

Potential savings when re-instating mine DSM projects

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Abstract

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The increasing electricity demand in South Africa has led to a shortage in electricity supply. In response to this problem Eskom has introduced multiple capacity expansion programs. Unfortunately the electricity shortage is expected to continue until Eskom's capacity expansion programs are completed. Demand Side Management (DSM) is widely accepted as an immediate solution to the high electricity demand of South Africa.

Numerous DSM projects implemented by ESCo's have been successful, but over the years have not been sustainable. Without regular maintenance from the relevant ESCo, many projects have failed to achieve sustainable savings.

After the implementation of DSM projects, all installed equipment and software becomes the property of the client. Experience has illustrated that some mines did not always have the expertise or available resources to monitor and maintain the projects. As a result the electrical energy savings of the project would gradually deteriorate.

A feasibility study was conducted to determine whether the re-instatement of redundant and debilitated mine DSM projects could be marketed as the "low hanging fruit" of the industry. A key driver for this study, was the fact that costs involved for re-instatement of such DSM projects are generally considerably lower than those of new projects, yet still producing lucrative electricity savings.

Three major mining entities discussed in this dissertation have neglected to realise a collaborative cost saving of R 55,5 Million per annum. This loss of opportunity can mainly be attributed to a lack of maintenance and monitoring of operational DSM projects on their mining sites.

Three DSM projects related to the water reticulation system of the mine were investigated. It was discerned in all three cases that the successful re-instatement of DSM projects are indeed possible, but only when subjected to continuous monitoring.

The maintenance performed on two of the three projects, respectively realised approximately R 2,7 Million and R 750 000. This was achieved through the process of load shifting, over a period of one year. Maintenance on the third project realised approximately R 1,5 Million through energy efficiency over a three month period.

This dissertation illustrates that attractive savings in electricity and cost can be realised when re-instating redundant DSM projects in the mining industry. It also demonstrates the cost and time effectiveness of implementing such projects, compared to the focus on new DSM installations.

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List of Abbreviations

DME	Department of Minerals and Energy
DoE	Department of Energy
DSM	Demand Side Management
ECS	Energy Conservation Scheme
ESCo	Energy Services Company
IDM	Integrated Demand Management
kW	kilo-Watt
kWh	kilo-Watt hour
MW	Mega-Watt
MWh	Mega-Watt hour
Mtoe	Million Tonnes of Oil Equivalent
NERSA	National Electricity Regulator of South Africa
OAN	Optimisation of Air Networks
PCP	Power Conservation Programme
PES	Pressure Exchange System
REMS	Real Time Energy Management System
SCADA	Supervisory Control and Data Acquisition
SOP	Standard Offer Program
TOU	Time of Use
VNC	Virtual Network Computing
WSO	Water Supply Optimisation
3CPFS	Three Chamber Pipe Feeder System

1. CHAPTER 1 – Introduction

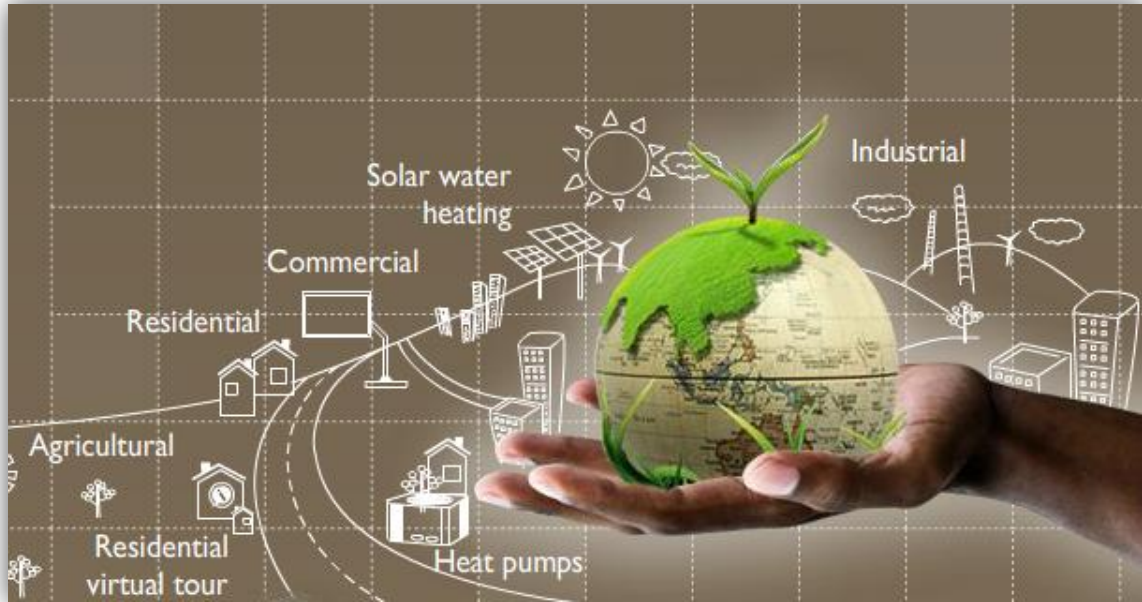


Image available at: <http://www.eskomidm.co.za/>

This chapter will provide a summary of the South African electricity supply shortfall, Demand side Management (DSM) and the possibilities and potential for DSM in the South African mining industry.

1.1. South African electricity supply shortage

South Africa's energy sector is largely dominated by coal fired power stations because of the abundant coal reserves in the country. South Africa imports crude oil to fulfil its liquid fuel requirements which is its second largest primary energy supply. Uranium is exported for enrichment and then imported back into the country to fuel South Africa's nuclear power plant, Koeberg.[1]

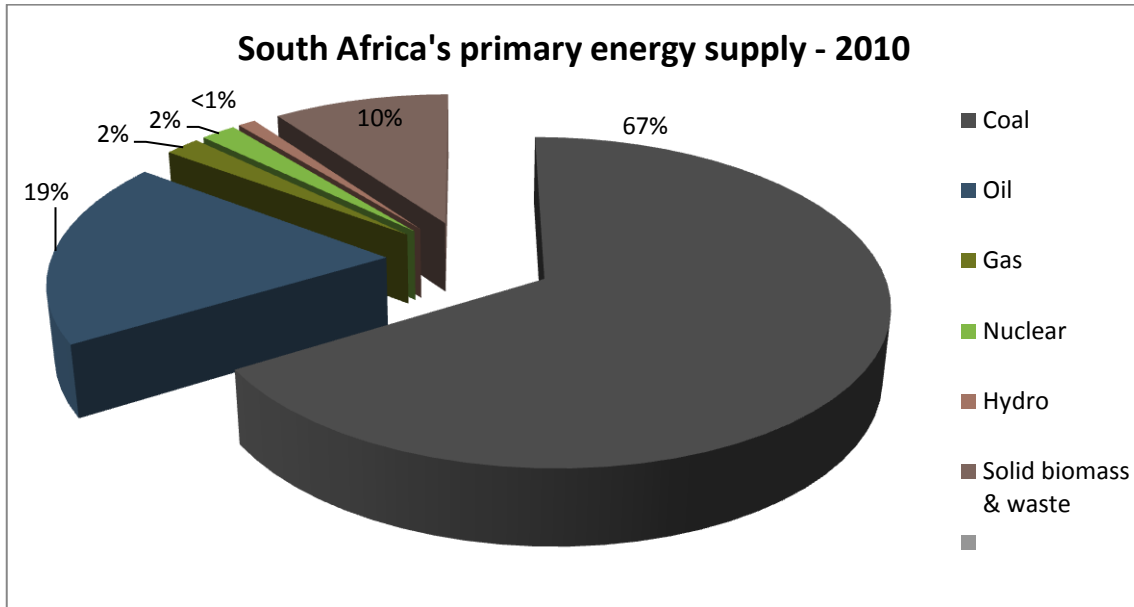


Figure 1: South Africa's primary energy supply as recorded in 2010 [2].

South Africa has enjoyed a generous history of electrical energy supply reserve margin. Since 2005 South Africa has experienced a rapid economic growth. From 2006 to 2007 South Africa's total growth in energy consumption increased by 4,31%. The year-on-year growth in peak power demand was 4,90% [1]. Figure 2 shows how South Africa's demand has fluctuated from 2006 to 2012.

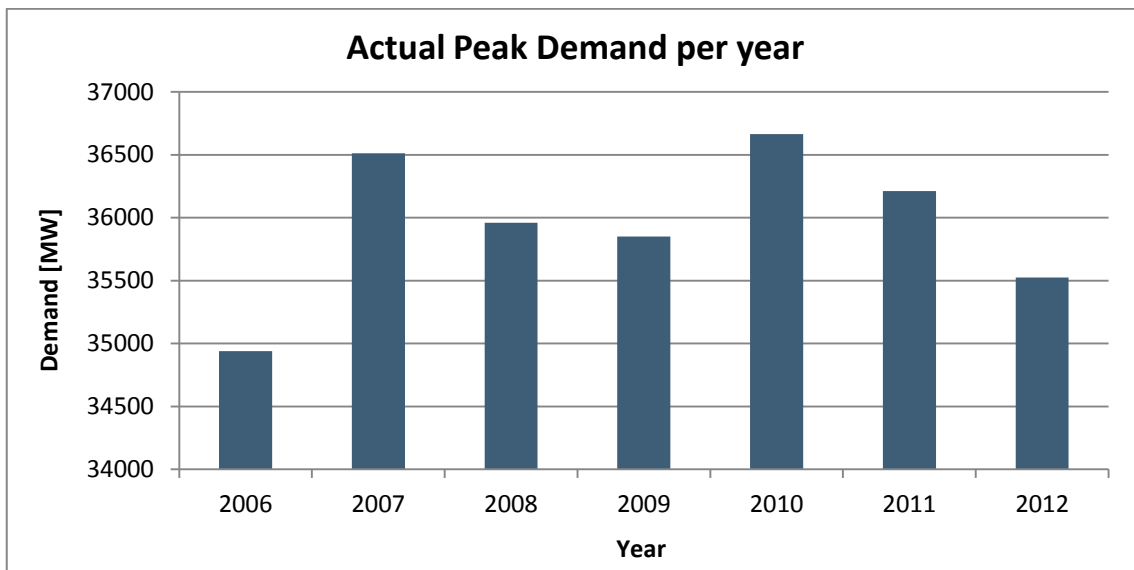


Figure 2: Year-on-year peak demand [3].

For South Africa a reserve margin of 15% will provide Eskom with sufficient time for maintenance [1]. Figure 3 shows South Africa's reserve margin history while Figure 4 illustrates South Africa's projected

demand and Eskom’s projected capacity and reserve margin. It can be noted from Figure 4 that Eskom does not project to reach an adequate reserve margin by 2017.

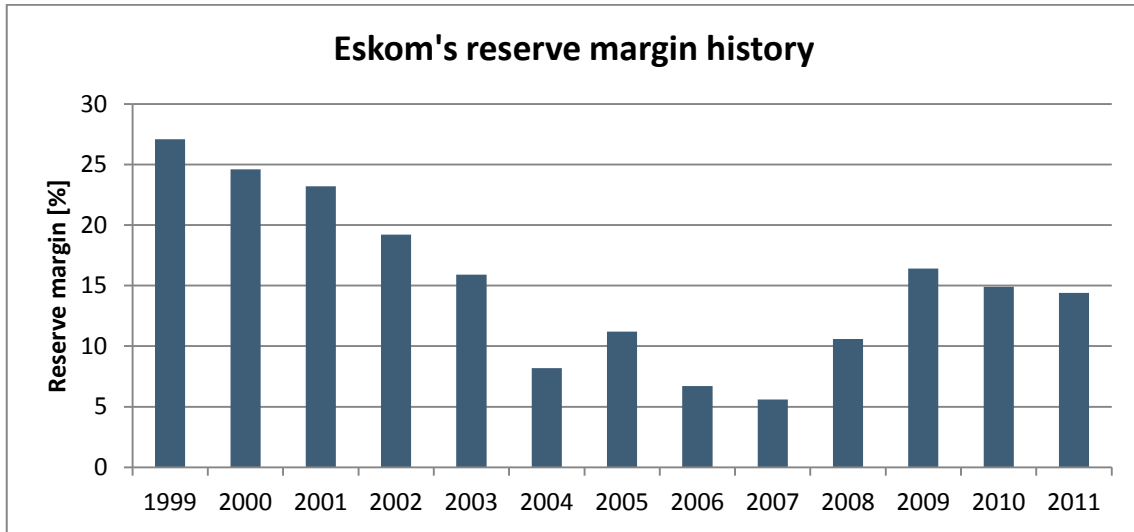


Figure 3: Eskom’s reserve margin history [4].

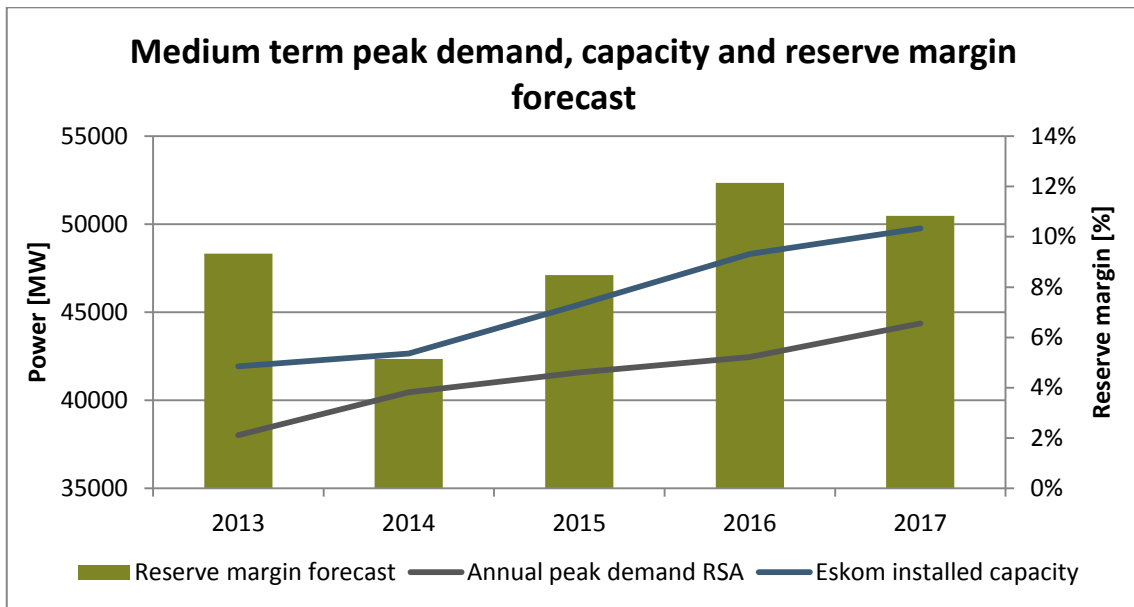


Figure 4: Eskom’s projected peak demand, capacity and reserve margin forecast [3].

From Figure 3 it can be noted that at the end of 2007 into 2008 Eskom could no longer supply the electrical energy demands of South Africa. The global economic downturn in 2008 provided temporary relief, but South Africa’s electrical energy demand grew as the economy recovered. [5]

In 2005 Eskom started on a bold expansion programme to increase the country’s electrical energy supply. This project started with the re-commissioning of three “mothballed” plants that have been in storage for approximately twenty years. These plants are Camden power plant (eight coal-fired units producing a total of 1 520 MW each), Grootvlei power plant (six units producing a total of 1 200 MW) and Komati power plant (nine coal-fired units producing a total of 965 MW). This was expected to meet the short-term growth in demand, majority of which were recommissioned between 2008 and 2010.[6]

In October 2007 the formal opening of two open cycle gas turbine stations took place. These stations were Ankerlig and Gourikwa. By March 2009 two more units were added to Gourikwa, each with a capacity of 148 MW. During this same period Ankerlig gained an additional five units with individual capacities ranging from 148,3 MW to 149,2 MW. [7]

New coal fired power stations under construction were the Medupi power station (a 4 764 MW power station scheduled for commissioning of its units from 2012 to 2015), Kusile power station (a 4 800 MW power station scheduled for commissioning between June 2013 and October 2016) and Ingula pumped storage scheme (1 352 MW project scheduled for commissioning its units from January 2013 to October 2013).

Figure 5 shows the forecasted electrical power generation capacity by Eskom [8].

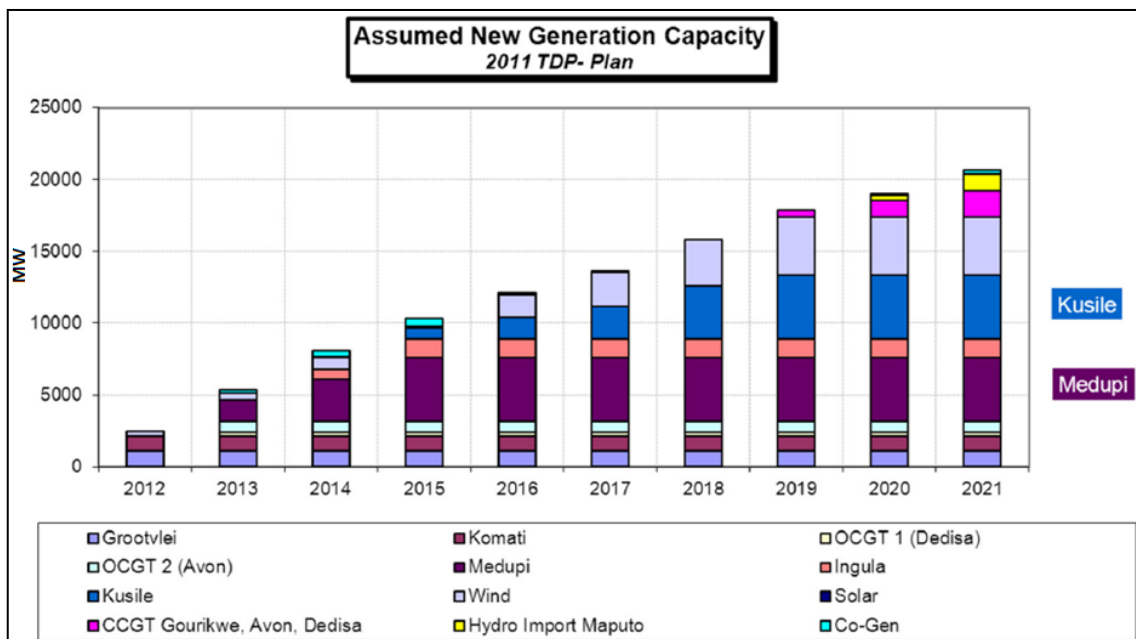


Figure 5: Assumed new generation capacity [8].

Table 1 summarises the capacity expansion projects and the expected completion dates of Eskom’s new generation capacity projects. [6]

Table 1: Eskom capacity expansion projects estimated completion dates. [6].

MW	F2009-2010	F2010-2011	F2011-2012	F2012-2013	F2013-2014	F2014-2015	F2015-2016	F2016-2017	Total
Grootvlei (Coal fired)	800								800
Komati (Coal fired)	125	325	300						750
Arnot (Coal fired)	70	30							100
Medupi (Coal fired)				1588	794	1588	794		4764
Kusile (Coal fired)					1600	800	1600	800	4800
Ingula (Pumped storage)				338	1014				1352
Annual total MW	995	355	300	1926	3408	2388	2394	800	12566

The recommissioned power plants could only meet the short-to-medium term growth in demand. The earliest completion dates of the new power plants are only expected during 2013. A short term solution had to be introduced to reduce the risk of Eskom re-introducing load shedding schedules. One of the short term solutions for immediate relief came in the form of DSM (Demand Side Management). [1][6]

1.2. DSM in South Africa compared to experiences elsewhere

South Africa's electrical energy history has slight differences from other countries' history. This history largely influenced the way in which the DSM programs were motivated and executed.

1.2.1. DSM in the United States of America

In the United States the rise of oil prices in the mid to late 1970s raised the cost of electrical energy. The result was that industry created a rationale to conserve energy. The first wave of DSM activity was born and it was focussed on energy conservation and load management programs. The presumption was made that it was more expensive to build new power plants than to reduce loads. As a result DSM was introduced.[9]

In the late 1980s concerns surfaced that large DSM expenditures were resulting in revenue losses to utilities. In the 1990s new regulatory mechanisms were introduced for the implementation of DSM programs in the United States. Cost recovery incentives were made to shareholders for investing in DSM programs. From the year 2000 and onwards dynamic pricing structures became of interest.[9]

The accuracy of the United States' utility-reported DSM effectiveness and actual achieved savings were investigated by the following authors; Parformak and Lave (1996), Loughran and Kulick (2004) and lastly by Auffhammer, Blumstein and Fowlie (2008). Parformak and Lave studied the relationship between DSM efforts and electricity sales. It was concluded that the actual achieved savings of the utility-led DSM programmes closely resembled the reported savings [10]. The study was continued by Loughran and Kulick and it was found that DSM expenditures were related to electricity sales, but to a lesser extent than reported by the utilities [11]. Auffhammer, Blumstein and Fowlie revisited and improved Loughran and Kulick's analysis. The findings supported Parformak and Lave's original analysis [12]. All these studies conclude that DSM efforts are cost-effective and have a significant potential to decrease electricity prices [13]. As a result DSM is widely accepted as the low-hanging fruit of the electrical energy savings sector [14].

1.2.2. DSM in Germany

Germany's government has set an official target to provide more than 30% of its energy from renewable energy by the year 2020 [15]. Majority of which will be produced from wind power. Two major challenges emerge when relying on wind power; the first is to meet the actual energy goals with wind power and the second is to overcome wind power's unresponsive nature to system needs. The volatile nature of wind leads to high levels of uncertainty. The need for positive and negative balancing power is consequently increasing in Germany. DSM is distinguished as a stabilising mechanism to provide the required flexibility to the power system. [16]

A balance between supply and demand can be manifested by the end user to provide flexibility to utilities by implementing DSM strategies. This can be done by either reducing energy consumption or rescheduling energy demand. DSM can therefore provide Germany with the ability to decrease its demand when its systems fail to supply sufficient capacity. [16]

1.2.3. DSM in Japan

In Japan, 30% of electricity supply is dependent on nuclear power. This was expected to increase to 40% in the Strategic Energy Plan (SEP) issued by Japan's government in 2010 [17]. The Fukushima Daiichi nuclear disaster following the Tohoku earthquake and tsunami on 11 March 2011 has changed Japan's electricity supply structure dramatically [18].

The Japanese government as well as Japan's electricity suppliers had to initiate a variety of measures to address the sudden decrease in capacity. To reduce Japan's demand side, Japan introduced a maximum usage target of at least 15% below the previous year's usage for TEPCO and Tohoku supplied regions and 10% for Kansai supplied regions. The Japanese government and electricity suppliers promoted electricity savings measures to households, business offices and large industries [19]. The Japanese government also issued the Electricity Business Act (Article 27) which authorises the government to restrict the electricity consumption of voluntary enterprises with a demand of 500 kW or more. This would be done in the event of a supply shortage which affects the Japanese economy and the lives of citizens. [20]

1.2.4. DSM in China

In 2003 China was in the process of reforming its power sector. China's government was planning on placing a premium on price stability and didn't want to rush into a new pricing structure. The consequence was that increasing demand was resulting in electricity shortages. This was threatening the economic growth of China. China therefore started to launch price-based programs. Large tariff differences between

peak and off-peak periods and compensation for demand reductions during peak times were introduced [21].

1.2.5. Reflection on South Africa

South Africa's history of relatively low-cost energy supply together with its large mining industry has reaped a highly energy-intensive economy. In 2002 South Africa hosted the "Plan of Implementation" in Johannesburg. World leaders gathered at a summit on sustainable development in South Africa with the ultimate goal of phasing out subsidies in energy markets [9]. Since, South Africa has adopted similar DSM strategies as the U.S. and China did. Short-term solutions such as DSM became necessary to lower the electrical energy demand of South Africa [22].

In the same way as China, South Africa introduced the variable tariff structure. Large customers were also compensated for reducing their demand during the peak periods [9]. Eskom offers financial assistance through its DSM Profitable Partnership Programme to entities that are serious about energy and cost savings [23]. Eskom presently has four key funding mechanisms and programs for the industrial and commercial sector [4]:

- ESCo model
- Performance contracting
- Standard offer
- Standard product

By 2005 South Africa had managed to reduce its peak time demand by 350- 400 MW for up to three consecutive hours when faced with high peak tariff prices[9].

In summary; DSM projects in the United States were initiated by industry itself as a result of the high electricity prices. Germany is relying on DSM to provide stability to its power system. In China and South Africa DSM is initiated as a result of a supply shortage.

This dissertation will focus on the ESCo model since it is applicable to the case studies of this dissertation.

1.3. Overview of Demand Side Management (DSM)

Demand side management (DSM) is the process by which electric utilities achieve predictable load profile changes in collaboration with the consumers [24]. South Africa's imminent electricity supply shortage relied on demand side management (DSM) as a short term solution to allow time for long term solutions. The purpose of DSM is to introduce significant reductions in peak loads that can be implemented in a relatively short time. [25]

Demand side management projects were initiated and measured since 2004. Since then the savings achieved have grown cumulatively. The accumulated demand savings from 2005 to 2011 were 2 717 MW. This is the equivalent of more than four single power station generators (on average 600 MW each). A typical power station will consist of six power station generators. [26]

The annual savings achieved during 2011 were 1 339 GWh, which exceeded the target of 994 GWh by 35%. The electrical energy average evening peak time demand savings achieved were 354,1 MWh.[26]

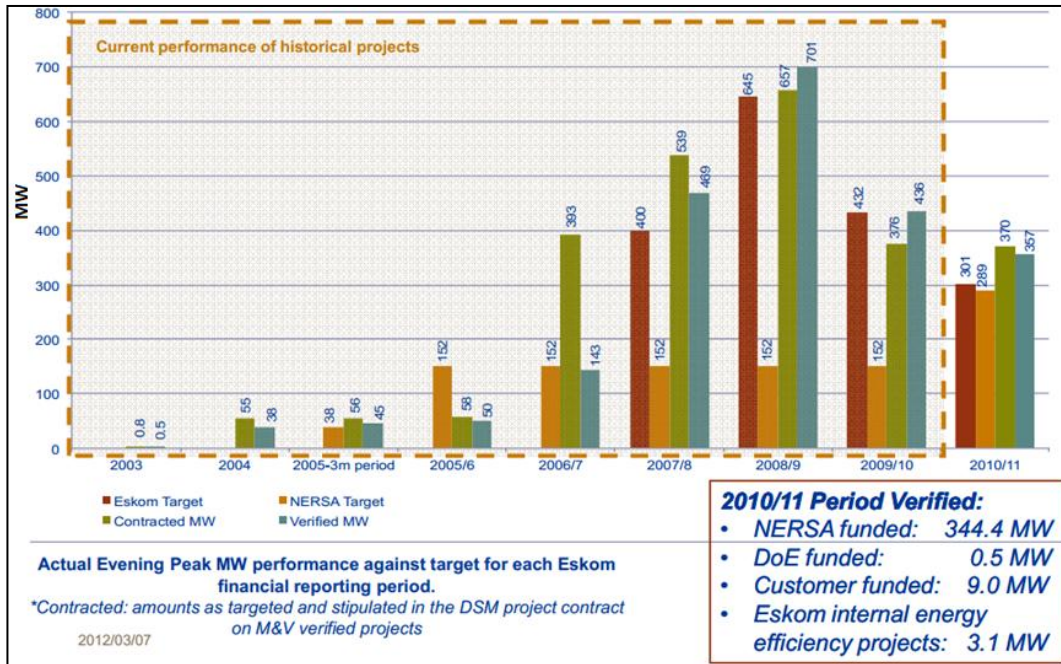


Figure 6: History of impact of DSM [4].

1.3.1. Implementation of DSM

Two basic methods of DSM can be implemented. They are energy efficiency, (EE), and load management:

1.3.1.1. Energy efficiency

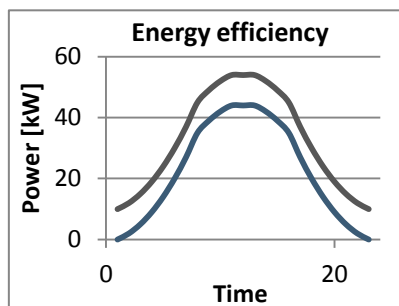


Figure 7: Energy efficiency. Adapted from [27].

