Implementing DSM interventions on water reticulation systems of marginal deep level mines

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It all starts here ™

Abstract

Title: Implementing DSM interventions on water reticulation systems of marginal deep level mines

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Keywords: Demand side management; Energy management; Water system optimisation; Water reticulation system

Because of a continuous increase in the demand for electricity in South Africa the country's largest electricity utility (Eskom) has been under strain to provide electricity. An expansion programme to generate more electricity has caused a continuous increase in utility costs. Steep electricity tariff increases have forced large electricity consumers, such as the mining industry, to focus on energy efficiency and demand side management (DSM).

More recently, large industrial action has affected the marginality of the mining industry in such a way that mining groups were forced to cut down on production cost and even sell mining shafts. A solution has to be found to improve the marginality of these mines.

DSM intervention on mine water reticulation systems has shown great promise in the past and has been implemented on many South African mines with great success. Many mines with smaller systems have not been optimised because the priority of DSM intervention was to achieve the largest saving; therefore, larger systems enjoyed priority over smaller systems. This only added to the increased financial pressure on already marginal mines.

In this study the operation of a mine water reticulation system will be studied to identify the most efficient DSM interventions to implement. DSM intervention on dewatering-, refrigeration- and water distribution systems will be investigated to get a better understanding of the functions of these operations. Previous project data will be analysed to create tools that would assist in the decision-making process for DSM intervention regarding saving potential, cost benefit and cost implication. This data would ultimately assist in determining a project's payback period that is used to prioritise DSM intervention applications.

A mining group will be analysed to identify possible DSM intervention potential. The systems will be investigated and the best strategy for DSM intervention will be selected. This study will conclude that it is financially feasible to implement DSM interventions on marginal mines' dewatering systems.

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My friends for supporting me throughout

Thank you sincerely

Table of Contents

List of Symbols and Abbreviations

^oC	Degrees Celsius
3CPFS	Three Chamber Pipe Feeder System
A	Ampere
BAC	Bulk Air Cooler
bn	Billion
c/kWh	Cent per Kilowatt-Hour
CA	Cooling Auxiliaries
COP	Coefficient of Performance
DE	Drive End
DSM	Demand Side Management
ESCo	Energy Services Company
FP	Fridge Plant
GW	Gigawatt
GWh	Gigawatt-Hour
h	Hour
H	Head
HMI	Human Machine Interface
kg/m^3	Kilogram per Cubic Metre
kPa	Kilopascal
kW	Kilowatt
kWh	Kilowatt-Hour
l/s	Litres per Second
m	Metre
m^3	Cubic Metre
Ml	Megalitre
mm	Millimetre
MVA	Megavolt-Ampere
MW	Megawatt
NDE	Non-Drive End
NERSA	National Energy Regulator of South Africa
p	Pressure
P	Power
PLC	Programmable Logic Controller
PRV	Pressure-Reducing Valve
R	Rand
REMS	Real-Time Energy Management System
SCADA	Supervisory Control and Data Acquisitioning
TOU	Time-of-Use
V	Volt
VSD	Variable Speed Drive
WSO	Water System Optimisation

List of Figures

List of Tables

Chapter 1. INTRODUCTION – ELECTRICITY IN SOUTH AFRICA

This chapter will focus on South Africa's electricity consumption, and more specifically the electricity consumption of the mining industry. Eskom's pricing structures will be investigated as well as different demand side management strategies. The effect that the mining industry has on the country's economy will be highlighted. Mine dewatering and cooling systems are also investigated together with the corresponding electricity consumption required for operation.

1.1 THE PAST, PRESENT AND FUTURE OF SOUTH AFRICA'S ELECTRICITY

INTRODUCTION

Eskom is South Africa's largest electricity supply utility and, when considering generation capacity, one of the top twenty in the world. Eskom has a maximum generation capacity of 41.2 GW. This equates to nearly half of the total electricity in Africa and around 95% of the electricity used in South Africa [1].

Eskom directly supplies roughly 45% of all the consumed electricity in South Africa; the remaining 55% of Eskom's is sold via redistributors such as municipalities. Eskom sells electricity to about 3 000 industrial customers, 1 000 mining customers, 49 000 industrial customers, 84 000 agricultural customers and more than 4 million residential customers [1].

Coal is abundant in South Africa; therefore it can be supplied at a reasonable price when compared to international coal standard prices. Coal-fired power stations generate approximately 35 GW, or nearly 85% of South Africa's electricity supply. The remaining 15% is obtained from gas/liquid fuel turbine stations, a nuclear power station, hydro-electric storage dams and wind energy. Figure 1 shows the percentage contribution of the various different generation sources utilised by Eskom [1].

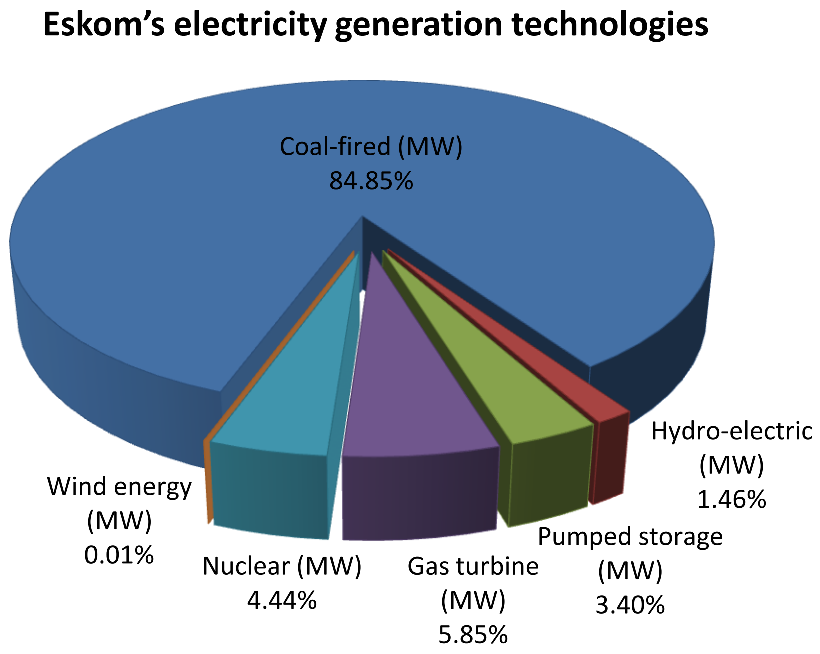


Figure 1: Eskom's electricity generation technologies

South Africa's electricity supply shortage

South Africa experienced frequent electricity supply failures during the first quarter of 2008. Due to blackouts that occurred major cities were paralysed by traffic congestions, food-processing companies lost their stock and at least one person died on the operating table. The national grid could have collapsed, which in turn could have caused the entire country to be completely without electricity for several days [2].

The internationally accepted standard for a safe electricity supply reserve margin is 15% of the maximum demand. The reserve margin is the difference between the net system capability and the system's maximum load requirements (peak load or peak demand). Historically South Africa has enjoyed a generous reserve margin. South Africa has, however, experienced ongoing economic growth. As a result the demand for electricity has also increased [3]. The increased demand for electricity caused the South African reserve margin to decrease from a safe 20% in 2004 to a dangerously low 8% by March 2008 [4]. Figure 2 shows the growth of the peak demand and highlights how the reserve margin started to decrease.

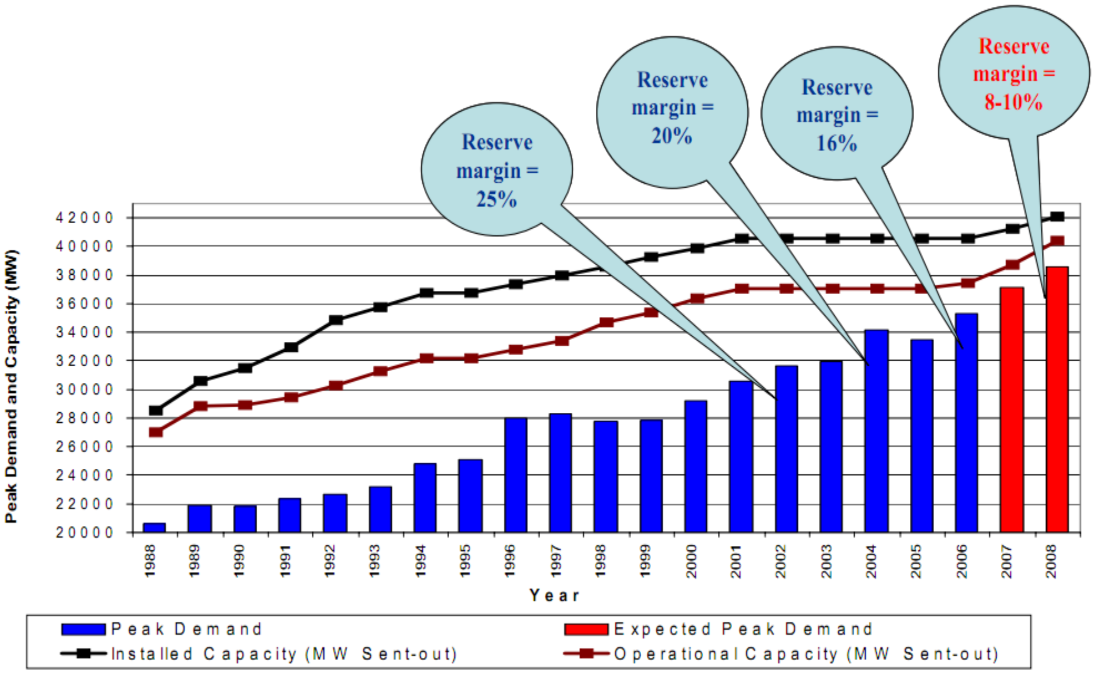


Figure 2: Eskom reserve margin history [5]

According to Eskom, the main reasons for the energy crisis were the imbalance between electricity supply and demand and the delay in the 2004 decision by government to fund the building of a new power station. An additional contributing factor was the 50% increase in electricity demand in the country between 1994 and 2007 [6].

To prevent a total collapse of the national grid in 2008 gold- and platinum mines were forced to stop all production for five days from 25 January to 30 January of that year. Production was only restarted after the mines committed to a continuous 10% reduction in their electricity consumption [7].

Eskom's expansion programme and tariff increases

Additional power stations and major power lines have to be built on a massive scale to meet rising electricity demand in South Africa. This started in 2004 when cabinet approved a five-year, R93-billion investment plan in South Africa's electricity infrastructure. The plan included the generation, transmission and distribution of electricity with Eskom funding R84 billion of the total amount; the remainder was funded by independent power producers [8].

Since the capacity expansion programme started in 2005 an additional 4 453.5 MW has already been commissioned [9]. The capacity expansion programme includes the following expansions:

- The recommissioning of the Camden power plant (eight coal-fired units with a total capacity of 1 520 MW);
- The recommissioning of the Grootvlei power plant (six units with a total capacity of 1 200 MW);
- The recommissioning of the Komati power plant (nine coal-fired units with a total capacity of 965 MW);
- Ankerlig open cycle gas turbine station with a total capacity of 1 332 MW; and
- Gourikwa open cycle gas turbine station with a total capacity of 740 MW.

Other expansions scheduled for the future include the Medupi power station with a total capacity of 4 764 MW; the Kusile power station with a total capacity of 4 800 MW; and the Ingula pumped storage scheme with a total capacity of 1 352 MW. Additional power stations and major power lines are also being built. Up to 2013 Eskom's capacity expansion budget has increased to R385 billion and is expected to grow to more than a trillion rand by 2026. Eskom is planning to double its capacity to 80 000 MW by 2026 [9]. Figure 3 shows the capacity Eskom added in five-year periods.

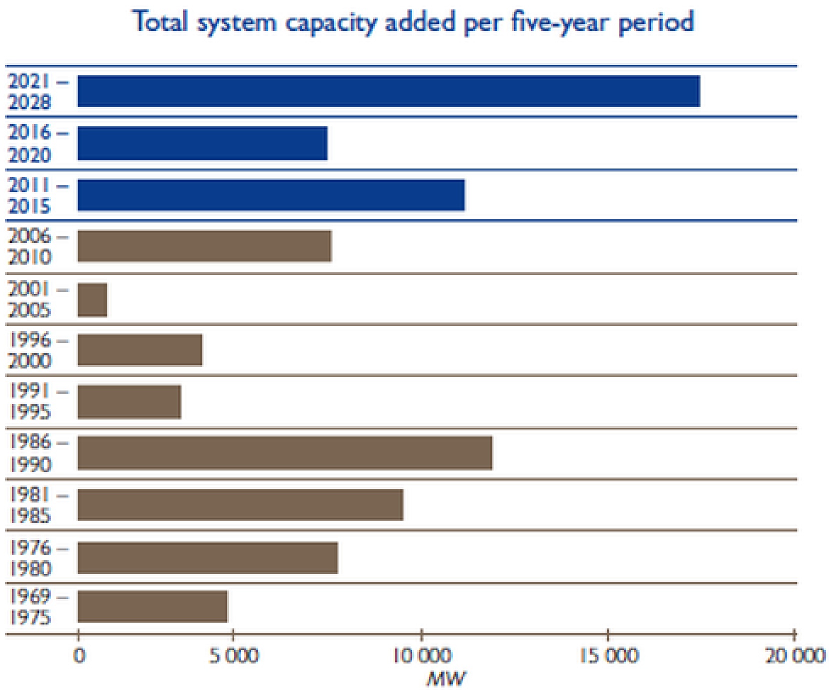


Figure 3: History of capacity added [10]

Even after the South African government's R60-billion funding commitment in 2004, Eskom still struggled to raise capital internationally. Eskom had to source funding in the local market [11]. Steep tariff increases were implemented and consumption penalties were enforced on consumers to enable Eskom to successfully complete the abovementioned upgrades. Hereafter, Eskom's tariffs have been adjusted on an annual basis. The adjustment coincides with Eskom's financial-year price adjustments on 1 April. Figure 4 shows Eskom's average price increase history over the last fifteen years [12].

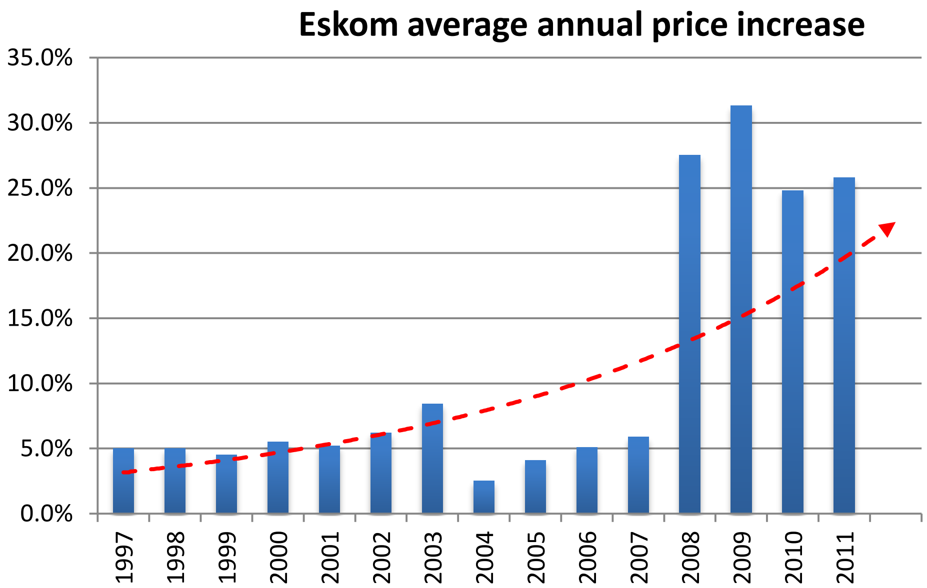


Figure 4: Eskom's average annual price increase history [12]

In 2009 the National Energy Regulator of South Africa (NERSA) allowed Eskom to implement a 31.3% increase in the average standard tariff for the last nine months of the national financial year 2009/10. This increase was followed by further price increase grants of 24.8% for 2010/11, 25.8% for 2011/12 and 25.9% for 2012/13 for the generation and sale of bulk electricity [13].

On 28 February 2013, NERSA approved an 8% average price increase per annum for the next five years. The average electricity price will increase to 65.51c/Kwh in 2013/14, and to 89.13c/kWh in 2018. The total revenue approved for the five years amounts to R906,553 million [14].

TIME-OF-USE PRICING STRUCTURES

Eskom introduced multiple tariff structures to discourage peak-time consumption. Eskom accomplished the multiple tariffs by increasing the peak and standard time tariffs. This was done to ensure economic efficiency, sustainability as well as to provide adequate revenue for reliable electricity supply [15].

Large industrial consumers, for example mines, have the advantage of a time-of-use (TOU) based electricity tariff structure such as Megaflex. Megaflex is a TOU electricity tariff for urban customers with a notified maximum demand greater than 1 MVA that are able to shift load [16]. This tariff structure is tailored to industries that operate on a 24-hour production schedule. The different time intervals for the Megaflex pricing periods are shown in Figure 5.

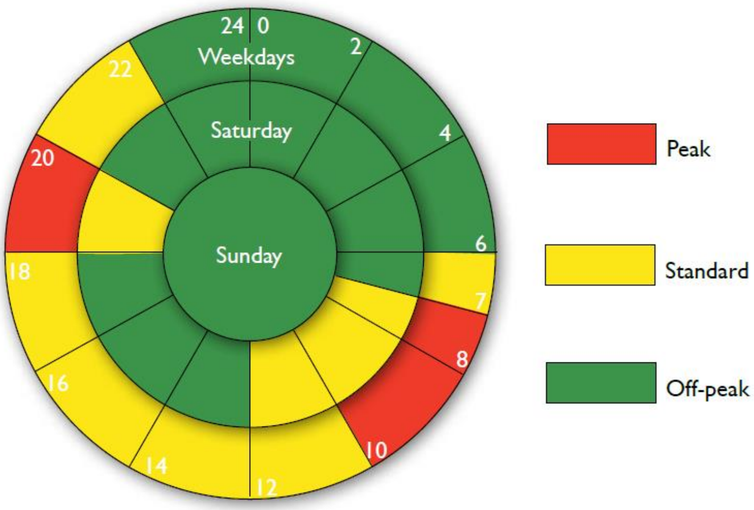


Figure 5: Megaflex variable pricing structure chart [17]

1.2 ESKOM DEMAND SIDE MANAGEMENT

Demand side management (DSM) is one method for reducing electricity demand. The most common DSM intervention strategies can be characterised by two general categories: energy efficiency and load management [18].

ENERGY EFFICIENCY

Energy efficiency refers to the practice where electricity is utilised more efficiently. Energy efficiency can be achieved by implementing more efficient equipment, or reconfiguring processes to be more efficient. In essence, less electricity is used to achieve the same production result. Figure 6 shows a simplified energy profile for a typical energy efficiency project.

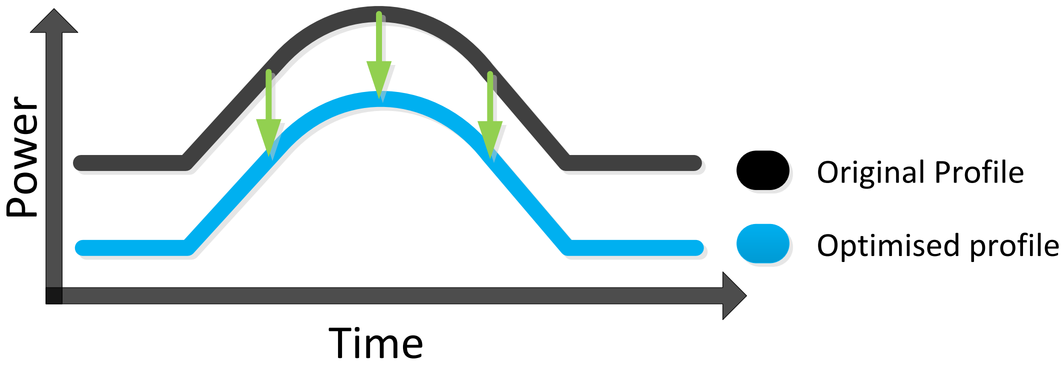


Figure 6: Energy efficiency power profile

LOAD MANAGEMENT (LOAD SHIFTING AND PEAK CLIPPING)

Load management refers to an intervention where electrical load is reduced during a peak-demand period. Load management consists of two concepts: load shifting and peak clipping.

Load-shifting projects result in a reduction in electricity costs by shifting system load from expensive TOU periods to less expensive periods. It is important to note that load-shifting projects do not reduce average power consumption. Figure 7 shows a simplified energy profile for a typical load-shifting project.

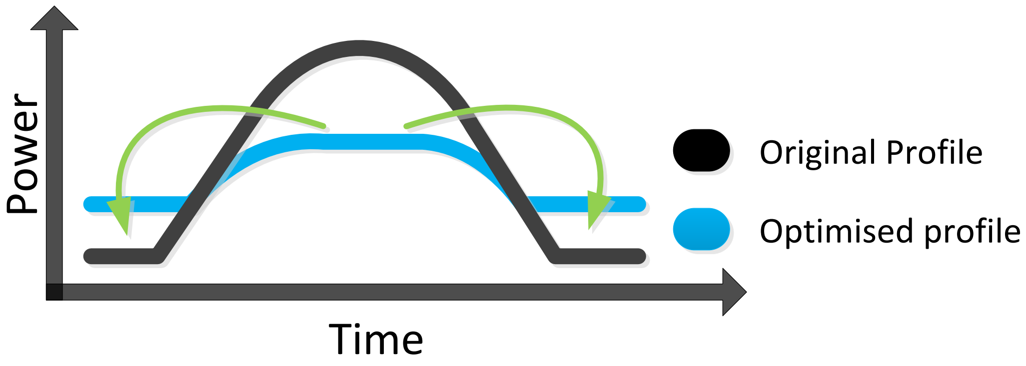


Figure 7: Load-shifting power profile

Peak clipping refers to an intervention where peak electrical demand is reduced during Eskom's peak periods. The electrical demand reduction is made possible by switching off, or stopping a process or system. Peak clipping will reduce the total electricity consumption but could also lead to a reduction in production. Figure 8 shows a simplified energy profile for a typical peak-clipping project.

