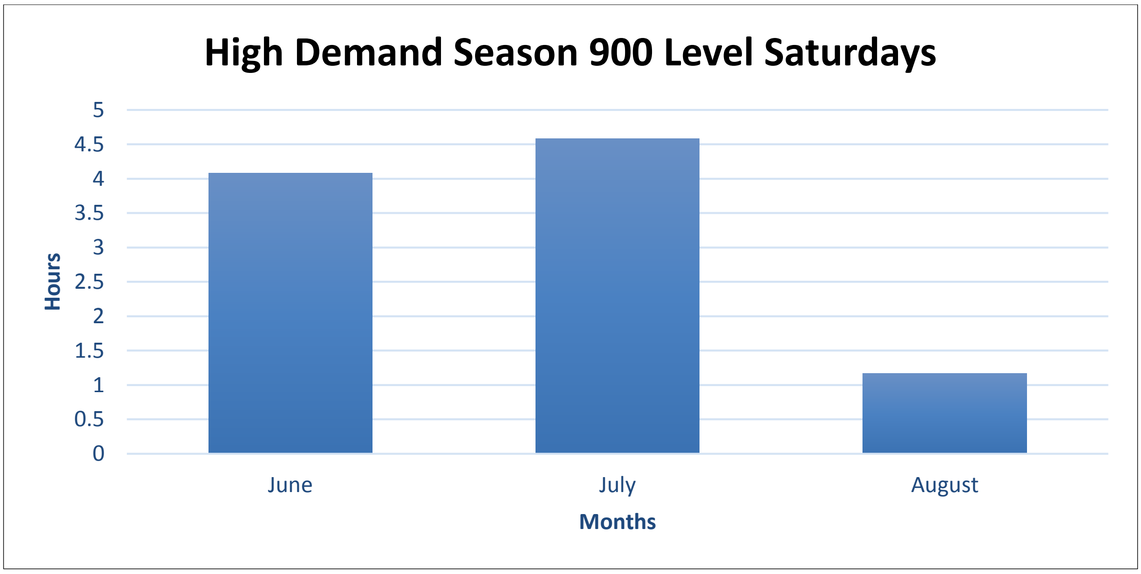

Figure 46: Pumps running profile for 900 level Saturdays high demand season in Standard Time TOU

As depicted in Figure 44, the profile in Figure 46 may be used for cost saving calculations. The fluctuations are due to the non-working Saturdays, but the number of non-working Saturdays stay the same each year.

The following graphs will represent the running profiles of the pumps on 1734 level, during high demand season and low demand season for Saturdays and weekdays.

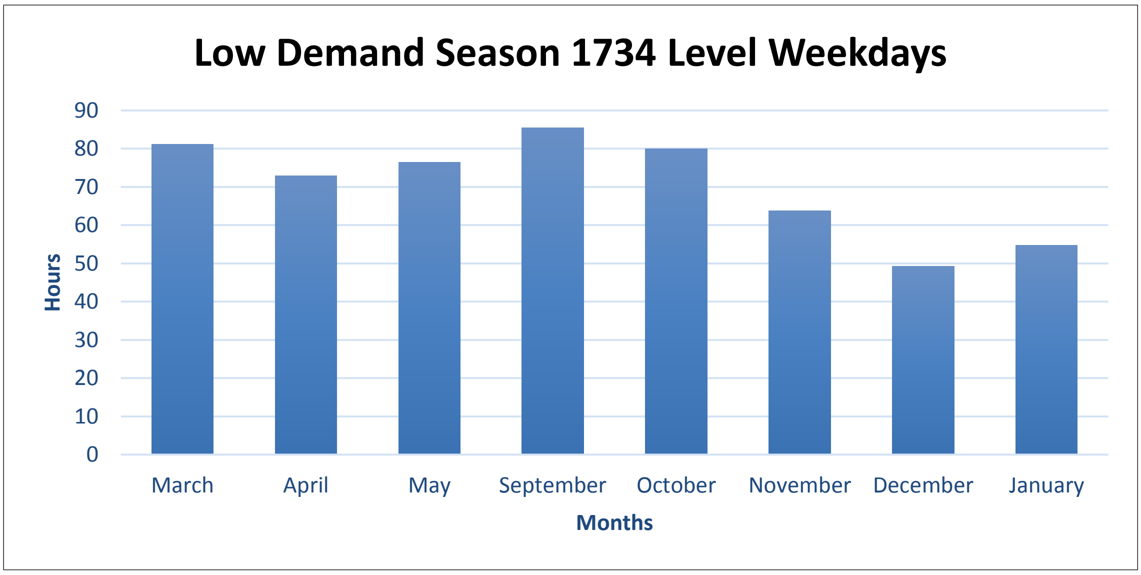

Figure 47: Pumps running profile for 1734 level weekdays low demand season in Standard Time TOU

Figure 47 shows a consistency in the running profile of the pumps, except for December and January. There is a decline in these two months because of the summer holiday and holidays during these two months. Thus, this data may be used for the cost calculations, because this pattern will be seen each year.

Figure 48 shows the same inconsistency as the previous Saturday’s profiles. Note that all Saturdays on December were non-working Saturdays. This is the reason for the zero value in in this graph.

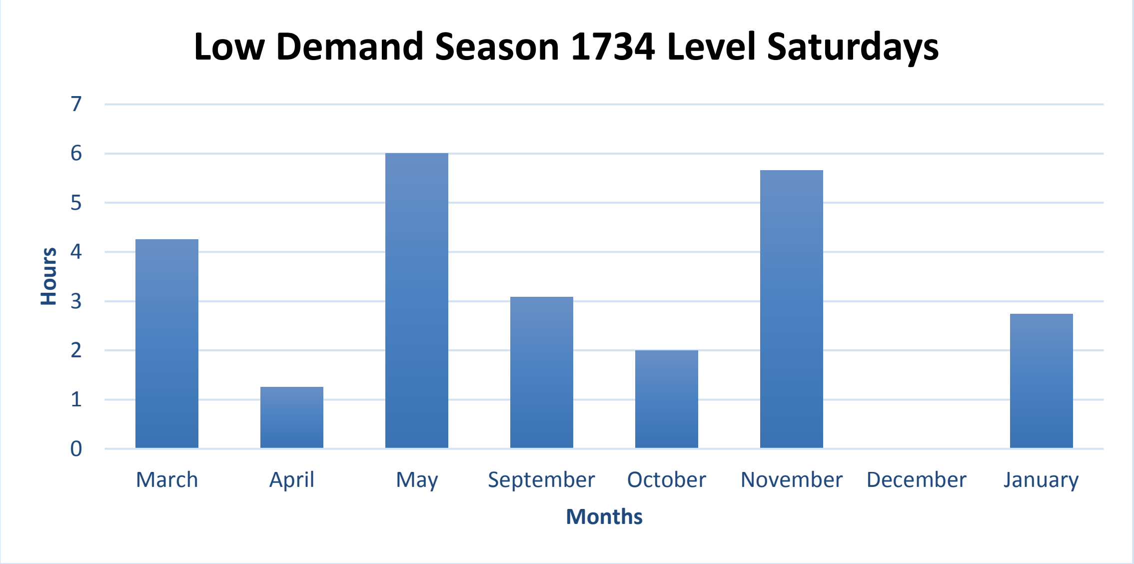

Figure 48: Pumps running profile for 1734 level Saturdays low demand season in Standard Time TOU

The following profiles for 1734 level are for high demand season.