Energy efficiency refers to a process through which the energy demand of a utility is reduced permanently [28] as shown in Figure 7. The load profile is reduced by a constant amount for the duration of its operational life time. Figure 7 shows power as a function of time, therefore the area under the graph ($\int P dt$) is energy. If the area under the power load profile is reduced, the total energy consumed will be less.

1.3.1.2. Load management (peak clipping, load shifting and valley filling)

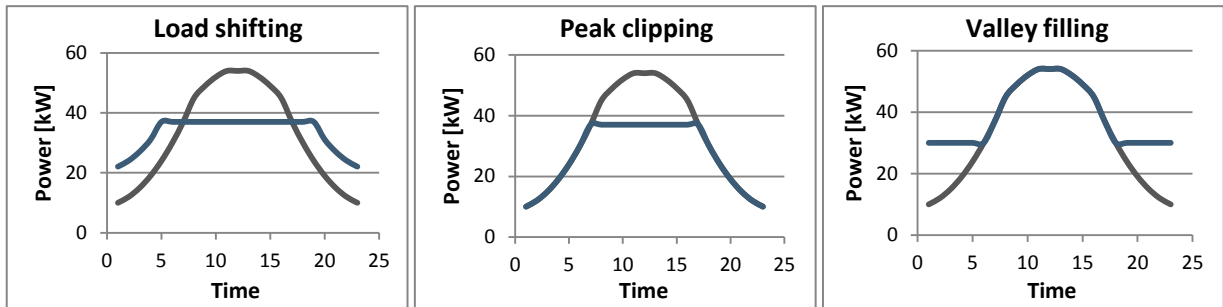


Figure 8: Load shifting and peak clipping. Adapted from [29].

Load management refers to a process through which the demand is reduced during a certain period of time [28] as shown in Figure 8. Three different load management methods can be implemented: load shifting, peak clipping and valley filling.

Load shifting is an energy neutral approach that shifts the load from peak periods to off-peak periods. Peak clipping generally involves the reduction of peak load by using direct load control, while valley filling encompasses on increasing off-peak loads.

This implies that load shifting and peak clipping can be used to reduce the load shape of a utility at times when the supply of electricity is not sufficient. The load is then usually used during lower demand periods.

Load management can be used to shift the load out of the peak times and into standard times, when Eskom’s supply cannot meet the demand of the national grid.

1.3.1.3. Eskom’s multiple tariff structures

Eskom introduced a multiple tariff structure. The aim of this structure is to ensure cost-effectiveness to large end-users, while at the same time discouraging peak time consumption [30].

Eskom increased the tariffs on peak and standard time dramatically, hence encouraged the large end-users to reduce their electricity consumption during peak and standard times. This was done to ensure

both economic efficiency and sustainability as well as provide adequate revenue for reliable energy supply [30].

Figure 9 shows how South Africa’s electricity tariffs change throughout the week. During the red zones (07:00 to 10:00 and 18:00 to 20:00 during week days), South Africa is at its highest electricity consumption.

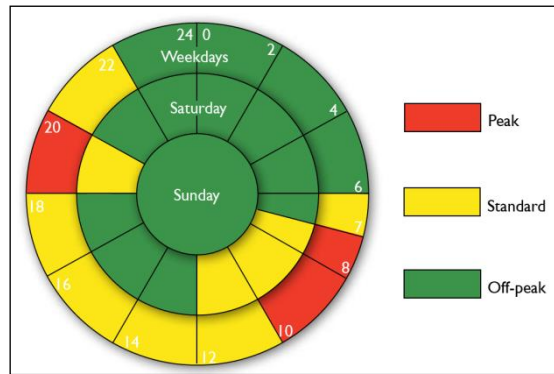


Figure 9: Eskom peak, off-peak and standard times for weekdays and weekends, schematic layout [31].

Load management can be used to influence the load profile of the large end-user to avoid the high electricity tariff shown in Figure 10.

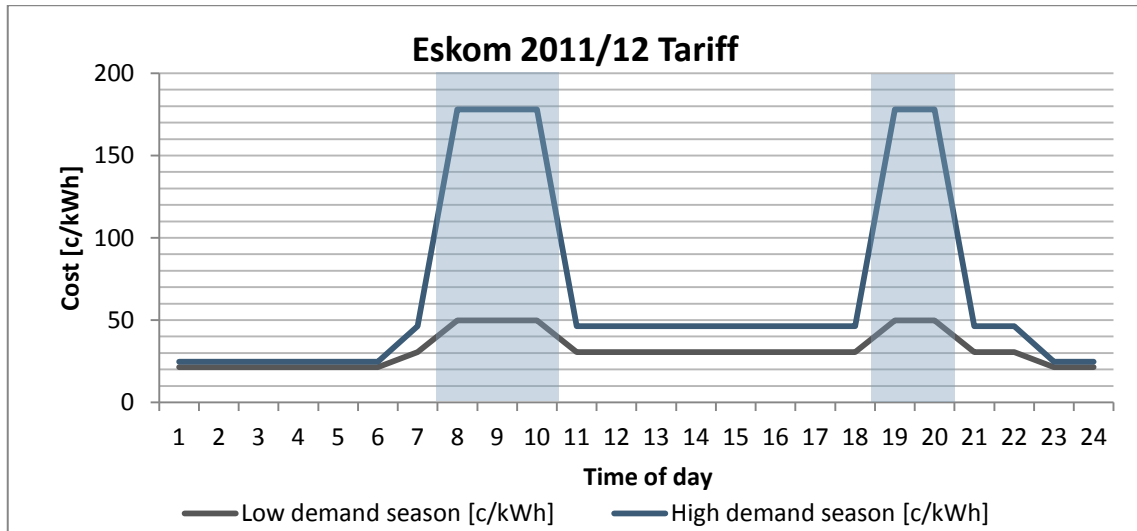


Figure 10: Eskom 2011 daily tariffs for Megaflex [31].

Figure 10 shows the price tariffs of Eskom for the 2011/12 period. The winter tariff is significantly higher during the morning peak time (07:00 to 10:00) and the evening peak time (18:00 to 20:00). During these periods, South Africa places Eskom under great strain. A summary of the Megaflex tariff is given in Appendix A.

Table 2: Eskom 2011/12 tariffs for off-peak, standard and peak times in the high and low demand seasons.

2011/12 Tariffs	Low demand season [c/kWh] (Sept – May)	High demand season [c/kWh] (Jun - Aug)
Off-peak	21,33	24,77
Standard	30,48	46,29
Peak	49,73	177,95

These price increases (as shown in Table 2) motivates industry to lower its electricity consumption during these peak times. When the industries reduce their consumption during these times, the load on the national power grid is relieved.

1.3.2. Electricity distribution in South Africa and the mines

The combined mining industry in South Africa consumes approximately 14,5% of Eskom’s annual output as shown in Figure 11. Of this output, the gold mining industry is the largest consumer, using 47% of the industry’s electricity. Platinum mining is a close second with a consumption of 33%. The remaining 20% is consumed by other means of mining. [32]

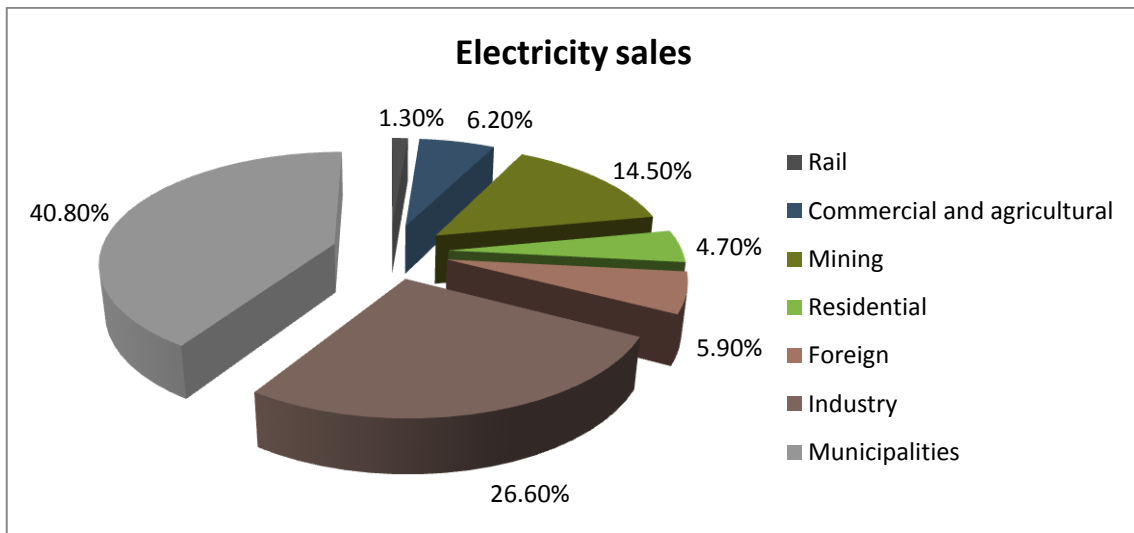


Figure 11: Electricity sales (GWh) by customer type [26].

The mining industry can be categorised into certain energy savings potential areas. These areas are summarised in Figure 12. Figure 12 will differ from mine to mine, but generally is an acceptable representation of the mining sector’s energy load distribution. [32]

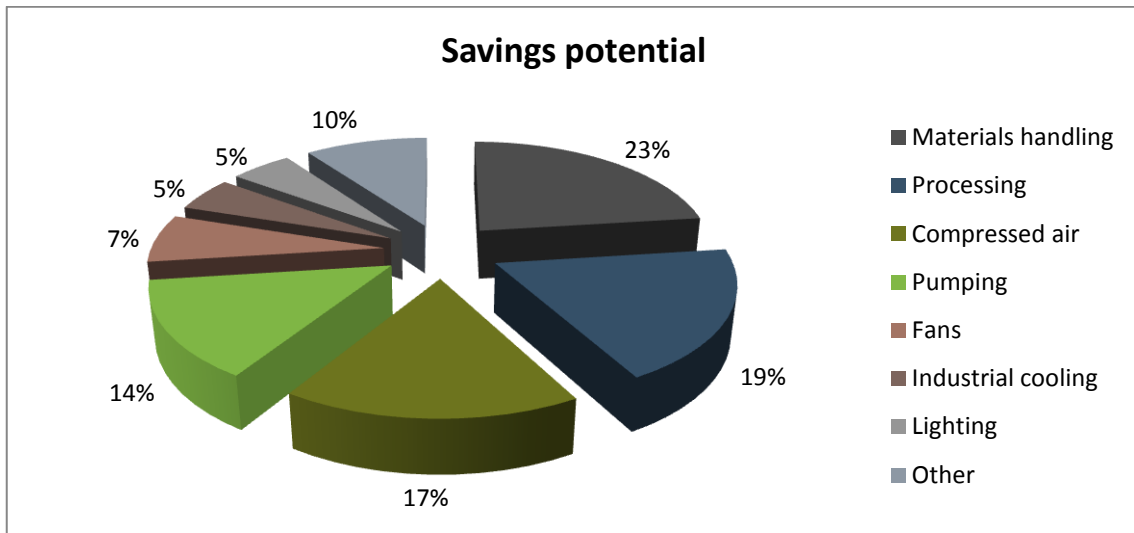


Figure 12: Energy saving potential areas in the mining industry [32].

Eskom, MIEO (Mining and Industrial Energy Optimisation group) and ESCo's continuously research energy savings techniques to make various processes more energy efficient. Electric motors account for up to 60% of industry's energy consumption. There is significant potential for energy savings where electric motors are used in the industry. [32]

From Figure 12 it can be noted that the pumping systems is the fourth highest energy consumer in the mining industry. This dissertation will mainly focus on the water reticulation systems on mines.

1.4. The need for restoring mine DSM projects

1.4.1. Negligence of DSM projects in South African gold mines

During the 3 months assessment period, the ESCo is liable for the performance of the project. If the project achieves the target undertaken by the ESCo, the mine is contractually required to maintain that target for the next five years. Should the project fail to achieve its initial target during the performance assessment period, the target can be adjusted accordingly. The mine will be held liable to achieve this new target, which has been shown to be viable for the next five years. Most DSM projects become incorporated into the mine operations without designating a specific person with the responsibility for the maintenance or performance.

Experience has shown that initially the project performs within the specifications, but with time it will gradually lose its efficiency until very little or no power savings are realised. This is as a result of the need to continually monitor and maintain certain elements of any project, as the mine operations are continuously changing. Since no specific person is allocated to maintain the DSM project, it is often found that the projects start to underperform and go unnoticed amongst the mining personnel. Due to the

evaluated ESCo not having contractual obligations towards the project after completion, it can only occasionally assist in maintenance and then only on request.

Figure 13 shows the monthly actual impact and the target impact of the evaluated ESCo. Large average power saving targets for all the projects were achieved during the first four to five years. A large decline in the savings were recorded from the end of 2009.

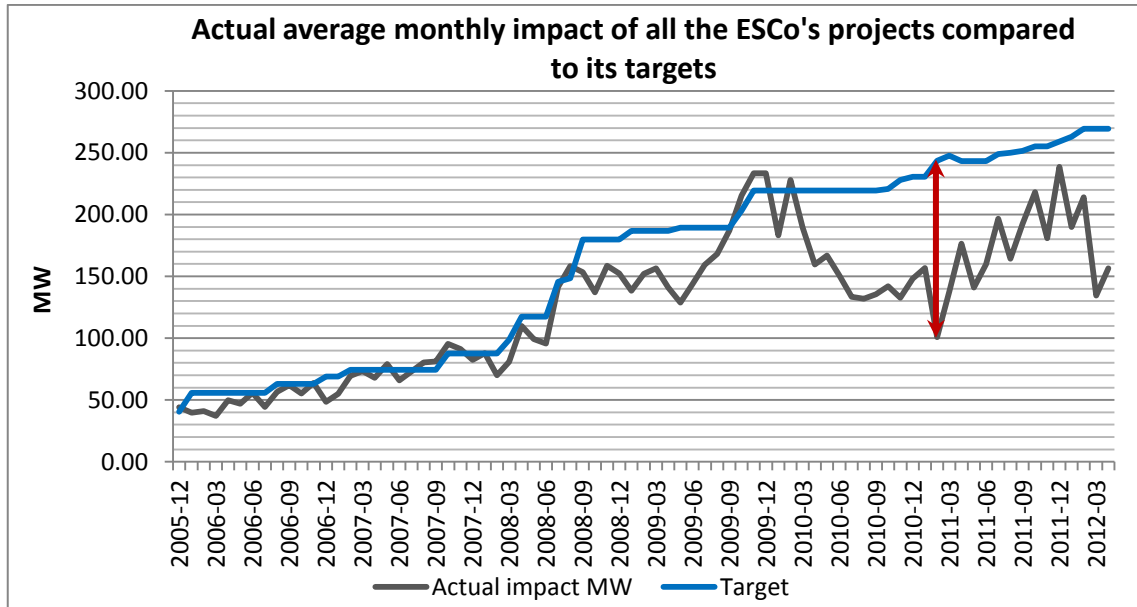


Figure 13: The evaluated ESCo's actual impact versus target impact.

In February 2011 the average monthly savings achieved had decreased from the expected 247 MW for the month to 101 MW (shown by the red arrow in Figure 13).

According to Eskom the average monthly electrical energy consumption of the South African household is approximately 1 100kWh [33]. Assuming there are 30,4 days in a month (365 days ÷ 12 months) the average daily energy consumption for the average household is 36 kWh per day (1 100kWh ÷ 30.4days). The collective average daily opportunities missed by all the mines in the evaluated ESCo's portfolio during February 2011 were 146 MW which is 3 504 MWh (146 MW × 24hours = 3 504 MWh) for each day that the projects were underperforming. The underperforming projects would have made energy available to supply up to 97 333 households (3 504 MWh ÷ 36kWh) if they were successful.

To more accurately assess the lifetime of projects, the performance of previous projects, completed during and before the end of 2005 were investigated. By the end of 2005 an estimated nine load shifting pumping projects were already completed and operational. Figure 14 clearly shows the gradual deterioration of savings as the projects grew older.

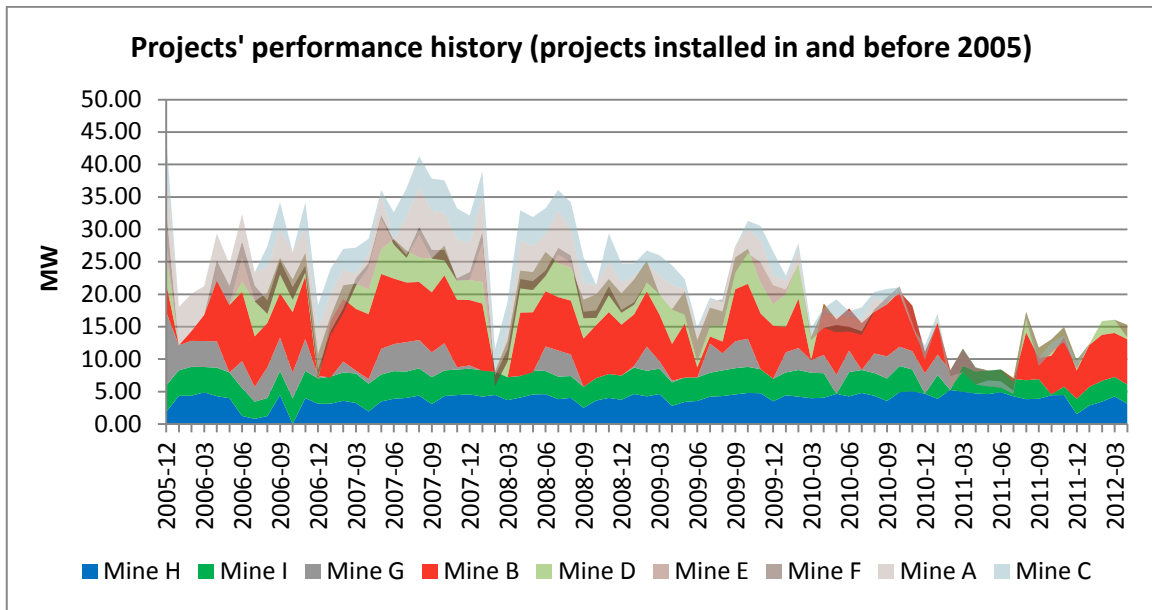


Figure 14: Projects' performance history (projects installed during and before 2005).

In Figure 14 there are only four projects that continuously reduced the power consumption. Mine H is the only project with a continuous successful record of realising energy and cost savings. This is the only mine that has a maintenance agreement with the evaluated ESCo (Mine H).

1.4.2. Monetary savings through reduced energy consumption

Energy Services Companies (ESCO's) work in a three-way partnership between themselves, Eskom and the mine (or any other customer) on DSM projects. The ESCo's use their knowledge and technologies to achieve the best possible savings at the customer's premises [34]. The ESCo will evaluate the existing electricity consumption of the relevant industries as well as its history of electricity consumption. From this data an electrical energy baseline is determined that is verified with the client as well as an independent measure & verification (M&V) team. During this process the ESCo will also propose a theoretical optimised profile based on a new control philosophy to Eskom.

Having the initial baseline (electricity consumption profile before implementation of DSM) as well as the proposed baseline (determined by the ESCo to achieve the DSM savings), the theoretical savings of the project can be determined.

The theoretical possible savings are used in the proposals to motivate the acceptance of the project implementation. When the project is signed off as being successful, it implies that the proposed savings were achieved during the three month performance assessment period. Proper monitoring and maintenance would ensure that the project would, at least, continue to achieve the original target savings.

Experience has shown that when DSM projects are correctly monitored and maintained they will usually exceed the initial proposed savings. Main reason being that the majority of projects' proposed baselines

are usually conservative. In reality the projects are generally capable of over performing after implementation.

DSM cost savings data during 2011 were collected for three major mining groups in South Africa and is shown in Figure 15, Figure 16 and Figure 17.¹

1.4.2.1. Mining Group I

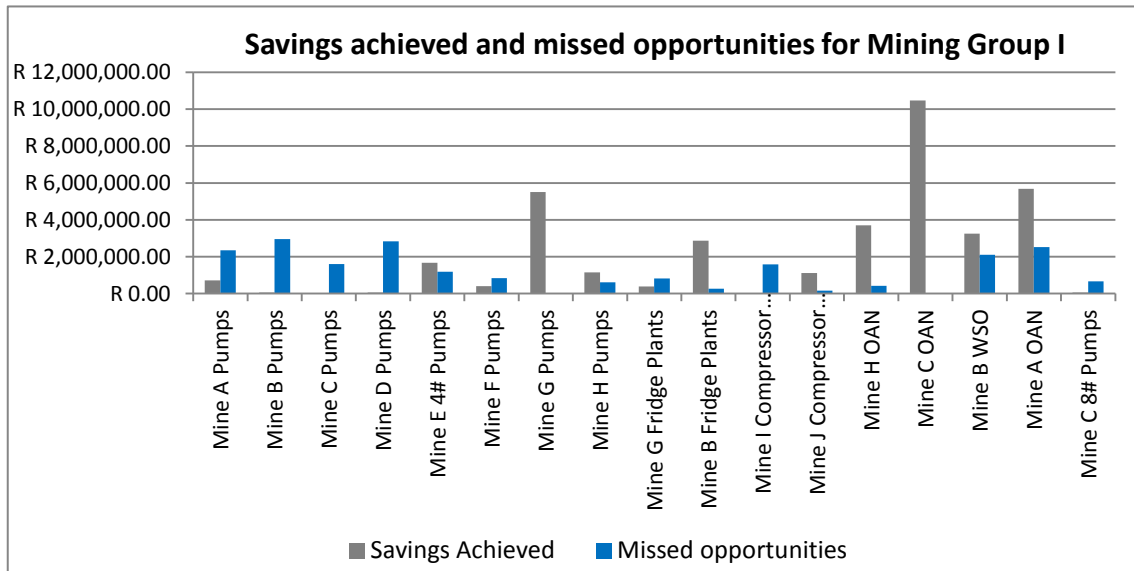


Figure 15: Monetary cost savings achieved and missed opportunities for Mining Group I.

From Figure 15 it can be noted that the majority of missed opportunities for 2011, resulted from pumping projects. This can be attributed to the load shifting pumping projects which were the first projects implemented by the evaluated ESCo. These projects were some of the first load shifting pumping projects implemented by the evaluated ESCo. Only one of these projects has a maintenance contract with the evaluated ESCo.

The OAN (Optimisation of Air Networks) and WSO (Water supply Optimisation) projects show missed opportunities, but are still achieving savings. This is because the OAN and WSO projects are less than two years old.

For Mining group I the savings achieved in 2011 were approximately R 37,1 Million. This mining group missed the opportunity of saving a further R 20,9 Million during 2011. This may be expected to increase if the projects continue to be neglected.

¹ The names of the mines and their mining groups have been omitted for confidentiality reasons.

1.4.2.2. Mining Group II

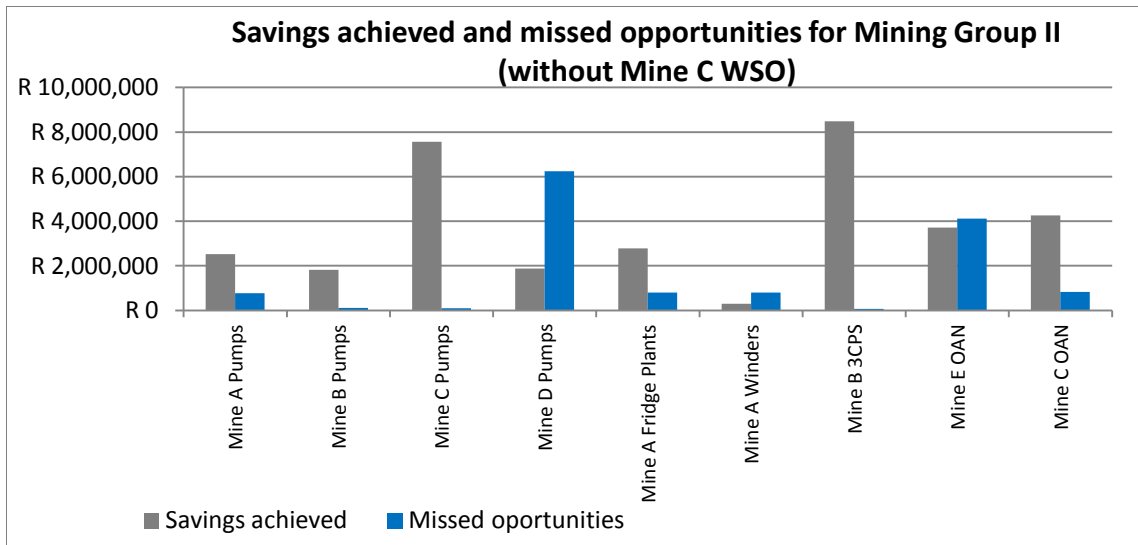


Figure 16: Savings achieved and missed opportunities for Mining Group II (without Mine C WSO)².

In general Mining Group II is more energy conscious. This mining group has energy departments that assist in energy savings projects, which is apparent from Figure 16. The missed opportunities for this mining group are predictably lower than other mining groups. The savings achieved by this mining group were approximately R 66,7 Million in 2011 with missed opportunities of approximately R13,8 Million.

Comparing Mining group I to Mining group II, a discernable difference in attitude towards maintenance becomes evident. Mining group I has 17 projects that collectively save approximately R 37,1 Million annually and missed opportunities of approximately R 20,9 Million. Mining group II only has nine projects that collectively save in the order of R 66,7 Million and only missed R 13,8 Million.

1.4.2.3. Mining Group III

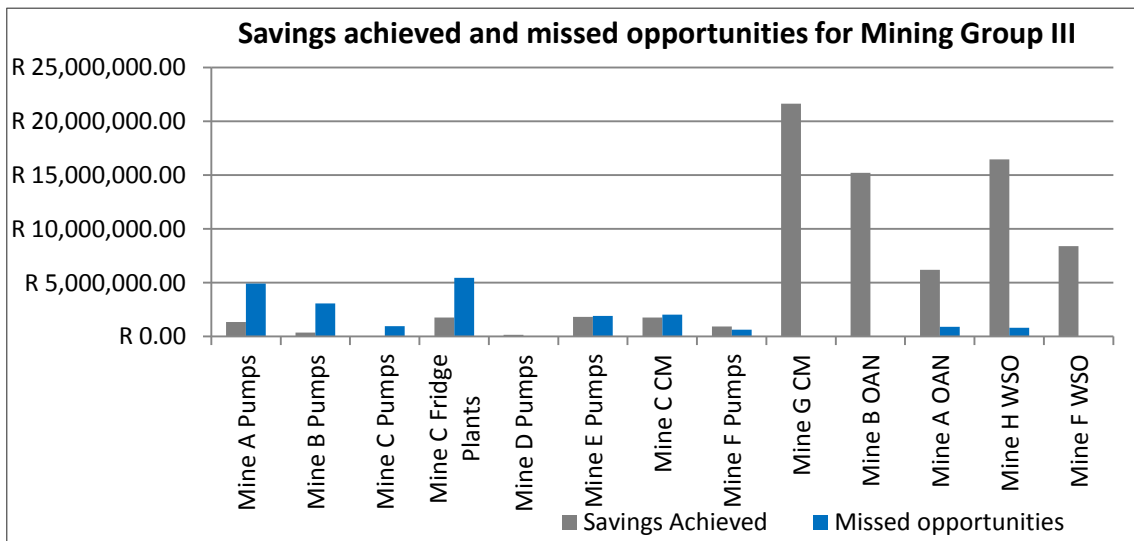


Figure 17: Savings achieved and missed opportunities for Mining Group III.

² Mine C WSO was not included in the graph because it had a saving of R33.3M. This was done to improve the graph scaling.

Mining group III's more recent projects proved to be more successful. The older projects (pumping and fridge plant projects) were for the most part underperforming. This mining group saved approximately R 76,1 Million and missed approximately R 20,8 Million during 2011.