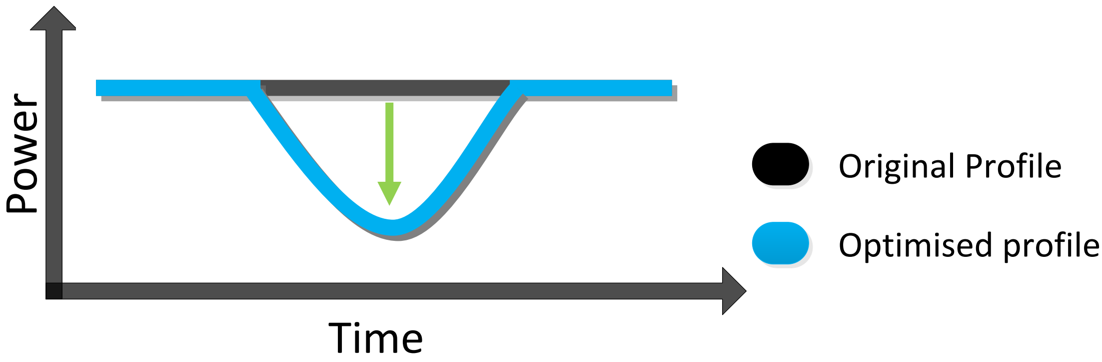


Figure 8: Peak-clipping power profile

A HISTORY OF SUCCESSFUL IMPLEMENTATION OF DSM PROJECTS

Since 2004, Eskom has been partnering with energy service companies (ESCos) to identify, implement and monitor DSM projects. Since then the savings achieved have grown cumulatively and so has the need for demand reduction.

From 2005 to 2011 Eskom accumulated demand savings of 2 717 MW. The annualised achieved savings for 2011 was 1 339 GWh; therefore exceeding the 994 GWh target by 345 GWh. For 2011 the evening peak-period demand saving was 354.1 MW [13]. Figure 9 shows the cumulative targeted and achieved results of DSM.

Figure 9: History of cumulative targeted and achieved results of DSM [13]

THE ROLE OF ESCOS IN DSM

ESCos are responsible for determining the best way of obtaining electricity savings at customer sites. These companies identify and implement opportunities for achieving reductions in electricity consumption by identifying and executing DSM projects.

To participate in Eskom's funding programme an ESCo has to submit a proposal for a potential electricity cost savings project larger than 100 kW. Eskom reviews these projects on their technical and financial merits as well as electricity savings potential. Once a contract has been signed, the ESCo is given the permission to implement the project [19].

Due to the large electricity consumption of the mining industry, there is great potential for DSM opportunities to be implemented. ESCos in South have successfully implemented various DSM projects in the mining industry [20].

At the start of the DSM programme the focus was on projects where large savings could be achieved with the least amount of capital investment. This has changed; it has become increasingly complex and expensive to perform high-impact industrial DSM implementations [21]. In the past, ESCos focussed on projects with the largest potential for electricity savings. This resulted in marginal mines and shafts having a lower priority for possible DSM interventions. For the purposes of this study a marginal mine is defined as a mine that barely receives enough revenue to cover the cost of the mining operations, and has a low profit margin.

1.3 ELECTRICITY CONSUMPTION OF THE MINING INDUSTRY

The South African mining industry consumes about 14.5% of the total electricity consumption in the country. This amounted to 32 630 GWh in 2011 [1]. The gold-mining industry consumes 47%, the platinum-mining industry 33%, and other mining industries about 20% of the total 14.5% electricity consumption [22]. Figure 10 shows Eskom's electricity sales by customer type.

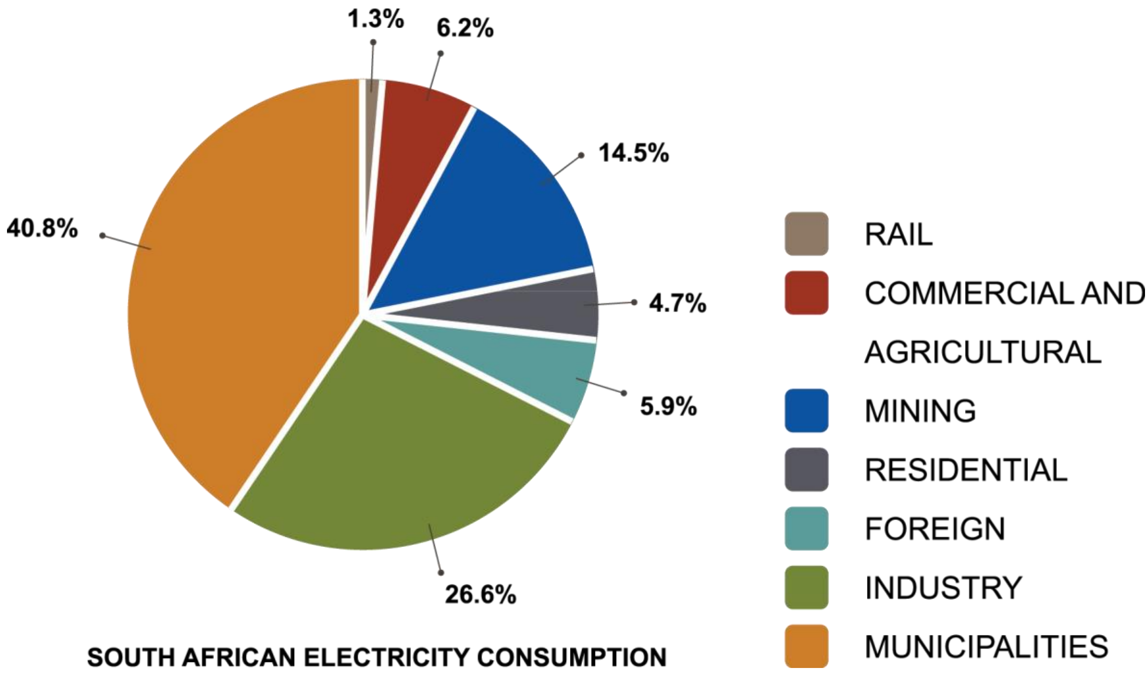


Figure 10: Electricity sales (GWh) by customer type [1]

Electrical motors drive several important systems on mines. The three major consumers of electricity are pump systems, refrigeration systems and compressed air systems. The motors driving these systems account for approximately 55% of electricity consumed in the mining industry. The total operational cost of a motor during its lifecycle can reach hundred times that of its acquisition. This provides significant scope for electricity saving [23]. Figure 11 shows a generalised breakdown of the electricity usage on mines.

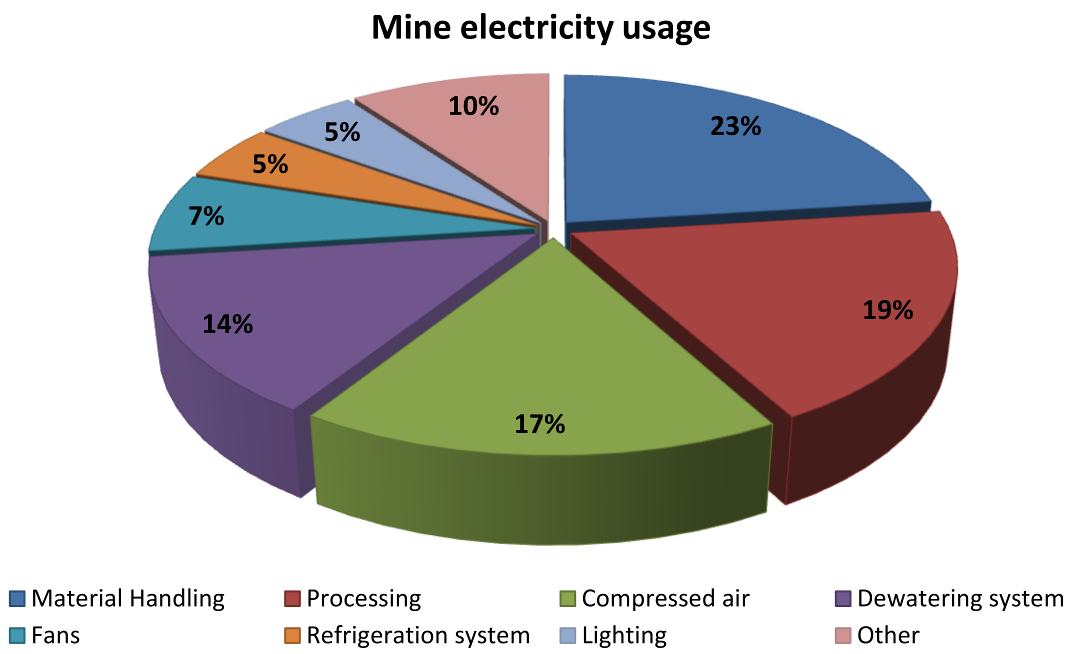


Figure 11: Generalised breakdown of electricity usage on mines [23]

1.4 FINANCIAL LOOK AT THE MINING INDUSTRY

South Africa is considered a major mineral producer. The country's mineral industry is export-orientated because the domestic market produced is relatively small for most of the mineral commodities [24]. South African mines are vital for the economic growth of the country. In 2008, South Africa's mining companies accounted for about 35% of the market capitalisation of the Johannesburg Stock Exchange. The mining industry accounted for about 32% of merchandise exports; about 50% if secondary beneficiated mineral exports were added [25]. South Africa's mining industry also contributes hundreds of billions of rands in exports every year [26]. Figure 12 shows the historical value of mining exports.

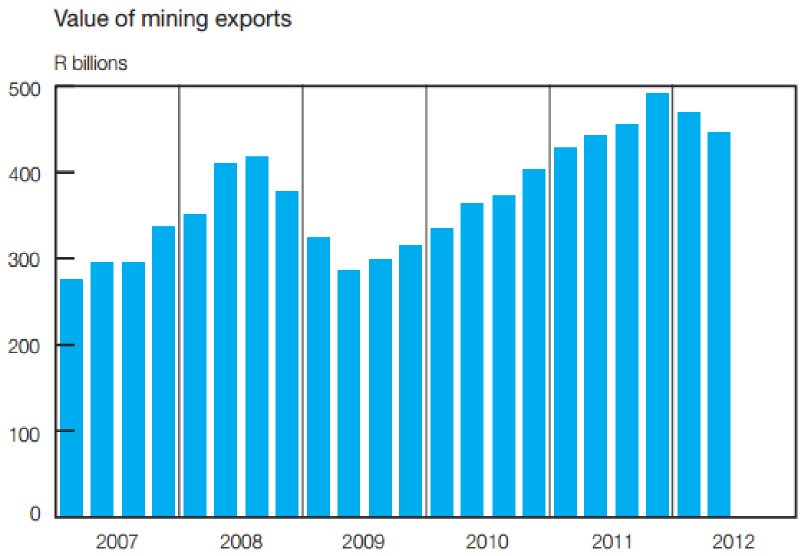


Figure 12: The value of mining exports [26]

THE EFFECT OF THE MINING INDUSTRY ON SOUTH AFRICA'S ECONOMY

In 2010, South Africa's economy grew by 2.9% after a decline of 1.7% in 2009. The mining sector played a key part in the recovery of the economy and the mining sector grew by 5.5% in 2010 [27]. By the third quarter of 2011 there was a steep decrease of 17.4% in the real output of the mining industry. This was caused mainly by widespread industrial action. Other factors that adversely affected production volumes during this period included ongoing logistical problems; temporary shutdowns due to accidents; higher electricity tariffs; and wage increases in excess of the current rate of inflation at the time [27]. The economic growth of the country recovered in 2011 and started to accelerate in 2012. This was mainly attributed to the 31.2% recovery in output from the mining industry [26]. Figure 13 shows the historical changes in the economic growth of South Africa.

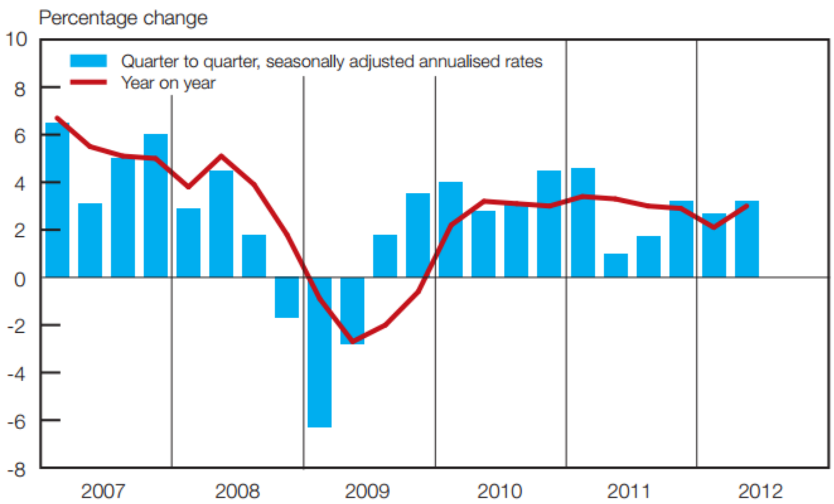


Figure 13: Historic percentage change in the economic growth of South Africa [26]

When comparing the percentage change in gross product output of the mining industry to the percentage change in the total gross domestic output growth of the country it is clear that the mining industry has a significant effect on the country's growth. Figure 14 shows how south Africa's gross domestic product output trend seems to follow that of the mining industry [26].

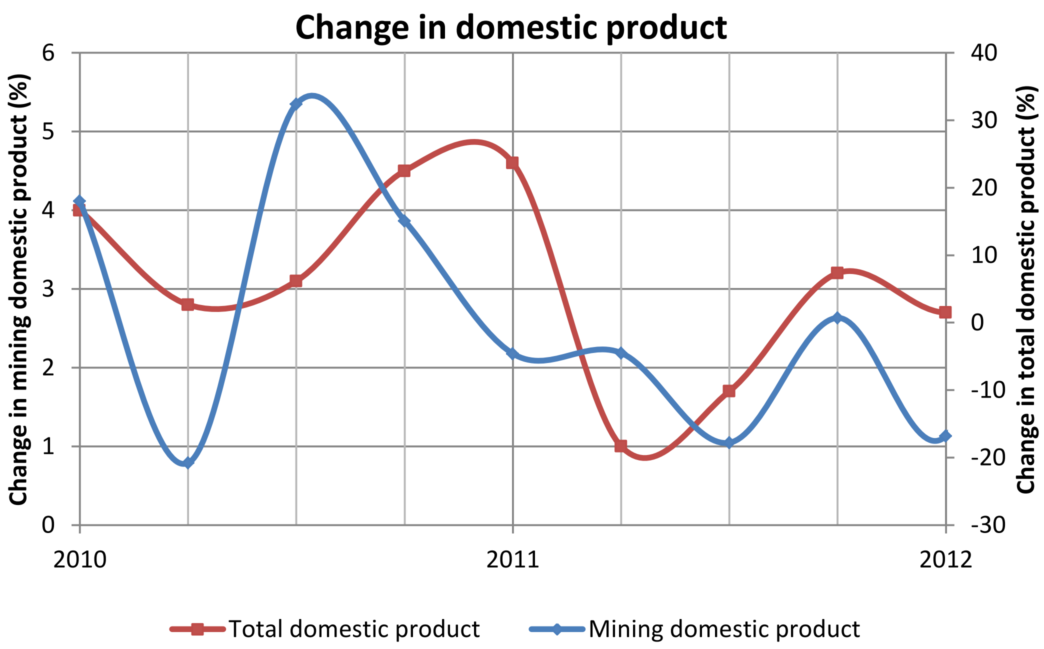


Figure 14: Mining industries gross output versus gross domestic output of South Africa

THE PRICE OF MINING

Operational expenses in the mining industry are continuously increasing as electricity prices, fuel prices and inflation increase. Operating expenses in the mining industry increased by 13% in 2012 after an already significant increase of 18% in 2011. Both these increases in operational expenses were well above inflation [28]. As production cost increases, so do commodity prices and capital expenses of mining groups. Figure 15 shows the operational cost of a major platinum mine group compared to the price of platinum sold.

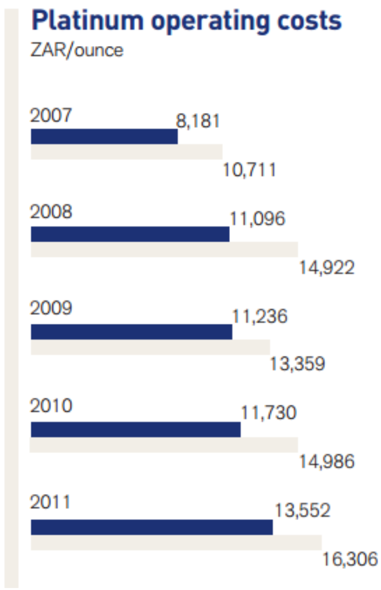


Figure 15: Platinum operational costs [29]

Some of the major operational expenses can be attributed to utility and employee costs. On average, employee costs make up 36% of the total production expenditure [28]. Figure 16 shows the contribution of different factors to the total production expenditure.

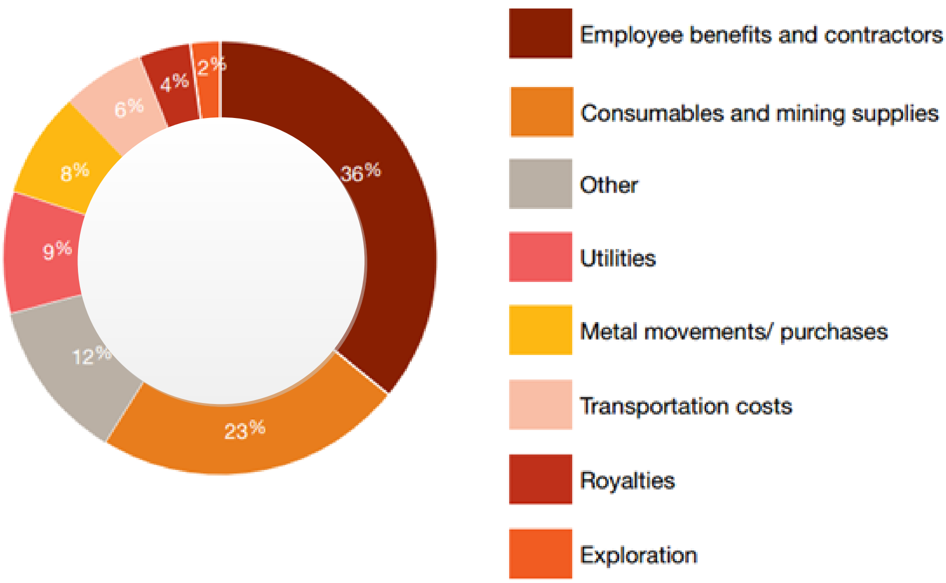


Figure 16: Typical production expenditure in the mining industry [28]

Because of the high electricity-to-production relationship of mining (given the high usage of electricity in pumping-, cooling- and ventilation systems) the ongoing 10% decline in electricity supply to the mining industry meant that only production electricity could be cut, which in turn cut production by about 10% [25].

THE DOWNFALL OF MARGINAL MINES AND AN UPRISING IN INDUSTRIAL ACTION

With the continuous increase of production costs the mining industry is forced to come up with creative strategies to keep making profit and to keep their investment portfolios strong. Every mine needs basic pumping-, cooling- and ventilation systems. These systems are usually much less electricity intensive on smaller mines, because smaller mines tend to be shallower than larger mines. The electricity consumption of a mine water reticulation system is proportional to the usage of underground water. Energy consumption also increases with the depth of the mine [30].

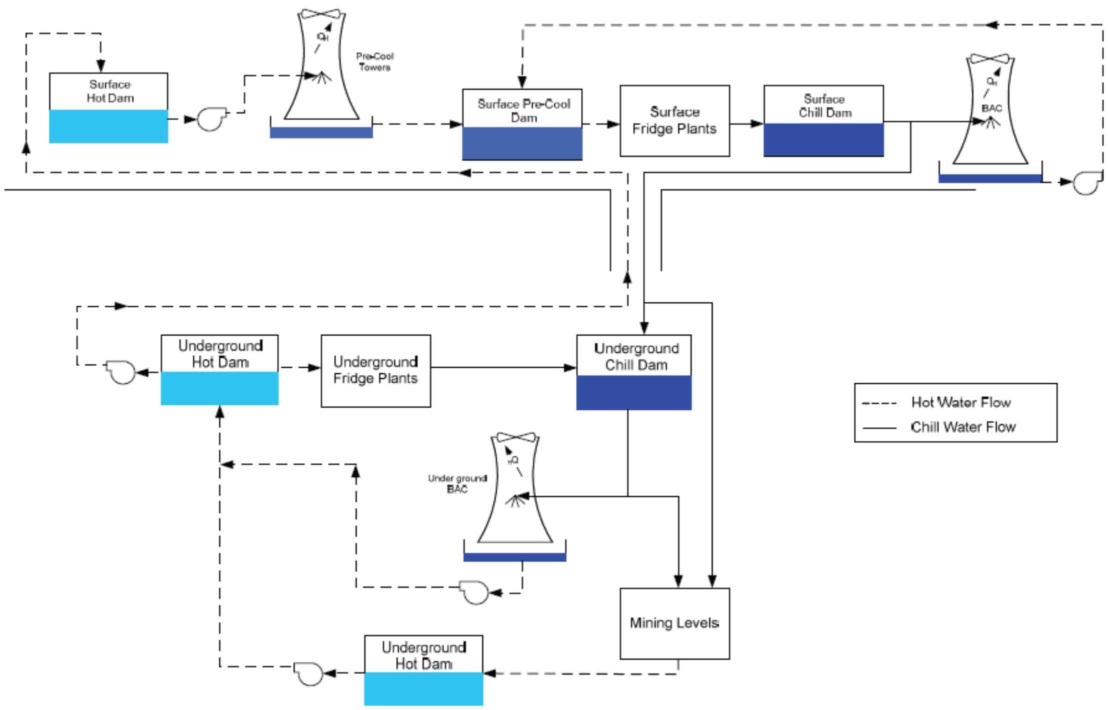
In 2012, the mining industry was crippled by widespread industrial action regarding wage disputes. Both the gold- and platinum sectors were influenced severely with losses amounting to billions of rands [31]. The widespread industrial action was the cause of several mine closures in the platinum industry in early 2013 [32]. In the gold-mining industry marginal mines have also been closed in order to increase their portfolios in the world market [33]. The total value of mining production lost as a result of strikes and stoppages in 2012 amounted to R15.3 billion [34]. Many funds have also dropped South African mining stocks, often on ethical grounds, resulting in the South African Basic Materials Index losing nearly 12% since the start of 2012 [35].