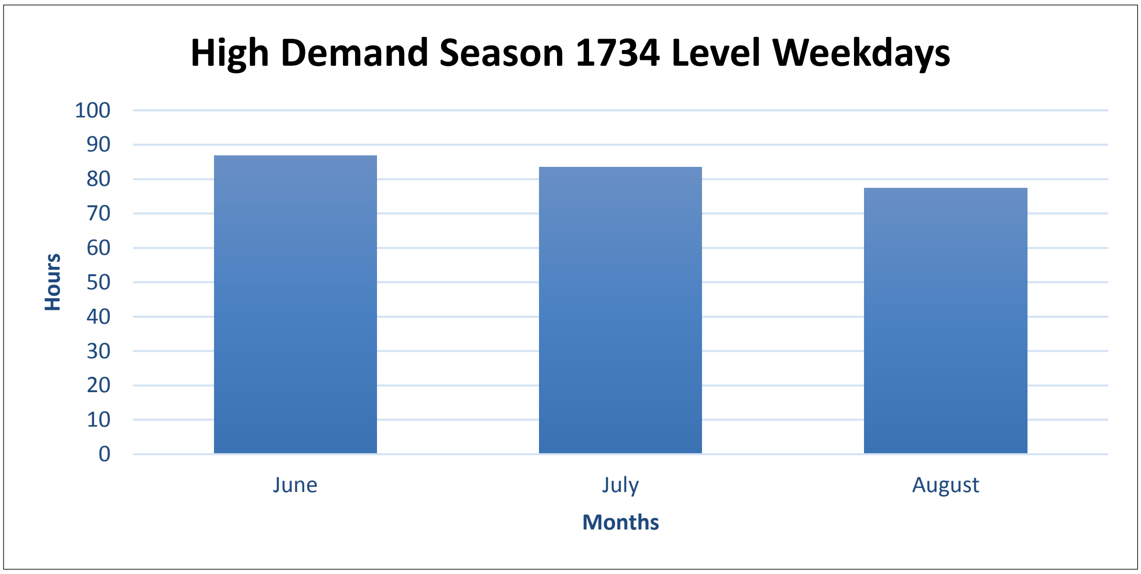

Figure 49: Pumps running profile for 1734 level Weekdays high demand season in Standard Time TOU

Note that the consistency in the usage of the pumps in figure 49. It is important to acknowledge that the profile of 900 level and the profile of 1734 level will not look the same. The machine water outflow out of the dams on 900 level eventually reaches the dams on 1734 level. That is why the pumps on1734 level run more hours than 900 level.

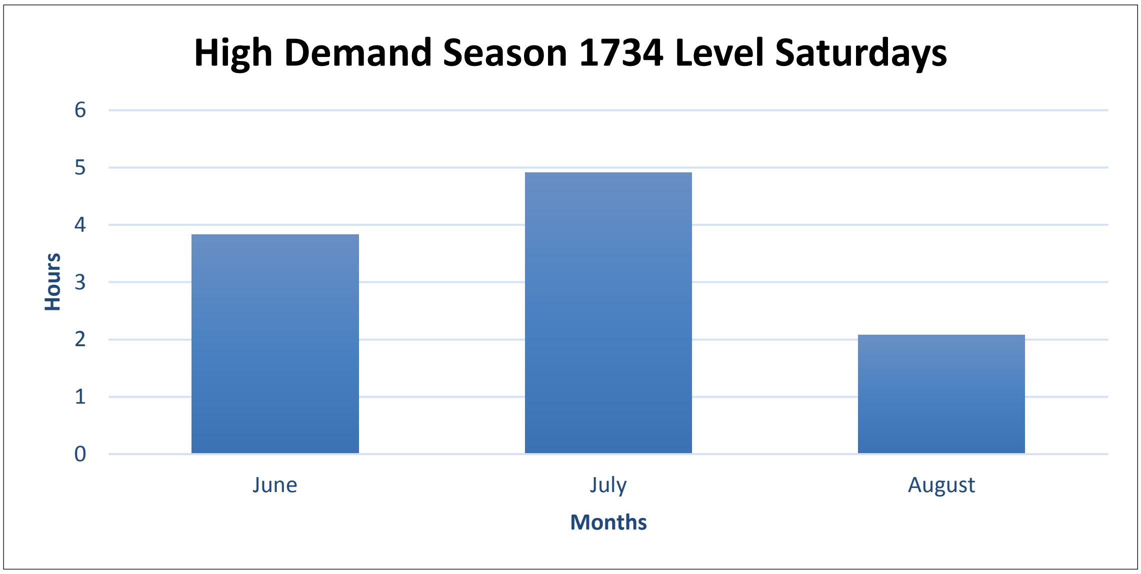

Figure 50 Pumps running profile for 1734 level Saturday's high demand season in Standard Time TOU

Note that the Saturday pump running profile fluctuates, this is also because of the non-working Saturdays.

With the data analysed above, the cost savings can be calculated. The following table shows the amount of Standard Time TOU hours was used during high demand season and low demand season, the energy being load shifted (pumps running at an efficiency of 74%) and costs saved at 21c/kW for low demand season and 34c/kW for the high demand season.

Table 11: Cost savings for 12 months

	Total Hours	Energy (MWh)	Costs saved (ZAR)
Low demand season	1180	2.1	515 000
High demand season	600	0.92	420 000

The costs saved by implementing the pumping scheduled are now realised by looking at Table 11. The project costs will be discussed in the next section and the influences theses costs have on the savings.

6.2 Project Expenses

The mine chosen in the Case Study does not have any expenses in implementing the pumping schedule designed in Chapter 5. The mine was already equipped with the necessary instrumentation to measure dam level and water flows.

Thus, it can be concluded that the financial expenditure for this project was 0.00 ZAR.

6.3 Total Cost Savings

The total cost savings of the project would be achieved by subtracting the cost savings achieved in 12 months from the expenses of the project. But since there were no expenses, the total cost savings will be equal to the cost savings achieved by implementing the pumping schedule.

Thus, the payback period will be immediate from the day the project is implemented.

The total cost savings is calculated to be 935 000 ZAR per annum.

6.4 Summary

To calculate the exact savings that could be achieved per annum, one year’s data was analysed. The cost savings was calculated by simulating a year’s data with the new simulation model created in Chapter 5.

The number of hours calculated to be load shifted to Off-peak periods amounted to 1180 hours (2.1MWh) in low demand season and 600 hours (0.92MWh) during high demand season. The total cost savings calculated were 935 000 ZAR per annum, which is equal to the direct saving per annum since the project had no expenses.