Even though this Mining group shows the largest savings of the three projects, there are ample opportunities for improvement.

With Mining group I, Mining group II and Mining group III missing R 20,1 Million, R 13,8 Million and R 20,8 Million respectively, it is concluded that these mining groups have missed the opportunity to realise a collaborative cost saving of R 55,5 Million.

1.5. Overview of this dissertation

In this chapter the South African energy situation was discussed. The neglect of DSM projects in South African gold mines was identified and the necessity for re-instating the neglected projects was highlighted.

Chapter 2 focuses on the water reticulation system of the typical South African gold mine. The theoretical background of DSM projects on the water reticulation system will be discussed. Case studies will be simulated and implemented.

Chapter 3 will discuss the outcomes of the implemented work will be discussed. The impact of the re-instated projects will be investigated. A business case study of the maintenance cost will be performed.

Chapter 4 draws final conclusions and recommendations for further study.

2. CHAPTER 2 – Methodology



[Image available at: http://ti-up.revolutiondata.com/uploads/public/Events/166/120/759368361_48ea64673f_o.jpg](http://ti-up.revolutiondata.com/uploads/public/Events/166/120/759368361_48ea64673f_o.jpg)

This chapter provides a background study of the water reticulation system in the mining industry as well as different Demand Side Management systems.

2.1. Introduction

In this chapter different DSM projects focussing on the water reticulation system of the mine will be discussed. The majority of the projects that require re-instatement are old water pumping projects.

To better understand how the projects work, as well as how they achieve their savings, this chapter will start with the theoretical background of a mine's water reticulation system. Factors that influence the working thereof will also be discussed in short. Case studies will be introduced to illustrate the re-instatement of old pumping projects.

2.2. Operation of water reticulation systems in gold mines

The gold mines in the Witwatersrand area operate at depths of up to 3 800 m and deeper where virgin rock temperatures (VRT) are in excess of 60°C. The great depth to which ventilation is required, combined with the VRT creates extremely challenging cooling requirements [35]. The mining industry relies on its water reticulation system to maintain a safe working environment underground [36]. Figure 18 depicts the water reticulation cycle of a typical deep-level mine [37].

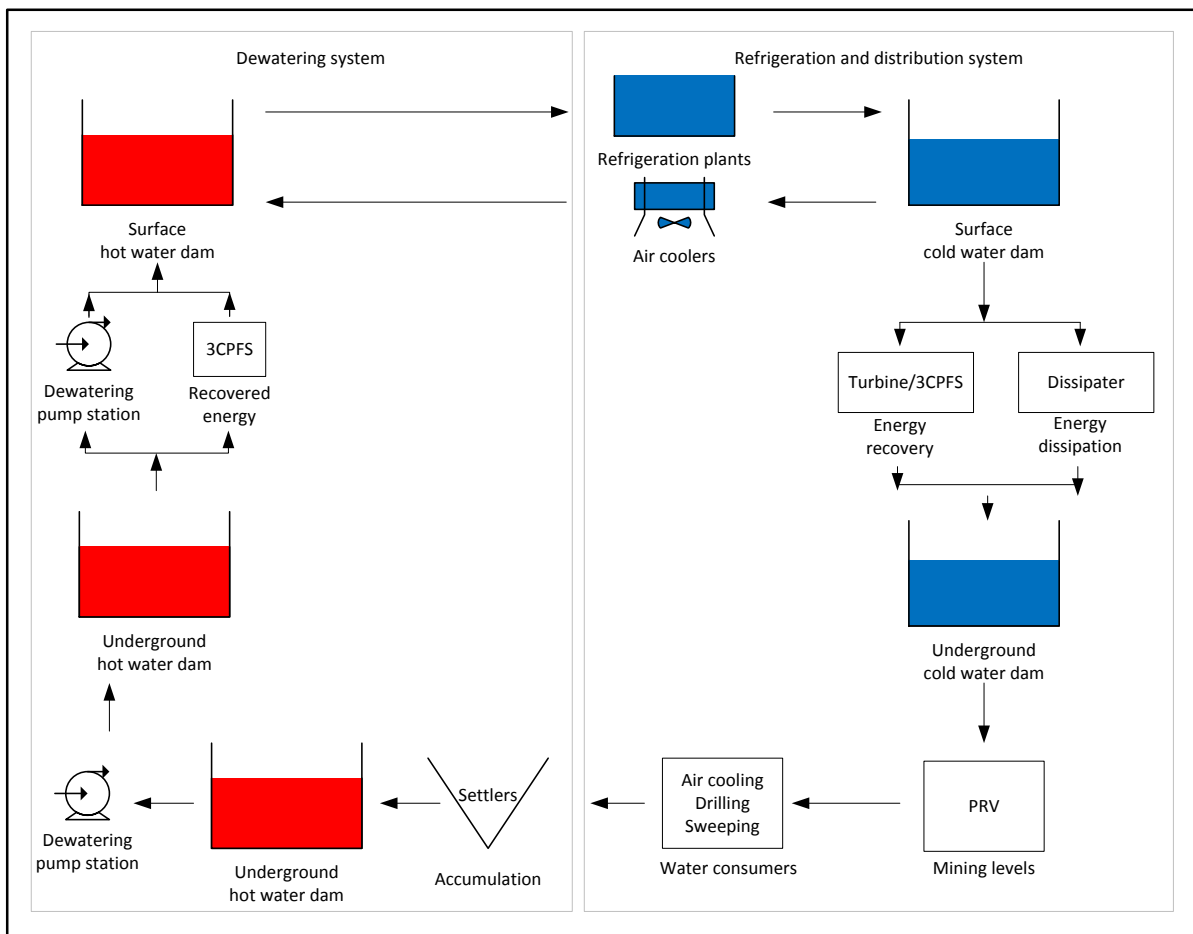


Figure 18: The water reticulation system of a typical deep-level mine [36].

The water reticulation system of the mine consists of two main systems:

- Refrigeration and distribution system
- Dewatering system

2.2.1.1. Refrigeration and distribution system

The refrigeration system is responsible for cooling the working areas of the mine to acceptable temperatures. The refrigeration systems are usually situated on surface, but can also be installed underground. The refrigeration system usually cools the water to below 5°C [36].

The cold water is sent underground and collected in cascade dams as it continues deeper into the mine. This is done to reduce the flow and pressure in the water distribution system's pipes, as the head increases with the increase in depth. In some, mines turbines are installed to convert the energy of the down flowing water into electrical or mechanical energy before the water is collected in the next cascade dam.

2.2.1.2. Dewatering system

Water that has been used for production purposes flows into settlers where the mud is separated from the water using suitable filters. The water then flows into hot water dams where it is pumped back to surface. The number of pumps and cascade dams necessary to pump the water back to the surface hot water dams varies from one mine to another.

When the hot water reaches the surface hot water dam, it usually passes through heat exchangers in the pre-cooling towers. Water chilling takes place in the refrigeration system. Depending on the design of the mine, this chilled water may be routed through the bulk air coolers (BAC) to cool the air that will be sent underground. The water continually circulates between the refrigeration and distribution system and the dewatering system as shown in Figure 19.

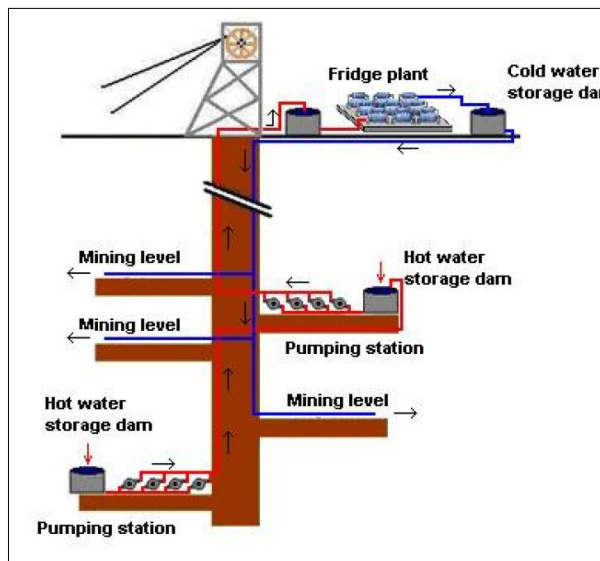


Figure 19: Typical mining water reticulation system [38].

There are many factors that have an influence on the design of a mine's pumping system. These are [38]:

- Quantities of water inflow from different sections of the mine
- Small pumping stations that pump directly to surface
- Location, quantity and installed capacity of the dewatering pumps
- Delivery pressure requirements
- Quantity of water necessary to be pumped
- Pipe friction losses versus the cost to reduce friction losses
- Dam capacity

2.3. Techniques used to optimise water reticulation systems

There are different methods presently used in the mining industry to optimise the water reticulation system. Some of these are:

- Three Chamber Pipe Feeder Systems
- Turbines
- Water Supply Optimisation (WSO) using pressure set point control
- Load Shifting on hot water pumping systems
- Stope isolation valves

Each of these methods will be briefly discussed to provide a background knowledge of the working of a mine's water reticulation system.

2.3.1. Three Chamber Pipe Feeder Systems

Some mines have Three Chamber Pipe Feeder Systems (3CPFS) installed (refer to Figure 20). The 3CPFS is very popular because it uses a great deal less electrical energy to achieve water reticulation than conventional dewatering systems. A 3CPFS has an estimated efficiency of 98% [39].

The basic working of a 3CPFS is fundamentally based on the "U-tube effect" as illustrated in Figure 21 [40]. The 3CPFS uses the chilled incoming water to displace the used hot water of the mine. Small, low power consuming booster pumps are used to keep the cycle operational, as well as to overcome the friction losses [41].

A 3CPFS is a Pressure Exchange System (PES). A PES is in principal the connection between a high pressure system and a low pressure system [30]. A 3CPFS uses the kinetic energy of the water that is being sent underground to pump the hot used water out of the mine [42].

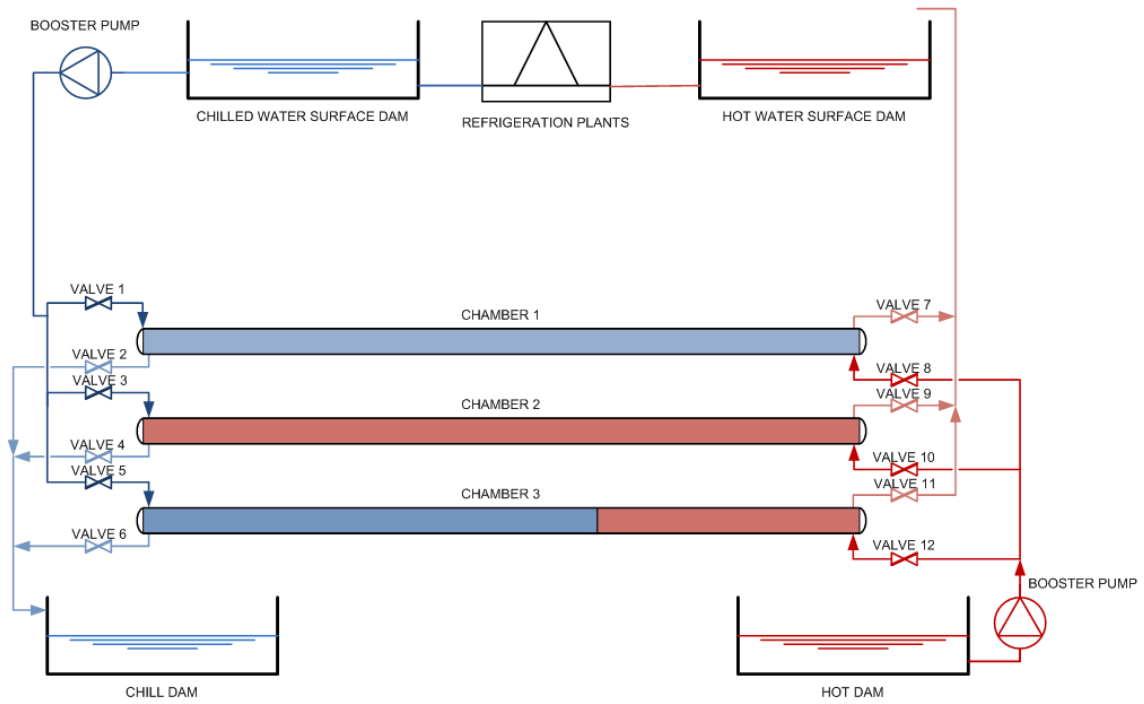


Figure 20: Schematic layout of a 3CPFS. Adapted from [41].

The 3CPFS consists of three chambers that act as the PES'. This is to ensure a relatively constant water flow as the chambers experience their stage changes. The payback period for a 3CPFS is normally five years, but with the funding that Eskom provides, the payback for the 3CPFS can be reduced to two and a half years [43].

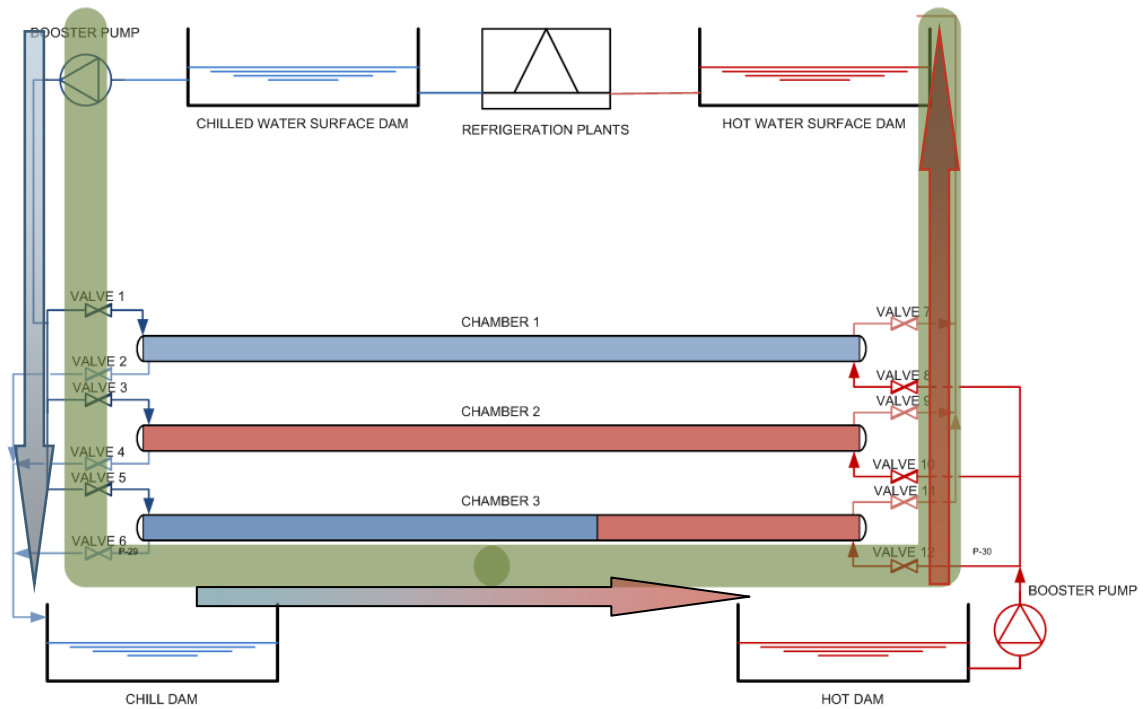


Figure 21: Schematic layout of U-tube effect of 3CPFS. Adapted from [41].

2.3.2. Water Supply Optimisation (WSO efficiency projects)

The water that is sent underground together with the fissure water (water that seeps through cracks from underground water sources) must be pumped to the surface to prevent the mine from flooding. This inflow of water will differ from day to day.

The approximate amount of water that flows underground on a specific day is assumed to be pumped out of the mine during that same day. For example, if approximately 30 *Ml* of water is sent underground throughout the day (including the inflow of fissure water), the pumping for that same day should add up to an approximate equivalent of 30 *Ml* as well. If the pumping of water out of the mine does not match the quantity of water inflow to the mine, the total water captured in the underground dams will gradually increase until the dams overflow.

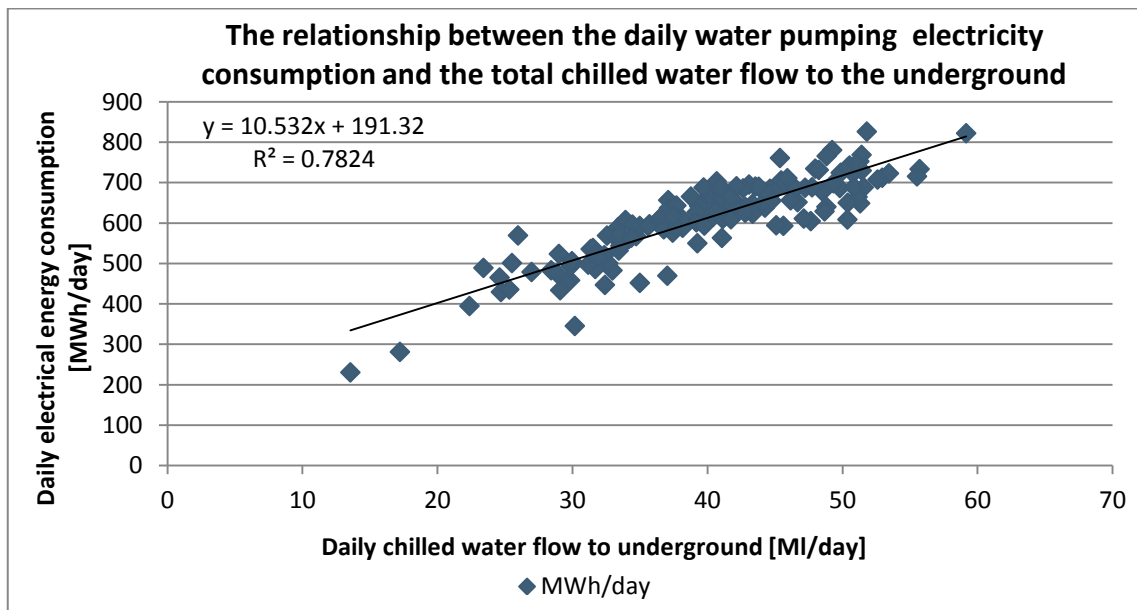


Figure 22: Energy consumption as a function of daily mine water consumption.

Figure 22 shows the linear correlation between energy consumption of a mine’s dewatering system as a function of the quantity of water used underground. The total daily water flow into the mine and the total daily energy consumption was captured over five months. For this specific mine, the relationship between the total electricity consumption and the amount of water sent underground may be represented by the following linear equation:

$$y = 10,53x + 191,32 \tag{1}$$

The intersect of the trend line in Figure 22 indicates that the system will use 191,32 MWh per day when the system is in operation but it does not contribute to the process. The slope gives the amount of energy required for each unit of water added to the system. [44]

Reducing the water consumption of the mine will result in a decrease of the electrical energy consumption of the pumps. A project to reduce the quantity of water captured underground through its water distribution system will be classified as an efficiency project (refer to section 1.3.1.1 on p.8), known as a Water Supply Optimisation project (WSO).

Most South African mines do not have the equipment installed to achieve this, largely due to budget constraints. Since Eskom started funding up to 50% of efficiency projects [41], it has become feasible for ESCOs to install efficiency projects like WSO's.

WSO projects focus on optimising the water supply to the underground mining activities by installing automated valves on the delivery water columns. The control valves were installed to reduce the mine's water consumption during non-production shifts.

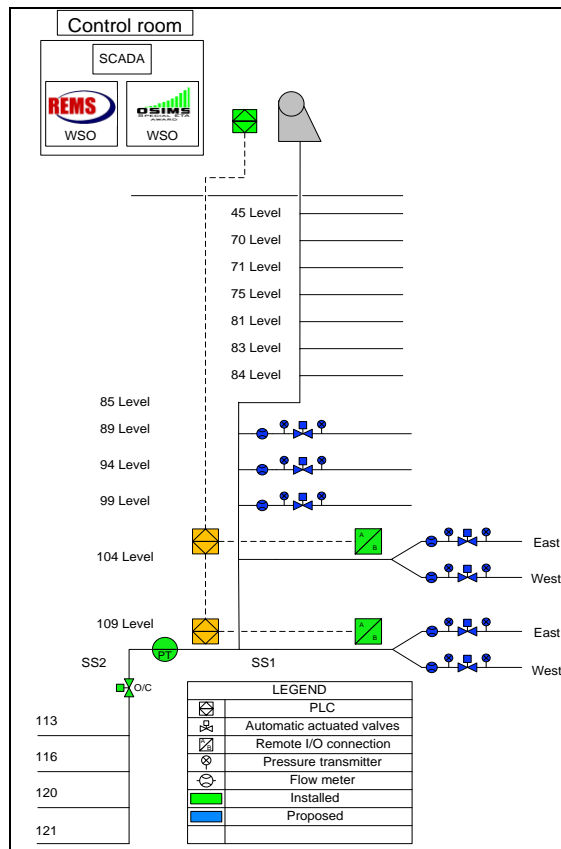


Figure 23: Layout of a typical WSO project.

Figure 23 shows the schematic layout of an installed WSO project. Control valves were installed on the main mining levels' water delivery pipes.

In the mining industry there are specific working shifts. During each shift there are specific tasks that need to be performed. These shifts can be categorised as morning shift, afternoon shift and night shift [36].

Because the necessary water pressures for each of these shifts are known, control valves can control according to its downstream water pressure. This will result in a minimising of water flow to the underground, which will ultimately result in power savings. Section 2.5.3 will discuss this in more detail.

2.3.3. Load shifting on hot water pumping systems

The variation of water flow into and out of the mine complicates the mine’s ability to have full control over its water reticulation system. Since the mine’s underground dam capacity can provide a reserve margin to fill up with water, pumping can be postponed to off peak periods if the underground dam capacities are large enough to hold the influx of water. A project performed on the dewatering pumping system of the mine will be classified as a load shifting project.

Load shifting projects do not save energy, but allocate the load to different times. This is to reduce the mine’s energy usage during a specific time, and locate it to a time where energy costs are lower. Load shifting performed by the mine is a method of saving money as well as reducing the electrical load during peak times. The national electricity grid is also relieved from its high peak demand.

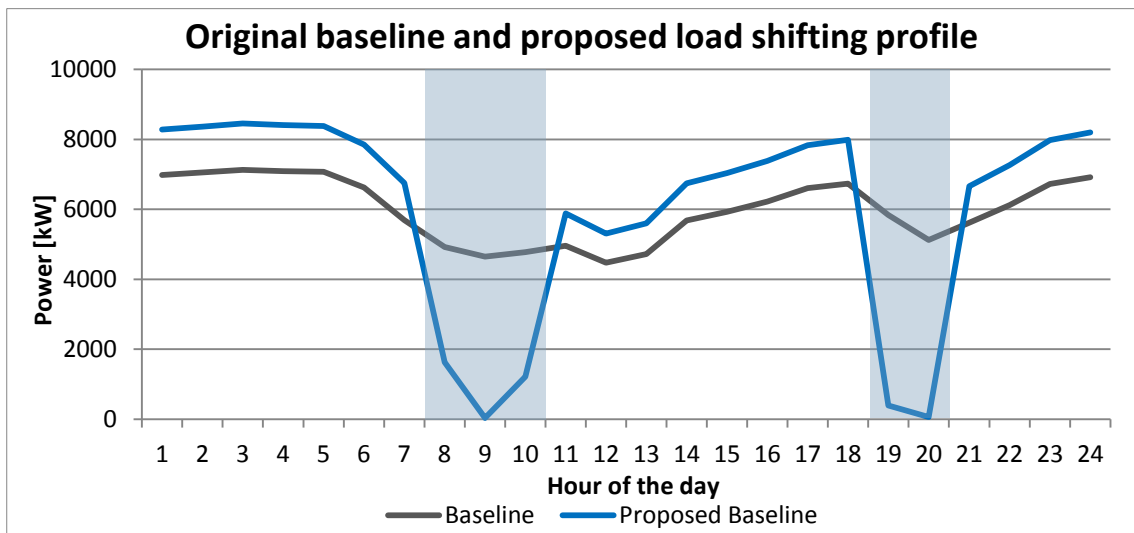


Figure 24: Original baseline and proposed load shifting profile on a mine pumping system.

Figure 24 clearly illustrates how the normal usage of the mine (represented by the baseline), can be altered to achieve load shifting. The pumping necessary to dewater the mine is now scheduled outside of the peak times.

It is important to note that the pumping projects referred to in this dissertation are load shifting projects and should not be confused with efficiency projects. In this dissertation the average power referred to in all *pumping* projects refer to the evening peak time load shifting achieved.

2.3.3.1. Load shifting baselines and baseline-scaling

Prior to implementation, a baseline of the average electrical power consumption is determined for each load shifting project. This baseline is used as an assessment tool to determine the impact of the project.

The total daily energy consumption can be expected to remain unchanged after a load shifting project has been implemented. This is accurate unless there is a change in external factors that may influence the energy consumption, such as changes in production or infrastructure. A load shifting project's baseline is scaled (multiplied by a calculated factor) according to the total average daily electrical energy consumption after it has been implemented. [46]

The scaled baseline is determined by multiplying the original baseline with a scaling factor. The scaling factor is calculated by dividing the total energy consumption of the specific day by the total electricity consumption of the original baseline. The following equations illustrate the method used to determine a scaled baseline to determine the savings achieved by means of load shifting:

$$\text{Scaling Factor} = \frac{\text{Actual electrical energy for the day}}{\text{Baseline electrical energy consumed for a day}} \quad (2)$$

$$\text{Scaled Baseline} = \text{Original Baseline} \times \text{Scaling Factor} \quad (3)$$

$$\text{Savings achieved} = \text{Scaled Baseline} - \text{Actual Baseline} \quad (4)$$

The baseline is scaled to compensate for the variations of total water quantities that must be pumped out daily and is done in accordance to the energy neutral approach as illustrated in Figure 25 [46]. The effectiveness of the load shifting for a specific day is determined by a scaled baseline.

As illustrated in Figure 25, the area under the scaled baseline's graph is in fact lower than the original baseline. This implies that the actual energy used in that specific day is less than the energy consumed in the original baseline period. If the water reticulation system remains unchanged and the electricity consumption is less for a specific day the intake for this specific day was in fact less than that of the period for which the baseline was determined. This is an example of an external factor that has changed the electricity consumption of the mine for that day. Such an external factor may be, for example, when one of the production levels experienced an accident and had to shut down for the day. The entire baseline must then be scaled down to remain energy neutral. The results are shown in Figure 25.

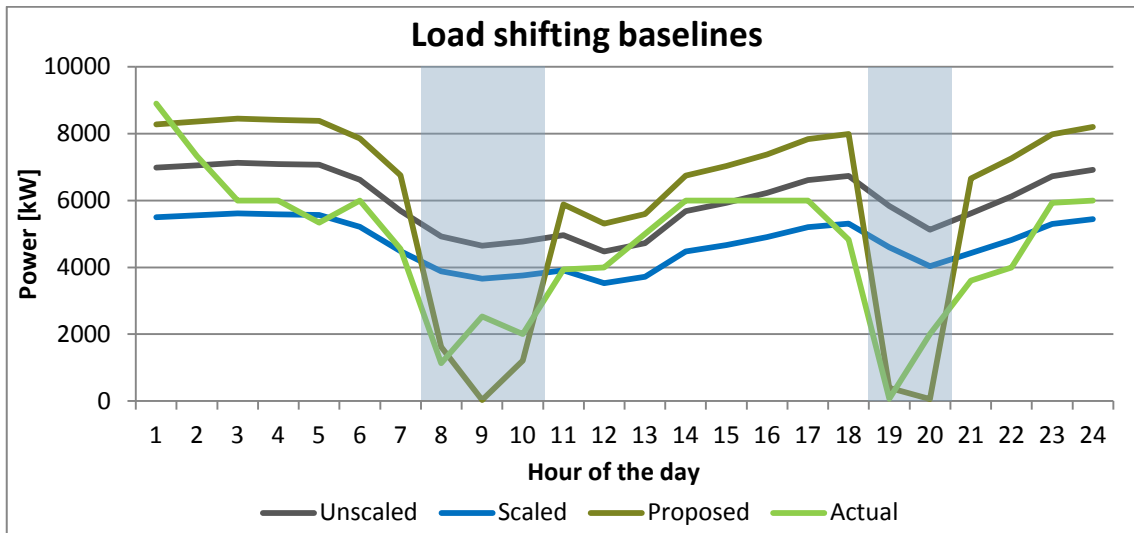


Figure 25: Load shifting baselines, unscaled-, scaled- and proposed baselines as well as the actual usage.