1.5 PROBLEM STATEMENT

The mining industry is vital to the growth of South Africa, but due to major industrial action and the continuous increasing costs of mining, more and more mines are becoming marginal mines. Even though employees and contractors are the largest expenses in the mining industry, cutting these costs may only provoke more industrial action.

Utility costs would be the safest expense component to optimise. The implementation of DSM projects on most large mines’ water reticulation systems in South Africa has had a very positive influence in the recovery of the electricity shortages that South Africa faced. However, many marginal mines have not yet been optimised through DSM intervention because of the smaller size of their electricity intensive operations. It is thus unknown if it is financially feasible to implement DSM on these systems. It is also unclear which intervention strategy would be the most beneficial. So, there is a need to know how to select the most cost-effective DSM application, how much the implementation would cost, and what possible savings could be expected.

Chapter 2. OPERATION OF MINE WATER RETICULATION SYSTEMS



This chapter will focus on the mine water reticulation system and the possible cost-effective strategies that could be implemented. Each component of the water reticulation system will be investigated to identify possible optimisation areas. Possible cost-effective operational strategies will be investigated as well as DSM interventions that have been implemented on the water reticulation system.

2.1 INTRODUCTION

A water reticulation system has to be understood before any optimisation of a mine water reticulation system can be done. In this chapter the components of a water reticulation system will be studied to understand how all of the integrated components in the system operate. The automation of these components will also be considered to identify possible savings strategies. Lastly, cost-effective optimisation strategies will be studied.

2.2 MINE WATER RETICULATION SYSTEMS

South Africa is home to some of the world‘s deepest mines. Some mines reach depths of more than 3 800 m below the surface [36]. As a result temperatures can reach 60°C to 70°C at the rock face. Ventilation and cooling is critical when mining at these depths. The mining industry relies on water reticulation systems to ensure a safe thermal working environment underground.

To understand the mechanism of a mine water reticulation system, each section must be viewed separately. A mine water reticulation system can be divided into three sub-systems, namely the dewatering-, refrigeration- and distribution systems. Figure 17 shows a simplified layout of a mine water reticulation system.

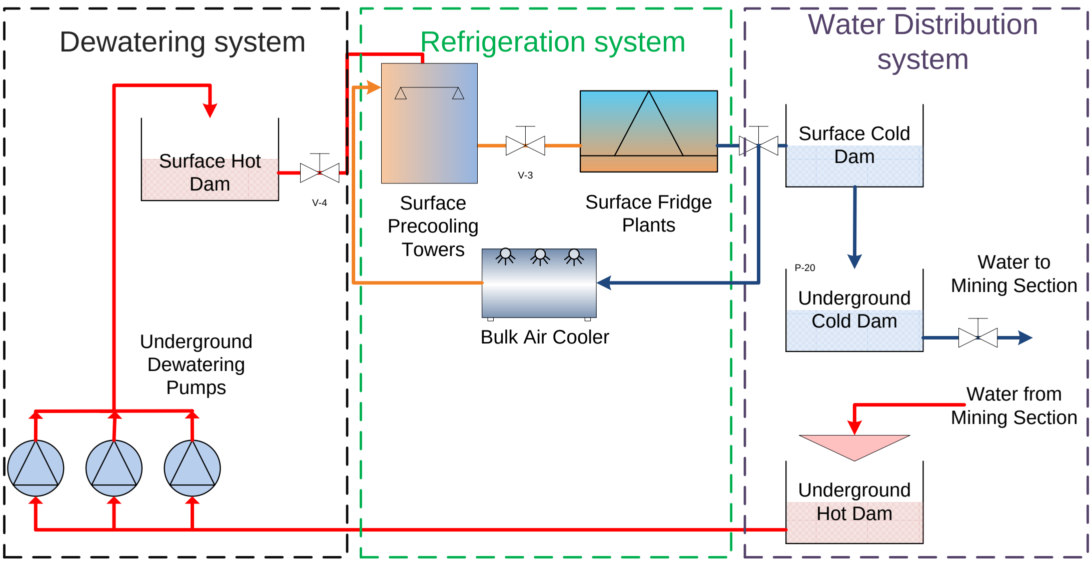


Figure 17: Simplified layout of a mine water reticulation system

WORKING ENVIRONMENT, REGULATIONS AND HAZARDS OF DEEP LEVEL MINING

Mining at extreme depths can be hazardous. Not only should the working conditions be safe and suitable for human and machines, but it is also critical for productivity. Productivity ultimately translates into achieving the required profit margins [37].

South Africa has a geothermal gradient that varies between 10 and 20°C/km. Consequentially, the virgin rock temperature increases by an average of 15°C per kilometre in depth [38]. If underground temperatures are not regulated it could lead to the following medical conditions [37]:

- **Heat cramps**

  Heat cramps are painful, brief muscle cramps. Heat cramps are caused by the body losing more fluid than it replaces; this usually happens during strenuous physical activity. The resulting loss of fluid causes an imbalance in the body's electrolytes that leads to dehydration and high body temperatures [39].
- **Heat exhaustion**

  Heat exhaustion is the body's failure to cool itself. Heat exhaustion usually occurs after continuous increases of body core temperature. The human body cools itself mostly through the evaporation of sweat. In humid conditions less sweat will evaporate off the body, resulting in the body increasing in temperature. Symptoms may include heavy sweating, fatigue, thirst and muscle cramps [40].
- **Heatstroke**

  Heatstroke is a very serious condition also known as a core temperature emergency It occurs as a result of the body's failure to cool itself down. The main cause of heatstroke is working or exercising in hot conditions or weather without drinking enough fluids. Heatstroke, if not promptly treated, has a mortality rate of up to 80%. High body temperatures associated with heatstroke can result in irreversible damage to organs such as the brain, kidneys and liver. Irreparable damage can also be caused to the body's nervous system [41].

WATER DISTRIBUTION SYSTEM

A mine water distribution system refers to the section of a mine water reticulation system by which cold water is sent underground for mining purposes. Water cooled by a mine refrigeration system is usually stored in large cold water storage dams on surface. Cold water storage dams act as buffers to the fluctuating water demand of different mining operations [42]. Figure 18 shows a simplified layout of a mine water distribution system.

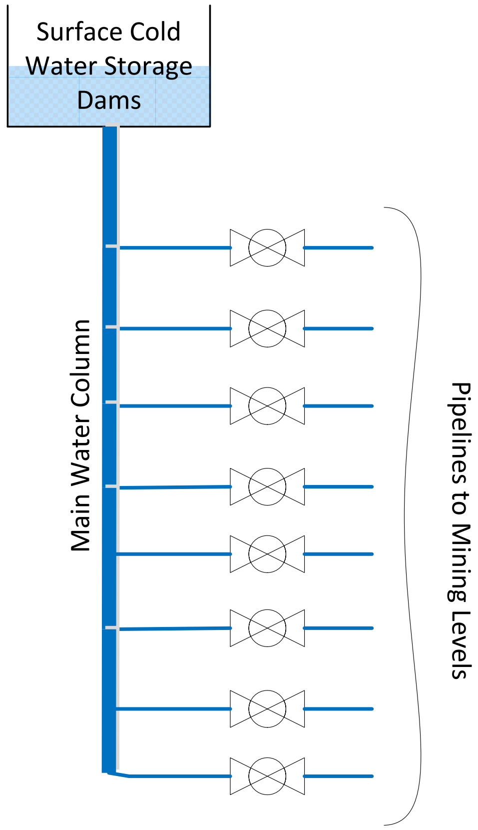


Figure 18: Simplified layout of mine water distribution system

Water is gravity-fed through a column down the mine. A column refers to a mine's main water pipeline down the mineshaft. Pipe networks branch of the column on different levels to supply the mining operations with water. Due to the depth of the mines the water reaches extreme hydraulic pressures. These pressures can become dangerously high which makes it difficult to distribute water safely underground [43]. The hydraulic pressure can be calculated using the following equation:

$$Hydraulic\ pressure = \rho * g * h \qquad \text{Equation 1}$$

Where: ρ = fluid density in kg/m^3

g = gravity acceleration constant in m/s^2

h = depth below surface in m

The extreme hydraulic pressure is usually reduced by means of dissipaters, pressure-reducing valves (PRVs) and underground cascading dams on consecutively lower levels [44]. PRVs are usually situated on each level near the main water column. Each valve typically reduces the water pressure to between 85% and 90% of the inlet pressure [45]. Multiple valves are used in series to form a pressure-reducing station. Figure 19 shows PRVs in series at a pressure-reducing station.

Figure 19: PRVs in series at a pressure-reducing station [45]

On many mines water pressure is also decreased by sending the water through a hydraulic Pelton wheel turbine. The advantage of a turbine is that it converts potential energy (water gravitated down the mine) into mechanical energy. The mechanical energy can then be converted into usable shaft work. These turbines can be coupled to an induction generator. The turbines can then be used to generate electricity. It can also be coupled directly to the shaft of a dewatering pump, in turn returning hot water to surface [46]. Figure 20 shows a simplified layout of the turbine pump water delivery system.

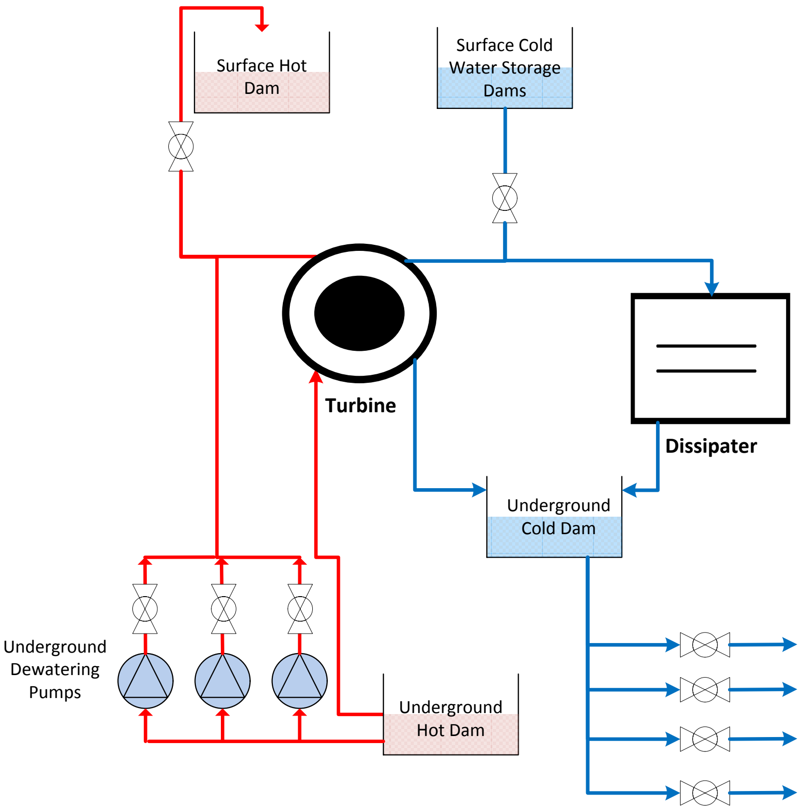


Figure 20: Simplified layout of turbine pump system

Another benefit of using Pelton wheel turbines is a reduction in the increase in water temperature as a result of pressure dissipation; this reduces the cost of refrigeration [47]. Figure 21 shows the components of a Pelton wheel turbine typically used on mines.

Figure 21: Pelton wheel turbine components

Kilometres of pipe columns transfer water from pressure-reducing devices to working stations in mines. These long pipelines make water leakage a common problem. Due to the high pressure of the water even a small hole can result in high volumes of water being lost. This wasted water will then have to be extruded by a mine dewatering system later on. Research on water leaks have shown that a great amount of money can be wasted if these leaks are not repaired [48]. Figure 22 shows the cost implication that different size holes may have on a mine water distribution network.

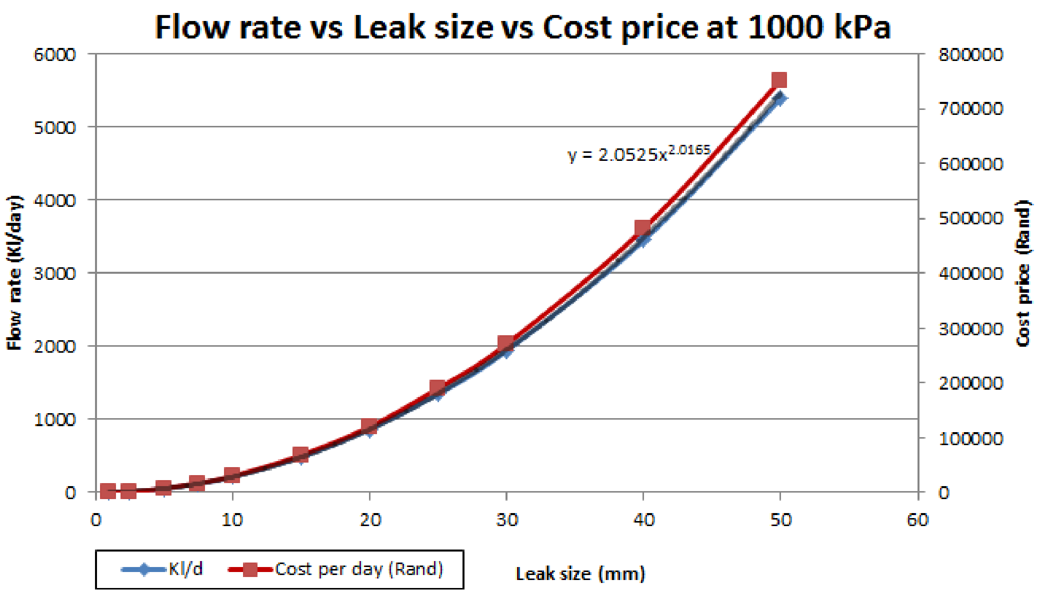


Figure 22: Cost implication of different leak sizes

DEWATERING

A mine dewatering system consists mainly of dewatering pump stations, hot water storage dams and settlers. Used service water or run-off mine water is channelled to the settlers where mud and other debris are separated from the water. The water is then collected in underground hot water storage dams. From these dams the hot water is pumped to surface storage hot water dams using large multistage centrifugal pumps. From the surface storage hot water dams the water is pumped to the refrigeration plants where the water is cooled for further use. This cycle continues throughout the day [49]. The dewatering system of a mine is a large electricity consumer as can be seen in Figure 11. This system uses up to 14% of the mine's total electricity consumption. Figure 23 shows a simplified layout of a mine dewatering system.

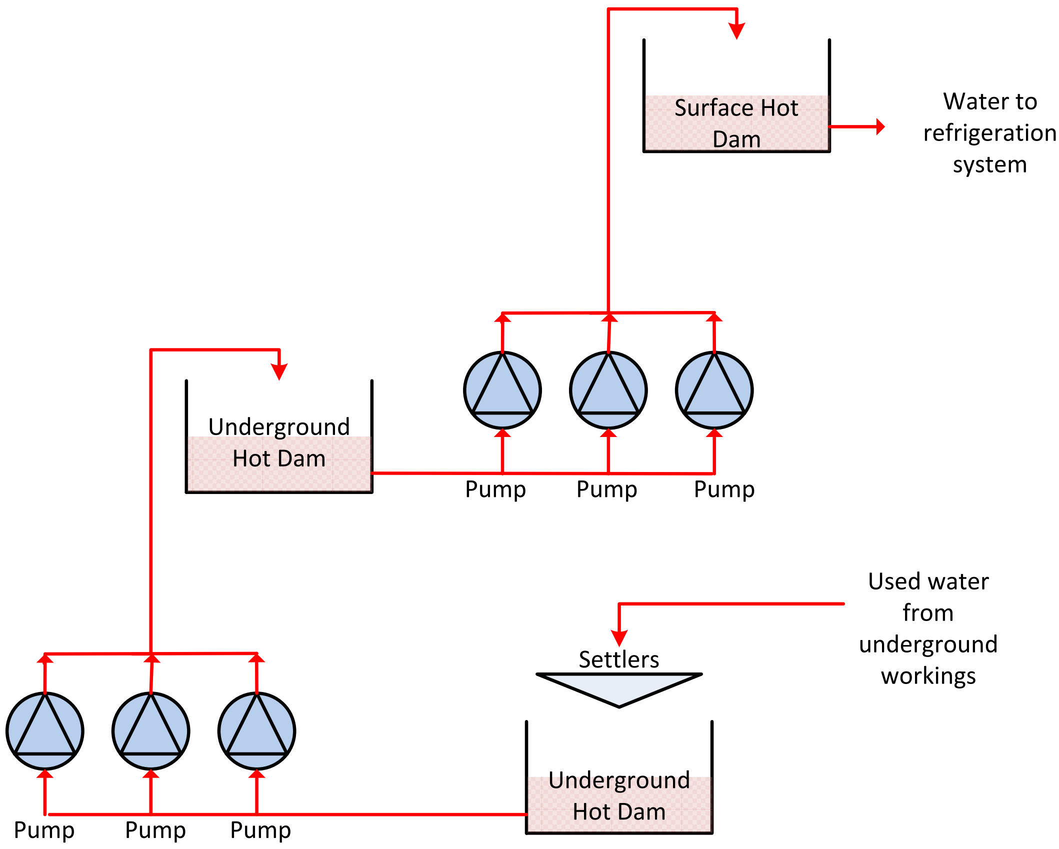


Figure 23: Simplified layout of a mine dewatering system

Many mines make use of conical settlers to separate mud from water. A flocculent is added to the run-off mine water to improve the settler's effectiveness. The flocculent forms a gelatinous substance that is difficult to dissolve. Small notched launders distribute mixed flocculent evenly across the water stream. The clear water flows over a lip launder into storage dams. Settled mud is extracted from the settler underflow in twenty-minute intervals and stored in a mud dam [50]. Figure 24 shows a cross section of a conical settler.

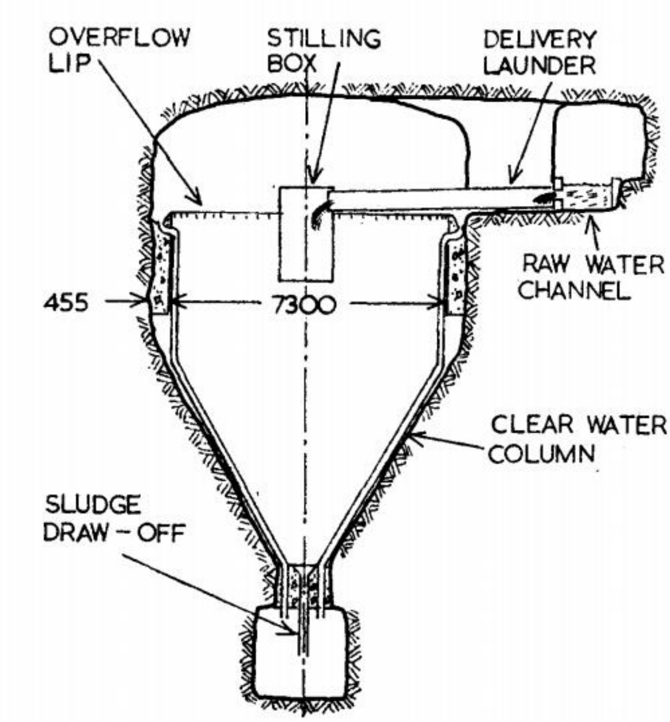


Figure 24: Cross section of a conical settler [50]

The mine dewatering pumps are usually large multistage centrifugal pumps placed at roughly 600 m vertical intervals. Mines usually run centrifugal pumps intermittently to accommodate the fluctuations in water supply [51]. Multistage centrifugal pumps have several impellers. The water that exits the discharge side of the first stage, or impeller, enters the suction end of the next stage. Each stage adds a certain amount of head which generates the total head produced by the pump [52]. Figure 25 shows the cross-cut of a multistage centrifugal pump.