Chapter 7

Conclusion and Recommendations

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7. Conclusion and Recommendations

7.1 Conclusion

It is a well-known fact that Eskom has difficulties in supplying South Africa with electricity. In recent years, blackouts (commonly referred to as load shedding) have been experienced due to the insufficient supply of electricity. Forecasts indicate that electricity shortages may still be experienced for years to come. This explains why South Africa needs innovative ideas to reduce electricity loads especially during peak periods.

Eskom introduced the Megaflex tariff to South Africa, hoping to reduce electricity consumptions during peak periods. The Megaflex tariff works on a TOU basis where the consumer pays for electricity according to their TOU.

In relation to this study, the mining industry is one of the largest consumers of electricity, and more specifically gold mines. That is why gold mines have been chosen as the study's topic. Past research indicates that pumps are one of the largest consumers within a gold mine, but more specifically the dewatering pumps. Moreover, a review of literature revealed studies that show that DSM on dewatering pumps have been covered extensively over the past ten years, however, the research is only applicable to conventional mines. However, to date, there has been no research data available that is applicable to DSM initiatives and hydropower mines, thus, this study's topic and findings are unique to the field of engineering and mining.

The mine chosen in the Case Study proves that the research conducted on hydropower mines is correct; no DSM initiatives are available for these systems. Thus, an opportunity was observed to improve the pumping schedule of the mine investigated. In order to create the pumping schedule, it was important to first create a method. The method was to create a mine model, verify it and use it to improve the schedule. New boundary areas were created and a pumping schedule could be obtained. The improved schedule was simulated using the verified mine model. The results of the model indicated that complete load shifting was possible by shifting peak periods and Standard Time periods to Off-peak. This resulted in a load shift of 2.1MWh in low demand season and 0.9MWh in high demand season to Off-peak. The successful load shift model indicated that a cost saving of 935 000 ZAR annually was possible.

7.2 Recommendations

The Case Study has not yet been implemented on the mine due to approvals that need to be signed-off by the engineering manager. It is highly recommended that the improved schedule should be implemented on the mine in order to achieve cost savings.

Recommendations for further study on the dewatering system of the Case Study include:

- Research cleaning methods for underground dams
- Research new methods in repairing cracks in dams that cause leakages
- Research in improving underground settler distribution and effectiveness

The study indicated that DSM projects have not been implemented on hydropower mines and that additional research is necessary in this field.

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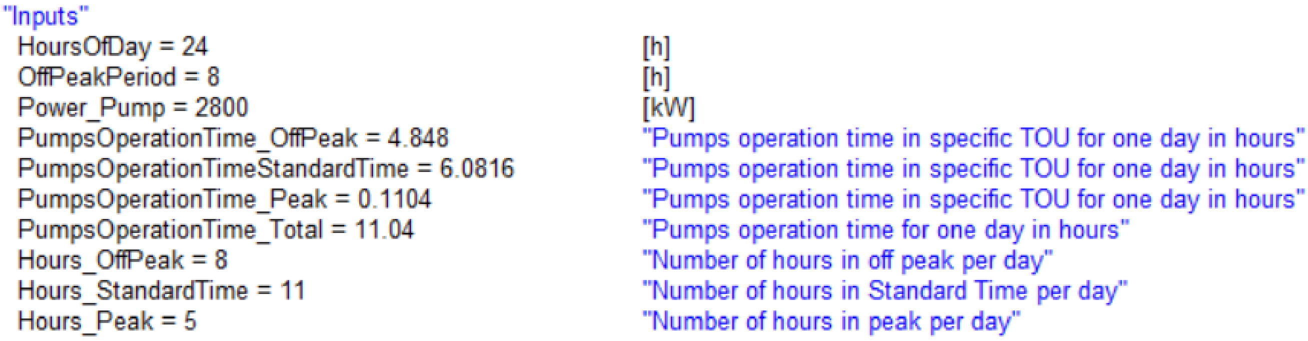
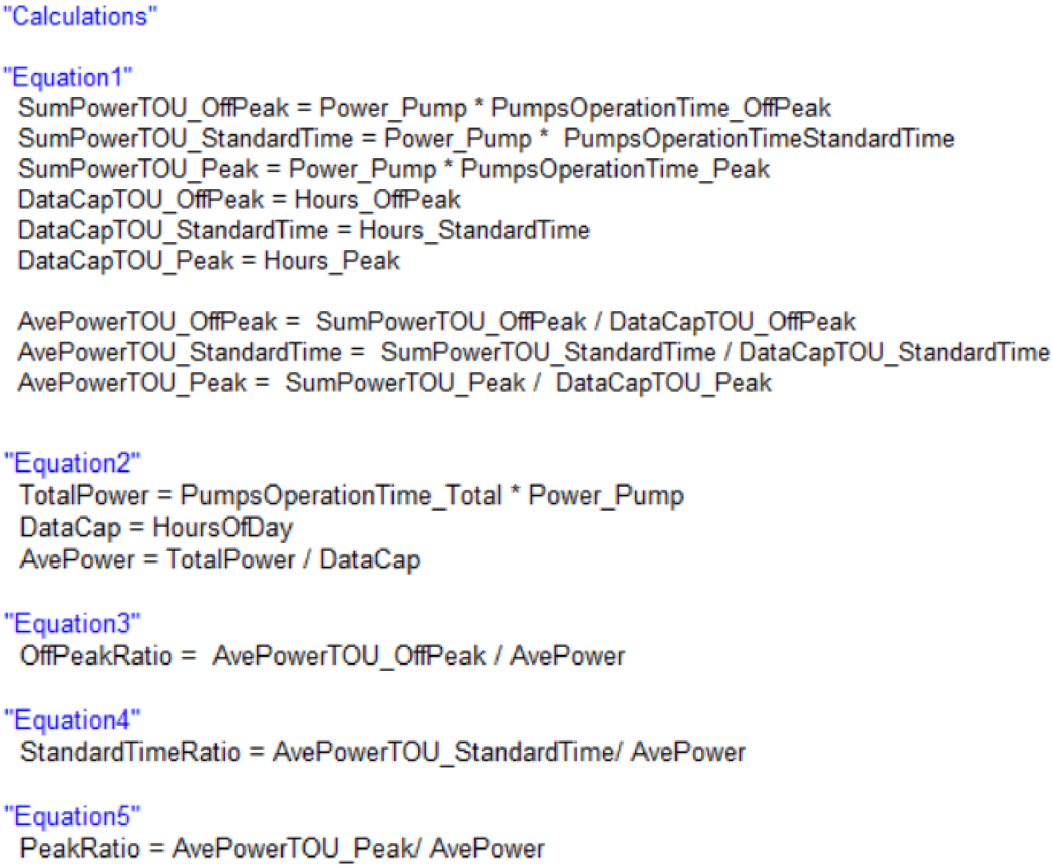
Appendix A