In Figure 25 the original baseline is represented by the “unscaled”-line. The “proposed”-profile is the theoretical profile determined by the ESCo to achieve a perfect load shift. The “actual”-profile displays a specific day’s actual electricity consumption. This specific day’s scaled baseline was determined by the day’s actual electricity consumption and is represented by the “scaled”-line.

2.4. Case studies

2.4.1. Energy saving history of selected projects

Two pumping projects and a WSO project were investigated to determine the cause of declining DSM performance in the mining industry’s water reticulation systems.

The three projects that will be discussed will be referred to as:

- Project A – the first pumping project investigated.
- Project B – the second pumping project investigated.
- Project C – the WSO project investigated.

The data used for the evaluation of the projects were supplied by the evaluated ESCo, hereafter referred to as “the ESCo”.

2.4.1.1. Project A - Pumping system I

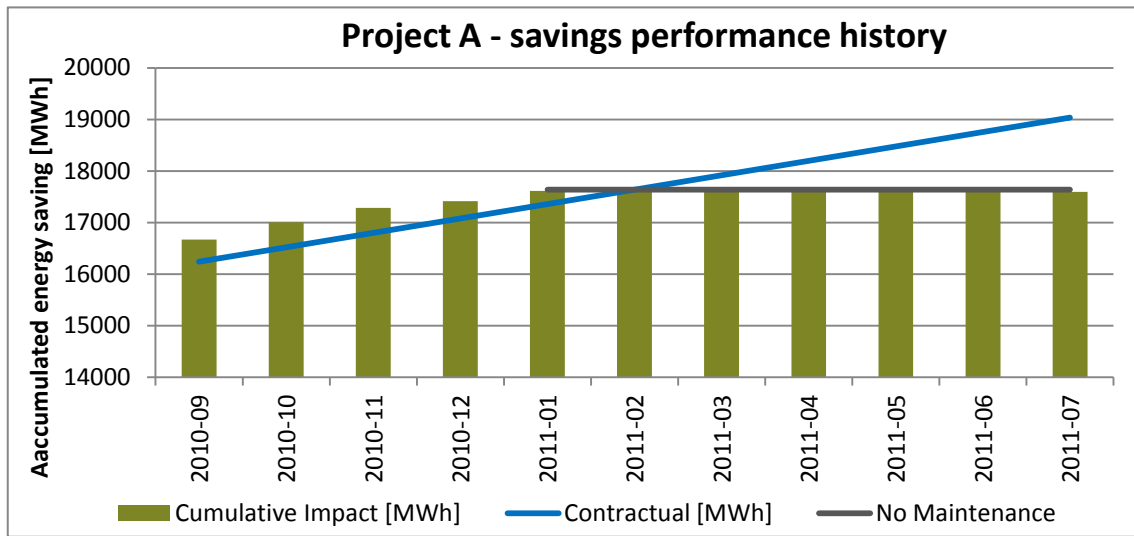


Figure 26: Project A performance history before maintenance.

This specific pumping system had a successful operational performance history. The cumulative impact of the period September 2010 to July 2011 is plotted in Figure 26. Only a portion of the project’s history was plotted to enlarge the period of interest in the graph. For a full project history refer to Appendix B.

The average evening peak time target for load shifting of this project is 7 MW. Figure 26 demonstrates how the project had been over performing until January 2011. During January 2011 the evaluated ESCo’s system failed abruptly. Since the system was out of order, no savings were recorded. The missed opportunities for this pumping system added up to approximately 17,6 GWh by July 2011.³ The monetary worth of savings totalled R 1,4 Million in no more than six months (from February 2011 to July 2011). Of these six months the two winter months alone were responsible for approximately R 1 Million. Taking the morning peak time into account (an extra three hours per day), this value would increase to R 3,65 Million.

2.4.1.2. Project B - Pumping system II

The full cumulative history of the project is shown in Figure 27. This project was delayed during its implementation, resulting in the area between the cumulative “contractual” line and the “trend line” in Figure 27. The “trend line” was introduced to show the historical trend of the project. Loss in achieved savings can be observed in the deviation from the trend line in Figure 27.

By June 2011 the mine had already missed the opportunity to shift an approximate 2,8 GWh of peak tariff electrical energy. The missed opportunity adds up to about R 1,8 Million. Including the morning peak time load shift, this value increases to R 4,67 Million.

³ It is assumed that null savings were achieved while the ESCo’s system was out of order.

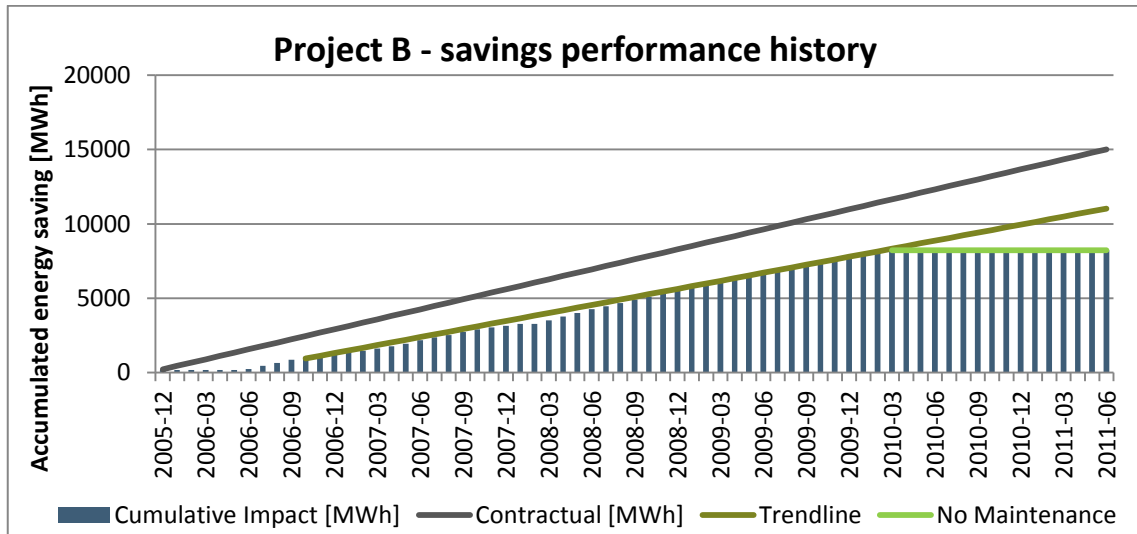


Figure 27: Project B performance history before maintenance.

2.4.1.3. Neglected WSO system

In the history of the ESCo not many WSO projects have been implemented. The WSO technology has only recently been developed and this particular system was one of the first to be implemented.

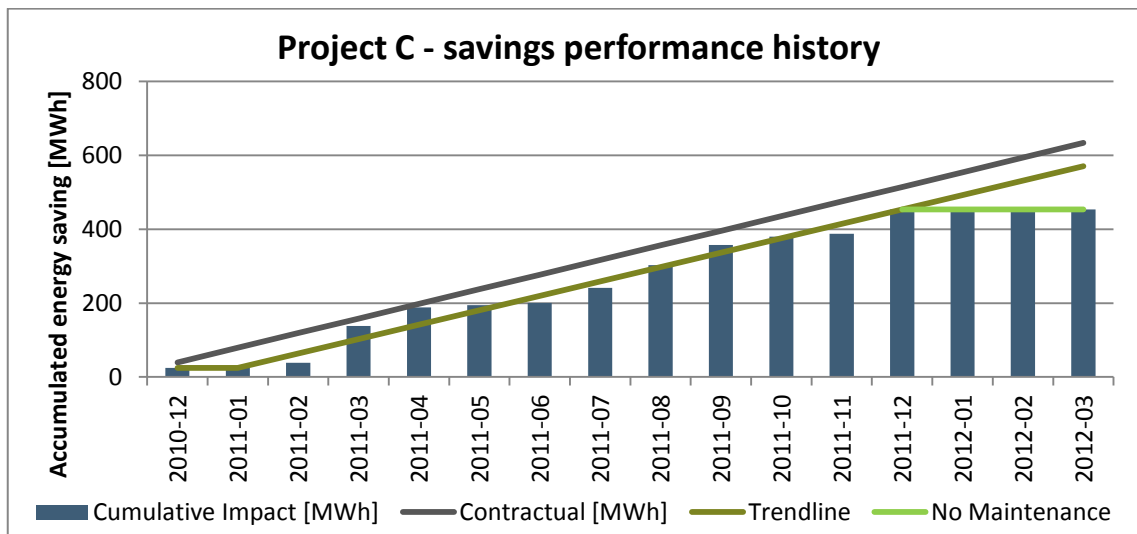


Figure 28: Neglected WSO system.

In Figure 28 the “trend line” shows the average actually achieved cumulative impact of the project up until December 2011. In December 2011 the WSO stopped achieving electrical energy savings. The “trend line” continues with the same gradient to illustrate the savings that would have been achievable if the project had still been operational. The monetary missed saving opportunity for December 2011 until March 2012 is approximately R 1 Million (“trend line” minus the “cumulative impact” at March 2012).

From Figure 26, Figure 27 and Figure 28 it can be ascertained that after a certain time each of these three projects experienced a decline in performance with no further energy savings. In Figure 26 the

project maintained its savings since the start of the project (since 2005, refer to Appendix B) but in a matter of one month stopped working. The same trend is shown in Figure 27 and Figure 28.

2.5. Simulations and calculations

In this section the simulations used to re-instate the old DSM projects are discussed. The ESCo has a computer program called REMS (Real Time Energy Management System) which may be used for both the simulation of the hot water pumping system as well as the real-time management thereof. Each simulation requires parameters such as:

- Flow rates of pumps [l/s]
- Installed capacities of pumps [MW]
- Availability of pumps
- Dam capacities [M]
- Water flow rates into the dams [l/s]
- Design of hot water pumping system (cascade structure of the dams)
- Water flow rates out of surface dams to the refrigeration plants
- Other processes that may influence the water reticulation system like 3CPFS or turbines (especially turbines coupled mechanically to pumps)

When REMS is installed on site, it will log all the relevant data in two minute intervals. The above mentioned parameters vary with time. REMS' responses to the parameters are logged with time as well. The same principle applies to the simulations. When a simulation is run, a virtual time is created in REMS to simulate the procedures that REMS would have carried out under the specific conditions as specified by the user. As the software of REMS on site is the same as that used for simulations, the simulations will provide an accurate indication of the real-time events, if the user selects the inputs and defines the controls of REMS correctly.

Since all the projects in this dissertation had historical data, an acceptable and accurate simulation was possible for each pumping project. Data of the actual operation of the mine were logged and could be used to simulate realistic flows and dam levels of the mine.

There are no flow meters installed to determine the flow of the water into the hot water dam. The water flow had to be determined by using data that were obtainable from historical logs. The only obtainable data to establish the inflow of water into the 25 level hot water dam were the flow rates of the pumps, the dam sizes, and the dam levels. This data could be used to determine the approximate historical water flow rates into the dam as displayed in Figure 30 and equation (5).

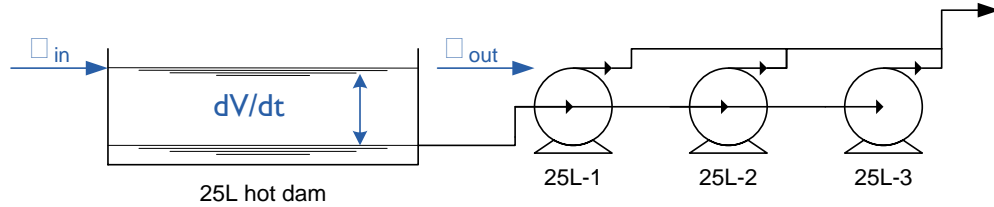


Figure 30: Schematic layout for the method used to determine the inflow of water into 25L hot dam.

The change in dam volume is a result of the mass water flow into the dam minus the mass water flow out of the dam as illustrated in equation (5):

$$\frac{\Delta V}{\Delta t} = in - out \quad (5)$$

$$\therefore in = \frac{\Delta V}{\Delta t} + out \quad (6)$$

From established historical dam level and pump status data equation (6) was used to determine what the unknown water flow rate into the dam was. The historical dam levels were used to determine the change in volume over two minute intervals and the water flow rate out of the dam was determined by the delivered flow rating of each pump (as supplied by the mine). Using this method, the hourly average of water flow into the hot water dams was determined.

A study was done by Van Rensburg and Liebenberg that showed in detail how the pumping efficiency of a system decreases as additional pumps are brought on-line. In the study it was found that the flow decreased by up to 17,2%. [47]

If an additional pump is started the friction loss inside the pipe would increase as the water flow rate increased. Consider the Darcy-Weishach equation [48]:

$$h_L = \frac{\Delta p}{\gamma} = f \frac{1}{2} v^2 \frac{p l}{\gamma D} = f \frac{v^2 l}{2gD} \quad (7)$$

Equation (7) determines the head loss (h_L) as a result of friction loss with the total water flow rate (v), the length of the pipe (l), the inside diameter of the pipe (D), gravitational acceleration (g) and the Darcy-

Weishach friction factor (f). As the water flow rate (v) increases, the friction losses inside the pipe will also increase.

Since the mine is very old, the pipes have been exposed to poor quality mining water for a very long time. The result is that the surface roughness of the pipe is unknown. The build up of scale or corrosion will influence the roughness of the pipe. The roughness can be influenced up to a factor of 10 in some cases and it may even be necessary to adjust the diameter of the pipe for calculation purposes [48].

For the simulations, the achievable flow rates of the system is of main concern. If a second pump is started the flow rate of the pumping station will increase, but the individual pumps will no longer be able to supply its optimum flow rate. If each pump in a pumping station is rated to deliver 250 l/s, one pump will deliver 250 l/s. If a second pump is started, the flow is expected to be increased to 500 l/s (2 x 250 l/s), but the friction losses inside the pipe will increase as the water flow rate increases. As a result the total deliverable water flow rate will now only be 200 l/s per pump (400 l/s in total). For a more accurate simulation it would be preferable to capture actual water flow data to determine what effect these losses may have on the specific system.

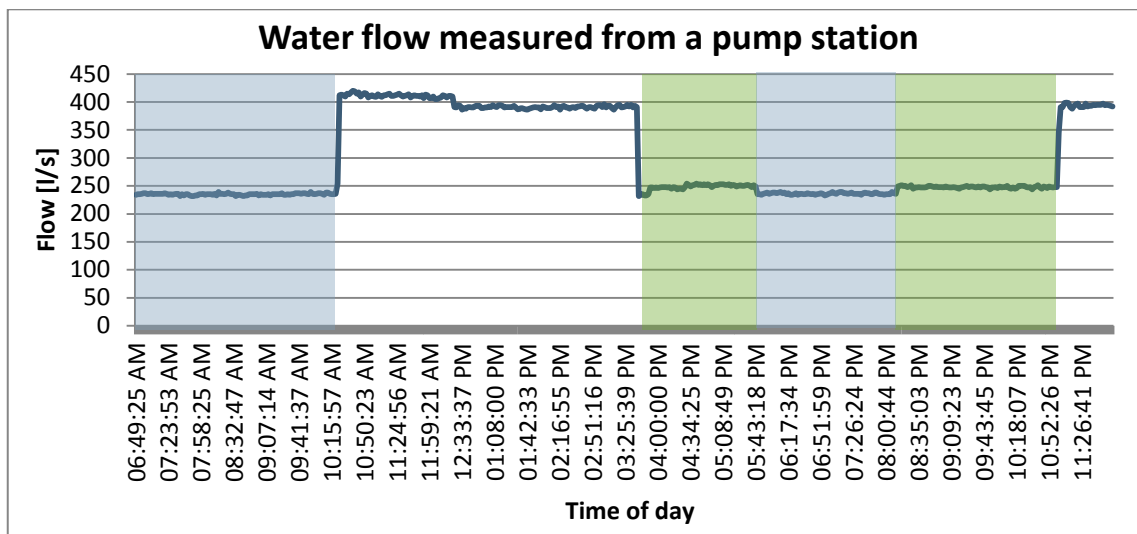


Figure 31: Influence of friction loss as a result of an increase of the water flow rate.

The delivery water flow rate of another mine is illustrated in Figure 31. The necessary instrumentation was already installed by the mine and available to capture the data for Figure 31. For the times that the delivered flow rate was approximately 240 l/s pump 1 was running (pumping period highlighted in blue). Pump 2's pumping period is highlighted in green in Figure 31 and its deliverable flow is approximately 250 l/s. As the second pump was started the flow rate increased in the same pipe to about 400 l/s. The friction losses were accountable for the loss of 90 l/s deliverable flow by the two pumps (250 + 240 l/s - 400 l/s = 90 l/s). The friction losses were accountable for 18% of the deliverable water flow rate.

The water flow into 25 level's hot water dam is most significant, because that is in effect where the mining operations' water enters the dewatering system. 21 Level hot water dam receives the majority of its water from 25 level pump station, and 5 level hot water dam receives the majority of its water from 21 L. All dams receive minor amounts of fissure water. The dewatering system is shown Figure 32.

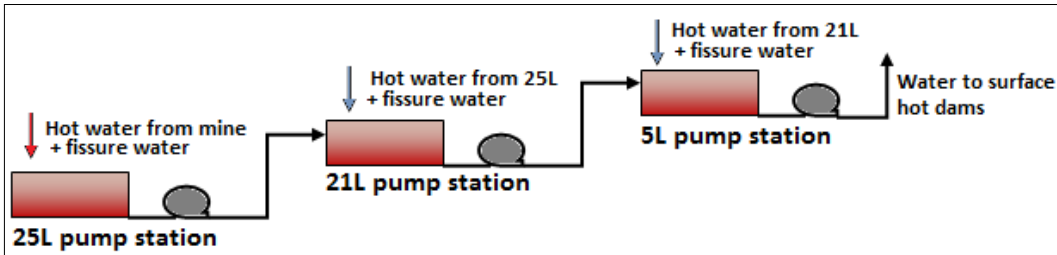


Figure 32: Water inflow of Project A's dewatering system

From the historical data of the dam levels logged every two minutes, jointly with the dam size, an indication of the change in volume could be calculated in litre per second. The inflow of water could be calculated using equation (6). The total delivered flow rate was assumed to decrease by 15% for each additional pump.

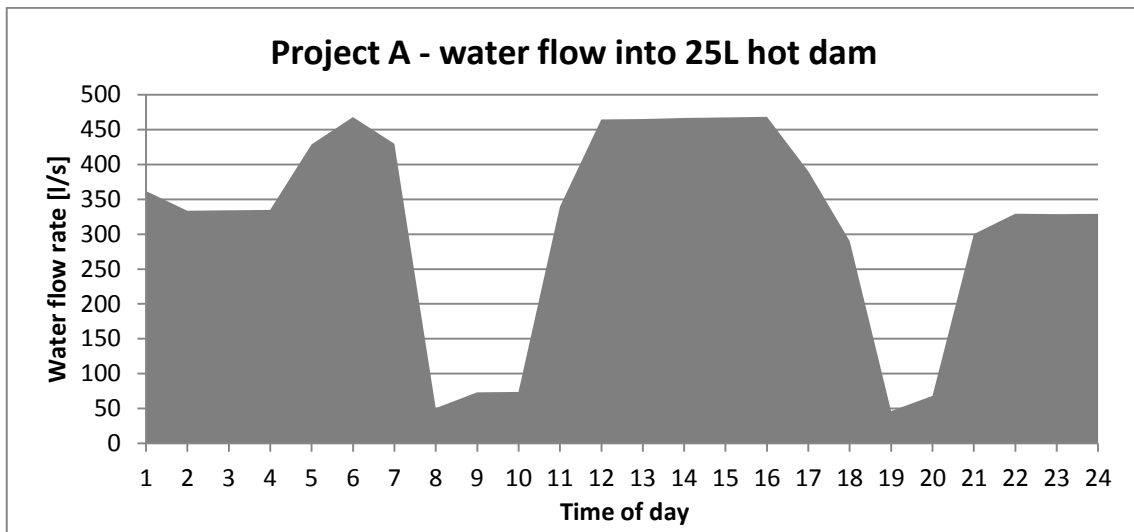


Figure 33: Approximate profile of 25L hot dam's water inflow – Project A.

Figure 33 shows the results of using equation (6) to determine the hourly average water flow into 25 level's hot water dam for a 24 hour cycle.

The primary flow of water into 21 level hot dam was as a result of 25 level's pumps. Any additional water was made up by fissure water and the underground bulk air coolers (BAC's) that directed its used water to the 21 level hot dam (refer to Appendix F). This was determined by using the same method as described to determine Figure 33.

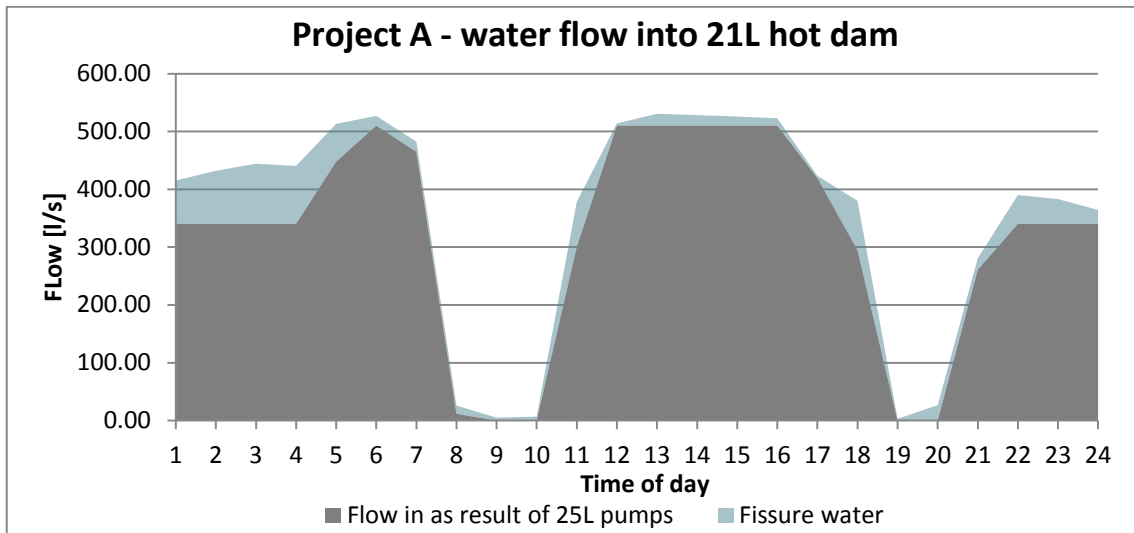


Figure 34: Approximate profile of 21L hot dam's water inflow – Project A.

Using the same method and with the running statuses of 21 level's pump station the water flow into 5 level hot dam could be calculated:

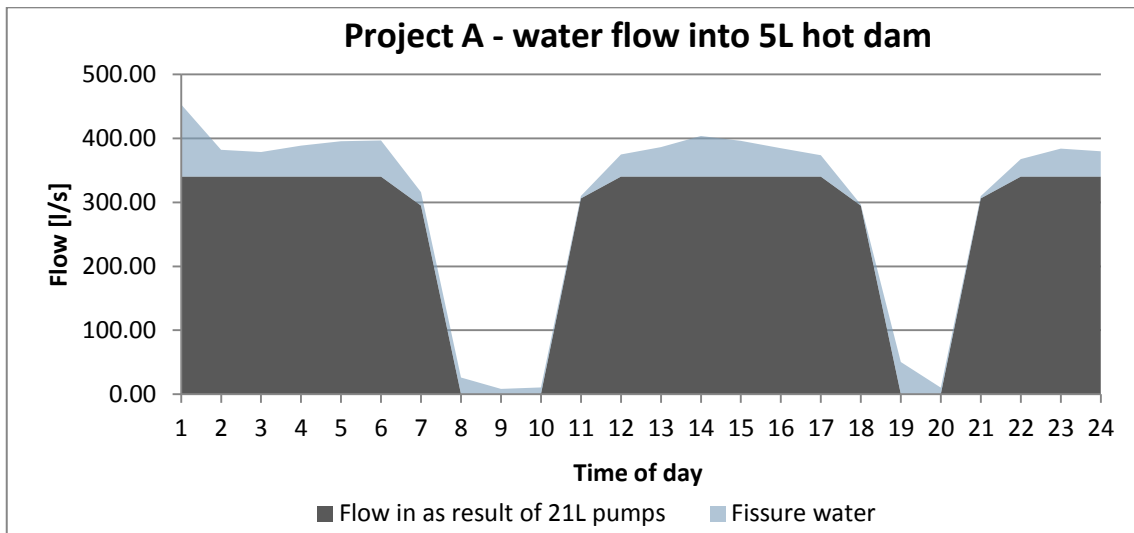


Figure 35: Approximate profile of 5L hot dam's water inflow – Project A.

The flow profiles shown in Figure 33, Figure 34 and Figure 35 were used in the REMS simulations as the water flows into the dams.

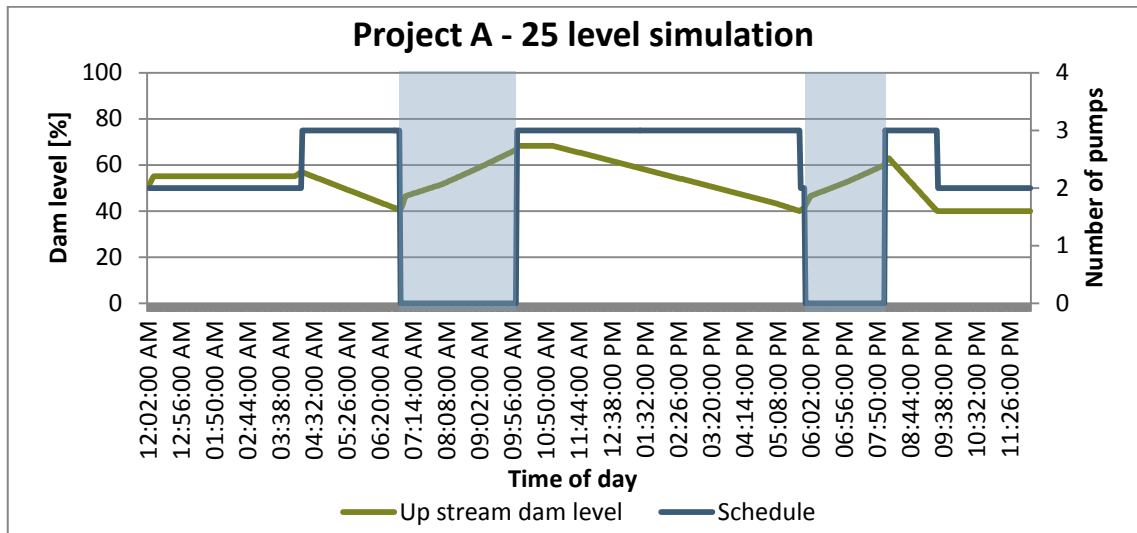


Figure 36: Simulation results for 25 level pump station – Project A.

Figure 36 shows the simulated results for the input flows of Figure 33. The “upstream dam level”-line represents the dam level of the dam from which the pump station pumps the water. The “schedule”-line represents the number of pumps scheduled by the REMS controller to run (relating to the “Number of pumps” on the secondary vertical axis). The peak periods are highlighted (07:00-10:00 and 18:00-20:00). If the “schedule”-line is zero in the highlighted areas, a load shift was achievable during that hour. From Figure 36 it can therefore be noted that a full load shift was achievable during the morning and evening peak time periods since no pumps were scheduled to run during this time by REMS.