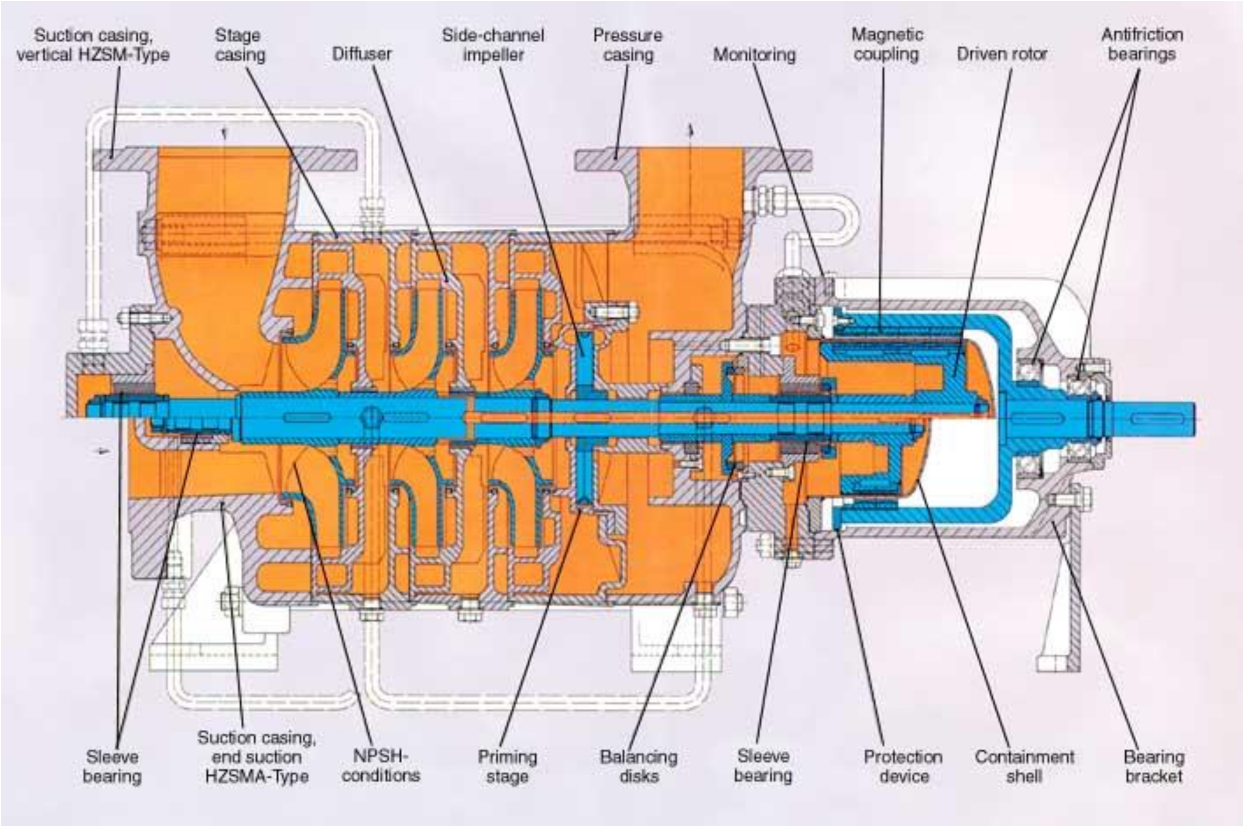


Figure 25: High pressure multistage centrifugal pump [53]

To understand how a centrifugal pump operates in the field, some fundamentals of fluid mechanics should be understood. For an incompressible fluid, such as water, the pressure difference between two elevations can be expressed as [54]:

$$p_2 - p_1 = -\rho g (z_2 - z_1) \qquad \text{Equation 2}$$

Where: p_2 = pressure at Level 2 in Pa

p_1 = pressure at Level 1 in Pa

z_2 = elevation Level 2 in m

z_1 = elevation Level 1 in m

ρ = density in kg/m^3

g = gravitational acceleration in m/s^2

If H = z_2 - z_1 (the depth down from location z_2) then the pressure head (H in Pa) can be given as:

$$H = (p_2 - p_1)/\rho g \qquad \text{Equation 3}$$

Using the description of head, a better understanding of the effect a pump has on the water is obtained. The power gained by the fluid from a pump can be expressed as [55]:

$$P = mgH \qquad \text{Equation 4}$$

Where: P = power

m = mass flow rate

g = gravitational acceleration in m/s^2

H = pressure head

If $m = \rho Q$ where Q is the volume flow rate, then the power gained by a fluid from a pump can be expressed as:

$$P = \rho gQH \qquad \text{Equation 5}$$

The overall efficiency of a pump can be defined by the fluid power (P in Watt) developed by the pump divided by the shaft power input (P_s in Watt) and can be expressed as [55]:

$$\eta = \rho gQH/P_s \qquad \text{Equation 6}$$

A typical clear-water pumping system makes use of multiple pumps operating simultaneously. Pumps operating in parallel usually have a joint intake manifold and a joint delivery manifold. The reason for using several pumps in parallel is to account for varying demand for dewatering. Figure 26 shows how the pumps are connected in a parallel configuration.

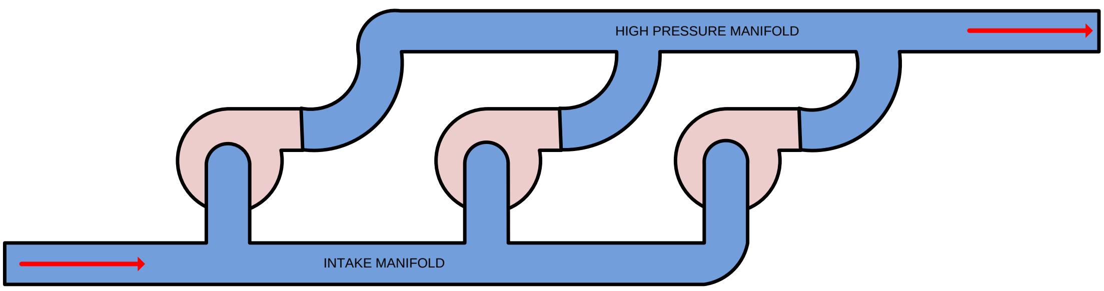


Figure 26: Pumps in parallel configuration

Pumps that operate in parallel will deliver a single combined performance curve for a pumping station. In ideal circumstances, the resulting pumping curve can be calculated by adding the pump flow rates at the same head. When operating pumps in parallel it would be ideal to use pumps with identical pump curves. This will ensure that the pumping load is distributed evenly between pumps. If pumps operating in parallel are not selected carefully, one pump can overpower the other and force its check valve to close, causing hydraulic shut off [56].

An increase in the number of pumps operating in parallel on a single column will reduce the flow rate through each pump. This could result in each pump only pumping at a fraction of its capacity. Figure 27 shows the performance curve for multiple pumps operating in parallel.

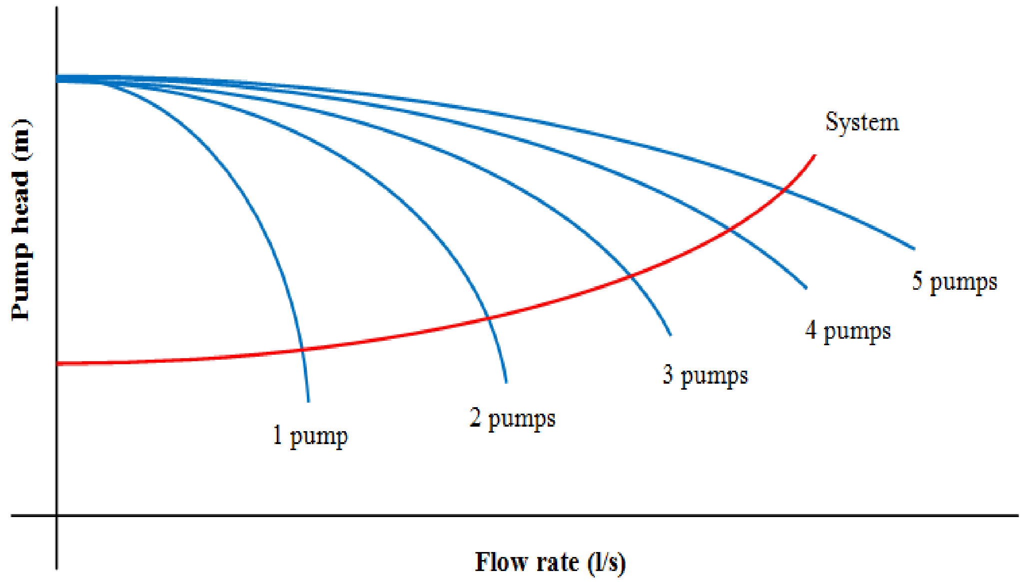


Figure 27: Performance curve for multiple pumps

Some deep mines also make use of three-chamber pipe feeder systems (3CPFS). A 3CPFS works on the U-tube principal, where the hydrostatic pressure of the supply water that is gravitated down the mine is used to withdraw used service water from underground.

The 3CPFS makes use of three horizontally installed pipes to exchange the resulting potential energy from the high pressure vertical column to a low pressure system. The 3CPFS system acts as the interface between the clear water sent down the mine and the used service water that must be pumped back to surface [57].

There are also booster and filler pumps installed on a 3CPFS system. The booster and filler pumps are situated on column A and B respectively as shown in Figure 28. The booster pump is used to increase the pressure of the high pressure side; the filler pumps are used to fill the chambers with the low pressure hot water. The filler and booster pumps give the 3CPFS system the ability to specify the flow rate at which the system operates [58].

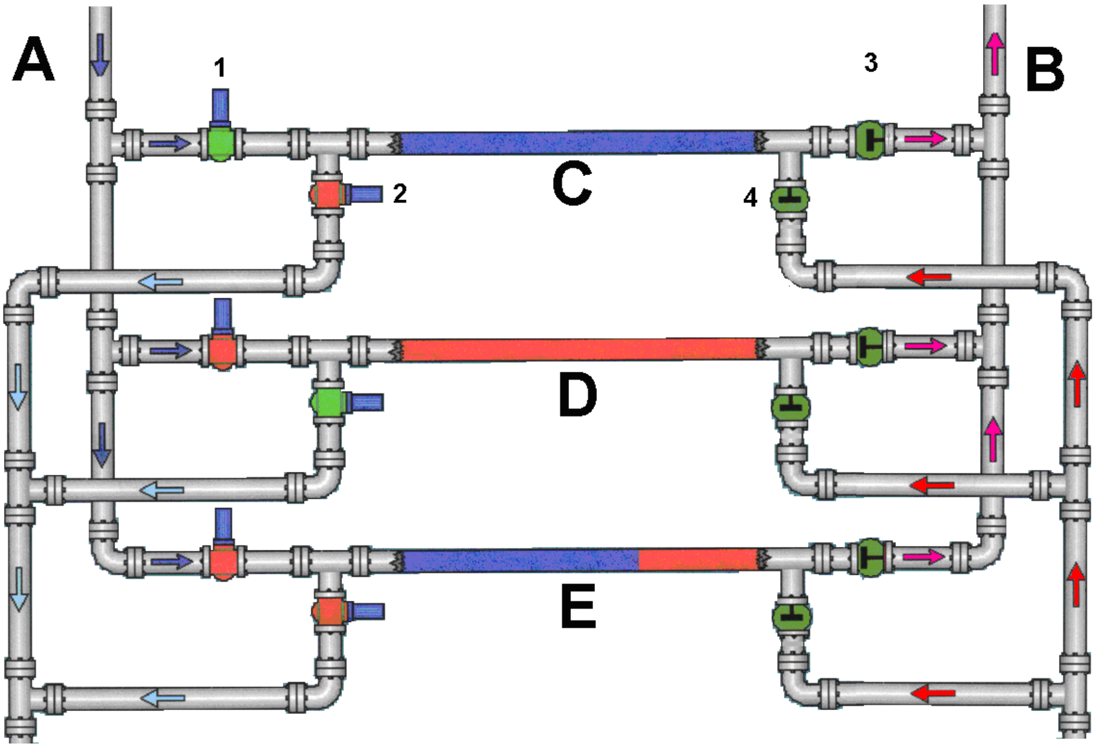


Figure 28: Schematic representation of a 3CPFS system

A 3CPFS system can be designed for pressures up to 16 000 KPa. This system uses much less electricity to pump used mine water back to surface than a conventional pumping system [59]. The 3CPFS can typically operate at an efficiency of 90% to 95%. This means that the system uses only 5% to 10% of electricity input by means of booster pumps [60].

Studies have shown that these systems can operate at an overall system efficiency of between 47% and 73%. Pumping costs are dramatically reduced because incoming chilled water displaces outgoing warm mine water. Additional savings or cooling benefits are incurred by the fact that energy recovered (from the hydrostatic pressure in the incoming water to pump water out of the system) means that potential thermal energy is not dissipated [57]. Normally, dissipation of the pressure results in the water temperature rising 2.34°C per 1 000 m depth. By transferring the potential energy to the outflow this temperature rise is avoided; translating either into a saving on the refrigeration load or better cooling in the mine for a given refrigeration input on surface [61].

Refrigeration

The refrigeration system refers to the section in the mine water reticulation system where hot water is cooled on a large scale. This system not only cools water for mining purposes, but also uses chilled water to cool air for ventilation purposes [62].

Air ventilation on mines becomes less effective as mining depth increases. Studies have shown that using large refrigeration plants is the best cooling technique for deep level mining [63]. The majority of refrigeration systems make use of so-called fridge plants. Typical fridge plants utilise a vapour compression cycle. Refrigerant is compressed and circulated through an enclosed circuit. Heat is absorbed and rejected through heat exchangers [64]. Figure 29 shows a simplified layout of a mine surface refrigeration system.

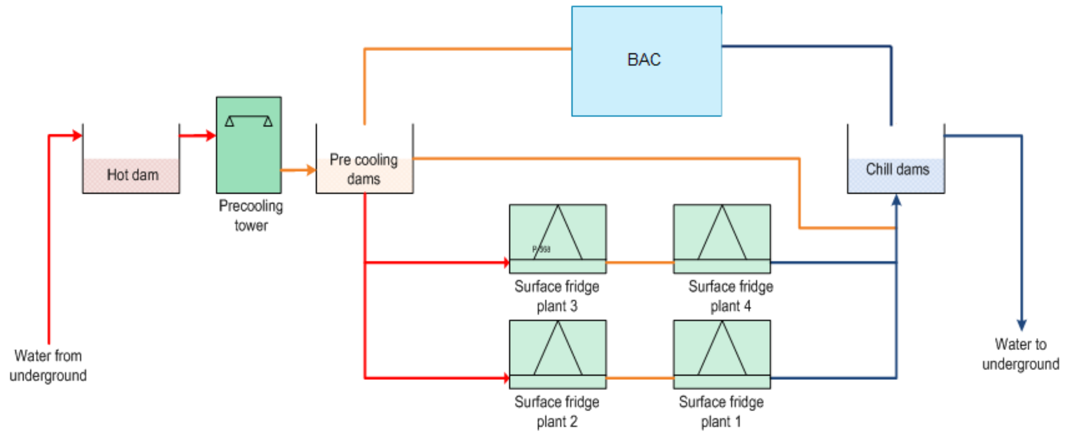


Figure 29: Simplified layout of a mine surface refrigeration plant system

Hot water is pumped from underground to the surface hot storage dams. This water is then precooled using cooling towers. The cooling towers make use of ambient air to cool the hot water. After passing through the cooling towers the water is fed into the refrigeration plants where further cooling takes place to the desired outlet temperature, which is typically about 3°C [64]. Figure 30 shows an example of cooling towers.

Figure 30: Cooling towers

The water that feeds the refrigeration plants is typically water that is pumped from underground. However, water can also be purchased from local water councils when low system water volumes cause demand shortfalls.

The power consumption of the surface refrigeration system is dependent on the atmospheric conditions and will therefore fluctuate with the changing seasons. The electricity demand of the refrigeration system can decrease by up to 12% during the winter months [65].

Because each mine is unique there is a great diversity in the designs of the existing cooling systems in South Africa's mines. Refrigeration plants reduce the water temperature significantly, depending on the actual underground working conditions. In many cases the installed refrigeration capacity is overdesigned to accommodate future development and expansion [63].

Positioning refrigeration plants on surface presents opportunities for the generation of large quantities of chilled water or ice during low demand periods for use during high demand periods. Thermal storage is a strategy that reduces power consumption during peak-tariff periods and makes chilled water available during the peak-consumption period [66].

As mines deepen, cost-effective cooling can no longer be provided by additional cold ventilation from surface. Due to the extreme depths of some mines, refrigeration plants are sometimes installed underground [63]. These refrigeration plants are usually installed at depths 1 000 - 2 000 m below the surface [67]. Figure 31 shows the different refrigeration strategies used as a mine's depth increases.

Figure 31: Refrigeration strategies for deep level mining [68]

In order to keep air temperatures safe, cold air also has to be sent down the mine. Some of the chilled water coming from the refrigeration plants is passed through a bulk air cooler (BAC). The main purpose of a BAC is to cool the ventilation air for the mine operations. Water usually exits the BAC at a useful temperature and is used for further underground cooling [69].

In some cases where the temperature in the shaft is acceptable but the temperatures in the haulages are not, underground BACs are installed. Haulages refer to the areas workers travel through to get to their working stations. These BACs are placed at strategic sites to cool the ventilation air whenever the air temperature rises to above the maximum design value. This ensures a safe thermal environment to work in.

2.3 THE AUTOMATION OF A WATER RETICULATION SYSTEM

Traditionally mines' underground pumping and refrigeration operations are controlled by operators. These operators control the underground dewatering- and refrigeration systems using their own discretion [70].

Underground dam levels are monitored using mechanical level floats. It is the operator's responsibility to make a decision whether to start or stop a pump or fridge plant. Operators communicate between pumping stations using a telephone system. Operators have to follow a start-up procedure formulated for each specific system. The operators at the refrigeration systems have to switch the fridge plant systems on and off according to temperature measurements taken at the beginning of each shift.

The manual operation control strategy is one of the most basic control strategies. Operators are not always equipped with the technical knowledge needed to most efficiently operate pumping and refrigeration systems. Optimal cost control strategies of the pumps and fridge plants are thus not maintained [70].

The automation of a water reticulation system involves the installation of instrumentation to operate the distribution, dewatering and refrigeration systems safely from a remote location. Although there are various types of infrastructure available to achieve this, only the most common instruments will be discussed. Every mine has specifications and regulations as to which instrumentation needs to be installed.

A mine group's dewatering stations were considered to determine which instrumentation was installed. The most commonly installed instruments on automated pumping stations were:

- Temperature probes installed to measure motor bearing-, pump bearing- and motor winding temperatures; these sensors will cause the pump's motor to trip should the bearing or winding temperature exceed a predefined set point. Figure 32 shows an example of an installed motor bearing temperature probe.

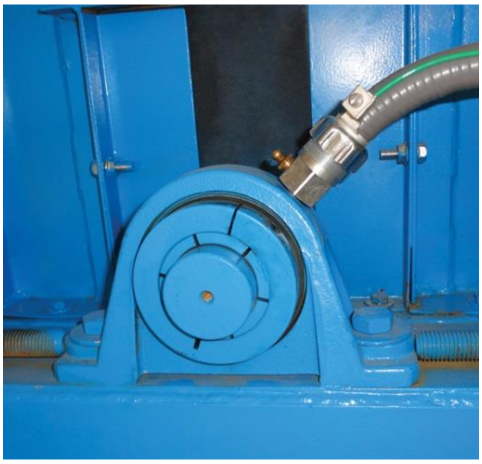


Figure 32: Installed bearing temperature probe [71]

- Vibration transmitters installed to monitor the start-, stop- and operating vibrations of a pump; these vibrations are most commonly measured with accelerometers. The mine uses the vibration data to analyse pump health. The data obtained can also help to detect cavitation and assist overall condition monitoring and maintenance planning [72].
- Motor shaft displacement sensors installed for condition monitoring purposes; these sensors measure the vibration, position and profile of the motor's shaft [73].
- Motor protection relay systems installed to safely start and stop the pump's motor.
- Valves and actuators installed to safely start up the dewatering pumps. Traditionally pump attendants would have opened and closed these valves by hand.

All the previously mentioned equipment will be integrated with a programmable logic controller (PLC) system to monitor the operation of the pump. The PLC system acts as the brain to which all the measuring equipment connects. The motor protection relay system usually includes a human machine interface (HMI) which can be used to program set points and restrictions [74].

Other instrumentation on dewatering systems include dam level sensors (usually pressure transmitters) and power meters. These are used to respectively monitor the demand and supply of water in the system, and the power consumption of the pump drive motors.

The automation of refrigeration systems can be very complex. A fridge plant has many more components that have to be automated and measured. These systems are much more complex than simple dewatering pump setups. The automation of a fridge plant system on a mine was investigated to develop a better understanding of which instruments could be installed to automate the system. Instruments that were installed on the mine's refrigeration system include:

- **Temperature transmitters**. These transmitters are used to measure compressor bearing temperature on the drive end (DE), non-drive end (NDE), thrust bearing, compressor thrust relay disk, discharge gas, oil sump, lubrication oil and suction gas.
  On the condenser temperature transmitters measure temperatures of the inlet water, outlet water, liquid gas and condensing gas. On the evaporator these transmitters measure temperatures of the inlet water, outlet water, liquid gas and evaporating gas.
  On the gearbox temperature transmitters measure temperatures on the bearings on DE and NDE for both the high speed side and the low speed side of the gearbox. They also measure the gearbox oil sump and lubrication oil temperatures. Temperature transmitters were also fitted on the main motor's DE and NDE bearings.
- **Pressure transmitters**. The installed pressure transmitters were fitted to measure pressures on the condenser, evaporator, condenser inlet and outlet water, evaporator inlet and outlet water, compressor oil differential pressure and the gearbox oil differential pressure.
- **Vibration sensors, current transducers and temperature switches**. These were installed on the main motor.
- **Actuators**. Actuators were installed on the fridge plant control vain, hot gas bypass valve, evaporator water flow control valve and chilled water distribution valve.
- **Flow meters**. Flow meters were installed on the condenser water and the return water from the BAC.

All the above mentioned instrumentation will be controlled and monitored using a PLC system. The next step in automating a mine water reticulation system is implementing a supervisory control and data acquisitioning (SCADA) system. These systems can be used to control geographically dispersed systems or components. A centralised control centre performs monitoring and control over long-distance communication networks.

SCADA systems make it possible to perform automated or operator-driven supervisory control based on the information received from remote stations or operations. Most of the control actions are performed automatically by remote terminal units or PLCs [75]. Some of the most popular SCADA systems used on mines include Adroit [76], Wonderware InTouch® [77] and WinCC [78]. Figure 33 shows an example of a SCADA layout of a mine refrigeration system.