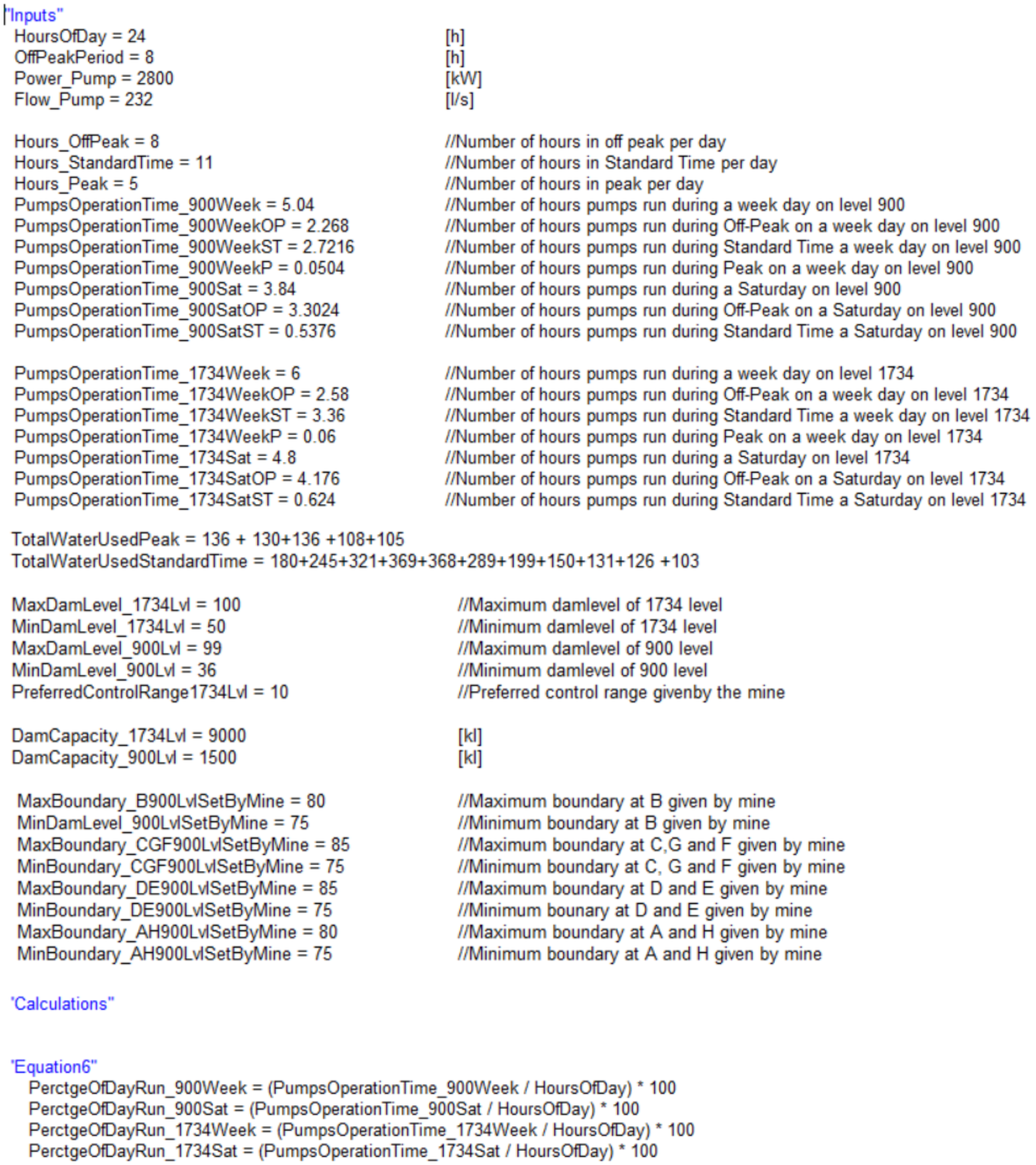
EES Calculations



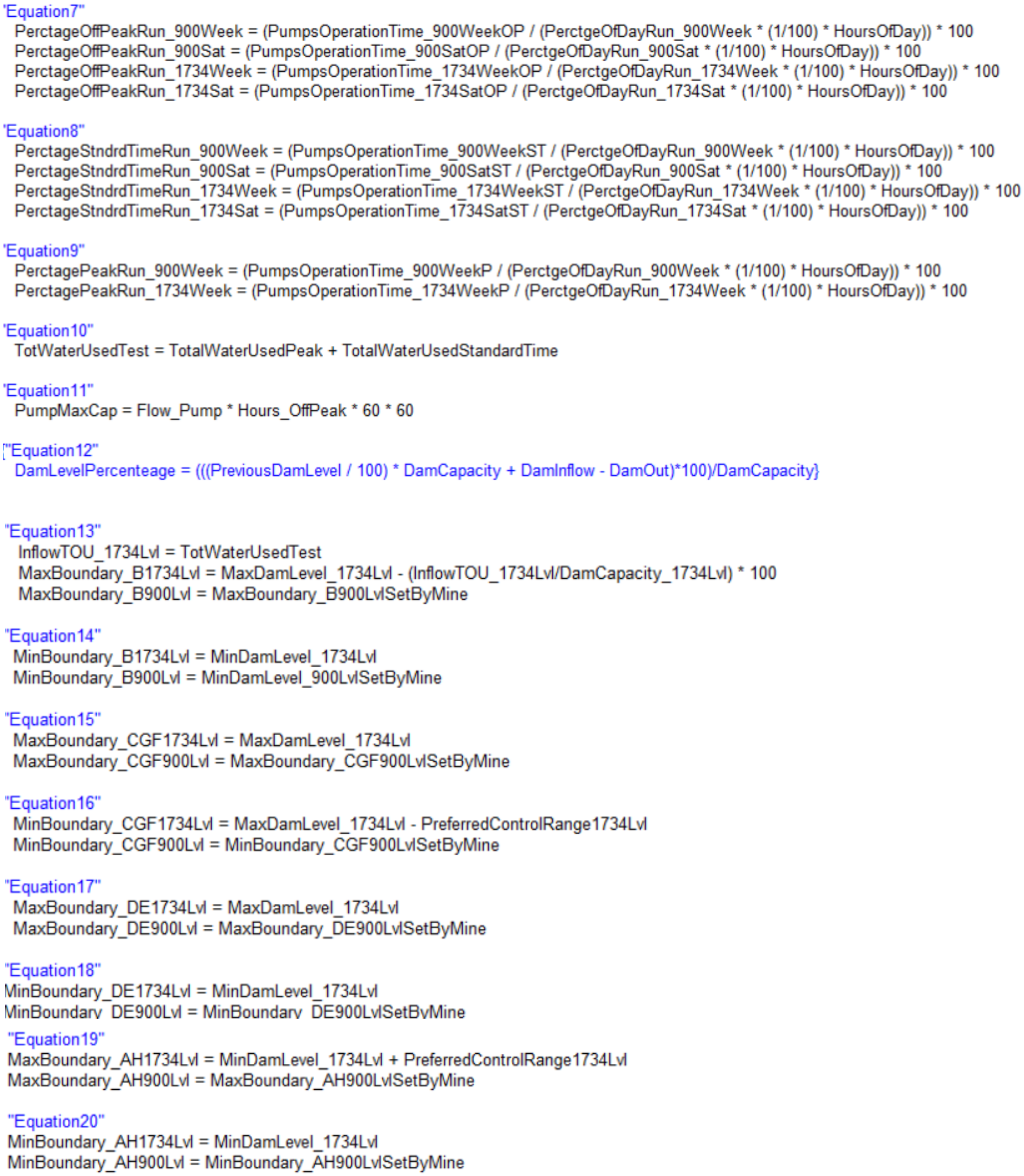
```
"Inputs"
  HoursOfDay = 24                                   [h]
  OffPeakPeriod = 8                                 [h]
  Power_Pump = 2800                                 [kW]
  PumpsOperationTime_OffPeak = 4.848                "Pumps operation time in specific TOU for one day in hours"
  PumpsOperationTimeStandardTime = 6.0816           "Pumps operation time in specific TOU for one day in hours"
  PumpsOperationTime_Peak = 0.1104                  "Pumps operation time in specific TOU for one day in hours"
  PumpsOperationTime_Total = 11.04                  "Pumps operation time for one day in hours"
  Hours_OffPeak = 8                                 "Number of hours in off peak per day"
  Hours_StandardTime = 11                           "Number of hours in Standard Time per day"
  Hours_Peak = 5                                    "Number of hours in peak per day"
```



```
"Calculations"

"Equation1"
  SumPowerTOU_OffPeak = Power_Pump * PumpsOperationTime_OffPeak
  SumPowerTOU_StandardTime = Power_Pump *  PumpsOperationTimeStandardTime
  SumPowerTOU_Peak = Power_Pump * PumpsOperationTime_Peak
  DataCapTOU_OffPeak = Hours_OffPeak
  DataCapTOU_StandardTime = Hours_StandardTime
  DataCapTOU_Peak = Hours_Peak

  AvePowerTOU_OffPeak =  SumPowerTOU_OffPeak / DataCapTOU_OffPeak
  AvePowerTOU_StandardTime =  SumPowerTOU_StandardTime / DataCapTOU_StandardTime
  AvePowerTOU_Peak =  SumPowerTOU_Peak /  DataCapTOU_Peak


"Equation2"
  TotalPower = PumpsOperationTime_Total * Power_Pump
  DataCap = HoursOfDay
  AvePower = TotalPower / DataCap

"Equation3"
  OffPeakRatio =  AvePowerTOU_OffPeak / AvePower

"Equation4"
  StandardTimeRatio = AvePowerTOU_StandardTime/ AvePower

"Equation5"
  PeakRatio = AvePowerTOU_Peak/ AvePower
```