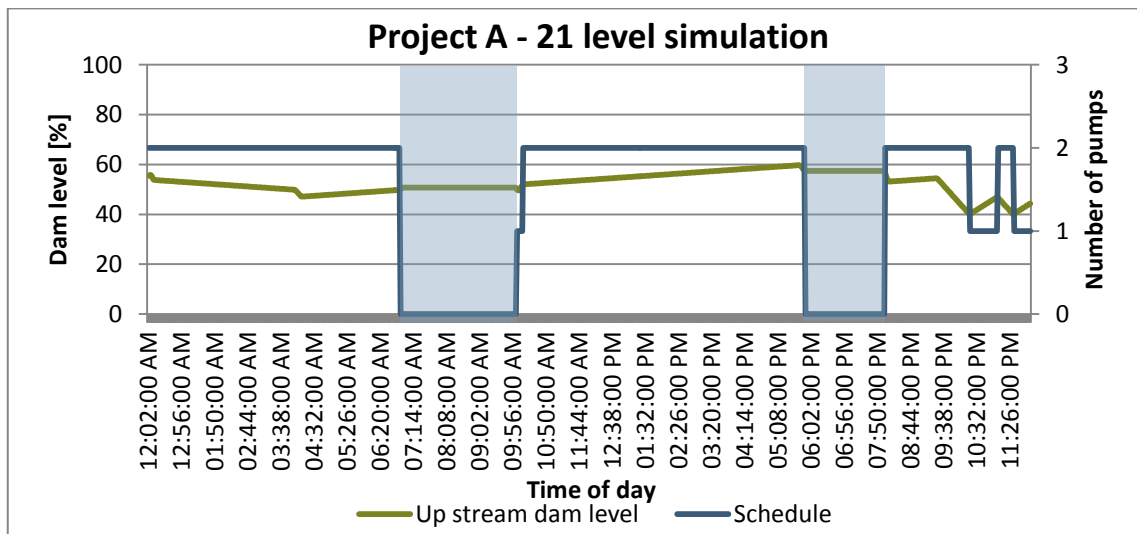


Figure 37: Simulation results for 21 level pump station – Project A.

If 25 level’s pump station was able to achieve load shifting, the probability of 21 level’s pump station as well as 5 level’s pump station to achieve load shifting would be high. This is because both these pump stations’ dams receive the majority of their water from 25 level pump station. If 25 level’s pump station does not pump during peak times, then 21 level’s hot dam and 5 level’s hot dam levels would stay reasonably stationary during peak times, because the majority of the water is received from 25 level hot dam’s pump station. This is illustrated in Figure 37 and Figure 38.

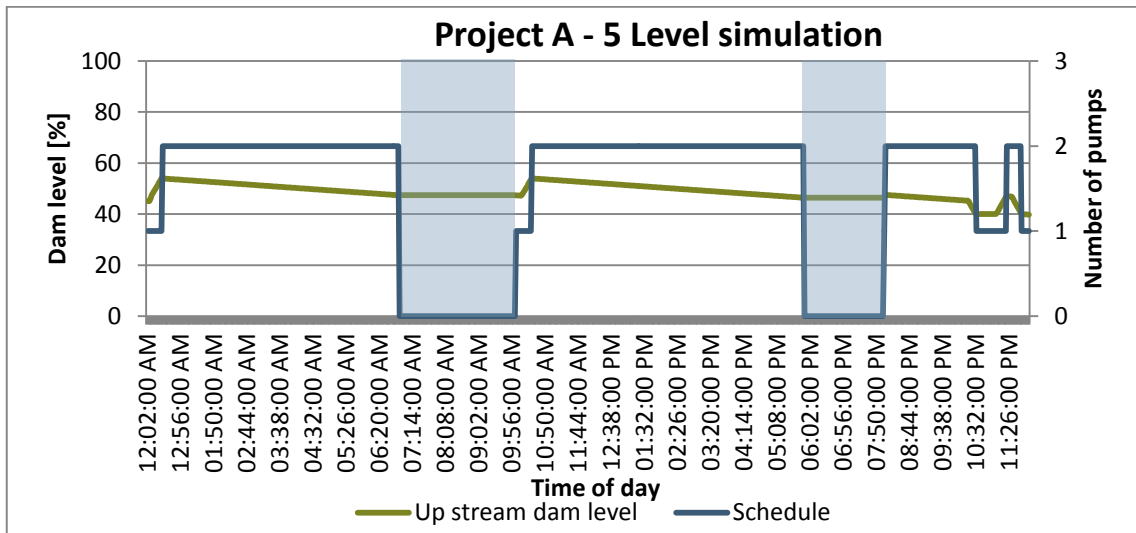


Figure 38: Simulation results for 5 level pump station- Project A.

2.5.2. Project B – Pumping system II

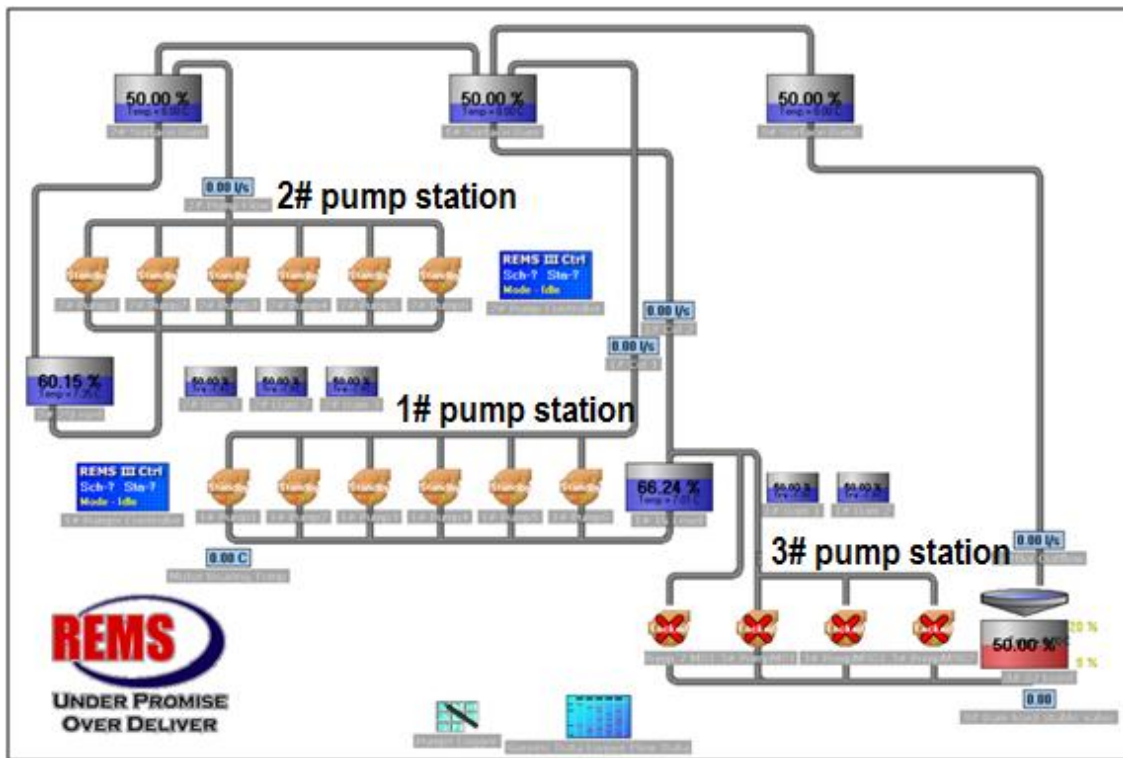


Figure 39: Design of Mine B's hot water pumping system for 1st, 2nd and 3rd shafts.

The design of Project B is given in Figure 39: The baseline for this system can be found in Appendix E.

The available parameters for the de-watering system of Project B are given in Table 4:

Table 4: Simulation inputs for Project B

Pump station	Installed capacity [MW]	Flow rate [l/s]	Total dam capacity [MI]
1#	4	250	4
2#	1.8	400	4
3#	1.8	300	2

For this project, 3# (read: *three-shaft*) pump station was not automated. The pump stations that had to be controlled were 1# and 2# pump stations. 3#'s water was pumped to 1#'s hot water dam. The water flow to 1#'s hot dam from 3#'s hot water dam is shown in Figure 40.

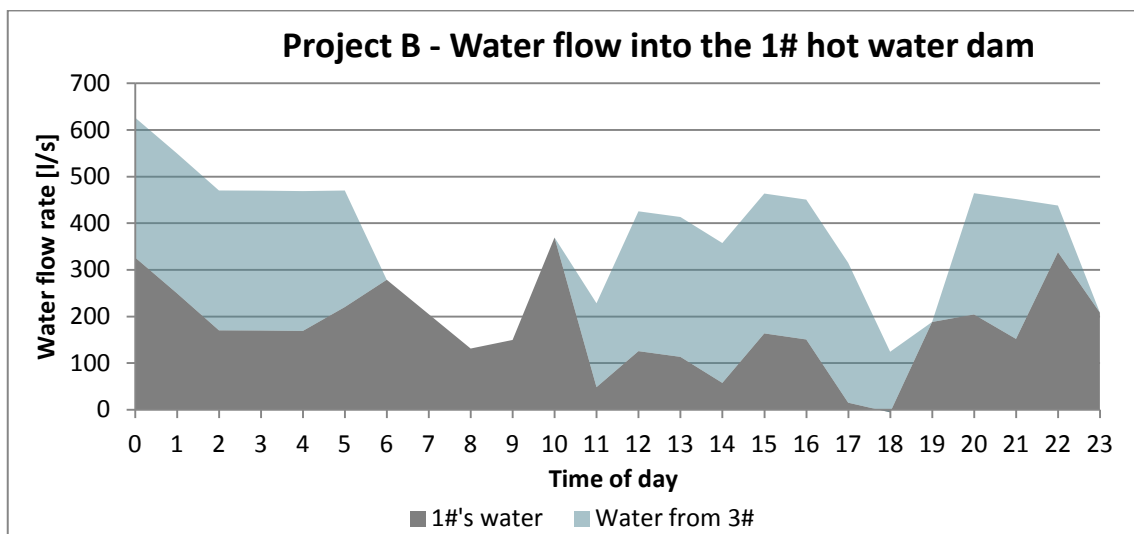


Figure 40: Approximate profile of 1#'s hot dam water influx – Project B.

As shown in Figure 40, the majority of the water influx of 1#'s hot water dam is sourced from 3#'s pump station. The pumping schedule of 3#'s pump station has a great influence on the dam level fluctuations of 1#'s hot dam. The simulation was conducted and the results were plotted as shown in Figure 41.

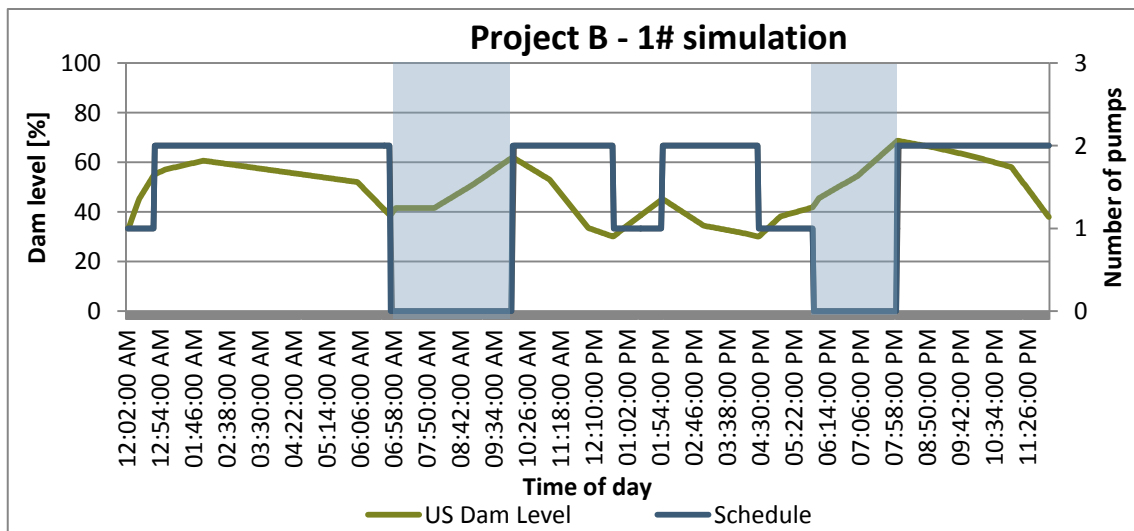


Figure 41: 1# Simulation – Project B.

The water influx of 2#'s hot water dam is as a result of 2# mining operations and 2# fissure water only. The water influx of 2#'s hot dam could simply be calculated with status data of the pumps and the dam level fluctuations (using equation (6)). The results are plotted in Figure 42:

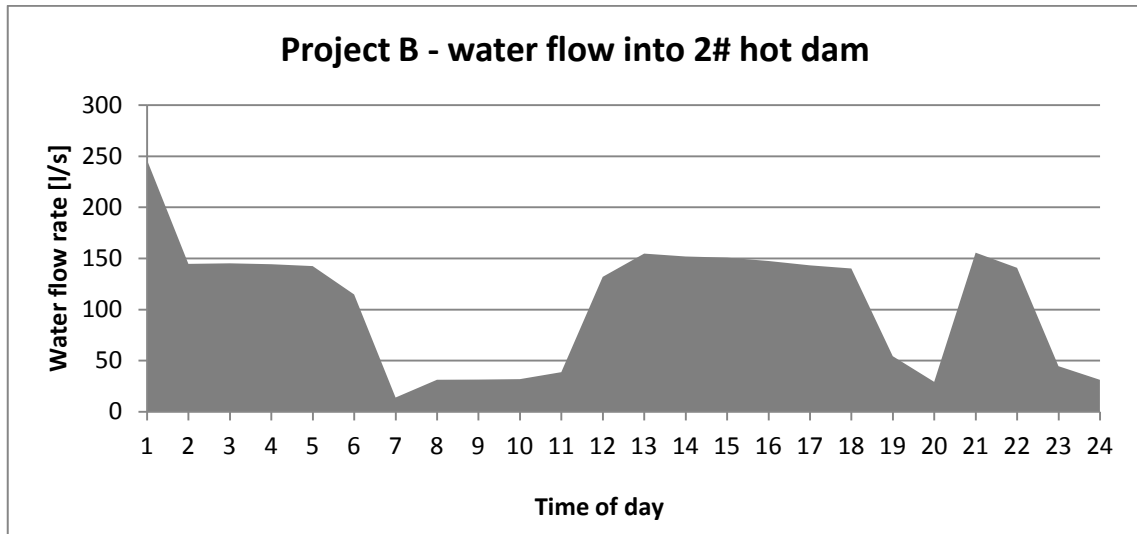


Figure 42: Water influx of the 2# hot dam – Project B.

The influx of water was used to simulate the 2# pumping behaviour. The REMS simulation’s results are shown in Figure 43.

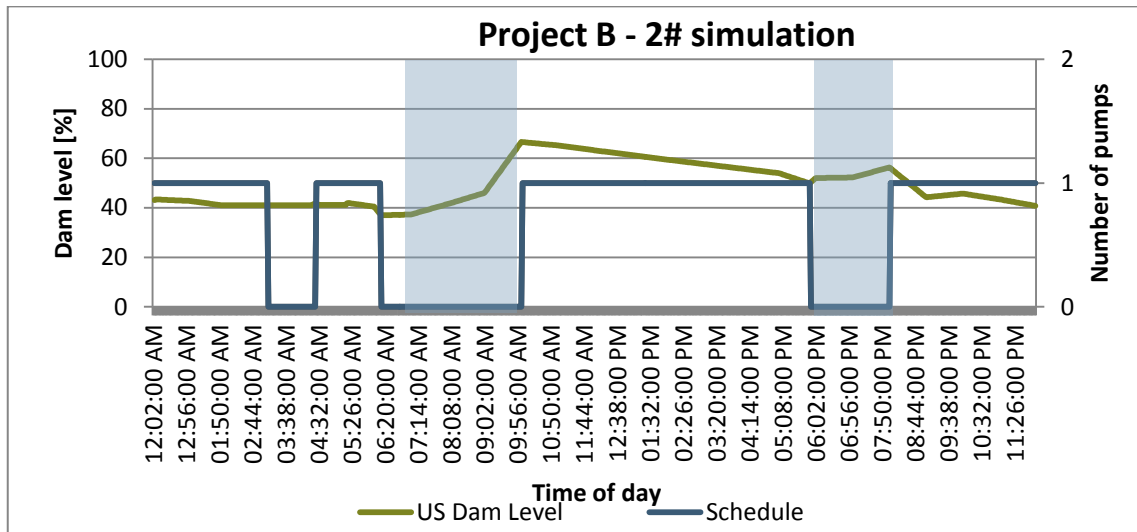


Figure 43: 2# Simulation – Project B.

Figure 43 shows that it will be possible for 2#'s pump station to achieve a load shift by using only one pump. The “US dam level” line represents the upstream dam level of 2#'s hot dam. The “schedule” line shows that REMS could schedule zero pumps to run during both the morning and evening peak periods. The water influx of 2#'s hot dam as shown in Figure 42 is relatively low if compared to that of 1#'s hot dam shown in Figure 40. The deliverable pumping flow rates of 2#'s pumps ensure that the dam level is low enough before the commencing of peak time periods. The total water flow rate of both the fissure water and the mining operations water during the peak time periods are low enough to not fill up the dam levels to its permissible capacity before the end of the peak periods.

2.5.3. Project C - WSO system

The layout of the original WSO project can be found in Appendix G.

The original project entailed the installation of automated valves underground. This was done to reduce the underground water supply of the water distribution system during nonproduction shifts. Due to the high cost of the globe control valves, it was decided to install more cost effective butterfly valves on the main column of the water distribution system (with a diameter of 250mm) together with smaller globe control valves on a bypass section (with a diameter of 100mm). The schematic layout of the valve configuration is shown in Figure 44:

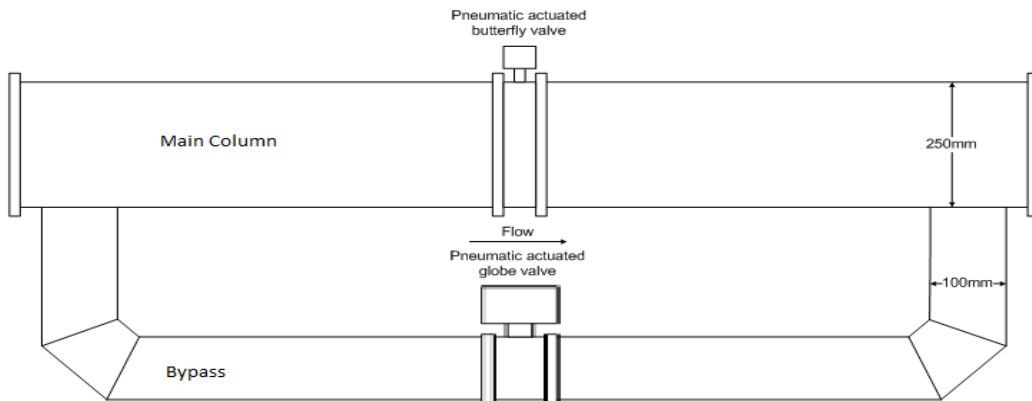


Figure 44: Valve configuration installed for the WSO project [36].

The abovementioned configuration was installed on the upper production levels shown in Figure 70 in Appendix G.

The control philosophy for this project was to close the butterfly valve and use the bypass globe control valve to control the downstream pressure during the nonproduction shifts. The valves are controlled by a programmable logic controller (PLC). A pressure set point is written out from REMS as input to the PLC, via the mine’s SCADA system. The PLC will then use its internal logic to control the actuator of the valve until the downstream pressure of the valve matches the pressure set point. The schedules of the set points are summarised in Table 5:

Table 5: WSO weekday control philosophy [36].

Time	Butterfly valve	Globe valve	Downstream pressure
00:00-16:00	100% open	100% open	1 000 kPa
14:00 22:00	0% open	Control enabled	300 kPa
22:00-00:00	100% open	100% open	1 000 kPa

To more accurately determine what actual impact the valves had on the chilled water distribution system, the pressure-flow curves were plotted from historical data. The two upper production levels that had the most significant flow rates were investigated, namely 88 level and 98 level.

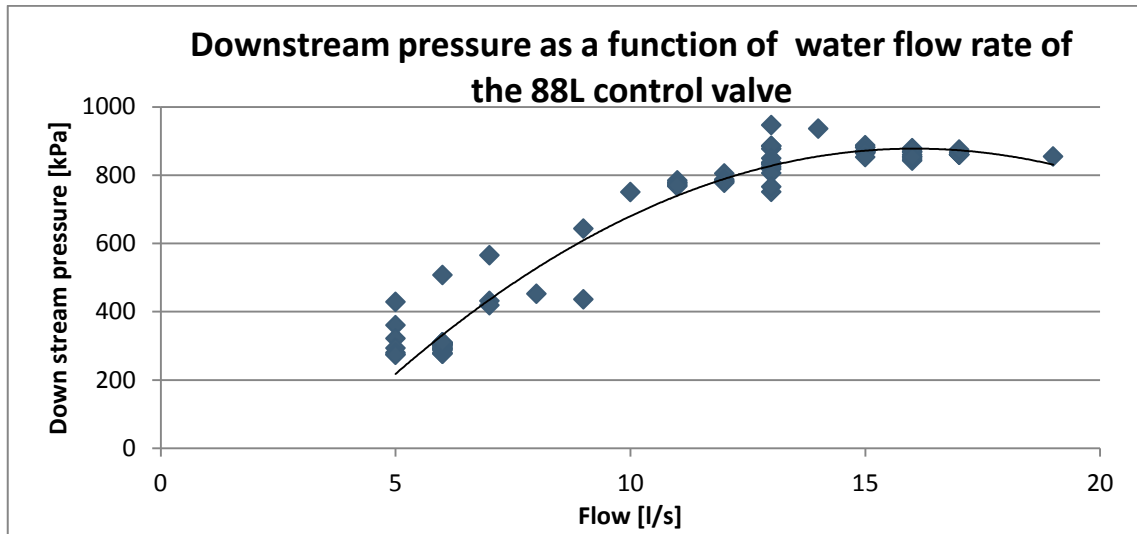


Figure 45: Pressure–flow rate curve of the valve installed on 88L.

Figure 45 and Figure 46 both show clear functions of the impact that the valves have on the water flow rates when controlled according to a downstream pressure set point.

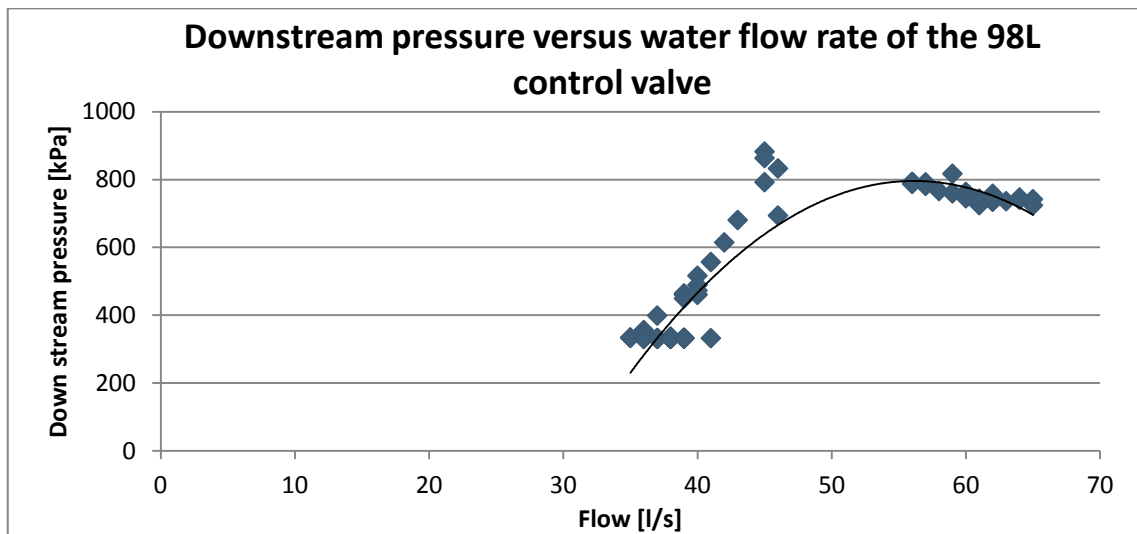


Figure 46: Pressure-flow curve of the valve installed on 98L.

From Figure 45 it can be ascertained that 88 level’s flow rate can be reduced from 19 l/s (at about 850 kPa) to approximately 5 l/s (at about 300 kPa). 98 Level’s flow rate is higher than that of 88 level, but in the same mode the flow reduces from approximately 65 l/s to 35 l/s when the valve is closed until the downstream pressure reaches the set point of 300 kPa.

From these two levels alone a flow reduction of 44 l/s can be expected from 14:00 until 22:00. The other two smaller levels (92 level and 95 level), collectively could be expected to reduce their flow by

approximately 15 l/s using the same method as mentioned for 88 level and 98 level. The collective flow reduction achievable from all the control valves was 60 l/s.

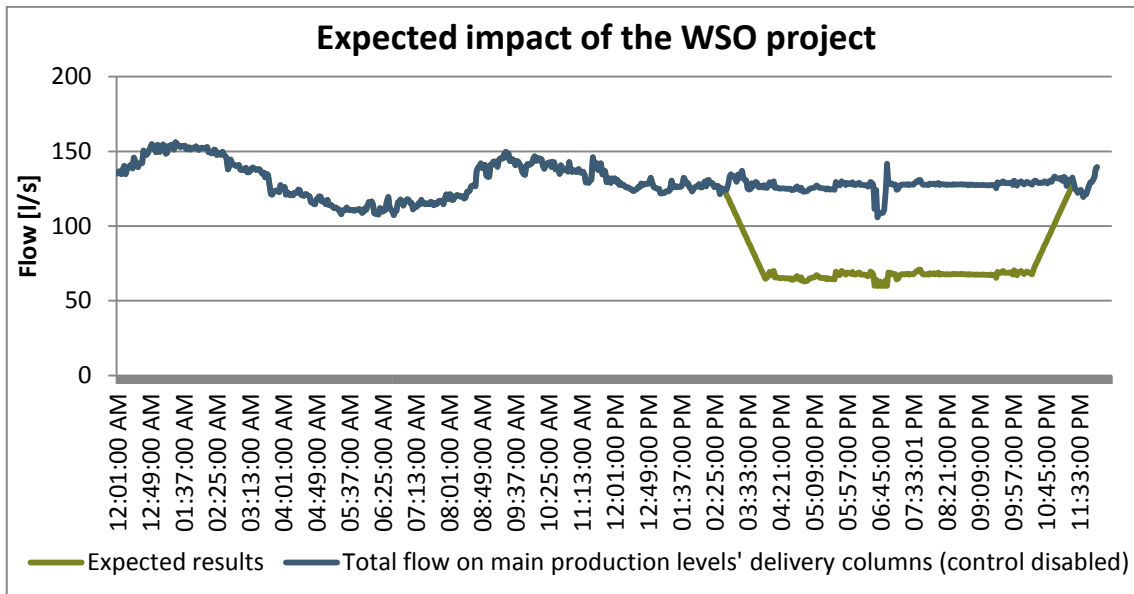


Figure 47: Expected impact of the control valves.

The expected flow rate results are illustrated in Figure 47: The four valves installed in the upper production levels should save at least 20 l/s per day on average by reducing the water flow into the mine in the manner displayed in Figure 47. This reduces the daily water consumption of the mine by approximately 1,7 MI of water per day.

To calculate what impact the reduction in flow rate would have on the de-watering system of the mine, a relationship had to be determined between the total power consumed in a day and the total daily water consumption of the water distribution system. This fairly linear relationship is shown in Figure 46.