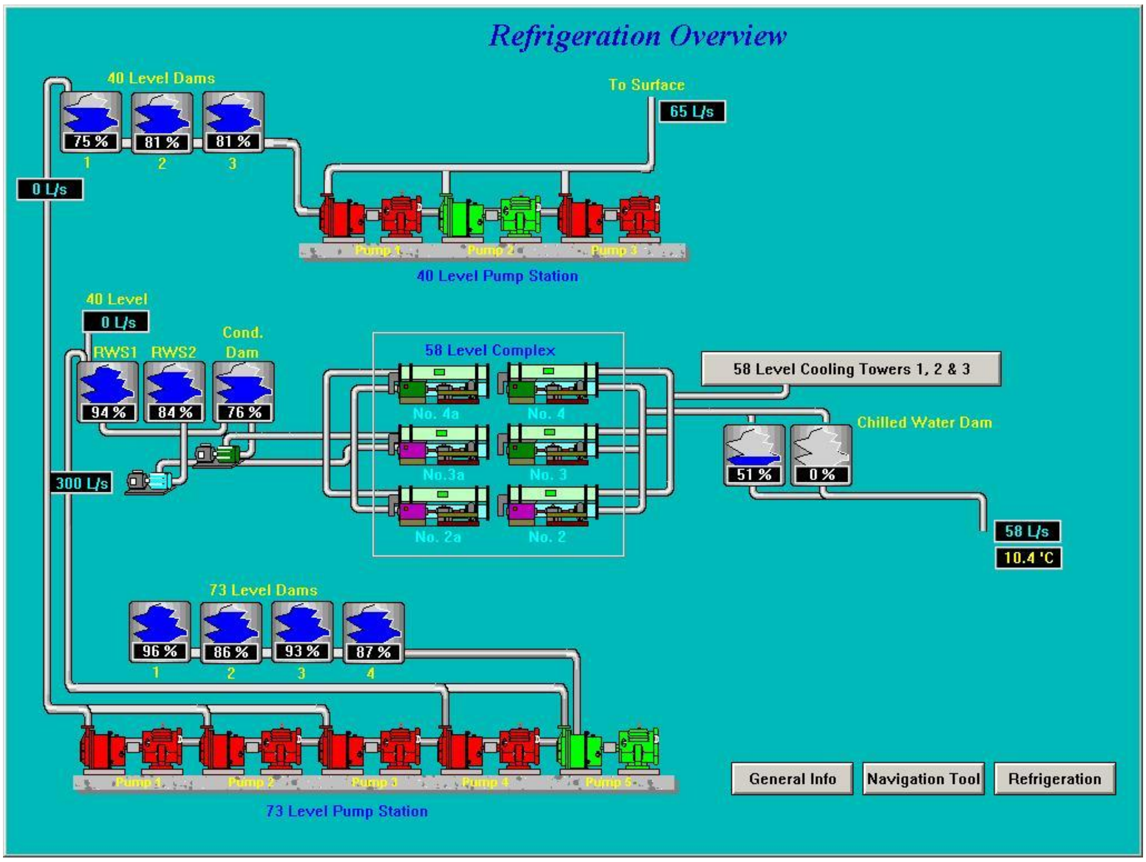


Figure 33: Example of a mine refrigeration system's SCADA layout

2.4 EFFICIENCY OF WATER RETICULATION SYSTEM COMPONENTS

Before investigating cost-effective strategies for mine water reticulation systems it is important to understand how to measure the efficiency of the different components. The three sub-systems of the water reticulation system have to be evaluated individually to understand how to measure their efficiencies. By understanding the efficiency of each individual system it is easier to understand how cost-effective strategies influence the considered systems. A better understanding of the cost effectiveness of implementing the cost-effective strategies is also gained.

CALCULATING THE EFFICIENCY OF THE DEWATERING SYSTEM

The easiest way of calculating the theoretical power consumption of a mine dewatering system is to use the following equation [60]:

$$E_{\mathrm{ps}} = M * g * H * 1000 * 3600 \qquad \text{Equation 7}$$

Where: E_{ps} = daily electricity used to extract water from the pump station in kWh

M = mass of water pumped in kg

g = gravity acceleration constant (9.81 m/s^2)

H = total head of pumping station

Power meter data is needed to calculate the actual power consumption of a pump station. If no power meter is installed on a mine an accurate alternative is to use the rated power of the pump motors. This method is less accurate than using power meter data, but remains relatively accurate due to the fixed static head of the system. The actual power consumption of the pump station can be calculated using the following equation [60]:

$$E_{\mathrm{act}} = \sum_{i}^{no\ of\ pumps} (Pr_{\mathrm{i}} * h_{\mathrm{i}}) * 1000 * 3600 \qquad \text{Equation 8}$$

Where: E_{act} = rated electricity consumption of pump station (kWh)

Pr_i = rated power consumption of pump i

h_i = number of hours pump i was running during the day

By using Equation 7 and Equation 8, the efficiency of the pump station can be determined using the following equation:

$$eff_{\mathrm{ps}} = \left(\frac{E_{\mathrm{ps}}}{E_{\mathrm{act}}}\right) * 100\% \qquad \text{Equation 9}$$

This equation can then be used to calculate the efficiency of the dewatering system.

$$eff_{\text{system}} = \frac{1}{N}\sum_{i}^{N}\left(\frac{E_{\text{ps}}}{E_{\text{act ps i}}}\right)\%$$ Equation 10

Where: eff_{system} = efficiency of dewatering system

i = pump station number

N = number of pump stations

From Equation 10 it is evident that the efficiency of a dewatering system can be increased by reducing the electricity consumption on the pumping stations.

CALCULATING THE EFFICIENCY OF THE REFRIGERATION SYSTEM

The energy efficient operation of an integrated refrigeration system is usually evaluated by considering the global system coefficient of performance (COP). The global COP can be calculated using the following equation [79]:

$$Global\ COP = \frac{\dot{Q}_{\text{cooling system}}}{\dot{W}_{\text{cooling system}}}$$ Equation 11

Where: $\dot{Q}_{\text{cooling system}}$ = heat transfer rate in W

$\dot{W}_{\text{cooling system}}$ = input electrical power in W

The factors that need to be considered when calculating the global COP include the total thermal load and the total input power of all electrical energy users of the integrated cooling system. The power users include fridge plant compressors, water pumps and cooling tower fans. The total thermal load of a refrigeration system can therefore be calculated using the following equation:

$$\dot{Q}_{\text{cooling system}} = \dot{m}_{\text{w,daily avg}} * C_{\text{pw}}(T_{\text{hot dam}} - T_{\text{chilled dam}})$$ Equation 12

Where: $\dot{m}_{\text{w, daily avg}}$ = average daily water mass flow rate in kg/s

C_{pw} = specific heat at a constant pressure of water in J/kg.^{o}C

$T_{\text{hot dam}}$ = hot dam temperature

$T_{\text{chilled dam}}$ = chilled dam temperature

From Equation 11 it is evident that the global COP of a refrigeration system can be increased if the input electrical power to the system is reduced without affecting the heat transfer rate of the system.

COST EFFECTIVENESS OF ELECTRICITY SAVING STRATEGIES

The cost effectiveness of electricity cost-saving strategies refers to the comparison between the relative costs, effects and outcomes of two or more courses of action. In the case of electricity cost-saving strategies it refers to the comparison between the relative costs and effects between implementation of a DSM intervention and present operation.

In most cases the reason for implementing a DSM intervention is to achieve electricity cost savings without affecting the outcomes of the considered operation. The two factors that will be considered to evaluate an intervention's cost effectiveness are payback period and cost to company.

The payback period refers to the period of time required for the return on an investment to reimburse the original investment. In the DSM environment, this means the time that it would take for the electricity cost savings achieved by implementing a DSM strategy to reach the cost incurred during implementation. The cost to company will refer to the amount of expenses the client underwent to implement and maintain such a DSM strategy.

2.5 ELECTRICITY COST-SAVING STRATEGIES FOR MINE WATER RETICULATION SYSTEMS

As mentioned previously many successful DSM projects have been implemented on mine water reticulation systems. These DSM projects involved electricity saving strategies such as load shifting (through pump automation and scheduling), fridge plant peak clipping, cooling auxiliary optimisation and water system optimisation.

In order to optimise a mine water reticulation system it is very important to study each mine's operating procedures. Each mine operates on a specific schedule unique to that mine. Mining shifts are usually divided into three main periods namely the morning, afternoon and night shifts.

Drilling usually takes place during the morning shift. Drilling is done in order to insert explosives deep into the underground rock face. Blasting usually takes place during the afternoon shift. All personnel exit the mine for safety reasons and the explosives are set off. Sweeping usually takes place during the night shift. It is also during the night shift that rock is removed from underground for further processing. It is important to keep these periods in mind when optimising a mine water reticulation systems so that production is unaffected by the implementation of any cost-saving strategies. The demand for power, water and cooling also vary during these periods. Figure 34 shows an example of the typical generalised demand profiles during the different mining shifts.

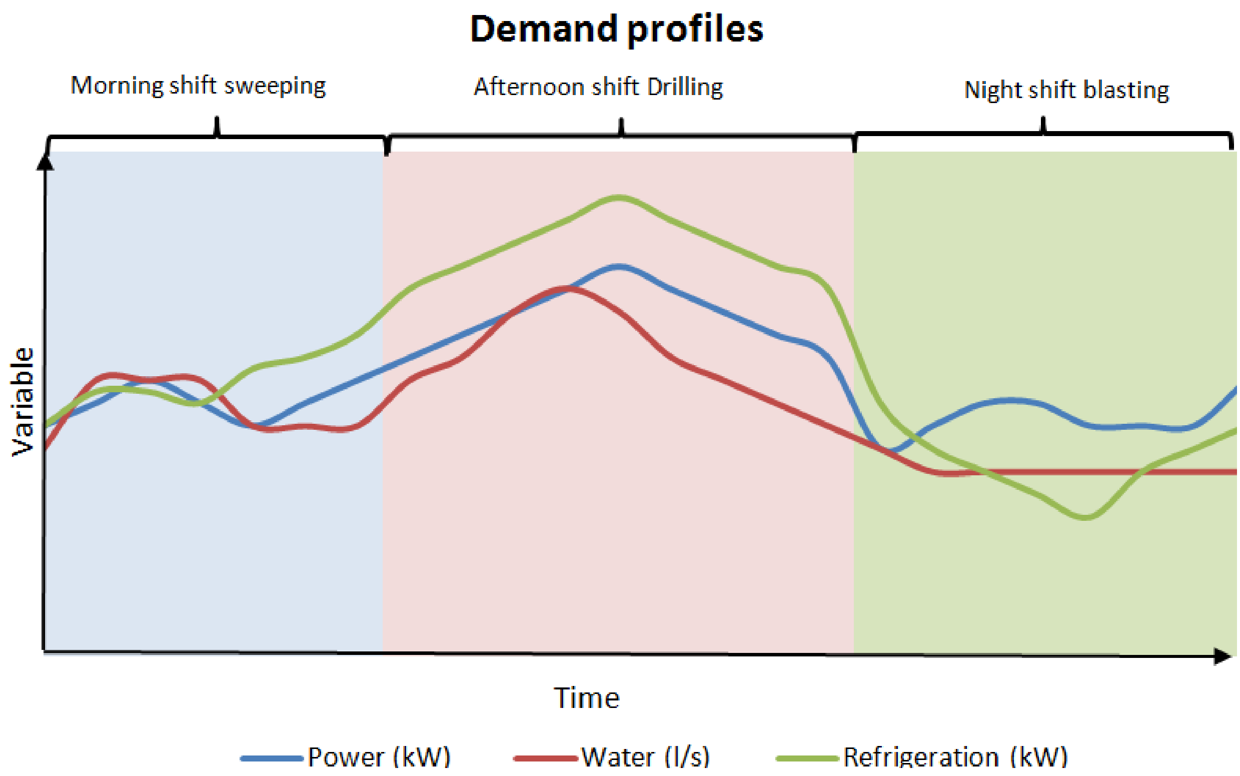


Figure 34: Example of demand profiles during different mining shifts

Load shifting through pump scheduling

Great potential for the implementation of load-shifting projects exists due to the large amount of water that has to be pumped from underground every day, and the excess pump and storage capacities [80]. One method to do load shifting is to automate the pumping system and automatically schedule the pumps according to TOU tariffs.

Traditionally, dewatering pumps were operated according to the maximum and minimum dam levels specified by the mine. This meant that dewatering pumps regularly operated during peak periods. The excess underground storage capacity makes it possible to store water during peak periods and extract the stored water during off-peak periods. To accomplish load shifting the dewatering pumps have to be scheduled accordingly. Due to the variable demand nature of the mine water reticulation system a set pumping schedule for each day cannot be predetermined. Thus the system has to be simulated and analysed in real time to calculate a pumping schedule that will ensure that the mine does not operate pumps during peak periods.

In order to automatically schedule a mine's dewatering operations an energy management system has to be implemented. HVAC International has created such a system called Real-time Energy Management System (REMS) Pumps. This system is capable of shifting load and realising electrical running cost reduction by automatically scheduling pump operations. REMS has been implemented on several South African mines [81]. Figure 35 shows an example of an implemented energy management system with automated pump scheduling.

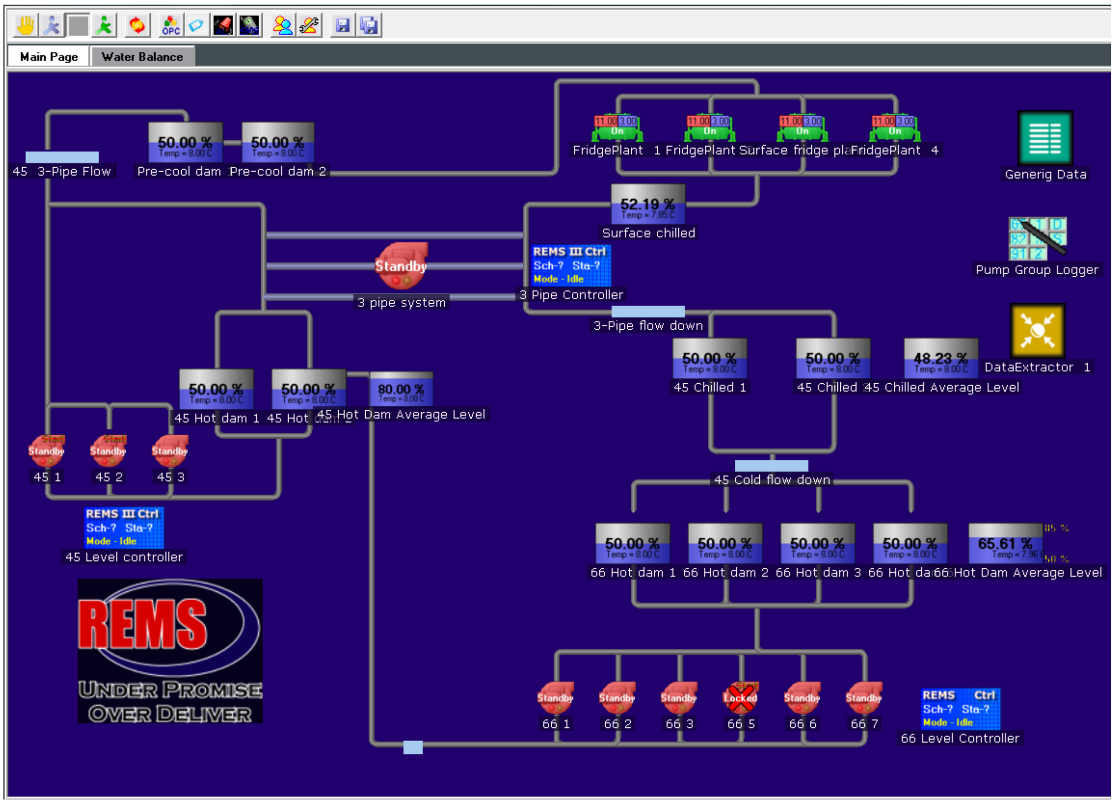


Figure 35: Example of an energy management system with automated pump scheduling

REMS links the components of the dewatering system with the variables of the dewatering model. These models are component-based and can be used to simulate a wide range of operating conditions. REMS can calculate the optimum schedule for pump operation and control the pumping systems accordingly [82]. In the past several of these projects have been done and have been proven to be extremely successful [82], [83].

Most load-shifting projects require buffer capacity where the process load can be stored. For water reticulation systems these buffers are hot and cold water dams. Figure 36 shows an example of what a typical load-shifting profile should look like.

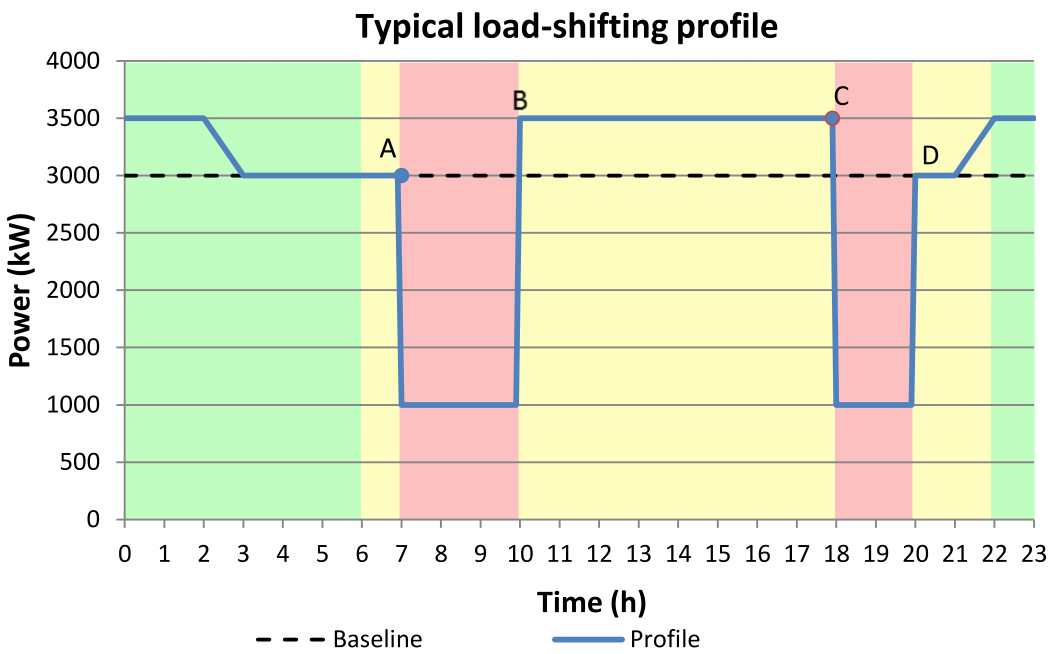


Figure 36: Example of a load-shifting profile

In order to determine if load shifting is possible on a pumping system the buffer capacity is evaluated. Firstly, the amount of water that can be stored in the underground hot water dams is determined. This is done by calculating the amount of water between the maximum and minimum constraints set by the mine.

$$Buffer = (Max - Min) * CAP \qquad \text{Equation 13}$$

Where: Max = maximum dam constraint percentage

Min = minimum dam constraint percentage

Cap = total dam capacity in Ml

For example: A mine has a dam that can hold 2.5 Ml. The dam has maximum and minimum constraints of 85% and 35% respectively. Thus there is a buffer of 1.25 Ml.

The next step is to determine the maximum flow that can be extracted from the dam. However, the maximum flow is difficult to determine without a system curve. As discussed in Section 2.2, pumps in parallel will deliver less flow with increasing number of pumps when supplying to a single column. To save time during preliminary investigations a system can be viewed as an ideal system. This means that no pump and system efficiencies will be included and also no pipe friction losses will be accounted for. However, it is suggested that a proper system curve is calculated before making a decision to implement a load-shifting strategy. The maximum amount of water that can be pumped in a particular time is thus given by the following equation.

$$Maximum\ flow\ out = \ Pump1\ rated\ flow + Pump2\ rated\ Flow \ldots\ldots$$ Equation 14

For example: On a mine pumping station there are three pumps each with a rated flow of 120 l/s. One pump is used as backup and the other two are operational. The maximum dam flow-out can then be calculated as 240 l/s.

The final variable that is determined is the inflow into a certain dam. Calculating the flow of water into an underground dam can be difficult. Mines send water underground for mining purposes according to demand. This means that the water flow to the underground dams is not constant. For preliminary investigation purposes a water inflow profile has to be calculated. This can be done by collecting pump log sheets from each pumping station. On these log sheets pump operators log when a pump is switched on and off, as well as the dam level at each incident on an hourly basis. The inflow profile can be calculated by converting the dam levels to volume of water and subtracting the amount of water pumped by the pumps according to their rated flows. This should be done hourly over a long period to calculate a fairly accurate average hourly inflow profile. The following equation is used to determine the dam inflow during a specific hour.

$$IPH = \left| \frac{\left((|DL1 - DLO| * CAP * 1000000) - (NP * RF * t * 3600)\right)}{3600} \right|$$ Equation 15

Where: IPH = inflow per hour in l/s

DL0 = dam level percentage at beginning of hour

DL1 = dam level percentage at end of hour

CAP = dam capacity in Ml

NP = number of pumps

RF = rated flow of pump(s) in l/s

t = period the pump(s) operated in hours

Once again, this is not an accurate way of determining the inflow profile but it is sufficient for preliminary investigations. The flow will typically vary every day as demand for underground water varies. The reserve buffer capacity is determined to evaluate the possibility of peak load shift. In addition the reserve pumping capacity is determined to evaluate the off-peak comeback pumping load. This can be done by assuming that the underground dams are at minimum capacity just before the morning peak (Point A in Figure 36). Using the inflow profile the rate at which the dam level will increase during the three-hour morning peak (Point A to Point B) is calculated. If the dam level does not exceed the maximum dam level, morning peak load shift is possible. This can be calculated with the following equation:

$$DL1 = \frac{(DL0*CAP)+\frac{WIR7+WIR8+WIR9}{10000}*36}{CAP}*100$$ Equation 16

Where: DL1 = dam level after morning peak

DL0 = dam level before morning peak

CAP = total dam capacity in Ml

WIR7 = water inflow rate for hour 7

WIR8 = water inflow rate for hour 8

WIR9 = water inflow rate for hour 9

For example: At 7:00 a dam with a total capacity of 2.5 Ml is 35% full. The maximum dam level constraint is 85%. According to the calculated inflow profile the inflow of water is constant at a rate of 100 l/s. The dam level at 10:00 will thus be 78.2%.

$$DL1 = \frac{(0.35*2.5)+\frac{100+100+100}{10000}*36}{2.5}*100$$

$$DL1 = 78.2\%$$

The dam level will not exceed the maximum constraint of 85% and has a further remaining buffer capacity of 8%. If this is not the case and the calculated dam level after the peak exceeds the maximum constraint, it means that a pump will have to be started during this peak period. This does not mean that load shifting is not feasible; it just means that a smaller load will be shifted to off-peak periods. If this is the case, the minimum number of pumps that have to be operated during the peak period has to be calculated. This can be done by calculating the amount of water that exceeds the maximum constraint. The minimum number of pumps needed to pump that amount of water in the shortest time can then be calculated.

$$EW = PO*CAP$$ Equation 17

Where: EW = extra water in

PO = percentage overshoot

CAP = total dam capacity

For example: The dam level percentage exceeding the maximum constraint is 10%. The pumping station has a dam with a storage capacity of 2.5 Ml. The pumping station also has two operational pumps with 120 l/s rated flow rate. There is thus an excess of 0.25 ML over the three-hour period.

$$EW = (0.1 * 2.5)$$
$$EW = 0.25\ Ml$$

This means that one pump can pump that amount of water in:

$$t = \frac{EW * 1000000}{NP * RF}$$
$$t = \frac{0.25 * 1000000}{1 * 120}$$
$$t = 2083.33\ seconds\ = 34.72\ minutes$$

The pump should thus be kept on at the beginning of the peak period and should be switched off 35 minutes after the start of the morning peak.