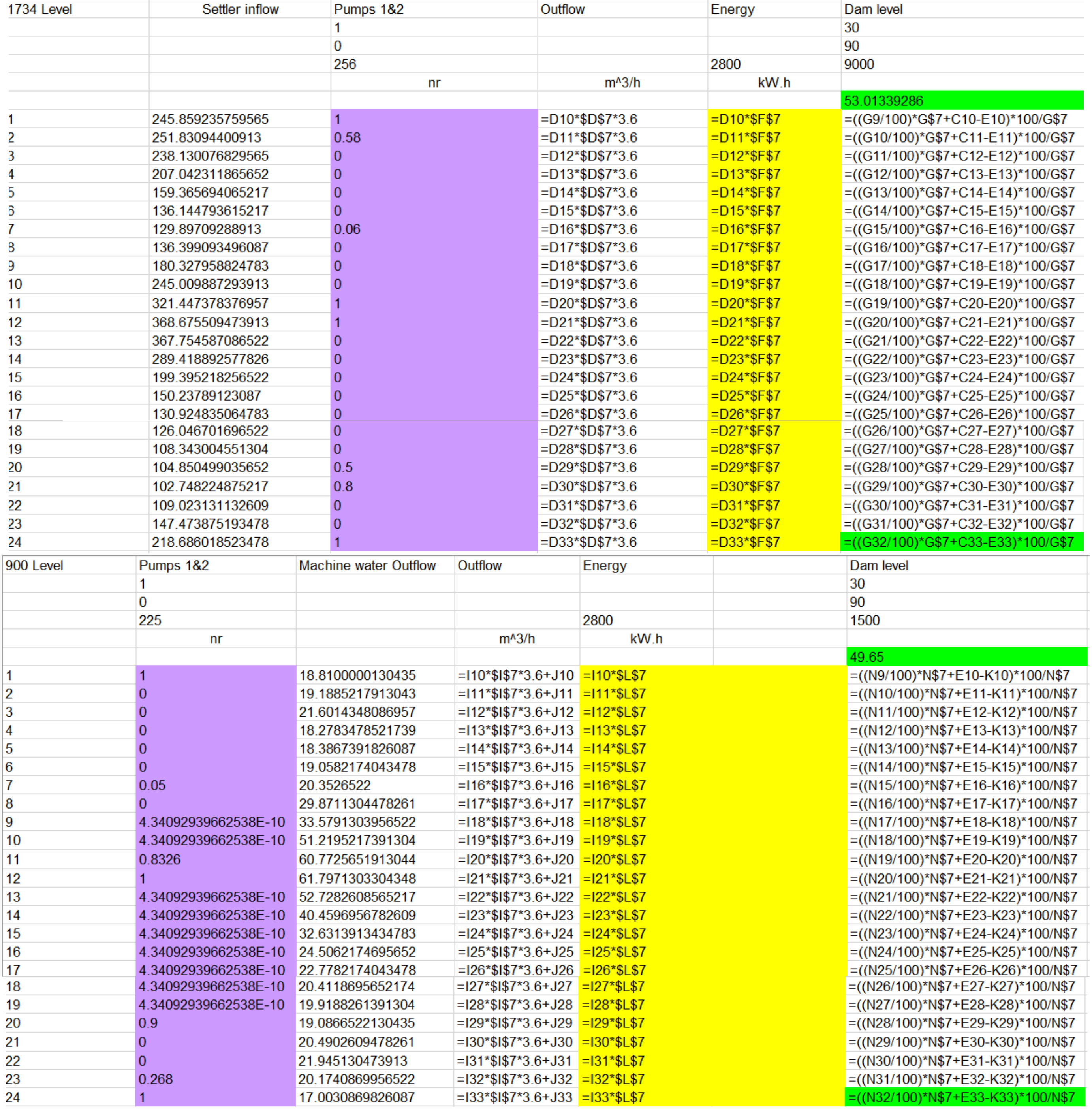
```
"Inputs"
 HoursOfDay = 24                          [h]
 OffPeakPeriod = 8                        [h]
 Power_Pump = 2800                        [kW]
 Flow_Pump = 232                          [l/s]

 Hours_OffPeak = 8                        //Number of hours in off peak per day
 Hours_StandardTime = 11                  //Number of hours in Standard Time per day
 Hours_Peak = 5                           //Number of hours in peak per day
 PumpsOperationTime_900Week = 5.04        //Number of hours pumps run during a week day on level 900
 PumpsOperationTime_900WeekOP = 2.268     //Number of hours pumps run during Off-Peak on a week day on level 900
 PumpsOperationTime_900WeekST = 2.7216    //Number of hours pumps run during Standard Time a week day on level 900
 PumpsOperationTime_900WeekP = 0.0504     //Number of hours pumps run during Peak on a week day on level 900
 PumpsOperationTime_900Sat = 3.84         //Number of hours pumps run during a Saturday on level 900
 PumpsOperationTime_900SatOP = 3.3024     //Number of hours pumps run during Off-Peak on a Saturday on level 900
 PumpsOperationTime_900SatST = 0.5376     //Number of hours pumps run during Standard Time a Saturday on level 900

 PumpsOperationTime_1734Week = 6          //Number of hours pumps run during a week day on level 1734
 PumpsOperationTime_1734WeekOP = 2.58     //Number of hours pumps run during Off-Peak on a week day on level 1734
 PumpsOperationTime_1734WeekST = 3.36     //Number of hours pumps run during Standard Time a week day on level 1734
 PumpsOperationTime_1734WeekP = 0.06      //Number of hours pumps run during Peak on a week day on level 1734
 PumpsOperationTime_1734Sat = 4.8         //Number of hours pumps run during a Saturday on level 1734
 PumpsOperationTime_1734SatOP = 4.176     //Number of hours pumps run during Off-Peak on a Saturday on level 1734
 PumpsOperationTime_1734SatST = 0.624     //Number of hours pumps run during Standard Time a Saturday on level 1734

TotalWaterUsedPeak = 136 + 130+136 +108+105
TotalWaterUsedStandardTime = 180+245+321+369+368+289+199+150+131+126 +103

MaxDamLevel_1734Lvl = 100                 //Maximum damlevel of 1734 level
MinDamLevel_1734Lvl = 50                  //Minimum damlevel of 1734 level
MaxDamLevel_900Lvl = 99                   //Maximum damlevel of 900 level
MinDamLevel_900Lvl = 36                   //Minimum damlevel of 900 level
PreferredControlRange1734Lvl = 10         //Preferred control range givenby the mine

DamCapacity_1734Lvl = 9000                [kl]
DamCapacity_900Lvl = 1500                 [kl]

 MaxBoundary_B900LvlSetByMine = 80        //Maximum boundary at B given by mine
 MinDamLevel_900LvlSetByMine = 75         //Minimum boundary at B given by mine
 MaxBoundary_CGF900LvlSetByMine = 85      //Maximum boundary at C,G and F given by mine
 MinBoundary_CGF900LvlSetByMine = 75      //Minimum boundary at C, G and F given by mine
 MaxBoundary_DE900LvlSetByMine = 85       //Maximum boundary at D and E given by mine
 MinBoundary_DE900LvlSetByMine = 75       //Minimum bounary at D and E given by mine