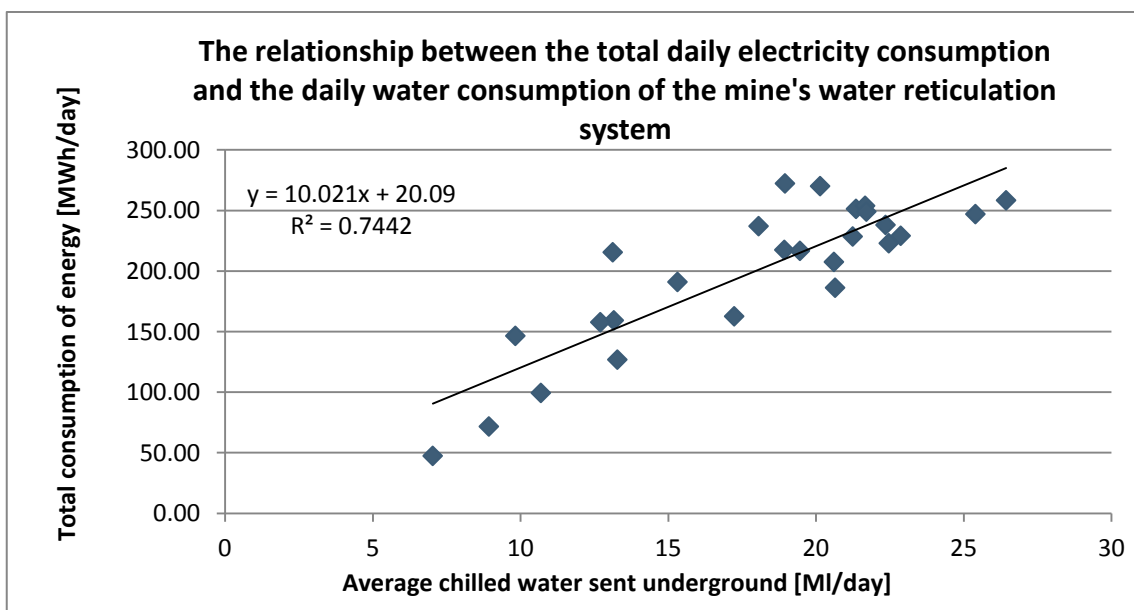


Figure 48: Relationship between the daily electricity consumption and the daily water consumption of the water reticulation system of the mine.

Knowing that the valves are capable of reducing the daily water consumption by 17,2 MI per day, the linear equation represented by the trend line in Figure 48 can be used to determine the approximate saving of the four control valves.

By simply reducing the water consumption of the water distribution system during the afternoon as illustrated in Figure 48, a saving of at least 37,3 MWh per day is achievable. This averages to approximately 1,55 MW per hour over a 24 hour profile.

The intersect of the trend line in Figure 48 indicates that the system consumes 20,09 MWh per day while the system is in operation but it does not contribute to the process. The slope indicates how much energy is required for each unit of water added to the reticulation system. [44]

Theoretically the power reduction can be calculated using the following equation:

$$P = Q\rho gh \quad (8)$$

P = power input [W]

Q = flow [$m^3/s = 1000 \text{ l/s}$] = 60 l/s = 0,06 m^3/s

h = head [m] = 2987 m

ρ = density [kg/m^3] = 1000 kg/m^3 for water

g = acceleration due to gravity [m/s^2] = 9,81 m/s^2

η = efficiency = assumed to be 90% [49]

$$P = \frac{Q\rho gh}{\eta}$$

$$P = \frac{\left(\frac{60}{1000}\right)(1000)(9.81)(9800 \times 0.3048)}{0.9}$$

$$P \approx 1,95 \text{ MW}$$

The theoretical calculation predicts a saving of 1,95 MW which is 400 kW larger than the empirical method.

3. CHAPTER 3 – Verification, assessment of results and validation



In this chapter the actual results of the re-instated projects will be determined.

3.1. Introduction

In this section the actual results of the re-instated projects will be discussed. Each project will be investigated from an operational approach. The operational approach compares the actual results to the simulated or calculated results.

The monetary approach in this chapter considers all monetary aspects for the re-instatement of the projects mentioned in the case studies.

3.2. Comparison of simulations and actual data

3.2.1. Project A - Re-instated pumping system I

The simulated results compared to the actual data captured on site are given in Figure 49 to Figure 51 for each individual pump station.

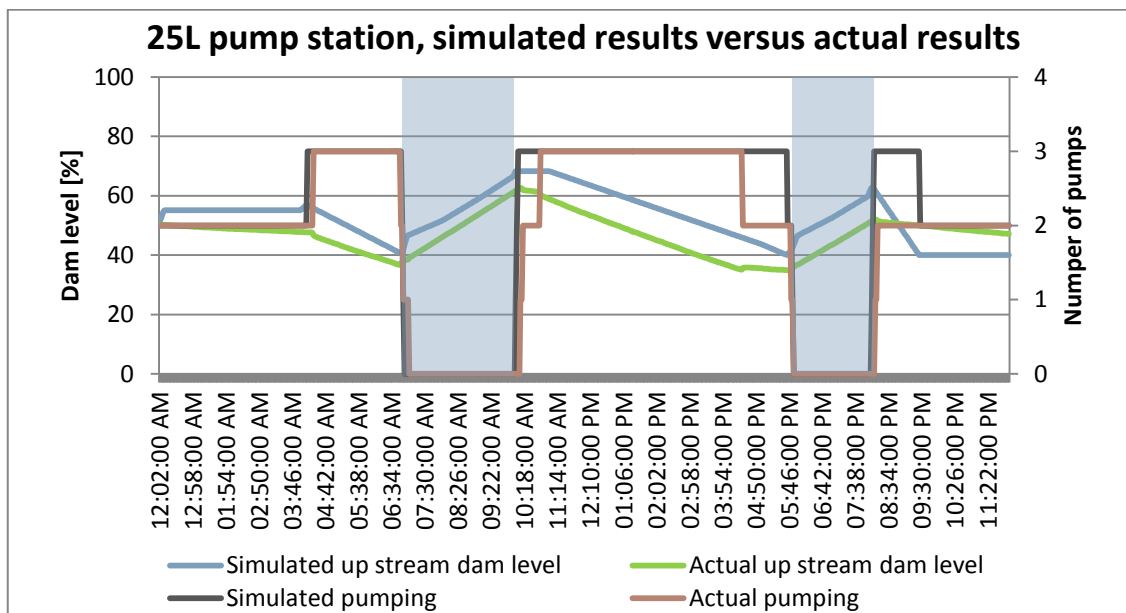


Figure 49: 25L pump station, simulated results versus actual results.

In Figure 49 the “actual pumping” profile and the “simulated pumping” profiles both indicate the number of pumps (secondary vertical axis) scheduled by REMS, either onsite or simulated. The “upstream dam level” is the level of the dam from which the pumping station pumps the water (primary vertical axis). The load shift was found to be possible as determined by the simulations. The “simulated pumping” and the “actual pumping” lines show that the control for the dam was simulated with acceptable accuracy. The dam level’s fluctuations showed the same rate of change. The simulation was successful in predicting that a full load shift for this level would be feasible and also in the prediction of the control schedules.

The simulated dam levels were slightly higher than the actual onsite dam levels. The result was that an extra pump would be scheduled in the simulations when it was not required (for example 20:00 to 21:00 in Figure 49).

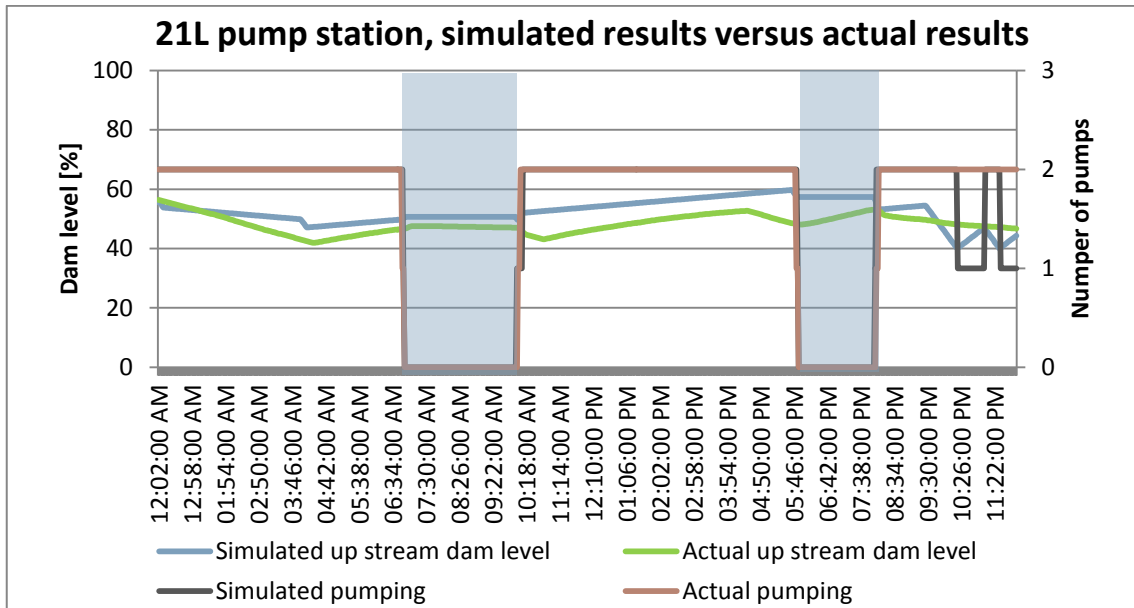


Figure 50: 21L pump station, simulated results versus actual results.

Figure 50 and Figure 51 show that a full load shift was indeed possible as simulated. The actual dam level fluctuations as well as the scheduling of the pumps were once again predicted accurately by the simulations, as was the feasibility of a full load shift. The same was found for 5 level's pump station displayed in Figure 51.

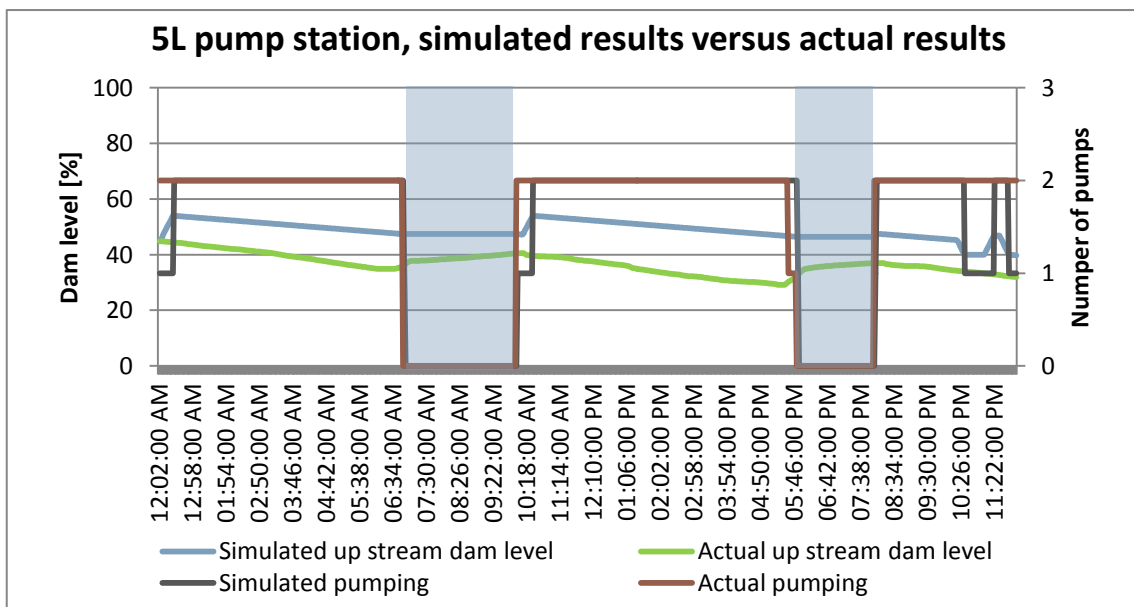


Figure 51: 5L pump station, simulated results versus actual results.

A full load shift was predicted for all the simulations and was also realised on site. The dam levels' fluctuations were considered to be accurate as well as the control of the number of pumps.

3.2.2. Project B - Re-instated pumping system II

The simulated results compared to the actual data captured on site are given in Figure 52 and Figure 53 for each individual pump station.

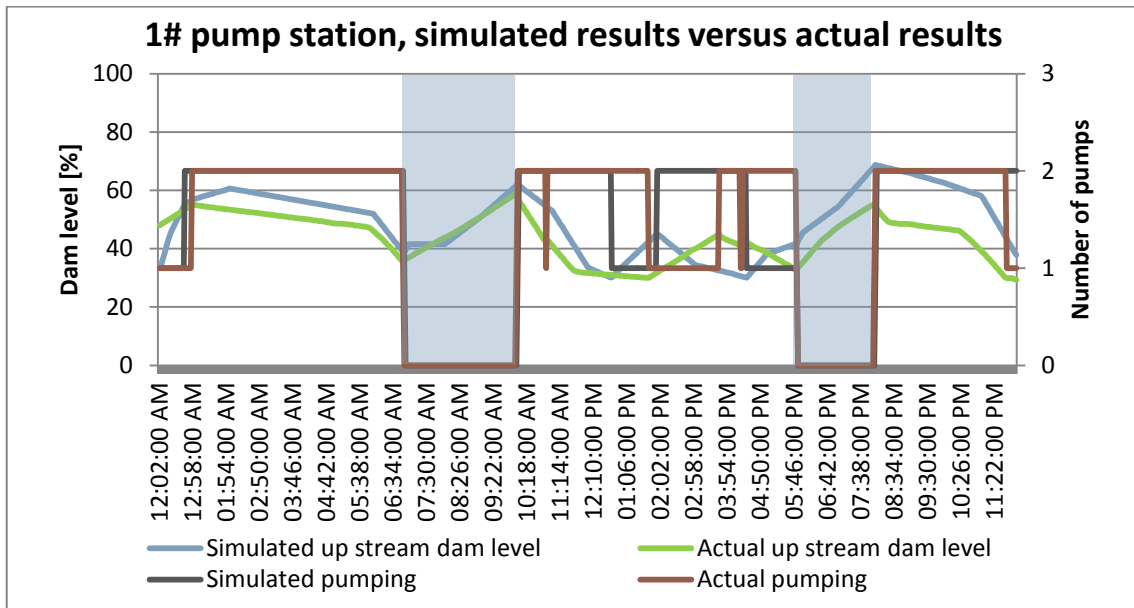


Figure 52: 1# pump station, simulated results versus actual results.

During the early morning and late evening periods, the simulation was accurate in predicting the pump scheduling as well as the dam level fluctuations. For the 1# pump station a full load shift was simulated to be achievable for both the morning and evening peak time periods. The system was able to achieve full load shifts and the system shown to be capable of controlling the pumps accurately. At times, the actual pumping differed from the simulated pumping, causing the difference in the dam level trends as well. These differences are a result of the actual water flow rates differing from the theoretically calculated and simulated flow rates. The simulation for 2#'s pump station is compared to the actual results in Figure 53:

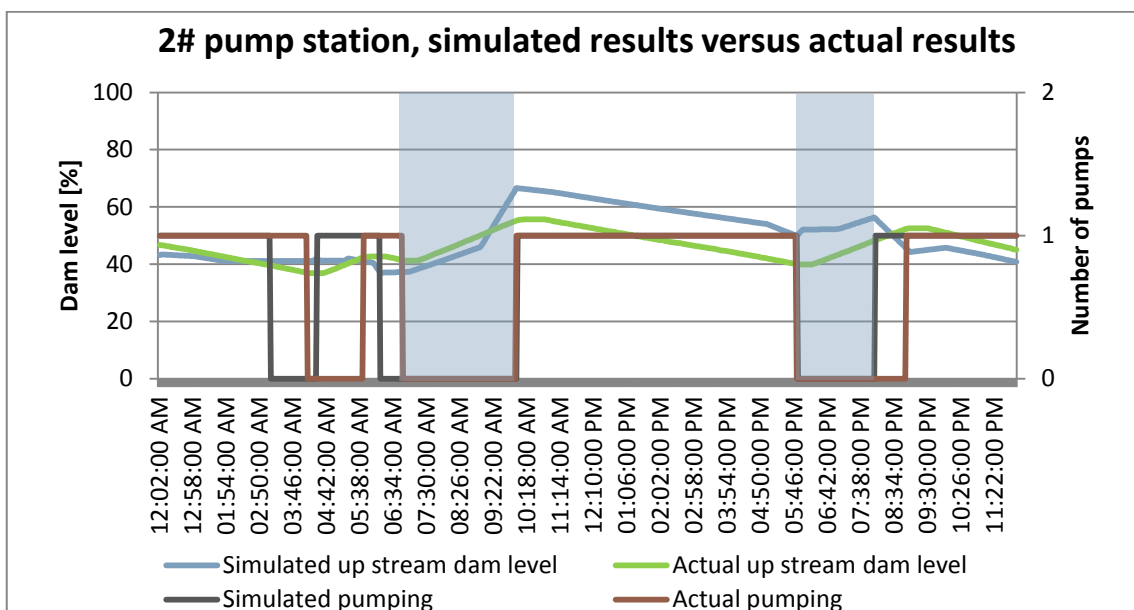


Figure 53: 2# pump station, simulated results versus actual results.

From Figure 53 it can be noted that the profiles of the simulated dam levels and pumping schedules were similar to the actual results captured on site. During the early morning, the schedules of the pumps in the simulation were similar to the actual on site schedule. The actual pumping profile is similar to that of the simulation. The same result occurred after the evening peak.

The simulation predicted that a full load shift would be possible. The actual results demonstrated similar pumping schedules and dam level trends than that of the simulation.

3.2.3. Project C - Re-instated WSO system

The flow rate of the upper mining levels before and after the re-implementation of the system is shown in Figure 54. It is apparent from Figure 54 that the re-instated total flow rate (“control enabled” graph) from 12:00 to 22:00 is considerably less when compared to the historical trend (“control disabled” graph).

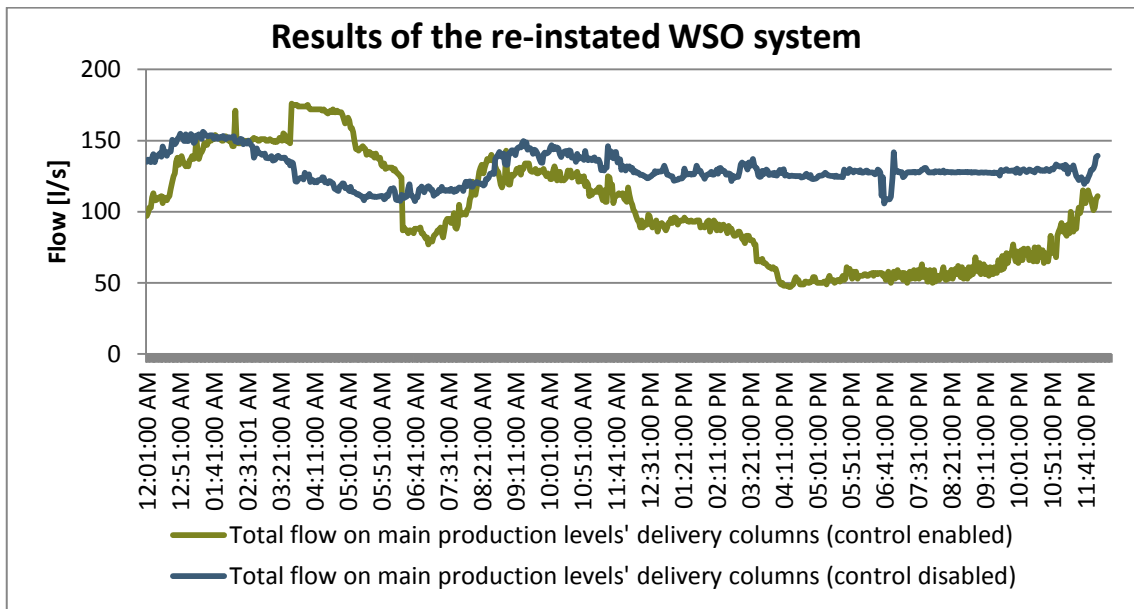


Figure 54: Results of the re-instated WSO system.

From the data plotted in Figure 54, the total reduction in water consumption of the water distribution system was 2,87 MI compared to the disabled system. This is an average reduction in water consumption of 33 l/s.

According to the same calculations completed in section 2.5.3, the daily reduction of 2,87 MI water realised electrical energy savings of 49 MWh. That is a daily average of electrical power saving of 2 MW. The reduction in water intake of the mine during the afternoon period also increases the mine’s ability to perform an evening load shift by its de-watering system. This is because the inflow of water into the underground hot water dams is reduced. The mine’s ability to achieve load shifting during the evening peak time will also improve. This will increase the overall monetary savings for the mine.

3.2.4. Validation of simulations

The deviations in the simulations were as a result of slight deviations between actual flow rates and theoretical flow rates used in the simulations. The dam sizes used in the simulations were also estimates of the actual available capacities of the dams. Underground Dams accumulate mud that leads to a reduction in capacity. This will impact the accuracy of a simulation. The daily production and changing procedures also change the cooling water demand needed underground. This influences the accuracy of theoretical calculations and simulations of all the systems mentioned in this study.

Although the simulations were successful, it must be taken into consideration that the simulations and calculations were compared to a typical average working week-day at the mine. In the mining industry, it is very rare that one day's operations are not at variance with the next. It is possible for the mine's dams to receive a sudden flood from an unknown underground water source, or from a large pipe leak. Consequently the viability of a full load shift throughout the peak time will decrease. 21 Level's hot water dam experienced this scenario after the re-instatement of Project A's system.

Other influencing factors include; mining operations, equipment failures and accidents. Certain mining operations may result in a sudden inflow of water to one of the underground dams, influencing the feasibility of a full load shift.

Pumps which are out of order often result in a hold-up in the dewatering system. The result is that the dam may be full before a peak time when it is, in fact, required to be empty to achieve a load shift. The pump station will then be required to pump throughout the peak time to dewater its underground dams.

The mining industry responds very stringently to accidents. Accidents have the potential to close down mining operations for long periods on end. The use of chilled water is then decreased which results in low dewatering.

3.3. Outcome of re-instated systems

In this section the results of the projects that were successfully re-instated will be discussed. After the re-instatement of the systems, the ESCo continuously monitored the systems to ensure sustainability. The performances of the projects were recorded and the accumulated savings were determined.

3.3.1. Project A - Re-instated pumping system I

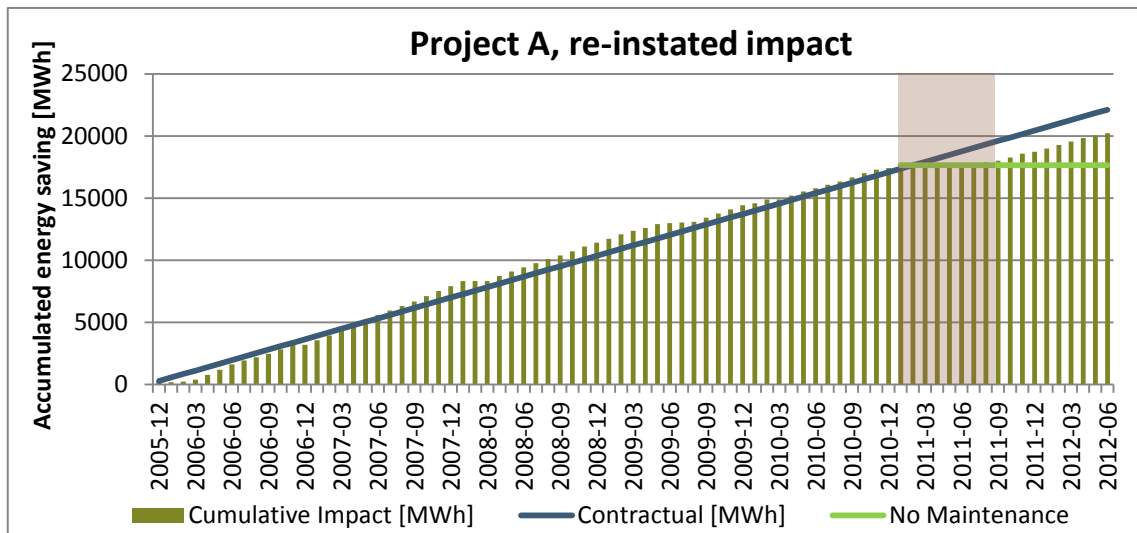


Figure 55: Project A – re-instated impact.

Figure 55 depicts the full cumulative saving history of Project A. The period in which the system was out of order is highlighted. After the system had been re-instated (in 2011) the savings accumulated as it had done before. The actual missed opportunities are calculated and compared to the trend line called “No maintenance”. “No maintenance” represents what the accumulated power graph would have been if no maintenance had been performed. If no maintenance had been performed, the “cumulative impact” line would have remained horizontal as the “no maintenance” line does from December 2012 onwards.

$$Actual\ missed = Contractual - Cumulative\ impact = 22\ 120 - 20\ 221 = 1\ 898\ MWh$$

$$No\ maintenance = Contractual - No\ maintenance = 22\ 120 - 17\ 643 = 4\ 476\ MWh$$

By June 2012 the cumulative missed opportunities were 1 898 MWh as a result of the re-instatement that was performed mid 2011. If the re-instatement was not performed, the missed opportunities would have been 4 476 MWh by April 2012.

3.3.2. Project B - Re-instated pumping system II

The second case of re-instatement is shown in Figure 56. The system was also re-instated mid 2011. The inclusion of the trend line is to illustrate the savings that were missed.

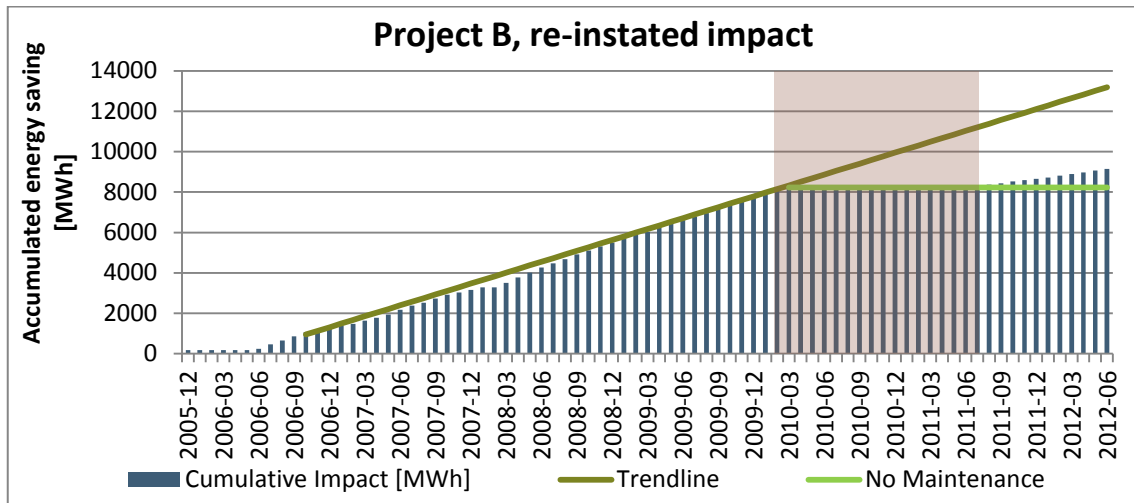


Figure 56: Re-instated pumping system II.

From Figure 56 it can be ascertained that the lack of maintenance resulted in missed opportunities of approximately 4 036 MWh. This specific project ceased to perform at the beginning of 2010. After the re-instatement of the system the average evening load shift of 2 MW was realised. The projects discussed in Figure 55 and Figure 56 are both at mines that belong to the same mining group. When the missed opportunities of different projects of a mining group are added, the total lost opportunities accumulate rapidly.

3.3.3. Project C – Re-instated WSO system

In contrast to the load shifting pumping projects, WSO projects are efficiency projects. The complete 24 hours of the day are relevant to the savings for that day. If an efficiency project is not performing, the missed opportunities can accumulate significantly.