The next step is to determine if the dewatering pumps will be able to empty the hot water dams fast enough to ensure that an evening load shift will be possible. This can be accomplished by first calculating the buffer size needed for an evening load shift and also determining if the dewatering pumps can extract enough water from the dams in the time between the morning and evening peaks.

For example: A dam with 2.5 Ml capacity is at a maximum level of 85% right after the morning peak. The pumping station has two operational pumps each with a rated flow of 120 l/s. The average inflow of water between the two peak periods is 200 l/s.

The water flowing into the dam between 10:00 and 18:00 is equal to:

$$Total\ water\ into\ dam = \frac{200 * 3600 * 8}{1000000}$$
$$Total\ water\ into\ dam = 5.67\ Ml$$

The maximum amount of water the two pumps can extract from the dam is equal to:

$$Total\ water\ pumped = \frac{(120*2*3600*8)}{1000000}$$
$$Total\ water\ pumped\ = 6.91\ Ml$$

This means that the dam level before the evening peak, if both pumps operate continuously, will be equal to 35.4 %. An evening load shift will be possible. Equations 9 and 10 can be used to calculate if it would be possible to implement an evening load shift.

Fridge plant load shifting

As mentioned previously, a mine refrigeration system is very energy intensive and can consume more than 20% of a mine's total electrical supply [84]. These systems thus offer great potential for the implementation of possible DSM strategies such as load shifting.

For it to be possible to do a load shift on a mine refrigeration system some sort of thermal storage is needed. Many ventilation and cooling systems make use of their hot and cold water dams to serve as thermal storage buffers. Thermal and electrical peak-time energy can thus be reduced by shutting down the fridge plan during peak periods [85].

The success of this strategy relies mainly on the mine refrigeration system's ability to produce and store enough cold water before peak periods. The cold water stored in the cold water dams can then be used for underground cooling and ventilation purposes.

Similar to the energy management system REMS Pumps, HVAC International has also created an energy management system specifically for shifting load on mine fridge plant systems. This system has been tested and has proven successful and beneficial to both the mine and to Eskom [85]. Figure 37 shows an example of a mine fridge plant system that has successfully implemented load shifting.

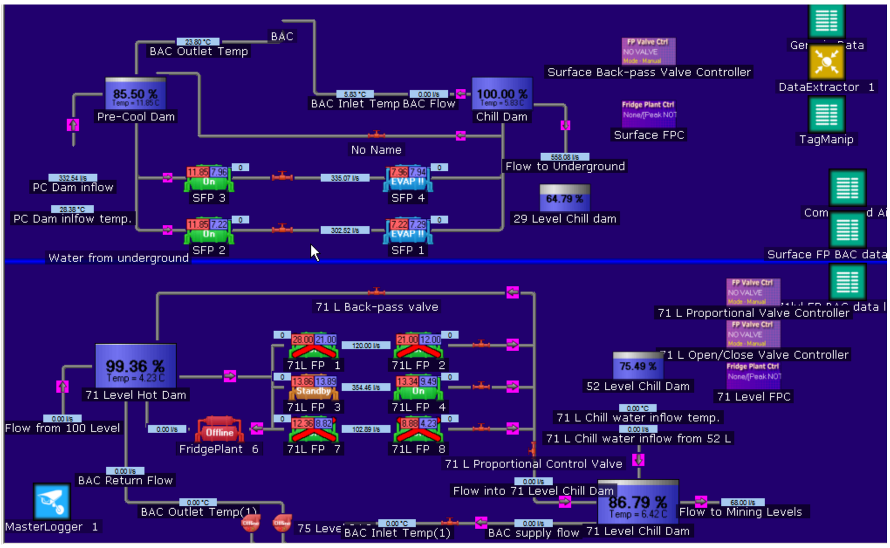


Figure 37: Example of a fridge plant system with load shifting

Implementing load shifting on pumping systems and implementing load shifting on fridge plant systems are very similar. The only difference is that the buffers are used in different ways. The fridge plant's cold water dam has to be as full as possible just before each peak period so that the underground works can still be supplied with cold water during the peak periods. The fridge plant has to produce enough cold water between peak periods to ensure that an evening peak load shift would be possible. The equations used to determine if a load shift will be possible on the dewatering system can easily be adapted for the implementation of load shift on fridge plant.

COOLING AUXILIARY OPTIMISATION

In some cases load shifting on a mine refrigeration system is not possible due to thermal storage constraints or high ventilation- and cooling demands. In such cases the focus could be on operating the refrigeration system's cooling auxiliaries more efficiently. This strategy focusses on optimising the normal operation of a mine refrigeration system by matching the operation of the evaporators with the demand of chilled water, adapting condenser operation to the heat load, and matching the BAC operation to the ventilation air requirements [86].

The primary function of a mine refrigeration system is to supply the mine with chilled water on demand, at the correct temperature. This electricity saving strategy focusses on the control of the evaporator-, condenser- and BAC water flow. This can be accomplished by installing variable speed drives (VSDs) and control valves on a mine and cooling auxiliaries to control the supply of cooling according to the demand.

Electricity cost savings are achieved by automatically synchronising ventilation air cooling requirements with the changes in ambient conditions. A decrease in ambient conditions results in less cooling required; less chilling water to the necessary temperatures; as well as less cold water needed by the BAC system to cool ventilation air [84].

VSDs are typically used to control the shaft speed of pump motors. Motor electricity consumption and water flow rate can be thus controlled. The water flow rate can also be controlled by electric or pneumatic actuators.

Cooling auxiliary optimisation reduces water usage from the cold water dam, resulting in less water that has to be chilled as well as less water that has to be pumped back to the precooling dam. This strategy has been implemented successfully on South African mine refrigeration systems [86]. Figure 38 shows an example of a mine fridge plant system and cooling auxiliaries. This figure shows the typical components that have to monitored and controlled in order to achieve savings with this strategy.

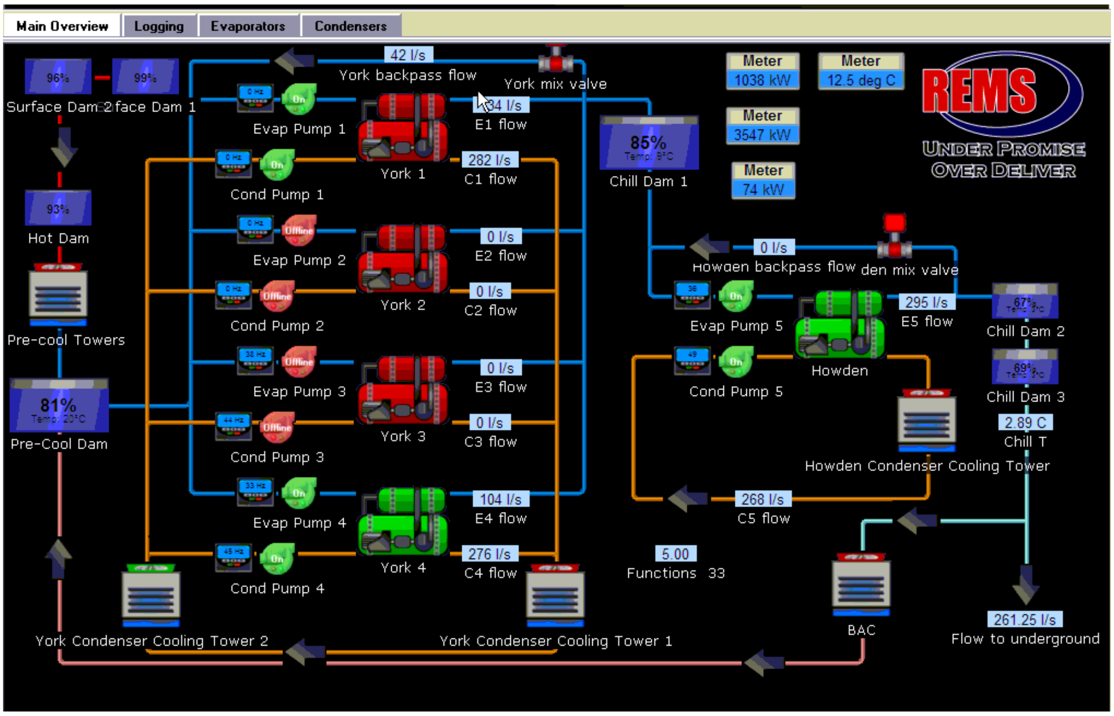


Figure 38: Example of a refrigeration plant system with cooling auxiliary control

When optimising a mine cooling auxiliary system it is challenging to determine which savings could be achieved due to the unpredictable fluctuations in ambient conditions. On some mines water flow pumped through the fridge plants is restricted by using valves set to a specific designed set point. This means that the pumps feeding into the fridge plants can supply more water than is necessary. Savings can be achieved by reducing the flow through the fridge plants. Savings are also achieved by installing VSDs on the condenser and evaporator auxiliaries. When ambient temperatures decrease, less water has to be sent through the condenser and evaporator towers. Typically most of the savings generated when implementing this strategy is achieved during winter months when ambient temperatures are at their lowest.

To implement this strategy it is necessary to know what the temperature and flow requirements are for safe mining operation. These requirements differ from mine to mine. Saving potential is also greatly influenced by the installed equipment of these systems. Each component that a VSD can be installed on contributes to the savings potential.

Determining the savings potential of a cooling auxiliary optimisation intervention can be quite difficult. A strategy to simulate and calculate the possible savings that can be expected has been developed and proved to be reliable [79].

WATER SYSTEM OPTIMISATION

Another method for reducing the electricity consumption of a mine water reticulation system is by reducing the amount of water that needs to be extracted from underground. One way to accomplish this is to isolate the water when no water-consuming mining operations are taking place. A typical mine will schedule certain water-consuming mining activities during different shifts.

During the morning shift drilling usually takes place. Water is then used to keep the drill bit cool and to suppress dust. During the afternoon shifts blasting usually takes place. During this shift water is utilised once again to suppress dust and also to cool the blasting area so that it is safe for mining personnel to work. During the night shift the blasted rock has to be recovered from underground. During this process water is used for water jets and scrapers.

One way of isolating water is by stope isolation control. Stopes refer to the areas where the actual mining takes place; these are the areas where the drilling, blasting and sweeping take place. Water supply pipes usually branch off the main water supply column at the shaft. These pipes are situated along the travel ways leading to the stopes and supply the stope areas with water. By installing control valves on these branches the water to the stope can be regulated or isolated during times when water is not needed [87].

The control strategy for the isolation valves are mostly determined by set point pressure at a certain time for each water consumption area. During production shifts the water pressure is regulated using a pressure-regulating value so as not to interfere with the mine‘s production. During afternoon shifts minimal water is required. Water pressure can thus be reduced to sustain sufficient flow to the fridge plants, BACs and cooling cars. In some mines where there are no underground BACs or other water consumers installed, the water supply can be isolated completely.

This water system optimisation (WSO) strategy has been implemented on some of South Africa's municipal water distribution networks and has been proven successful. WSO not only reduced pumping costs, but also reduced leakage losses and reduced downtime due to system failures [88]. Figure 39 shows a layout of a mine water distribution system as well as the control valves on the different levels.

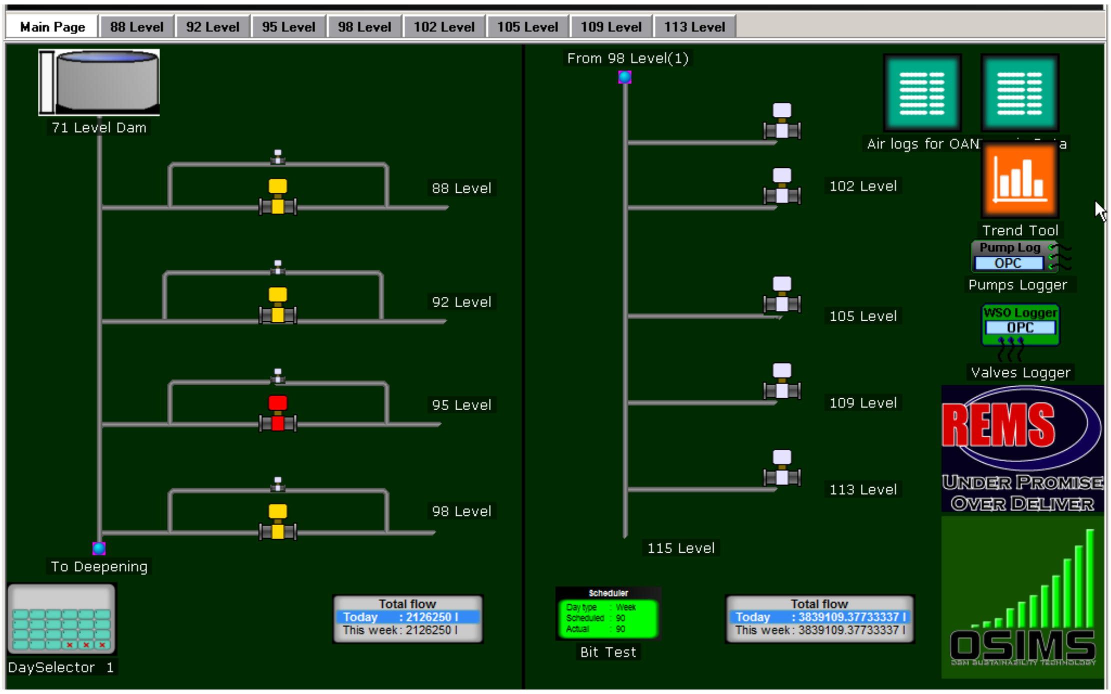


Figure 39: Example of a mine water distribution layout and control system

The first step in determining WSO potential is to investigate each mining level to determine what the minimum demand for water on that level would be. This can be accomplished by identifying the underground equipment that need a specific amount of water to operate and also by identifying leaks in the water distribution pipelines. This type of equipment usually includes cooling cars and BACs. This equipment can be seen as constant flow demand users. By combining the mine's shift schedule and equipment data it is possible to compile a flow profile for each underground level. An example of a flow profile can be seen in Figure 40.

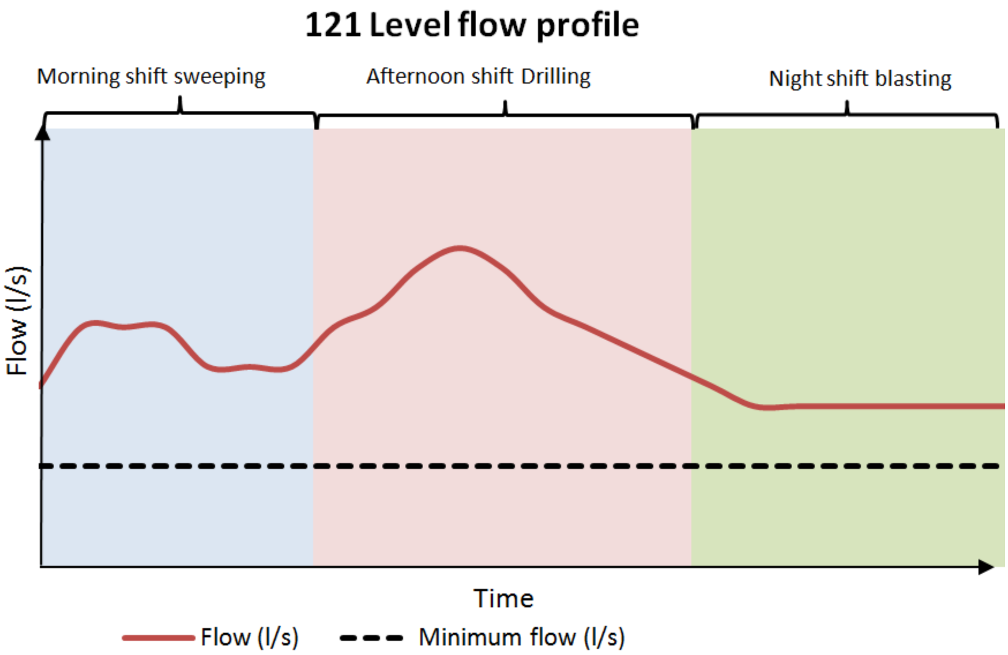


Figure 40: Example of an underground level flow profile

By using the flow profile in Figure 40 and the mine's shift schedule, a proposed profile can be created. This is done by reducing water on each level to such an extent that there is still enough water for the constant flow demand equipment to operate sufficiently. The water supply cannot be reduced during drilling and sweeping shifts because it could have an influence on production. An example of an optimised underground flow profile can be seen in Figure 41.

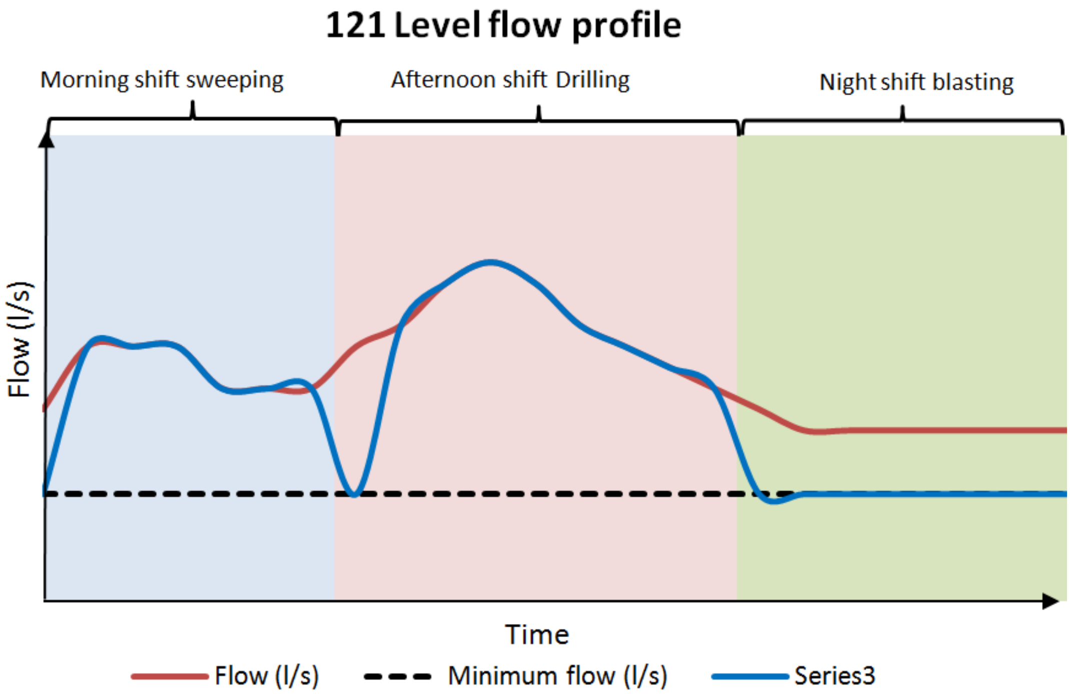


Figure 41: Example of an optimised underground flow profile

There is a direct relation between the water sent underground and the amount of energy used to extract that water from underground. The possible savings can be calculated by subtracting the total amount of water used in a day for the optimised profile from the total amount of water used in a day of the actual profile. The reduction in water flow of all the levels can then be summed and compared with the amount of water used before and after optimisation.

A proven software package available for the simulation of a WSO intervention is KYPipe. This software package has been used successfully to simulate a mine water distribution system and to simulate the savings potential of such an intervention [48].

2.6 CONCLUSION

The mining industry relies heavily on water reticulation systems to ensure safe underground thermal working conditions. Mine water reticulation systems are complex systems consisting of dewatering-, refrigeration- and water distribution systems; these systems consist of many components including refrigeration plants, heat exchangers, storage dams, pumps, valves and instrumentation. It becomes possible to optimise dewatering-, refrigeration- and water distribution systems when implementing DSM interventions by automating component operation. Typical DSM interventions such as load shifting, water system optimisation and cooling auxiliary optimisation have been implemented on the water reticulation systems of South African mines and have been proven successful. Implementing these systems on marginal mines might improve the marginality of the mines or result in electricity cost savings. The next chapter describes the financial feasibly of these interventions as well as the selection process for implementing these systems.