 MaxBoundary_AH900LvlSetByMine = 80       //Maximum boundary at A and H given by mine
 MinBoundary_AH900LvlSetByMine = 75       //Minimum boundary at A and H given by mine

"Calculations"


"Equation6"
  PerctgeOfDayRun_900Week = (PumpsOperationTime_900Week / HoursOfDay) * 100
  PerctgeOfDayRun_900Sat = (PumpsOperationTime_900Sat / HoursOfDay) * 100
  PerctgeOfDayRun_1734Week = (PumpsOperationTime_1734Week / HoursOfDay) * 100
  PerctgeOfDayRun_1734Sat = (PumpsOperationTime_1734Sat / HoursOfDay) * 100
```



```
'Equation7"
  PerctageOffPeakRun_900Week = (PumpsOperationTime_900WeekOP / (PerctgeOfDayRun_900Week * (1/100) * HoursOfDay)) * 100
  PerctageOffPeakRun_900Sat = (PumpsOperationTime_900SatOP / (PerctgeOfDayRun_900Sat * (1/100) * HoursOfDay)) * 100
  PerctageOffPeakRun_1734Week = (PumpsOperationTime_1734WeekOP / (PerctgeOfDayRun_1734Week * (1/100) * HoursOfDay)) * 100
  PerctageOffPeakRun_1734Sat = (PumpsOperationTime_1734SatOP / (PerctgeOfDayRun_1734Sat * (1/100) * HoursOfDay)) * 100

'Equation8"
  PerctageStndrdTimeRun_900Week = (PumpsOperationTime_900WeekST / (PerctgeOfDayRun_900Week * (1/100) * HoursOfDay)) * 100
  PerctageStndrdTimeRun_900Sat = (PumpsOperationTime_900SatST / (PerctgeOfDayRun_900Sat * (1/100) * HoursOfDay)) * 100
  PerctageStndrdTimeRun_1734Week = (PumpsOperationTime_1734WeekST / (PerctgeOfDayRun_1734Week * (1/100) * HoursOfDay)) * 100
  PerctageStndrdTimeRun_1734Sat = (PumpsOperationTime_1734SatST / (PerctgeOfDayRun_1734Sat * (1/100) * HoursOfDay)) * 100

'Equation9"
  PerctagePeakRun_900Week = (PumpsOperationTime_900WeekP / (PerctgeOfDayRun_900Week * (1/100) * HoursOfDay)) * 100
  PerctagePeakRun_1734Week = (PumpsOperationTime_1734WeekP / (PerctgeOfDayRun_1734Week * (1/100) * HoursOfDay)) * 100

'Equation10"
  TotWaterUsedTest = TotalWaterUsedPeak + TotalWaterUsedStandardTime

'Equation11"
  PumpMaxCap = Flow_Pump * Hours_OffPeak * 60 * 60

["Equation12"
  DamLevelPercenteage = (((PreviousDamLevel / 100) * DamCapacity + DamInflow - DamOut)*100)/DamCapacity}


 "Equation13"
  InflowTOU_1734Lvl = TotWaterUsedTest
  MaxBoundary_B1734Lvl = MaxDamLevel_1734Lvl - (InflowTOU_1734Lvl/DamCapacity_1734Lvl) * 100
  MaxBoundary_B900Lvl = MaxBoundary_B900LvlSetByMine

 "Equation14"
  MinBoundary_B1734Lvl = MinDamLevel_1734Lvl
  MinBoundary_B900Lvl = MinDamLevel_900LvlSetByMine

 "Equation15"
  MaxBoundary_CGF1734Lvl = MaxDamLevel_1734Lvl
  MaxBoundary_CGF900Lvl = MaxBoundary_CGF900LvlSetByMine

 "Equation16"
  MinBoundary_CGF1734Lvl = MaxDamLevel_1734Lvl - PreferredControlRange1734Lvl
  MinBoundary_CGF900Lvl = MinBoundary_CGF900LvlSetByMine

 "Equation17"
  MaxBoundary_DE1734Lvl = MaxDamLevel_1734Lvl
  MaxBoundary_DE900Lvl = MaxBoundary_DE900LvlSetByMine

 "Equation18"
MinBoundary_DE1734Lvl = MinDamLevel_1734Lvl
MinBoundary  DE900Lvl = MinBoundary  DE900LvlSetByMine
 "Equation19"
 MaxBoundary_AH1734Lvl = MinDamLevel_1734Lvl + PreferredControlRange1734Lvl
 MaxBoundary_AH900Lvl = MaxBoundary_AH900LvlSetByMine

 "Equation20"
 MinBoundary_AH1734Lvl = MinDamLevel_1734Lvl
 MinBoundary_AH900Lvl = MinBoundary_AH900LvlSetByMine
```