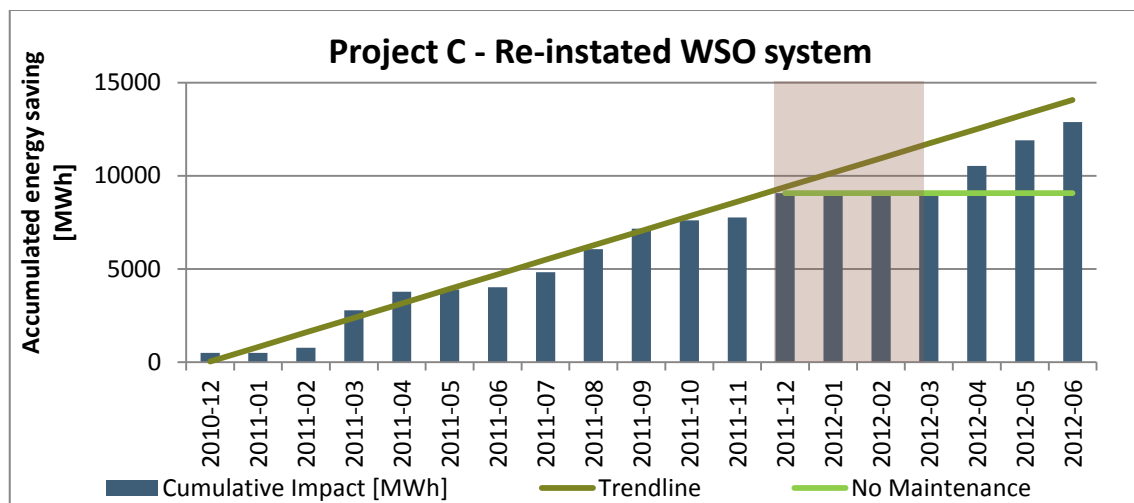


Figure 57: Re-instated WSO system.

Figure 57 shows the full history of the re-instated WSO project. During the first three months the project was still in its implementation phase, and did not function at its full capacity. The trend line was constructed to average the savings' gradient.

If an efficiency project is expected to reduce the load by 1 MW, it is expected to save 24 MWh in a day (1MW*24hours). It is for this reason that the WSO project could accumulate an actual missed opportunity of 2 654 MWh in only four months (the accumulated missed opportunities before the re-instatement of the project in April 2012). If the system had not been re-instated the missed opportunities would have escalated to 4 994 MWh by June 2012.

Table 6: Project C's average electrical power savings after re-instatement.

Date	Impact [MW]
2012-04	3.04
2012-05	2.86
2012-06	2.04
Average	2.64

An average reduction of 2,64 MW was achieved for the three months after the re-instatement of the system, which is almost 1 MW more than calculated. This is a result of the load reduction that was expanded over a larger period than anticipated, as shown in Figure 54 compared to Figure 47.

3.3.4. Maintained pumping system

The following pumping system has been maintained by both the ESCo and the mine since its commissioning.

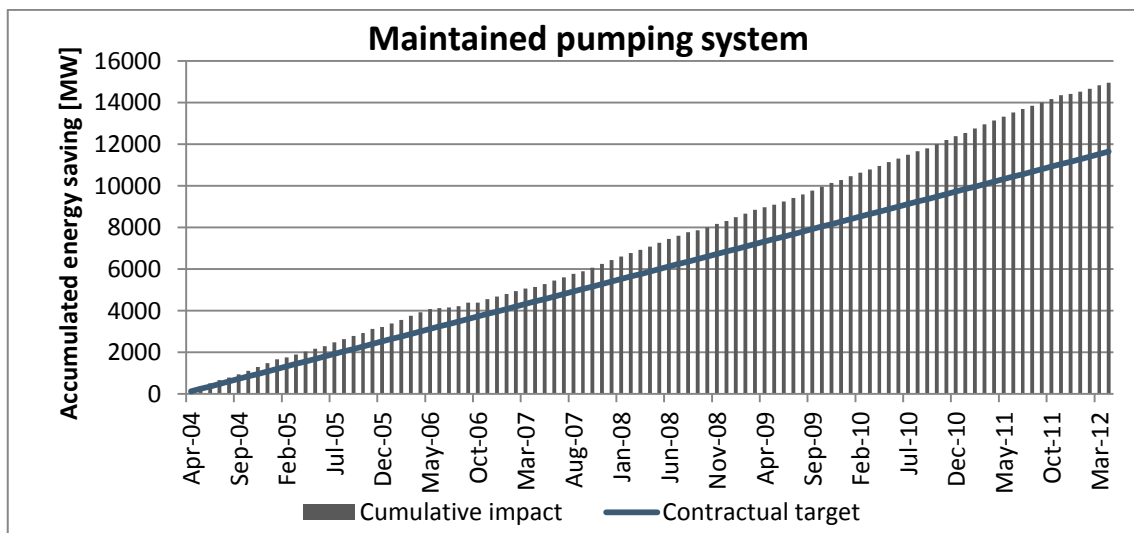


Figure 58: Maintained pumping system.

Figure 58 clearly illustrates the savings of a well maintained project. Compared to the previously discussed pumping projects this project has achieved 3.3 GWh in over performance.

3.3.5. Maintained WSO system

The WSO system depicted in Figure 59 was continually maintained. At this specific mine the instrumentation technician was appointed specifically to continuously maintain and optimise the system. The mine also has energy engineers who are responsible for energy related projects.

The neglected WSO system, as discussed in section 2.5.3, did not receive the same consideration by its mining personnel as the maintained WSO system did, both from an installation and maintenance point of view. Had the maintained WSO system’s mine applied the same amount of attention to the WSO system, as that of the neglected WSO system, it would most probably have achieved the same savings as that shown in Figure 57.

The over performance of this system is a clear indication as to what potential lies in a WSO system. A 26,5 GWh over performance in only a year was achieved by this WSO system.

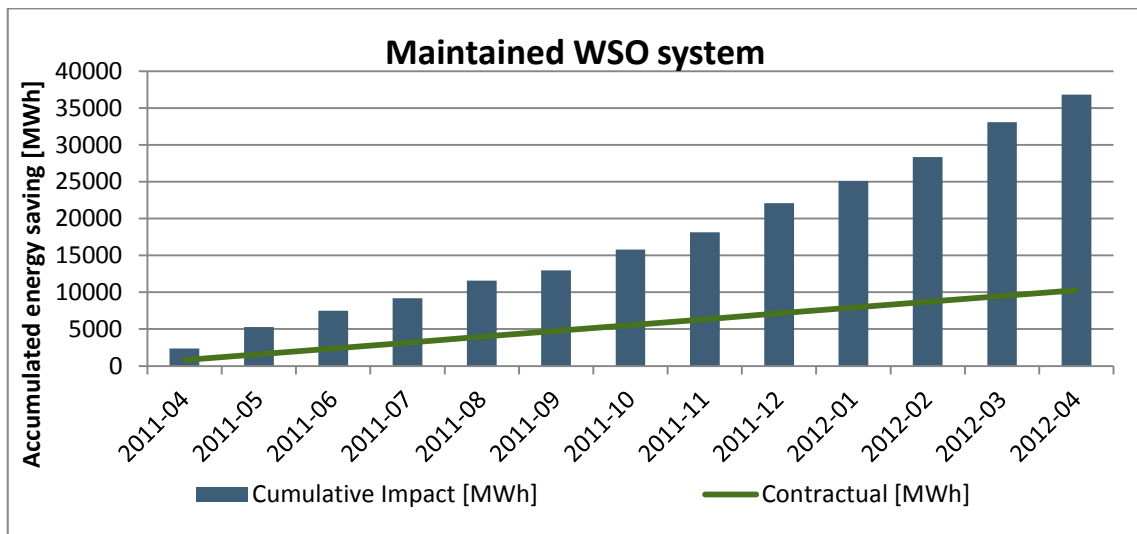


Figure 59: Maintained WSO system.

3.4. Business case for re-instating DSM projects

Figure 60 below summarises the theoretical monetary savings for the case studies discussed from section 2.4 onwards. The missed opportunities were calculated by comparing the actual achieved savings to the proposed savings. The proposed savings are derived from a 24hr profile that would achieve optimal results for the system. The missed opportunities for the two maintained systems were either very small or zero, respectively.

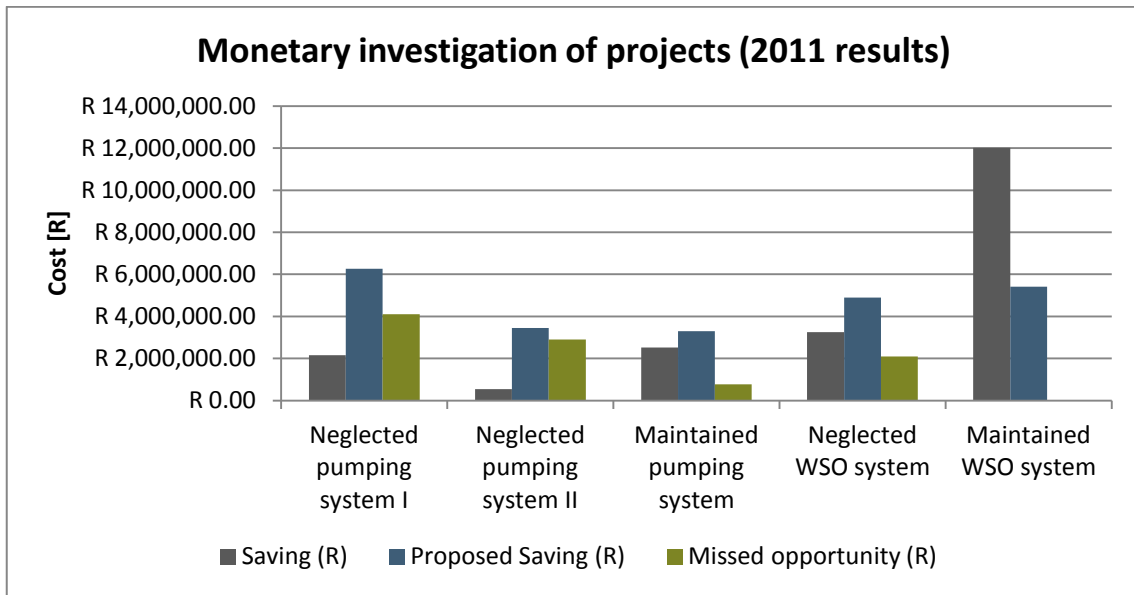


Figure 60: Monetary values of projects' performances.

Table 7: Savings, proposed savings and missed opportunities of investigated systems.

	Saving (R)	Proposed Saving (R)	Missed opportunity (R)
Project A	R 2 159 708.60	R 6 268 945.37	R 4 109 236.82
Project B	R 543 064.61	R 3 445 273.68	R 2 902 209.07
Maintained pumping system	R 2 527 055.40	R 3 294 729.78	R 767 674.37
Neglected WSO system	R 3 256 418.30	R 4 890 110.12	R 2 101 496.53
Maintained WSO system	R 12 025 850.00	R 5 410 627.47	R 0.00

The supporting tables with values for Figure 60 and Table 7 can be found in Appendix D. Unfortunately there was loss of data for the old pumping projects in particular. Values were assumed based on the other data entries for 2011 (displayed in red in the tables of Appendix D). This is to ensure that the monetary values calculated are conservative.

3.4.1. Re-instating Projects A and B

Neglected pumping systems I and II are part of the same mining group and are located close to each other. The maintenance performed on the systems was addressed during the same period of time.

The total expenses added up to a total of approximately R 230 000 for the restoration of both the pumping systems. The cost involved was about R 115 000 per system. Included in these costs are all hardware replacements such as servers, communication devices, software, etc. No underground

equipment needed to be replaced for the restoration of the systems. If there were underground equipment that required replacement, the responsibility would have been that of the mine.

Figure 61 and Figure 62 show the savings that the re-instated pumping systems achieved in a year. Re-instated pumping system I's savings accumulated to R 2,7 Million and re-instated pumping system II's savings accumulated to about R 750 000. The R 115 000 investment necessary to re-instate the system was made up in only one month by re-instated pumping system I. Re-instated pumping system II doubled the maintenance investment in only one winter month as illustrated in Figure 62.

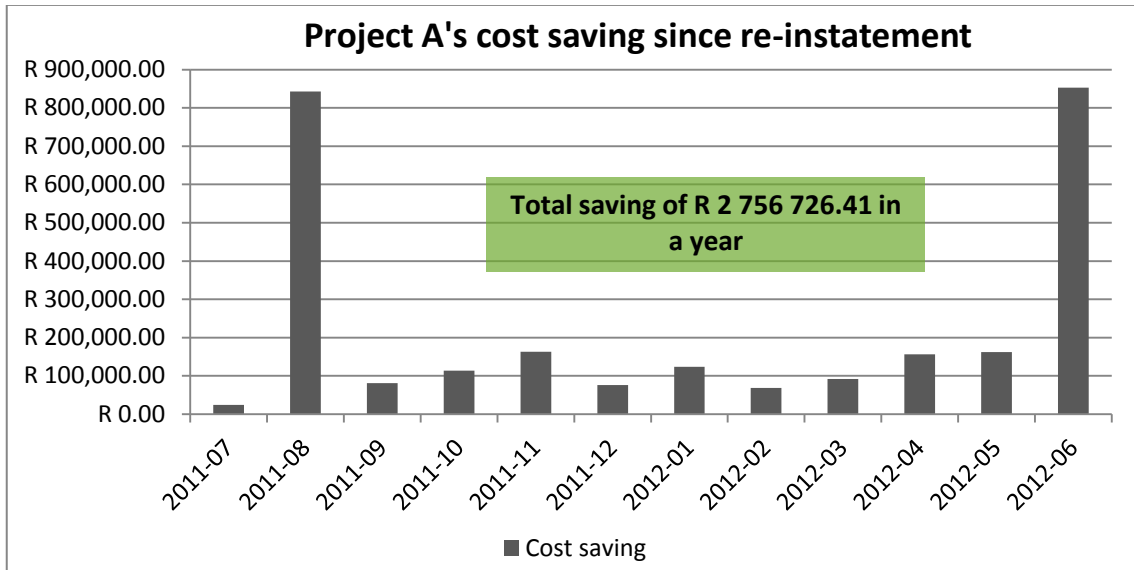


Figure 61: Project A's cost saving since re-instatement.

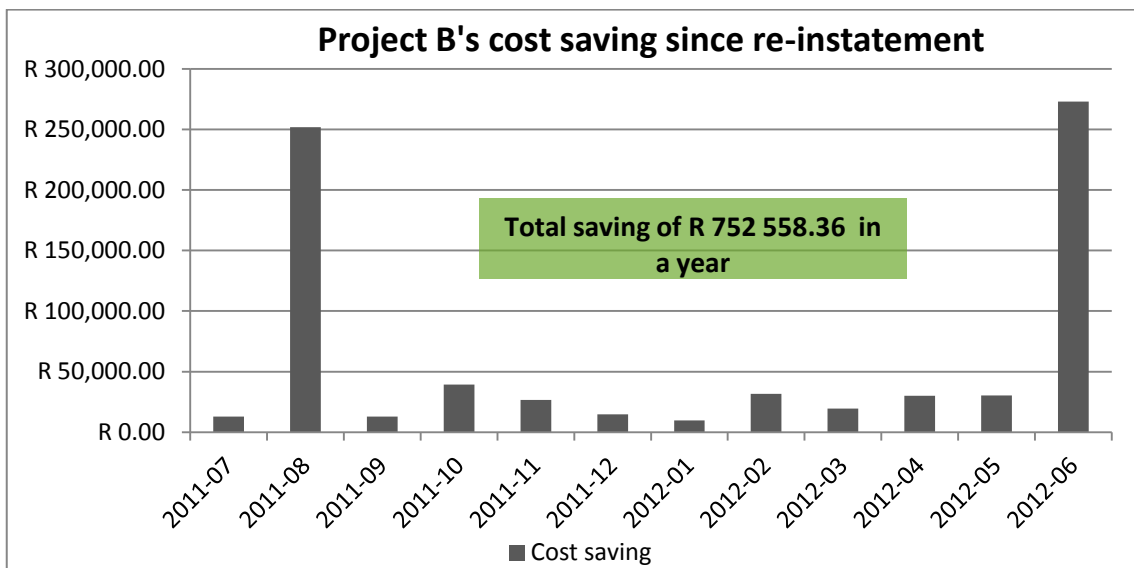


Figure 62: Project B's cost saving since re-instatement.

3.4.2. Re-instating the WSO system – Project C

The amount of money saved by the WSO project after re-instatement added up to R 1,5 Million in only three months after re-instatement. The cost to re-instate the project was less than 1% of the savings achieved in the three months shown in Figure 63:

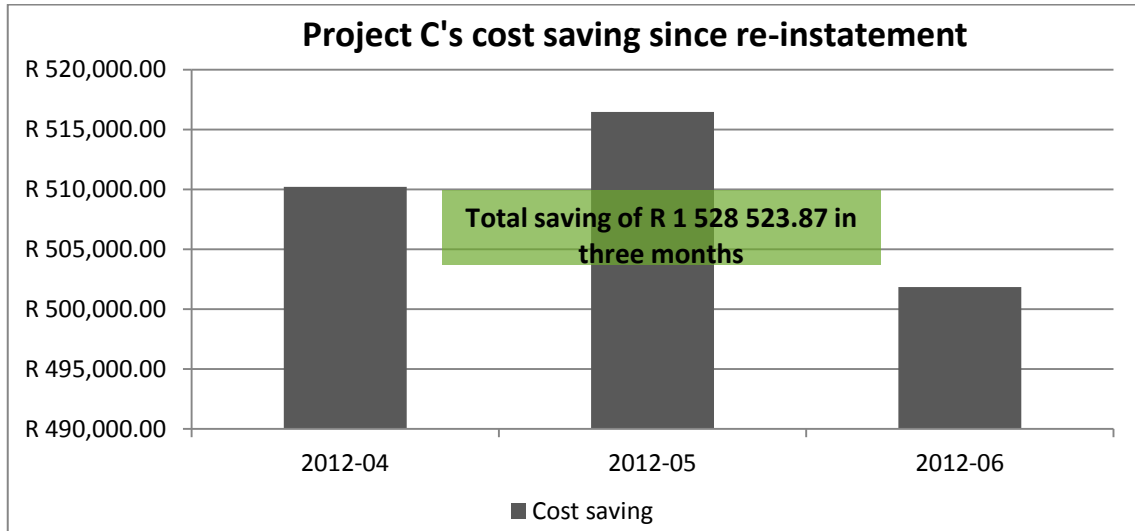


Figure 63: Project C's cost saving since re-instatement.

3.5. Sustainability of re-instated systems

An investigation was done to identify factors that lead to the decommissioning of DSM projects. The major problems were identified as:

1. Hardware failures.
2. Changes or upgrades on the communication network.
3. Process changes.
4. Business and operation changes.
5. Inconsistent priorities.

For the projects mentioned in this dissertation failures were mostly related to the computational aspects of the project. The computers and software were outdated. The communication networks were unstable and communication was regularly interrupted. The mine's inconsistent priorities between production and saving frequently led to equipment being decommissioned.

After the re-instatement of each of the systems, it was found that frequent changes to the system were required as a result of the mine's regular operational changes. This was the case for the pumping systems in particular.

Initially, modifications were necessary on a weekly basis. The changes became less frequent as each system was adjusted for the mining requirements. Months after the re-implementation of the systems, the changes required for each system were not as frequent, however changes were still made when requested by the mine. Communication failures are also inevitable in the systems where the communication networks are unstable, in which case attention to the system are essential.

The resources to be able to log onto the system at the mine from a remote location have proven to be of utmost importance. If an automated system is expected to control a sector of a mine, the necessary support must be available within a short period of time. Since the mines are located throughout South Africa, immediate access to the system can be achieved more easily via a secure network connection to provide remote support. Such a connection can be established with the help of internet service providers' networks and programs like VNC (Virtual Network Computing).

3.5.1. Problems encountered regularly

After re-instatement of the projects, the following problems were encountered:

1. Pumping systems would need adjustments as a result of irregular and unexpected high masses of water inflow in the form of fissure water. At the pumping systems of projects A and B, operators would pump water out of small dams that fill up gradually, but are not part of the main hot water de-watering system. The sudden extra inflow of water would cause one of the dams to fill up quicker than normal. Initially adjustments needed to be made regularly to compensate for these instances.
2. The network at project A was unstable as a result of high network traffic. The result was that precautions had to be implemented to counter both the unstable network of the mine as well as the bad connection to the internet service provider. The unstable network of the mine would break the connection to the REMS system at random intervals. To counter this, internal functions were written to the REMS system to reconnect every time the connection was dissected.
3. Equipment operators would often override the water control valves to allow more water at the request of the mine workers. This was instituted only for work done out of routine, but the operators would then forget to set the control back to REMS's control, resulting in a lack of savings.

As a result, the daily reports of the REMS system are of high importance. The ESCo sends out daily emails of the mine's performance of the previous day. These reports are fully detailed and are the first indication to an engineer when there may be a problem. The engineers are not available to monitor the systems at all hours of the day, and therefore these reports are essential. It is for that reason imperative to ensure that all the systems' communication functions are fully operational.

3.5.2. Change in achievable load shifting

For load shifting projects the baseline is scaled according to the total energy consumption of the day. If the total energy consumption for the day of interest is less than that of the baseline period, the baseline will scale lower. The achievable load shift out of the peak time will therefore reduce. This is shown in Figure 64 (highlighted areas). The area under the “Unscaled baseline”-line during the peak times is reduced to the area under the “Baseline scaled lower”-line during the peak times as a result of the “Low pumping totals” for that specific day.

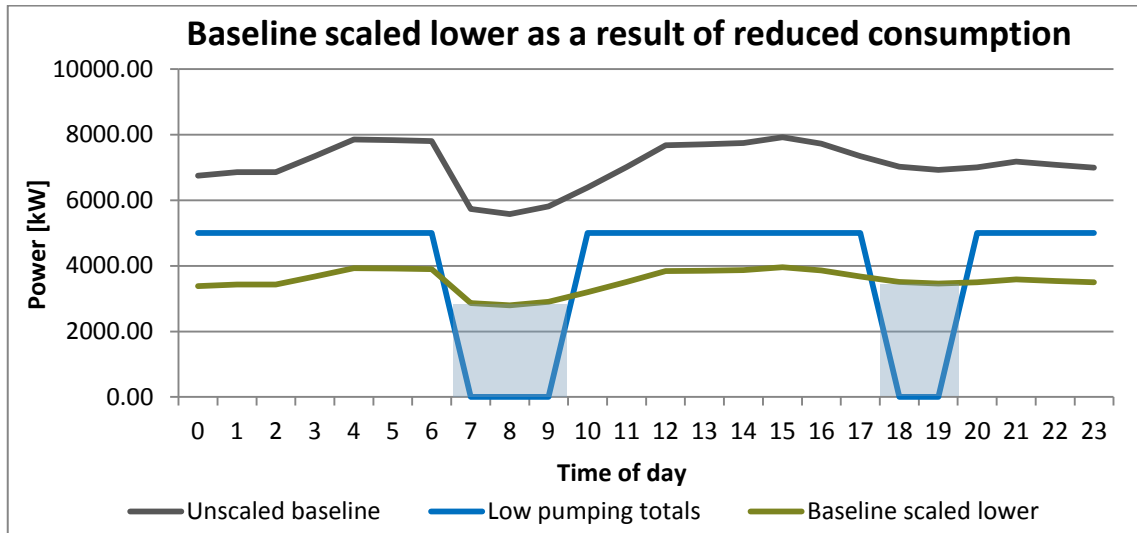


Figure 64: Lower water consumption resulting in lower achievable load shifting.

Before Project B deteriorated, an average load shift of approximately 5 MW was achieved in the evening peak time. After the re-instatement 2 MW savings were realised daily. The total water pumped daily decreased. The system is still capable of shifting its entire load to off-peak hours, but this load has decreased as the total load of the mine has decreased over the years. It is therefore not achieving a load shift of 5 MW as it did in the past, but only 2 MW. The dewatering system is physically not capable of achieving a larger load shift. This will influence the deliverable load shift promised to the client and must be kept in mind when determining the sustainability of the project during the investigation phase of the project.

The reduction in total energy consumption of the mine may be as a result of:

- Reduction in production. The mine has/will close down sections of the mine.
- Other DSM projects that reduces the mine’s water usage, such as a WSO project.
- Changes to the water reticulation system of the mine, for example the addition of an underground fridge plant.

4. CHAPTER 4 – Conclusions and recommendations



<http://www.enterprisesmartgrid.org>

This chapter concludes this dissertation. Recommendations for further work are also presented in this chapter.

4.1. Conclusion

South Africa is presently administering a large number of DSM projects to effectively reduce the high electricity demand on the national grid. DSM is perceived as a sustainable solution to reduce the electricity demand side and gain time for Eskom to expand its supply capacity.

Numerous private companies (ESCO's) are contracted to implement DSM projects. These companies implement DSM projects in industry and are rewarded per project. When the project has been completed and the contractual performance has been verified the implemented system becomes the property of the client.

This dissertation has illustrated that the systems implemented by the evaluated ESCo in this study were not maintained by the mine at which it was installed. The result was that the systems gradually started to underperform to the extent where the systems were entirely discontinued, or were no longer capturing data.

The financial investments made to fund these projects were high and the discontinuation of projects is a loss. The aim of this dissertation was to investigate the feasibility of re-instating decommissioned projects.

The reasons for the gradual decommissioning of the projects are based on the lack of expertise and funding from the mining side. The mine's personnel are not skilled in operating the evaluated ESCo's systems and consequently are not capable of identifying problems and providing the necessary solutions.

This dissertation has shown that there is potential in re-instating mine DSM projects. It was also found that the investments necessary for the re-instatements are negligible compared to the costs of installing new projects.

4.2. Recommendation

4.2.1. Recommendations for further research

It is recommended that a study be done on similar non-operational projects where a secondary source of data is available. For this dissertation it was assumed that there were no savings achieved during the periods in which the evaluated ESCo's systems were out of order, because the systems were not functioning during that time.

It is also recommended that mines store the data relevant to DSM projects, even though the systems installed by the evaluated ESCo store the data. This is to prevent data losses in cases where there is a communication failure between the evaluated ESCo's system and the mine's SCADA system. Improvements can be made to synchronise the different systems to ensure that data loss is minimal.

4.2.2. Recommendations for further work

It is recommended that the evaluated ESCo continues to upgrade and improve its software. One of the primary flaws in the pumping projects, in particular, was that the software was obsolete. The more recent software versions had already made many improvements. These errors are amongst other reasons, one of the first symptoms of a decaying system. Since all mines are unique, the software and the engineers will always face new challenges. It is recommended that the evaluated ESCo continues to offer programming support to the engineers that need to implement the projects at the mines.

4.2.3. Recommendations for sustainability

It is advisable that the evaluated ESCo, the mine and Eskom implement maintenance contracts or procedures to ensure the sustainability of the projects.