Chapter 3. SELECTING COST-EFFECTIVE STRATEGIES FOR ELECTRICITY COST-SAVING

This chapter will focus on the methodology for the identification and selection of a feasible, cost-effective DSM solution for marginal mines. This chapter will also reveal tools to assist in estimating cost implication and cost benefits from implementing DSM interventions.

3.1 INTRODUCTION

Before implementing a cost-effective strategy on the different components of a water reticulation system, the feasibility of these interventions needs to be determined. To accomplish this, tools are developed to assist in the decision-making process.

This chapter gives a step-by-step outline of the decision-making process used to identify potential savings in a mining group's water reticulation systems. These tools include methods for determining the estimated implementation cost projections as well as the expected savings. These tools are created using historic project data as well as hands-on experience with DSM and water reticulation systems.

This section will explain the methodology behind the implementation of cost-effective strategies on a mine water reticulation systems based on:

- Selecting shafts to be considered for implementation
- Identifying the critical system components
- Determining the relevant operational procedure for each strategy
- Estimating the saving potential and cost implication of each strategy
- Selecting the best strategies for implementation

3.2 ON-SITE INVESTIGATION AND OPPORTUNITY IDENTIFICATION

SITE AND SYSTEMS IDENTIFICATION

The goal is to develop a quick and easy way to identify mining shafts with the most electricity cost-saving potential. The first step is to identify all mining shafts where production takes place. Some mining shafts are used solely for ventilation, dewatering and water distribution to and from other mining shafts and may not have any production levels. Shafts without production levels tend to be less electricity intensive.

After identifying relevant shafts, it is important to know which components of the water reticulation system are present. Lastly, it is important to know which of these systems have already been optimised. A basic flow chart was developed that shows the step-by-step identification process of shafts that may have electricity cost-saving potential. This flow chart can be seen in Figure 42.

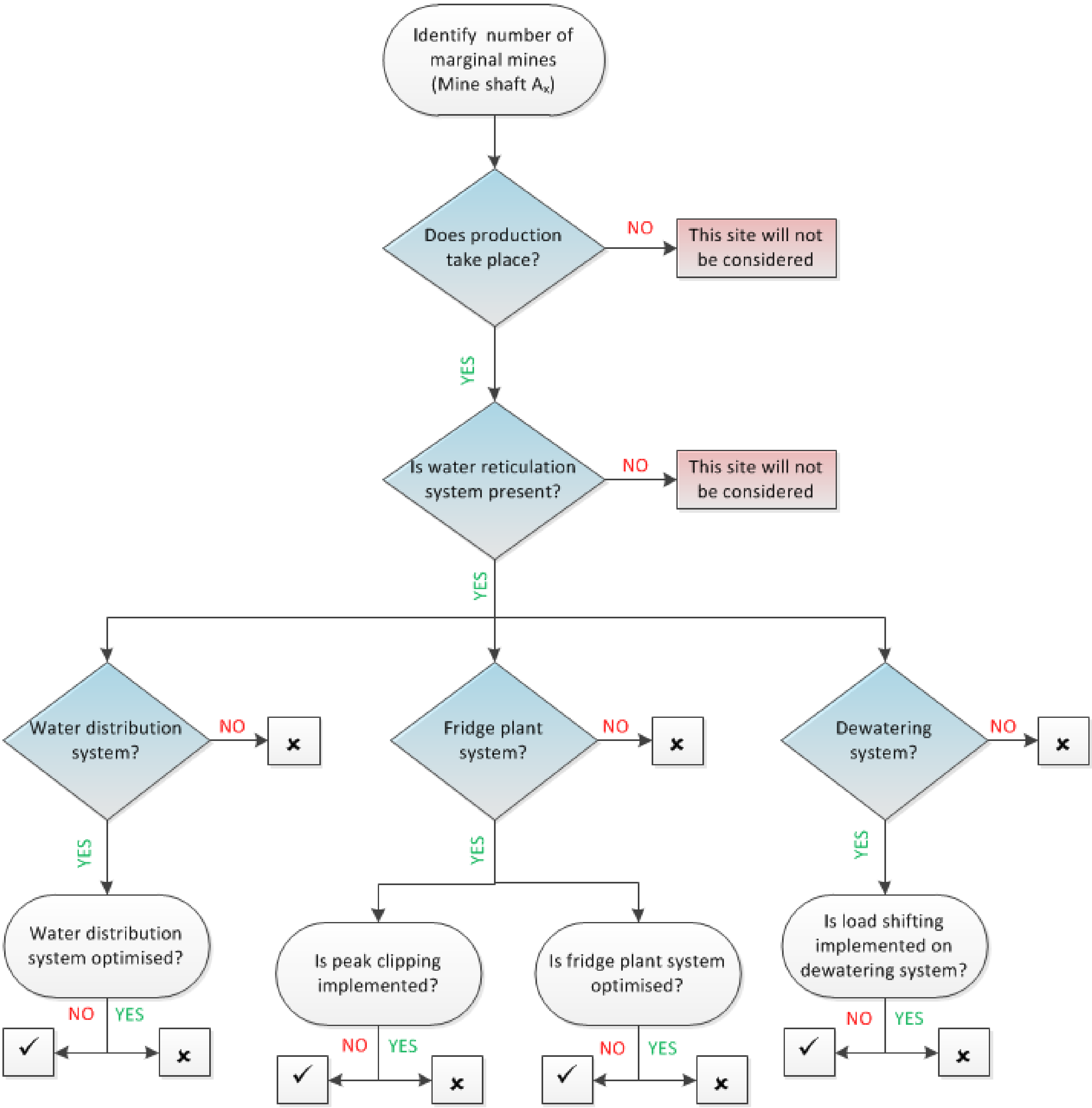


Figure 42: Mineshaft selection flow chart

The flow diagram in Figure 42 identifies which mineshafts have to be investigated further for potential electricity cost savings. The results of the flow diagram can be summarised in a table as shown in Table 1.

Table 1: Example of mineshaft selection table

Marginal Mineshafts	WSO	FP	CA	P	Score
Mineshaft A_1	✓	✗	✗	✗	**1**
Mineshaft A_2	✓	✓	✓	✗	**3**
Mineshaft A_3	✗	✓	✓	✗	**2**
Mineshaft A_4	✗	✗	✗	✗	**0**
Mineshaft A_5	✗	✓	✓	✗	**2**
Mineshaft A_6	✓	✓	✗	✗	**2**

Where: ✓ = Possibility for DSM intervention

✗ = No possibility for DSM intervention

Using Table 1 it is possible to identify which mineshaft's water reticulation system has not been fully optimised according to the four DSM strategies mentioned in previous sections. The table also makes it possible to identify which strategies have already been implemented. For example: on mineshaft A_2 load shifting is already being implemented on the dewatering system. There may still be opportunities to implement any or all of the other strategies. Mineshaft A_2 also has the highest score and thus gets first priority for further investigation.

SYSTEM COMPONENT IDENTIFICATION

After a mineshaft has been selected for further investigation, all the relevant components of the mine water reticulation system have to be investigated. The information gathered will be used later on to simulate and optimise the various operations and to determine the savings potential of each strategy. Information sheets are developed for each component to ensure that all relevant information is obtained.

Figure 43 shows the system component identification flow chart that has to be followed during on-site investigations.

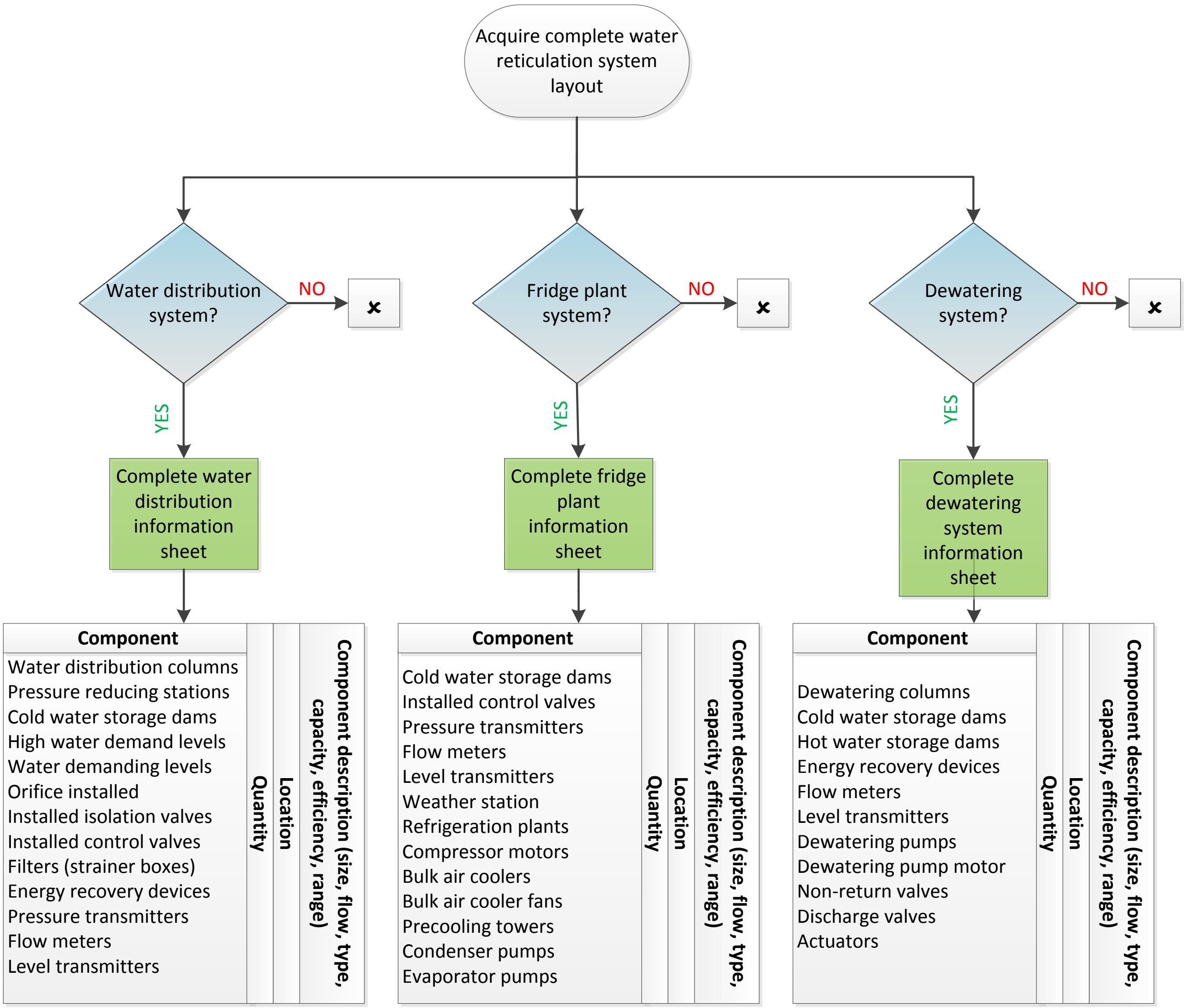


Figure 43: System component identification flow chart

The first step in system component identification is to obtain a complete water reticulation system layout. It is necessary to understand how all the components of the water reticulation system tie in with each other. A good understanding of how the different components of the water reticulation system interact is very important to create accurate simulations later on. The next step is to gather the relevant component information and compile an information sheet for each sub-system. Table 2 shows an example of a populated information sheet.

Table 2: Example of a populated dewatering system information sheet

<table>
<tr><th colspan="6">Dewatering system information sheet</th></tr>
<tr><th>Component</th><th>Qty.</th><th>Location</th><th colspan="3">Description</th></tr>
<tr><td>Dewatering columns</td><td>1</td><td>73 Level to 40 Level;
40 Level to surface</td><td>Size:</td><td colspan="2">250 mm</td></tr>
<tr><td rowspan="3">Cold water storage dams</td><td rowspan="3">6</td><td rowspan="3">2 x Surface
2 x 35 Level
2 x 70 Level</td><td rowspan="3">Volume:</td><td>Dam 1 and 2</td><td>653 m^3</td></tr>
<tr><td>Dam 1 and 3</td><td>649 m^3</td></tr>
<tr><td>Dam 1 and 4</td><td>655 m^3</td></tr>
<tr><td rowspan="4">Hot water storage dams</td><td rowspan="4">5</td><td rowspan="2">3 x 40 Level</td><td rowspan="2">Volume:</td><td>Dam 1</td><td>254m^3</td></tr>
<tr><td>Dam 2 and 3</td><td>568m^3</td></tr>
<tr><td rowspan="2">2 x 73 Level</td><td rowspan="2">Volume:</td><td>Dam 1</td><td>558 m^3</td></tr>
<tr><td>Dam 2</td><td>696 m^3</td></tr>
<tr><td>Energy recovery devices</td><td>0</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Flow meters</td><td>0</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Level transmitters</td><td>11</td><td>One in each dam</td><td>Type:</td><td colspan="2">Pressure transmitter</td></tr>
<tr><td>Dewatering pumps</td><td>6</td><td>3 x 40 Level
3 x 73 Level</td><td>Size:</td><td colspan="2">MRA 10 stage with 62 L/sec
MRA 9 stage with 62 L/sec</td></tr>
<tr><td rowspan="6">Dewatering pump motors</td><td rowspan="6">6</td><td rowspan="3">3 x 40 Level</td><td>Output:</td><td colspan="2">1200 kW</td></tr>
<tr><td>Current:</td><td colspan="2">128 A</td></tr>
<tr><td>Volts:</td><td colspan="2">6600 V</td></tr>
<tr><td rowspan="3">3 x 73 Level</td><td>Output:</td><td colspan="2">1200 kW</td></tr>
<tr><td>Current:</td><td colspan="2">124 A</td></tr>
<tr><td>Volts:</td><td colspan="2">6600 V</td></tr>
<tr><td>Non-return valves</td><td>6</td><td>One on each pump</td><td>Size:</td><td colspan="2">250 mm</td></tr>
<tr><td>Discharge valves</td><td>6</td><td>One on each pump</td><td>Size:</td><td colspan="2">251 mm</td></tr>
<tr><td>Actuators</td><td>0</td><td></td><td></td><td colspan="2"></td></tr>
</table>

Calculating the baseline

Before saving potential can be determined a baseline must be calculated. The baseline represents the existing electricity consumption before DSM intervention. The baseline will be used to calculate the savings potential and the savings achieved after implementation. To determine the baseline it is necessary to measure the existing operating load in kW.

Eskom has minimum requirements that every baseline must adhere to. Generally data has to be collected over three consecutive months in thirty-minute integrated intervals. Data loss should be kept to a minimum. All electrical equipment that will be directly affected by DSM intervention have to be included in the baseline. Data can be collected from log sheets, SCADA systems and data loggers.

Most mines have operators stationed at pumping stations and refrigeration plants. These workers are responsible for keeping written logs of the operation of these systems. This data, together with the rated electrical capacity of each individual component, can be used to calculate a 24-hour load profile for each specific operation.

Some mines have existing SCADA systems. These systems sometimes have logging capabilities where all operational data is stored on a server. SCADA systems log data every few minutes. Ideally the power meter data would be available for each individual system component.

On mines without SCADA systems or reliable operator logs, a portable data logger must be installed on all relevant equipment. These loggers will record the amperage and voltage over predetermined time intervals. The power meters are installed on electric motors, therefore it can be assumed that the phases are balanced. The following equation can be used to calculate the power consumption of the motor [60]:

$$P = \sqrt{3} * V * I * cos\emptyset \qquad \text{Equation 18}$$

Where: P = power consumed in W

V = line voltage in V

I = line current in A

cosØ = power factor

For load-shifting interventions the baseline should be scaled energy neutral. This is to ensure that the baseline take the volume of water pumped or cooled per day into account. The assumption is made that the volume of underground water pumped or cooled is directly proportional to the electricity consumed. This assumption also makes it possible to estimate WSO intervention savings.

IDENTIFYING OPERATIONAL PROCEDURES FOR LOAD-SHIFTING PROJECTS

The aim of load shifting is to shift system electrical load out of expensive peak periods into less expensive periods. Certain constraints must, however, be understood before considering implementing a load-shifting intervention. Figure 44 shows an example of a typical load-shifting profile.

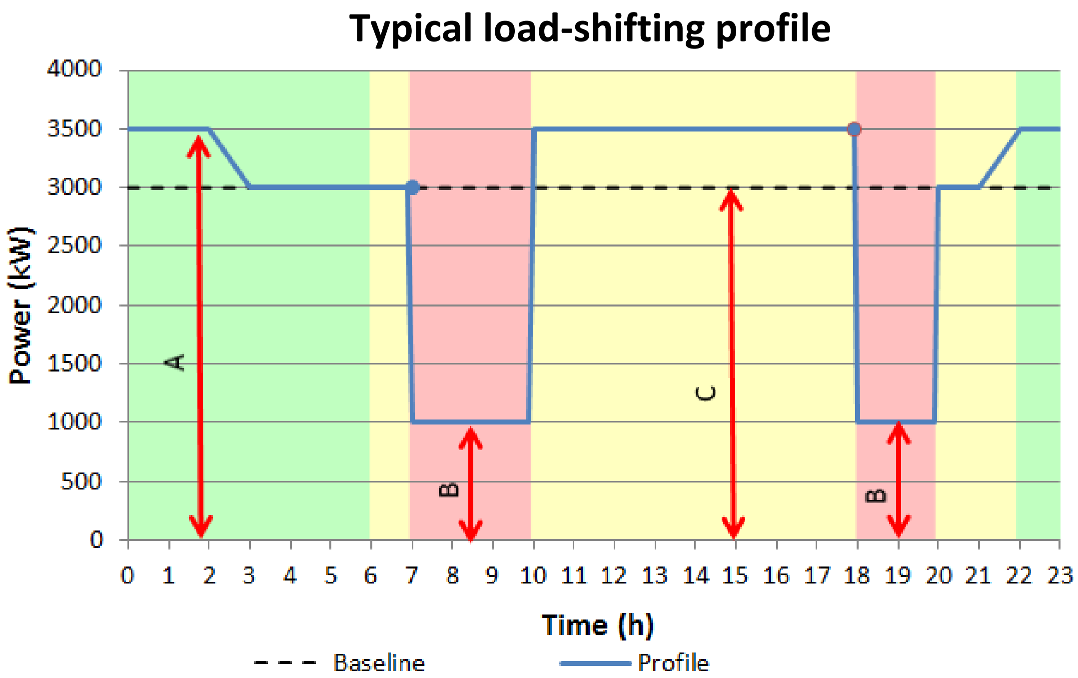


Figure 44: Typical load-shifting profile

The first constraint for load shifting is the installed capacity of the pumps or fridge plants. If a system has sufficient capacity, the maximum possible load that can be shifted is limited to the maximum installed capacity (indicated by line A) in Figure 44. The amount of load shifted out of peak periods cannot be larger than the remaining capacity in the off-peak and standard periods. The second constraint is the minimum number of pumps or fridge plants specified by the mines. Some mines have small dams and therefore require a minimum number of fridge plants or pumps to operate at all times. This minimum amount is specified for safety reasons. The third constraint is the baseline. The maximum claimable load shift cannot be more than the baseline.

IDENTIFYING OPERATIONAL PROCEDURES FOR ENERGY EFFICIENCY PROJECTS

The principle behind energy efficiency projects is to optimise systems or certain processes to be more efficient. The two processes that are focussed on are the water distribution and refrigeration. In the past these systems have been successfully optimised by installing control valves on the water distribution system and by installing variable speed drives on cooling auxiliaries. Once again there are certain constraints that have to be considered before deciding to implement an energy efficient DSM intervention. Due to the large difference between the two systems, each strategy's constraints will be discussed separately.

The principal idea behind using control valves in a WSO intervention is to reduce the amount of water sent down the mine. Figure 45 shows an example of the pressure profile for a production level's water demand.

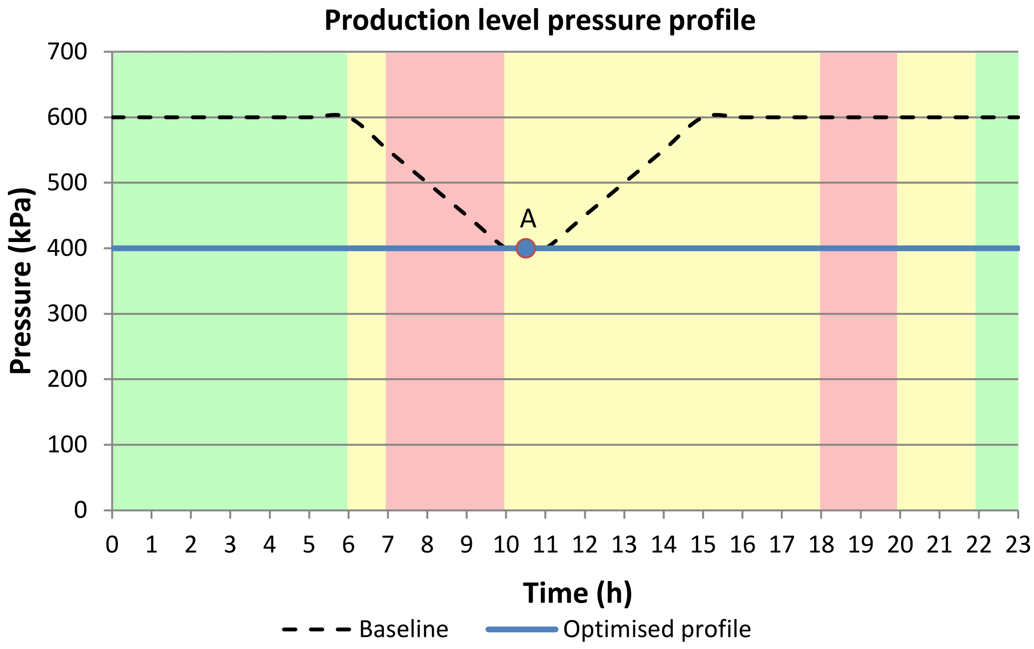


Figure 45: Example of typical water distribution pressure profile

The maximum demand for water usually occurs during the drilling shift. During this period the water flow rate will increase which will result in a decrease in water pressure. The drilling machines have a minimum required water pressure. This minimum requirement can be seen at point A. Point A also represents the maximum water pressure needed by the mining level. After the drilling shift the flow of water will decrease which would result in an increase of water pressure. The constraint in this case is thus the pressure at point A. The water pressure should be regulated throughout the day to a maximum of 400 kPa. This would result in a reduced water flow to the level. In a study done by Vosloo [46] it shows that there is a very strong correlation between the reduction of pressure and the resulting reduction of water flow to an underground level.