Appendix B

Equation 12 Excel calculations



1734 Level	Settler inflow	Pumps 1&2	Outflow	Energy	Dam level
		1			30
		0			90
		256		2800	9000
		nr	m^3/h	kW.h	
					53.01339286
1	245.859235759565	1	=D10*D7*3.6	=D10*F7	=((G9/100)*G$7+C10-E10)*100/G$7
2	251.83094400913	0.58	=D11*D7*3.6	=D11*F7	=((G10/100)*G$7+C11-E11)*100/G$7
3	238.130076829565	0	=D12*D7*3.6	=D12*F7	=((G11/100)*G$7+C12-E12)*100/G$7
4	207.042311865652	0	=D13*D7*3.6	=D13*F7	=((G12/100)*G$7+C13-E13)*100/G$7
5	159.365694065217	0	=D14*D7*3.6	=D14*F7	=((G13/100)*G$7+C14-E14)*100/G$7
6	136.144793615217	0	=D15*D7*3.6	=D15*F7	=((G14/100)*G$7+C15-E15)*100/G$7
7	129.89709288913	0.06	=D16*D7*3.6	=D16*F7	=((G15/100)*G$7+C16-E16)*100/G$7
8	136.399093496087	0	=D17*D7*3.6	=D17*F7	=((G16/100)*G$7+C17-E17)*100/G$7
9	180.327958824783	0	=D18*D7*3.6	=D18*F7	=((G17/100)*G$7+C18-E18)*100/G$7
10	245.009887293913	0	=D19*D7*3.6	=D19*F7	=((G18/100)*G$7+C19-E19)*100/G$7
11	321.447378376957	1	=D20*D7*3.6	=D20*F7	=((G19/100)*G$7+C20-E20)*100/G$7
12	368.675509473913	1	=D21*D7*3.6	=D21*F7	=((G20/100)*G$7+C21-E21)*100/G$7
13	367.754587086522	0	=D22*D7*3.6	=D22*F7	=((G21/100)*G$7+C22-E22)*100/G$7
14	289.418892577826	0	=D23*D7*3.6	=D23*F7	=((G22/100)*G$7+C23-E23)*100/G$7
15	199.395218256522	0	=D24*D7*3.6	=D24*F7	=((G23/100)*G$7+C24-E24)*100/G$7
16	150.23789123087	0	=D25*D7*3.6	=D25*F7	=((G24/100)*G$7+C25-E25)*100/G$7
17	130.924835064783	0	=D26*D7*3.6	=D26*F7	=((G25/100)*G$7+C26-E26)*100/G$7
18	126.046701696522	0	=D27*D7*3.6	=D27*F7	=((G26/100)*G$7+C27-E27)*100/G$7
19	108.343004551304	0	=D28*D7*3.6	=D28*F7	=((G27/100)*G$7+C28-E28)*100/G$7
20	104.850499035652	0.5	=D29*D7*3.6	=D29*F7	=((G28/100)*G$7+C29-E29)*100/G$7
21	102.748224875217	0.8	=D30*D7*3.6	=D30*F7	=((G29/100)*G$7+C30-E30)*100/G$7
22	109.023131132609	0	=D31*D7*3.6	=D31*F7	=((G30/100)*G$7+C31-E31)*100/G$7
23	147.473875193478	0	=D32*D7*3.6	=D32*F7	=((G31/100)*G$7+C32-E32)*100/G$7
24	218.686018523478	1	=D33*D7*3.6	=D33*F7	=((G32/100)*G$7+C33-E33)*100/G$7

900 Level	Pumps 1&2	Machine water Outflow	Outflow	Energy		Dam level
	1					30
	0					90
	225			2800		1500
	nr		m^3/h	kW.h		
						49.65
1	1	18.8100000130435	=I10*I7*3.6+J10	=I10*L7		=((N9/100)*N$7+E10-K10)*100/N$7
2	0	19.1885217913043	=I11*I7*3.6+J11	=I11*L7		=((N10/100)*N$7+E11-K11)*100/N$7
3	0	21.6014348086957	=I12*I7*3.6+J12	=I12*L7		=((N11/100)*N$7+E12-K12)*100/N$7
4	0	18.2783478521739	=I13*I7*3.6+J13	=I13*L7		=((N12/100)*N$7+E13-K13)*100/N$7
5	0	18.3867391826087	=I14*I7*3.6+J14	=I14*L7		=((N13/100)*N$7+E14-K14)*100/N$7
6	0	19.0582174043478	=I15*I7*3.6+J15	=I15*L7		=((N14/100)*N$7+E15-K15)*100/N$7
7	0.05	20.3526522	=I16*I7*3.6+J16	=I16*L7		=((N15/100)*N$7+E16-K16)*100/N$7
8	0	29.8711304478261	=I17*I7*3.6+J17	=I17*L7		=((N16/100)*N$7+E17-K17)*100/N$7
9	4.34092939662538E-10	33.5791303956522	=I18*I7*3.6+J18	=I18*L7		=((N17/100)*N$7+E18-K18)*100/N$7
10	4.34092939662538E-10	51.2195217391304	=I19*I7*3.6+J19	=I19*L7		=((N18/100)*N$7+E19-K19)*100/N$7
11	0.8326	60.7725651913044	=I20*I7*3.6+J20	=I20*L7		=((N19/100)*N$7+E20-K20)*100/N$7
12	1	61.7971303304348	=I21*I7*3.6+J21	=I21*L7		=((N20/100)*N$7+E21-K21)*100/N$7
13	4.34092939662538E-10	52.7282608565217	=I22*I7*3.6+J22	=I22*L7		=((N21/100)*N$7+E22-K22)*100/N$7
14	4.34092939662538E-10	40.4596956782609	=I23*I7*3.6+J23	=I23*L7		=((N22/100)*N$7+E23-K23)*100/N$7
15	4.34092939662538E-10	32.6313913434783	=I24*I7*3.6+J24	=I24*L7		=((N23/100)*N$7+E24-K24)*100/N$7
16	4.34092939662538E-10	24.5062174695652	=I25*I7*3.6+J25	=I25*L7		=((N24/100)*N$7+E25-K25)*100/N$7
17	4.34092939662538E-10	22.7782174043478	=I26*I7*3.6+J26	=I26*L7		=((N25/100)*N$7+E26-K26)*100/N$7
18	4.34092939662538E-10	20.4118695652174	=I27*I7*3.6+J27	=I27*L7		=((N26/100)*N$7+E27-K27)*100/N$7
19	4.34092939662538E-10	19.9188261391304	=I28*I7*3.6+J28	=I28*L7		=((N27/100)*N$7+E28-K28)*100/N$7
20	0.9	19.0866522130435	=I29*I7*3.6+J29	=I29*L7		=((N28/100)*N$7+E29-K29)*100/N$7
21	0	20.4902609478261	=I30*I7*3.6+J30	=I30*L7		=((N29/100)*N$7+E30-K30)*100/N$7
22	0	21.945130473913	=I31*I7*3.6+J31	=I31*L7		=((N30/100)*N$7+E31-K31)*100/N$7
23	0.268	20.1740869956522	=I32*I7*3.6+J32	=I32*L7		=((N31/100)*N$7+E32-K32)*100/N$7
24	1	17.0030869826087	=I33*I7*3.6+J33	=I33*L7		=((N32/100)*N$7+E33-K33)*100/N$7