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Appendix A

5.1.1. Megaflex cost table [31]

Transmission zone	Voltage	Active energy charge (c/kWh)												Transmission network charges (R/kVA/mth)	
		High demand season (Jun-Aug)						Low demand season (Sep-May)						VAT excl.	VAT incl.
		Peak		Standard		Off Peak		Peak		Standard		Off Peak			
VAT excl.	VAT incl.	VAT excl.	VAT incl.	VAT excl.	VAT incl.	VAT excl.	VAT incl.	VAT excl.	VAT incl.	VAT excl.	VAT incl.	VAT excl.	VAT incl.		
≤ 300km	< 500V	188.87	215.31	49.05	55.92	26.17	29.83	52.69	60.07	32.26	36.78	22.54	25.70	R4.71	R5.37
	≥ 500V & < 66kV	182.83	208.43	47.52	54.17	25.39	28.94	51.04	58.19	31.27	35.65	21.87	24.93	R4.30	R4.90
	≥ 66kV & ≤ 132kV	176.20	200.87	45.84	52.26	24.54	27.98	49.25	56.15	30.19	34.42	21.15	24.11	R4.19	R4.78
	>132kV	170.08	193.89	44.31	50.51	23.73	27.05	47.56	54.22	29.20	33.29	20.47	23.34	R5.29	R6.03
> 300km and ≤ 600km	< 500V	190.73	217.43	49.51	56.44	26.44	30.14	53.20	60.65	32.54	37.10	22.75	25.94	R4.74	R5.40
	≥ 500V & < 66kV	184.62	210.47	47.97	54.69	25.63	29.22	51.53	58.74	31.56	35.98	22.07	25.16	R4.34	R4.95
	≥ 66kV & ≤ 132kV	177.95	202.86	46.29	52.77	24.77	28.24	49.73	56.69	30.48	34.75	21.33	24.32	R4.22	R4.81
	>132kV	171.75	195.80	44.73	50.99	23.95	27.30	48.05	54.78	29.48	33.61	20.64	23.53	R5.35	R6.10
> 600km and ≤ 900km	< 500V	192.62	219.59	50.00	57.00	26.67	30.40	53.71	61.23	32.86	37.46	22.95	26.16	R4.80	R5.47
	≥ 500V & < 66kV	186.45	212.55	48.45	55.23	25.85	29.47	52.03	59.31	31.86	36.32	22.25	25.37	R4.38	R4.99
	≥ 66kV & ≤ 132kV	179.71	204.87	46.72	53.26	24.98	28.48	50.20	57.23	30.75	35.06	21.51	24.52	R4.26	R4.86
	>132kV	173.44	197.72	45.15	51.47	24.17	27.55	48.51	55.30	29.74	33.90	20.84	23.76	R5.42	R6.18
> 900km	< 500V	194.53	221.76	50.47	57.54	26.91	30.68	54.20	61.79	33.16	37.80	23.17	26.41	R4.82	R5.49
	≥ 500V & < 66kV	188.30	214.66	48.91	55.76	26.09	29.74	52.52	59.87	32.13	36.63	22.47	25.62	R4.43	R5.05
	≥ 66kV & ≤ 132kV	181.51	206.92	47.16	53.76	25.22	28.75	50.67	57.76	31.05	35.40	21.71	24.75	R4.28	R4.88
	>132kV	175.18	199.71	45.56	51.94	24.39	27.80	48.94	55.79	30.02	34.22	21.01	23.95	R5.46	R6.22

Electrification & rural subsidy (c/kWh) All Seasons	Environmental levy charge (c/kWh) All Seasons	Reactive energy charge (c/kvarh)					
		High Season		Low Season			
		VAT excl.	VAT incl.	VAT excl.	VAT incl.		
3.97	4.53	2.00	2.28	7.56	8.62	0.00	0.00

Voltage	Distribution network charges			
	Network access charge (R/kVA/m)		Network demand charge (R/kVA/m)	
	VAT excl.	VAT incl.	VAT excl.	VAT incl.
< 500V	R9.40	R10.72	R17.82	R20.31
≥ 500V & < 66 kV	R8.63	R 9.84	R16.35	R18.64
≥ 66kV & ≤ 132 kV	R8.35	R 9.52	R15.85	R18.07
>132kV	R0.00	R 0.00	R14.28	R16.28

Monthly utilised capacity	Service charge (R/Account/day)		Administration charge (R/POD/day)	
	VAT excl.	VAT incl.	VAT excl.	VAT incl.
> 1 MVA	R 107.38	R 122.41	R48.40	R55.18
Key customers	R2,104.29	R2,398.89	R67.20	R76.61

Appendix B

5.1.2. Full project history of Project A

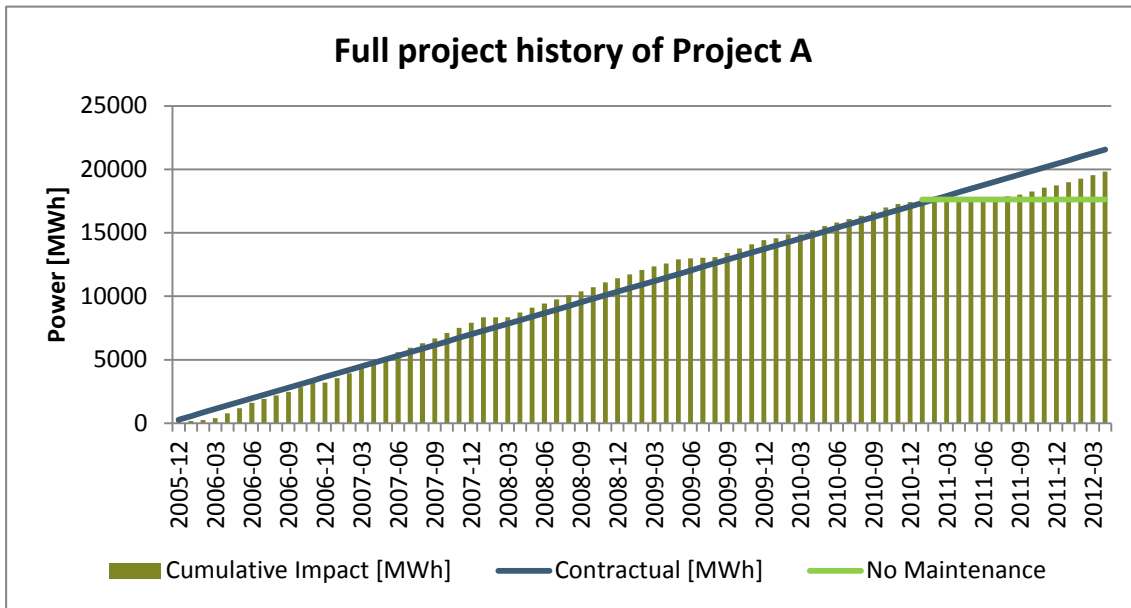


Figure 65: Full project history of Project A.

Appendix C

5.1.3. Savings achieved and missed opportunities of three mining groups

Table 8: Savings achieved and missed opportunities for Mining Group I for 2011.

Project	Savings Achieved	Missed opportunities
Mine A Pumps	R 719 752.03	R 2 350 019.64
Mine B Pumps	R 50 298.51	R 2 950 974.01
Mine C Pumps	R 0.00	R 1 602 236.22
Mine D Pumps	R 61 446.89	R 2 833 457.33
Mine E 4# Pumps	R 1 673 854.31	R 1 179 188.34
Mine F Pumps	R 407 994.52	R 835 415.14
Mine G Pumps	R 5 507 952.84	R 0.00
Mine H Pumps	R 1 155 666.92	R 616 429.28
Mine G Fridge Plants	R 386 955.11	R 825 410.69
Mine B Fridge Plants	R 2 866 637.40	R 259 894.62
Mine I CM	R 0.00	R 1 578 663.96
Mine J CM	R 1 115 331.50	R 162 939.26
Mine H OAN	R 3 693 310.85	R 416 602.39
Mine C OAN	R 10 465 734.27	R 0.00
Mine B WSO	R 3 256 418.29	R 2 101 496.53
Mine A OAN	R 5 687 526.18	R 2 529 383.48
Mine C 8# Pumps	R 56 116.42	R 662 725.91
Total	R 37 104 996.04	R 20 904 836.79

Table 9: Savings achieved and missed opportunities for the Mining Group II for 2011.

Project	Savings achieved	Missed opportunities
Mine A Pumps	R 2 527 055.41	R 767 674.37
Mine B Pumps	R 1 819 531.74	R 106 060.97
Mine C Pumps	R 7 571 575.43	R 102 350.28
Mine D Pumps	R 1 882 022.81	R 6 238 644.29
Mine A Fridge Plants	R 2 782 400.70	R 798 770.75
Mine A Winders	R 302 759.77	R 798 160.78
Mine B 3CPS	R 8 483 821.64	R 65 108.72
Mine E OAN	R 3 717 043.96	R 4 113 735.75
Mine C OAN	R 4 266 564.53	R 827 469.36
Mine C WSO	R 33 352 775.99	R 0.00
Total	R 66 705 551.99	R 13 817 975.27

Table 10: Savings achieved and missed opportunities for the Mining Group III for 2011.

Project	Savings Achieved	Missed opportunities
Mine A Pumps	R 1 344 258.55	R 4 924 686.81
Mine B Pumps	R 362 044.61	R 3 083 229.07
Mine C Pumps	R 0.00	R 952 298.33
Mine C Fridge Plants	R 1 771 806.41	R 5 464 001.66
Mine D Pumps	R 154 735.48	R 0.00
Mine E Pumps	R 1 821 334.89	R 1 914 075.87
Mine C CM	R 1 758 071.28	R 2 037 992.12
Mine F Pumps	R 929 211.10	R 632 452.95
Mine G CM	R 21 632 651.85	R 0.00
Mine B OAN	R 15 210 427.64	R 0.00
Mine A OAN	R 6 210 214.41	R 920 225.09
Mine H WSO	R 16 479 529.11	R 803 173.84
Mine F WSO	R 8 397 833.07	R 37 568.66
Total	R 76 072 118.42	R 20 769 704.38

Appendix D

5.1.4. Savings achieved and missed opportunities of the three neglected systems and the two maintained systems

In this appendix, the red values were assumed values due to data loss. The values were based on the values surrounding the data loss areas. Tariff changes were also considered in assuming these values.

Project A			
	Saving (R)	Proposed Saving (R)	Missed opportunity (R)
Jan	R 43 546.47	R 237 700.68	R 194 154.21
Feb	R 95 548.00	R 237 700.68	R 142 152.68
Mar	R 95 548.00	R 237 700.68	R 142 152.68
Apr	R 95 548.00	R 237 700.68	R 142 152.68
May	R 95 548.00	R 237 700.68	R 142 152.68
Jun	R 433 258.00	R 1 376 546.41	R 943 288.41
Jul	R 24 081.81	R 1 376 546.41	R 1 352 464.60
Aug	R 842 434.54	R 1 376 546.41	R 534 111.87
Sept	R 80 882.20	R 237 700.68	R 156 818.49
Oct	R 113 954.55	R 237 700.68	R 123 746.13
Nov	R 163 377.42	R 237 700.68	R 74 323.26
Dec	R 75 981.57	R 237 700.68	R 161 719.11
Total	R 2 159 708.55	R 6 268 945.37	R 4 109 236.81

Project B			
	Saving (R)	Proposed Saving (R)	Missed opportunity (R)
Jan	R 16 220.00	R 129 145.05	R 112 925.05
Feb	R 16 220.00	R 129 145.05	R 112 925.05
Mar	R 16 220.00	R 129 145.05	R 112 925.05
Apr	R 1 824.34	R 129 145.05	R 127 320.71
May	R 1 960.24	R 129 145.05	R 127 184.81
Jun	R 132 360.00	R 760 989.41	R 628 629.41
Jul	R 12 978.76	R 760 989.41	R 748 010.66
Aug	R 251 743.06	R 760 989.41	R 509 246.35
Sept	R 12 805.94	R 129 145.05	R 116 339.11
Oct	R 39 308.39	R 129 145.05	R 89 836.66
Nov	R 26 716.73	R 129 145.05	R 102 428.32
Dec	R 14 707.17	R 129 145.05	R 114 437.88
Total	R 543 064.61	R 3 445 273.68	R 2 902 209.07

Neglected WSO system			
	Saving (R)	Proposed Saving (R)	Missed opportunity (R)
Jan	Start of project	Start of project	Start of project
February	R 34 851.98	R 356 558.55	R 321 706.56
March	R 552 212.73	R 356 558.55	R 0.00
Apr	R 233 699.63	R 356 558.55	R 122 858.92
May	R 70 001.34	R 356 558.55	R 286 557.20
June	R 81 688.52	R 679 213.92	R 597 525.39
July	R 447 394.94	R 679 213.92	R 231 818.98
Aug	R 646 749.23	R 679 213.92	R 32 464.68
Sept	R 416 467.89	R 356 558.55	R 0.00
Oct	R 167 570.34	R 356 558.55	R 188 988.21
Nov	R 36 981.96	R 356 558.55	R 319 576.59
Dec	R 568 799.73	R 356 558.55	R 0.00
Total	R 3 256 418.29	R 4 890 110.12	R 2 101 496.53

Maintained pumping system			
	Saving (R)	Proposed Saving (R)	Missed opportunity (R)
Jan	65013.46474	124552.7	59539.23525
Feb	R 90 035.71	R 124 552.70	R 34 516.99
Mar	R 105 052.26	R 124 552.70	R 19 500.44
Apr	R 82 072.18	R 124 552.70	R 42 480.52
May	R 96 254.77	R 124 552.70	R 28 297.93
Jun	R 717 512.57	R 724 585.16	R 7 072.59
Jul	R 565 958.86	R 724 585.16	R 158 626.30
Aug	R 507 398.20	R 724 585.16	R 217 186.96
Sept	R 96 823.41	R 124 552.70	R 27 729.29
Oct	R 87 841.77	R 124 552.70	R 36 710.93
Nov	R 97 467.71	R 124 552.70	R 27 084.99
Dec	R 15 624.50	R 124 552.70	R 108 928.20
Total	R 2 527 055.41	R 3 294 729.78	R 767 674.37

Maintained WSO system			
	Saving (R)	Proposed Saving (R)	Missed opportunity (R)
Jan	0	367701.0394	
Feb	R 0.00	R 367 701.04	
Mar	R 296 286.44	R 367 701.04	
Apr	R 650 606.95	R 367 701.04	R 0.00
May	R 1 102 926.63	R 367 701.04	R 0.00
Jun	R 2 120 916.91	R 700 439.37	R 0.00
Jul	R 1 681 402.68	R 700 439.37	R 0.00
Aug	R 2 258 783.11	R 700 439.37	R 0.00
Sept	R 582 740.73	R 367 701.04	R 0.00
Oct	R 979 723.56	R 367 701.04	R 0.00
Nov	R 827 932.28	R 367 701.04	R 0.00
Dec	R 1 524 530.57	R 367 701.04	R 0.00
Total	R 12 025 849.87	R 5 410 627.47	R 0.00

Appendix E

5.1.5. Baselines and proposed profiles

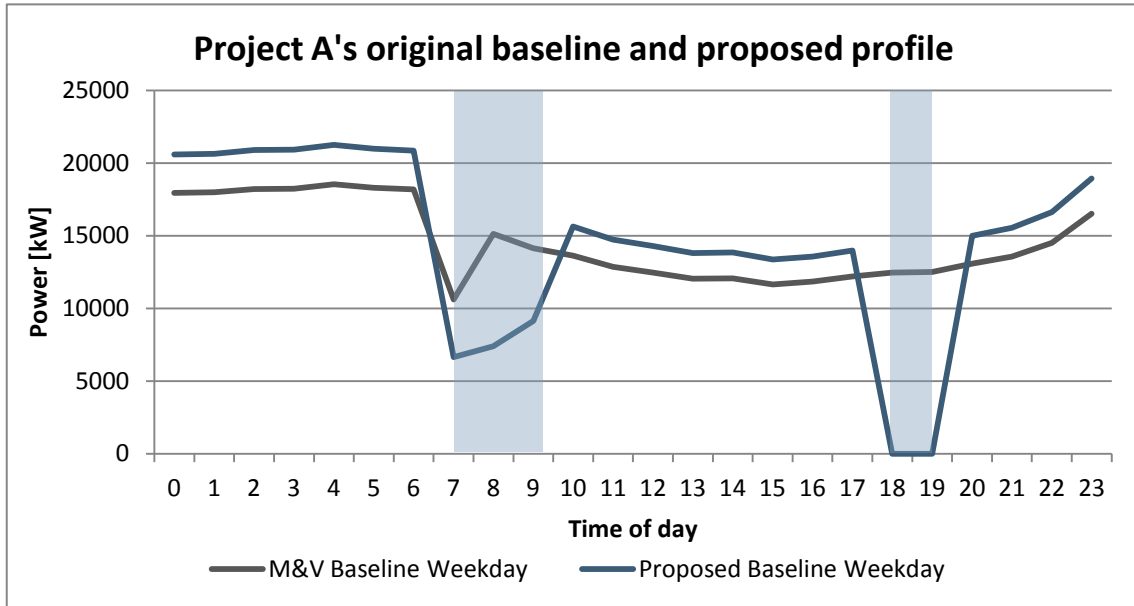


Figure 66: Project A's baseline and original profile.

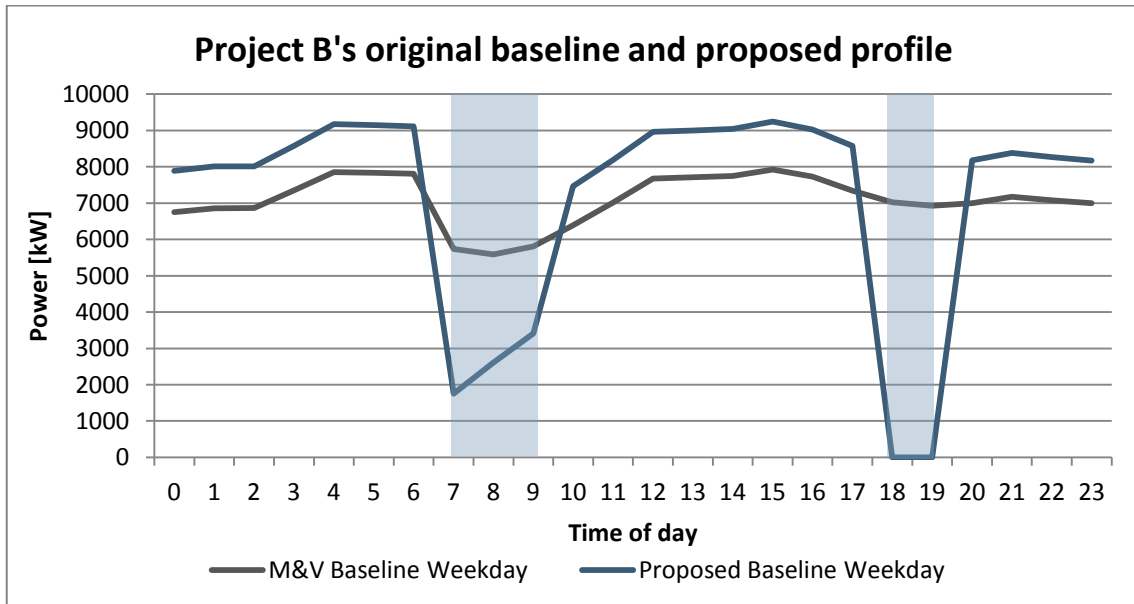


Figure 67: Project B's original baseline and proposed profile.

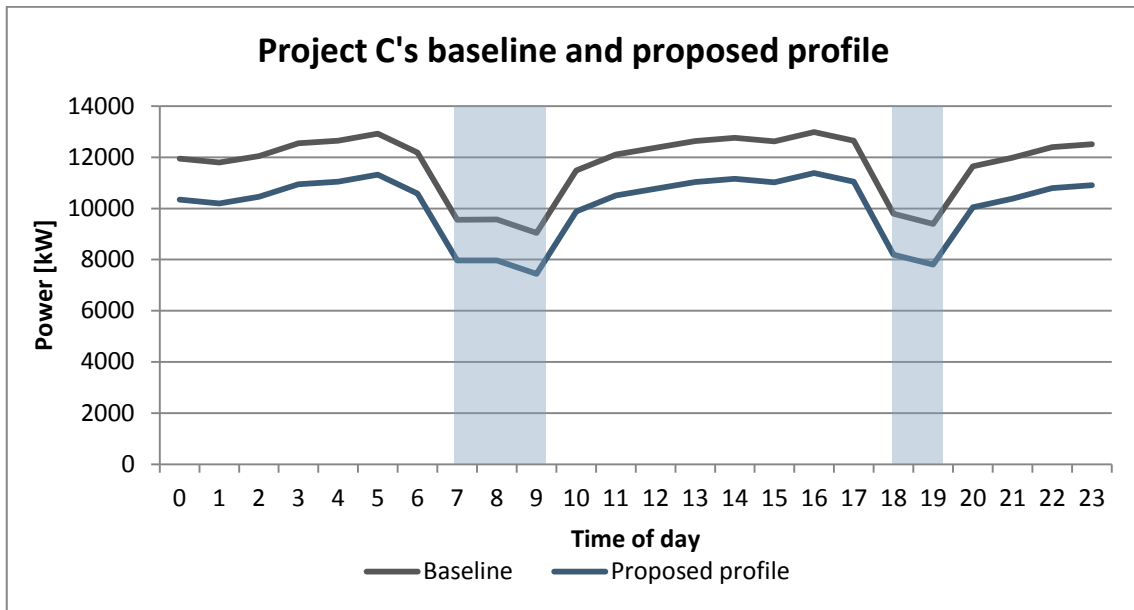


Figure 68: Project C's original baseline and proposed profile.

Appendix F

5.1.6. Schematic layout of Project A

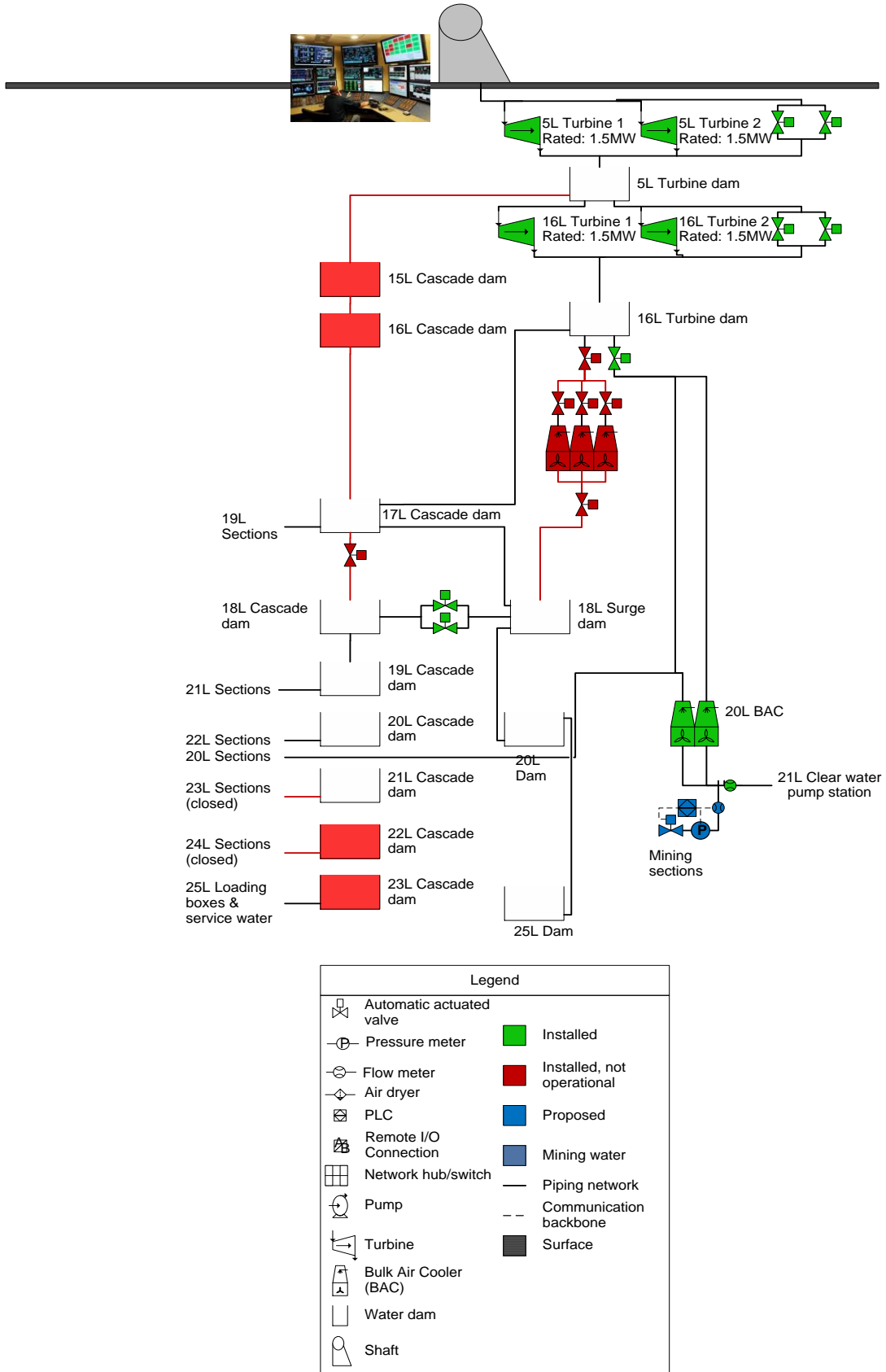


Figure 69: Project A's underground water reticulation system.

Appendix G

5.1.7. Schematic layout of Project C – WSO system

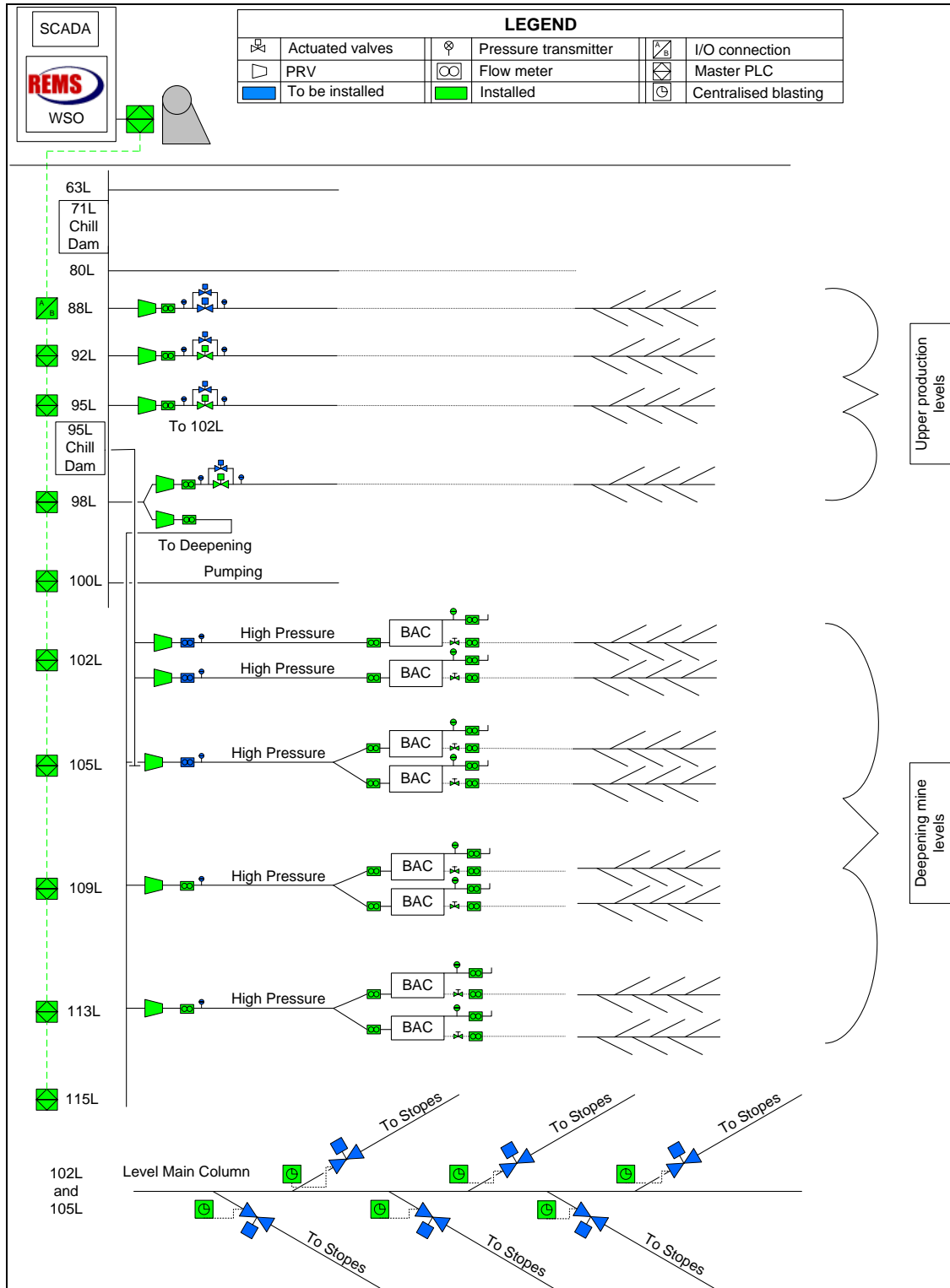


Figure 70: WSO project layout – Project C.