Appendix C

My SQL

```
Option Explicit
Function action
'--- Read values of variables
'--- OLEdb connection to SQL Server
'--- Update query

'Modify Notes
' Adjust Tag array Size
' Adjust VValue array size
' adjust For loop To value
' All 3 these should be the same

' declare variables
Dim sSQL
Dim VValue(81)
Dim Tags(81)
Dim myConn
Dim myCommand
Dim i

sSQL = ""
'Set tags

'900 LVL Pump 1
Tags(20) = "FT_BDP1"
Tags(21) = "ZS_0P102"
```

```
'900 LVL Pump 2
Tags(22) = "FT_BDP2"
Tags(23) = "ZS_0P202"

'900 LVL Pump 3
Tags(24) = "FT_BDP3"
Tags(25) = "ZS_0P302"

'901 LVL Pump 1
Tags(26) = "ZS_0P102"

'902 LVL Pump 1
Tags(27) = "FT_BDP2"
Tags(28) = "ZS_0P202"

'903 LVL Pump 1
Tags(29) = "FT_BDP3"
Tags(30) = "ZS_0P302"

'1734 LVL Pump 1
Tags(31) = "FT_BDP1"
Tags(32) = "ZS_7P102"

'1734 LVL Pump 2
Tags(33) = "FT_BDP2"
Tags(34) = "ZS_7P202"

'1734 LVL Pump 3
Tags(35) = "FT_BDP3"
Tags(36) = "ZS_7P302"
```

```
'Shaft Bottom Pump 1
Tags(37) = "ZS_8W114"
'Shaft Bottom Pump 2
Tags(38) = "ZS_8W115"

'10 MPA A System Pump 1-A
Tags(39) = "MA1_RUN"

'10 MPA A System Pump 2-A
Tags(40) = "MA2_RUN"

'10 MPA A System Pump 3-A
Tags(41) = "MA3_RUN"

'10 MPA A System Pump 4-A
Tags(42) = "MA4_RUN"

'10 MPA A System Pump 5-A
Tags(43) = "MA5_RUN"

'10 MPA A System Pump 6-A
Tags(44) = "MA6_RUN"

'10 MPA A System Pump 7-A
Tags(45) = "MA7_RUN"

'10 MPA A System Pump 1-B
Tags(46) = "MB1_RUN"

'10 MPA A System Pump 2-B
Tags(47) = "MB2_RUN"
```

```
'10 MPA A System Pump 3-B
Tags(48) = "MB3_RUN"

'10 MPA A System Pump 4-B
Tags(49) = "MB4_RUN"

'10 MPA A System Pump 5-B
Tags(50) = "MB5_RUN"

'10 MPA A System Pump 6-B
Tags(51) = "MB6_RUN"

'10 MPA A System Pump 7-B
Tags(52) = "MB7_RUN"

'Fridge Plant 1
Tags(53) = "ZT_R108" 'Vane Pos
Tags(54) = "IT_R01"   'Current
'Fridge Plant 2
Tags(55) = "ZT_R208" 'Vane Pos
Tags(56) = "IT_R201" 'Current
'Fridge Plant 1 & 2 Combined
Tags(57) = "FT_E001"          'Evaporator Flow

'Surface Dam
Tags(58) = "LT_CT002"         '1.2ML Surface dam
Tags(59) = "LT_CT004"         '5ML Surface dam
Tags(60) = "LT_CT003"         '1.8ML Surface dam
Tags(61) = "HWD_LEV"          '10ML Surface dam
```

```
'900 Level Dams
Tags(62) = "LT_0W01"        'Dam1
Tags(63) = "LT_0W02"        'Dam2

'1734 Dam
Tags(64) = "LT_7W01"        'Dam

'5Ml Dam Outlet Temperature
Tags(65) = "TT_CT004"       'Temperature

'Machine water flow
Tags(66) = "TOT_MACHINE_FLOW"        'flow

'1734
Tags(67) = "FT_0W04"        'Flow from 1734 to 900

'900
Tags(68) = "FT_w900"        'Flow from 900 to Surface

'Machine water
Tags(69) = "FT_0W02"        'Machine water flow to 900

'Potable Water
Tags(70) = "FT_0W07"        'Water to underground sections from 1050 to shaft bottom
Tags(71) = "FT_0H05"        'Potable water flow to 900

'Hydropower Flow
Tags(72) = "TOT_HYDRO_FLOW"   'Total Hydropower flow, 5MPA +10MPa
Tags(73) = "FT_H101C"       '10 MPa Total flow
Tags(74) = "FT_0H01"        '900 Level Total flow
```

```
Tags(75) = "FT_1H02"        '1050 South total flow
Tags(76) = "FT_2H02"        '1200 Level total flow
Tags(77) = "FT_H201C"       '5 MPa total flow
Tags(78) = "FT_3H01"        '1350 total flow
Tags(79) = "FT_4H01"        '1500 Total Flow
Tags(80) = "FT_5H01"        '1650 total flow

Const DB_CONNECT_STRING = "Provider=SQLOLEDB.1;Data Source=WINCCMASTER\WINCC;Initial Catalog=BBEn_Log;Integrated Security=SSPI;"

';user id =admin;password=pass"

' integrated security >> Integrated Security=SSPI;

' open connecctoin
Set myConn = CreateObject("ADODB.Connection")
Set myCommand = CreateObject("ADODB.Command" )
myConn.Open DB_CONNECT_STRING
Set myCommand.ActiveConnection = myConn

' get values
' generate sql
' insert for every 10th value



For i=0 To 80
        sSQL = sSQL + "insert into DataLog (Tag_ID,VValue) values ("& i &","& HMIRuntime.Tags(Tags(i)).Read &")"

                If i Mod 10 = 0 And   Len(sSQL) > 0 Then
```

```
                    myCommand.CommandText = sSQL
                    myCommand.Execute
                    sSQL = ""

            End If

Next

'check if there is something to insert
If Len(sSQL) > 0 Then
        myCommand.CommandText = sSQL
        myCommand.Execute
        sSQL = ""
end if

'close connection
myConn.Close

End Function
```