When implementing a cooling auxiliary (CA) intervention savings are usually achieved by matching the evaporator flow with the demand of chilled water; condensers flow adapting to the ambient heat; and the BAC matching the demand of ventilation air requirements. This can be achieved by installing VSDs. This strategy also has a constraint that has to be considered before implementation. Water cooled by the refrigeration system is stored in large chilled water dams before being distributed underground. Each mine has a specific target value for the water temperature in these dams depending on the mine's cooling requirements.

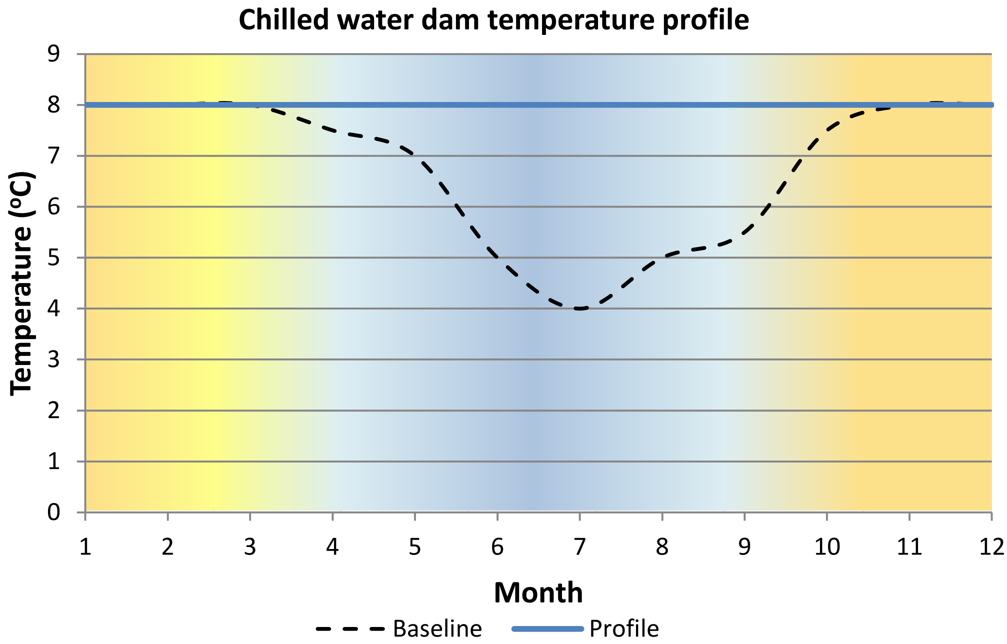


Figure 46: Chilled water dam temperature profile

During summer months, a mine refrigeration system is capable of cooling water to a certain design set point. As ambient temperatures decrease during winter months the cold water temperature produced by the refrigeration plants will also decrease due to colder water entering the fridge plant. The mine requires a certain temperature of chilled water and thus electricity is wasted by cooling water below that required temperature. The level constraint in this case is the maximum cold water temperature during the summer months.

3.3 DETERMINING THE SAVING POTENTIAL AND COST BENEFIT

It can become difficult to calculate exactly which expected savings will be from the implementation of a DSM strategy on a mine water reticulation system. The reason for this is that each mine water reticulation system is unique and each mine has unique operational procedures in place. Mining can sometimes also be very unpredictable because of breakdowns or unscheduled maintenance and repairs. This can all have an influence on the performance of the mentioned DSM strategies. For preliminary investigation purposes old projects were investigated and analysed to develop a rough estimation of the savings potential each of the DSM strategies may have.

Estimating savings potential for a load-shifting intervention

Several old load-shifting projects on mine water reticulation systems were analysed to see if there was any correlation between the power demand and the savings achieved on each specific project. The results from this analysis can be seen in Figure 47.

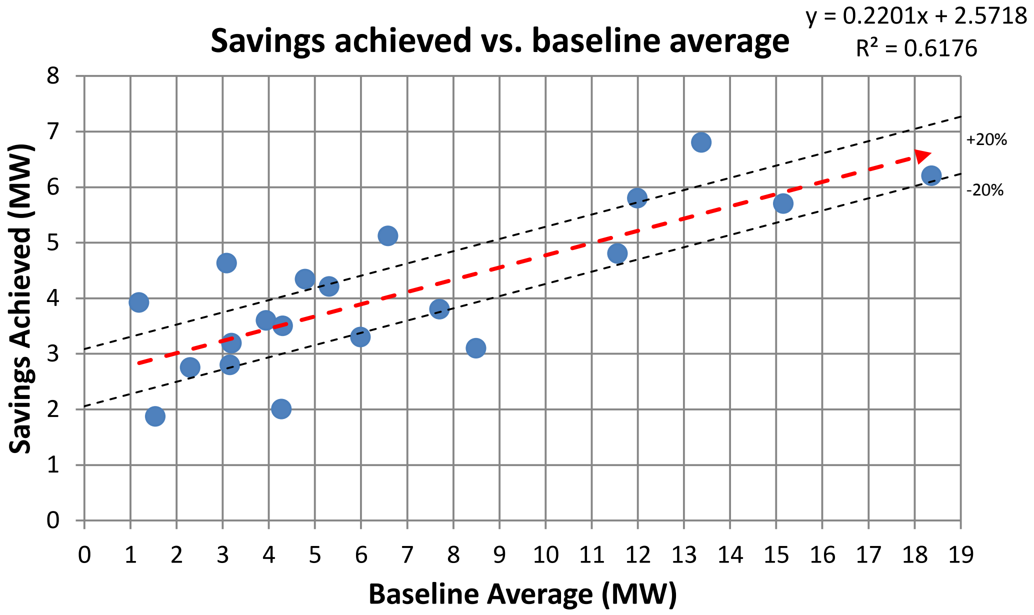


Figure 47: Load-shifting saving potential analysis from historic project data

From the old project data it appears that there is some correlation between the projects' power demand and the saving potential of a load-shifting intervention. This data can assist in estimating the savings that could be expected. If a more accurate estimation is required the system should be simulated.

A simulation package for pumping systems has been developed HVAC International. REMS Pumps is capable of simulating load shifting and calculating the electrical running cost reduction [60]. Other examples of suitable simulation software include Matlab®, Simulink® and Excel®.

Estimating savings potential for an energy efficiency intervention

Several old WSO and CA projects on mine water reticulation systems were analysed to see if there was any correlation between the power demand and the savings achieved on each specific project. The results from this analysis can be seen in Figure 38.

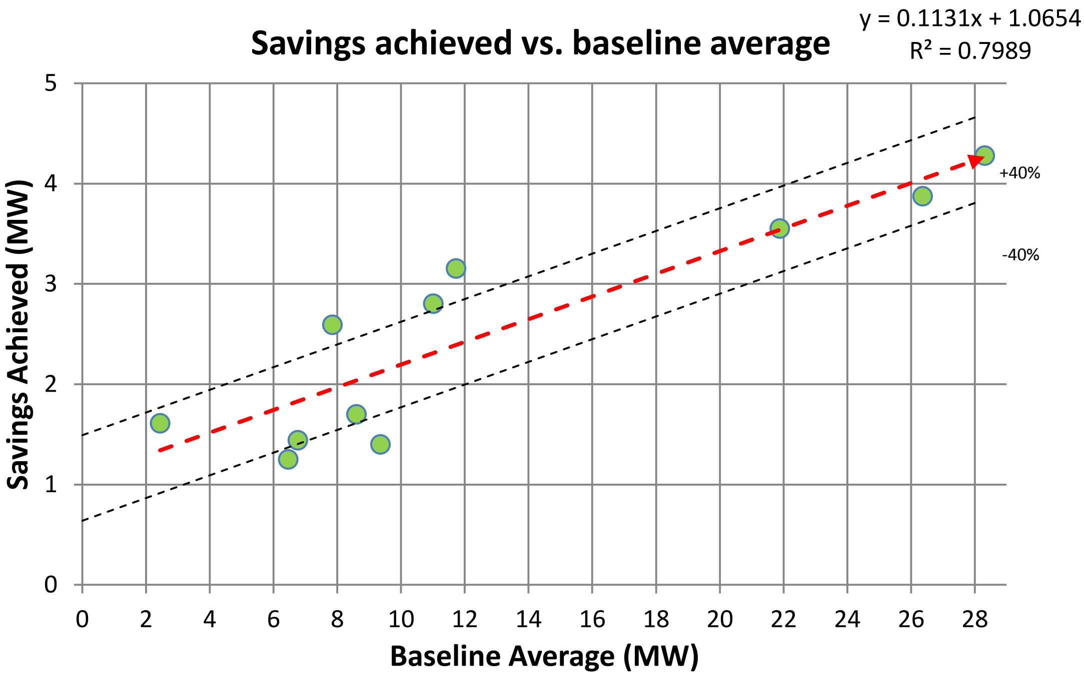


Figure 48: Energy efficiency possible savings from historic project data

From the old project data it appears that there is a correlation between a project's power demand and the saving potential. This data can assist in estimating which possible savings could be expected from implementing an energy efficiency strategy on a mine water distribution system or cooling auxiliaries without physically simulating the complete system.

Before implementing energy efficiency interventions it would be beneficial to simulate and optimise the water reticulation system using simulation software. There are many different software packages available to simulate mine water reticulation systems. The simulation software used depends on the application.

COMPARISON BETWEEN ENERGY EFFICIENCY AND LOAD-SHIFTING INTERVENTIONS

The data sets from Figure 47 and Figure 48 were compared to investigate if any significant difference between the measured savings of load-shifting projects and energy efficiency projects existed. These results can be seen in Figure 49.

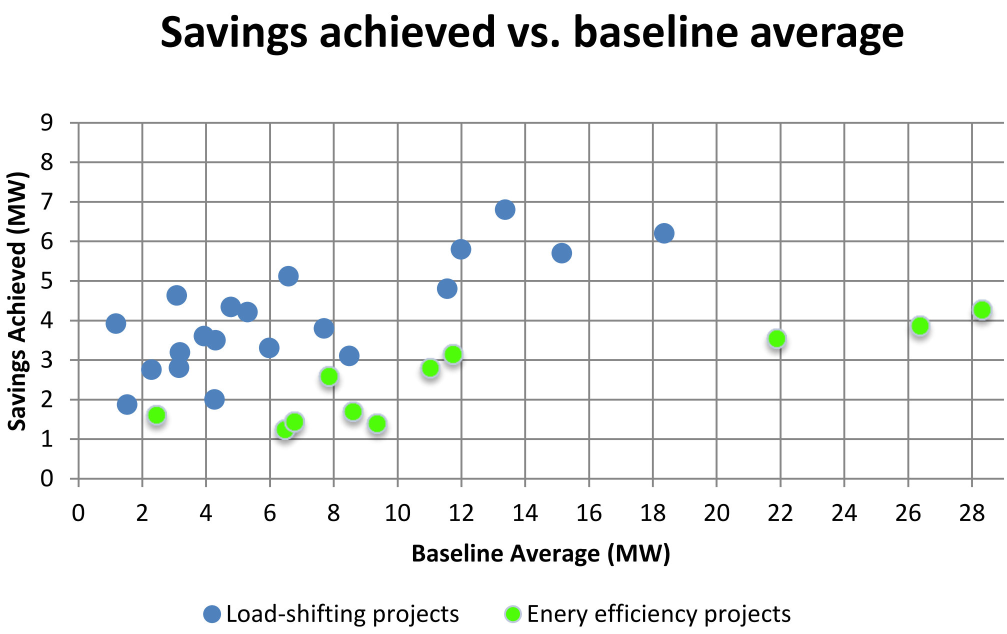


Figure 49: Comparing savings potential of load shifting and energy efficiency

From the data in Figure 49 it seems that load-shifting projects have higher electricity cost savings potential when considering the average baseline of the system components. This can be attributed to the differences between the two strategies. Load-shifting intervention savings are measured by the load shifted out of the peak-time periods; energy efficiency intervention savings are measured by the overall reduction in electricity demand.

Calculating the cost benefit

There is a distinct difference between the cost benefit calculation process for load-shifting interventions and energy efficiency interventions. Load-shifting cost benefits depend on the period that the load has been shifted to and the electricity cost of that period. Due to the variable nature of mining operations these interventions' savings have to be calculated using energy neutrality. Energy efficiency interventions' cost benefits are calculated during a 24-hour profile because electricity usage is reduced with an intervention.

When calculating the cost benefit of a load-shifting project the first step is to determine the optimised profile. This can be done using Excel® calculations or simulation software. The project baseline then has to be scaled in order to achieve energy neutrality. This means that the cumulative scaled baseline is equal so that total electricity consumed in a 24-hour day. Figure 50 shows a load-shifting profile with a scaled and unscaled baseline.

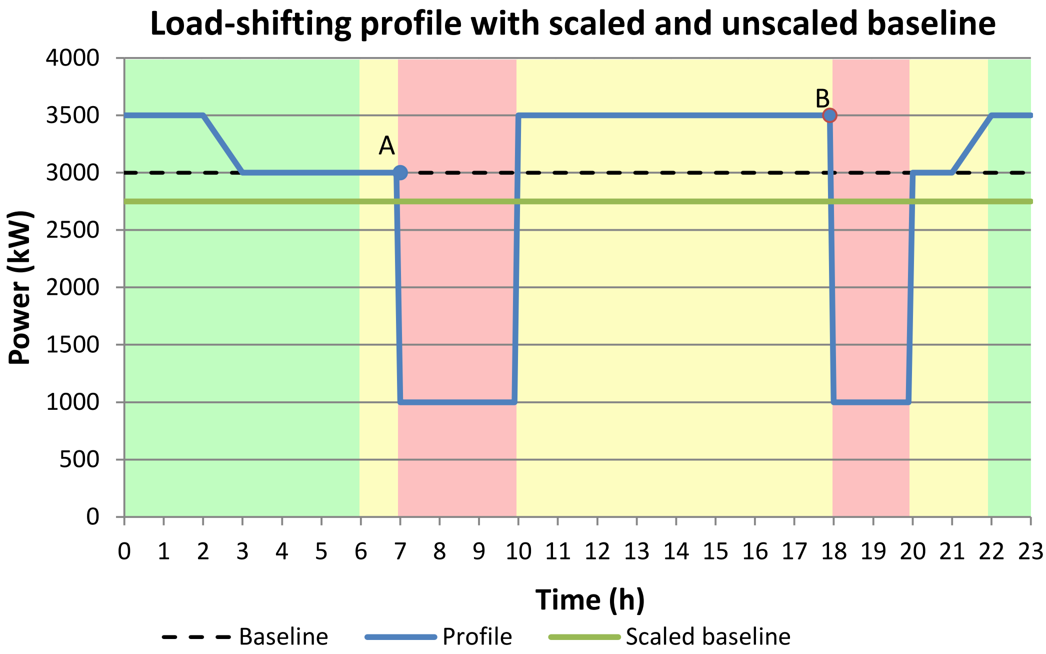


Figure 50: Load-shifting profile with baseline scaling

The 24-hour load-shifting profile can then be compared to the scaled baseline and using Eskom tariff rates the cost benefit can be calculated. The cost benefit is calculated for each hour using Eskom Megaflex rates. These rates can be seen in Table 3.

Table 3: Eskom 2013/2014 Megaflex rates

	Summer Tariff (c/kWh)			Winter Tariff (c/kWh)		
Hour	**Weekday**	**Saturday**	**Sunday**	**Weekday**	**Saturday**	**Sunday**
0	28.68	28.68	28.68	33.12	33.12	33.12
1	28.68	28.68	28.68	33.12	33.12	33.12
2	28.68	28.68	28.68	33.12	33.12	33.12
3	28.68	28.68	28.68	33.12	33.12	33.12
4	28.68	28.68	28.68	33.12	33.12	33.12
5	28.68	28.68	28.68	33.12	33.12	33.12
6	45.2	28.68	28.68	60.99	33.12	33.12
7	65.68	45.2	28.68	201.33	60.99	33.12
8	65.68	45.2	28.68	201.33	60.99	33.12
9	65.68	45.2	28.68	201.33	60.99	33.12
10	45.2	45.2	28.68	60.99	60.99	33.12
11	45.2	45.2	28.68	60.99	60.99	33.12
12	45.2	28.68	28.68	60.99	33.12	33.12
13	45.2	28.68	28.68	60.99	33.12	33.12

	Summer Tariff (c/kWh)			Winter Tariff (c/kWh)		
Hour	Weekday	Saturday	Sunday	Weekday	Saturday	Sunday
14	45.2	28.68	28.68	60.99	33.12	33.12
15	45.2	28.68	28.68	60.99	33.12	33.12
16	45.2	28.68	28.68	60.99	33.12	33.12
17	45.2	28.68	28.68	60.99	33.12	33.12
18	65.68	45.2	28.68	201.33	60.99	33.12
19	65.68	45.2	28.68	201.33	60.99	33.12
20	45.2	28.68	28.68	60.99	33.12	33.12
21	45.2	28.68	28.68	60.99	33.12	33.12
22	28.68	28.68	28.68	33.12	33.12	33.12
23	28.68	28.68	28.68	33.12	33.12	33.12

3.4 CALCULATING THE COST OF STRATEGIES

Due to the uniqueness of each water reticulation system, it can be difficult to estimate which equipment is needed for implementation during preliminary investigations. Before a decision can be made as to which electricity cost-saving strategy could be implemented a general understanding of the expenses for each strategy must be taken into consideration.

Automating and optimising a water reticulation system can be an expensive endeavour. This not only includes the automation of pumps, motors and fridge plants, but also the installation of instrumentation to adequately control and monitors these systems. The installation of the equipment needed is usually done by contractors. Equipment prices vary from contractor to contractor much like the price of items bought at different stores. Care should be taken to ensure a reliable cost-effective contractor is used in order to ensure the success of implementation.

A number of previously implemented electricity saving projects were analysed to get a better understanding of the expenditure required for the implementation of similar strategies. All values were normalised to accommodate for inflation (2013). It was assumed that the mines for each of the investigated projects had a previously implemented SCADA system.

Dewatering system automation costs

In order to get an estimation of the cost implication for automating a mine dewatering system a couple of previously implemented projects were analysed. This was done to establish an estimated cost implication per pump that needs to be automated. When automating pumping systems some of the most expensive components to install include measuring instrumentation, actuated valves and PLC equipment. The data for this analysis can be seen in Figure 51.

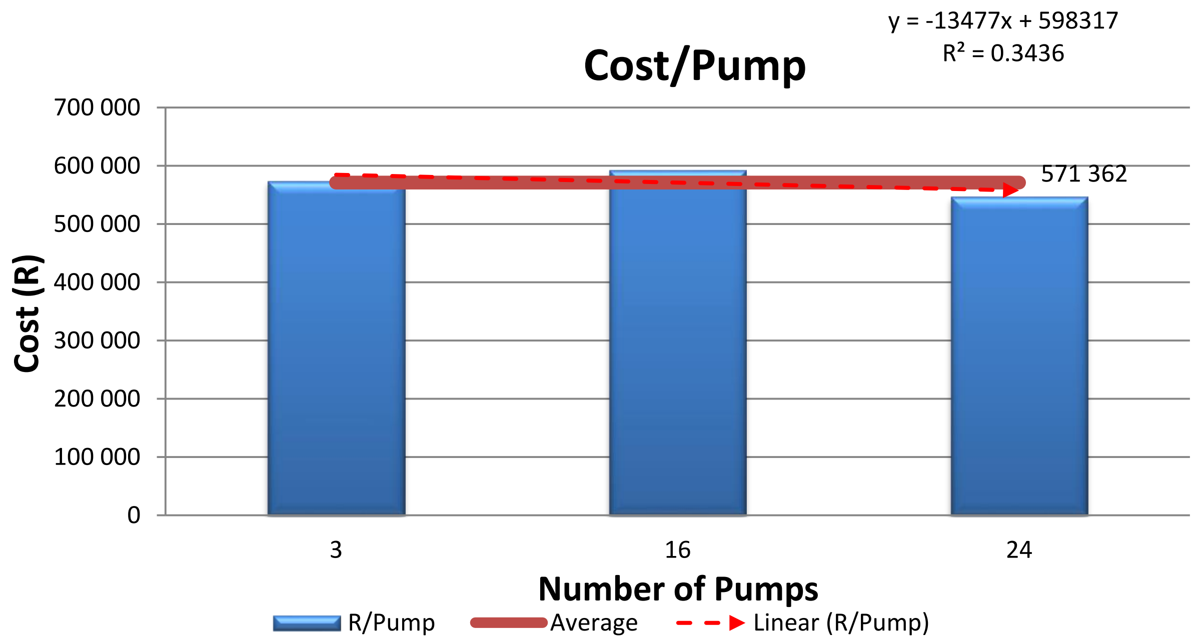


Figure 51: Previous projects pump automation costs

From the data above it is clear that there is only about a 7.8% difference between the minimum and maximum cost implication per pump. The average cost implication per pump for these projects resulted in about R570,000 per pump. With a 10% error margin it is then safe to say that it could cost between R540,000 and R600,000 per pump to automate depending on the amount of automation and communication equipment needed. On some mines, pumping stations are already equipped with some automation-, communication- and safety equipment. This could result in a much smaller cost implication per pump. A detailed investigation of each pumping station and auxiliary equipment is thus crucial for an accurate estimation of cost implication.

The same project data was analysed in order to establish if there was any correlation between the cost implication and the savings that these projects achieved. This data can be seen in Figure 52.

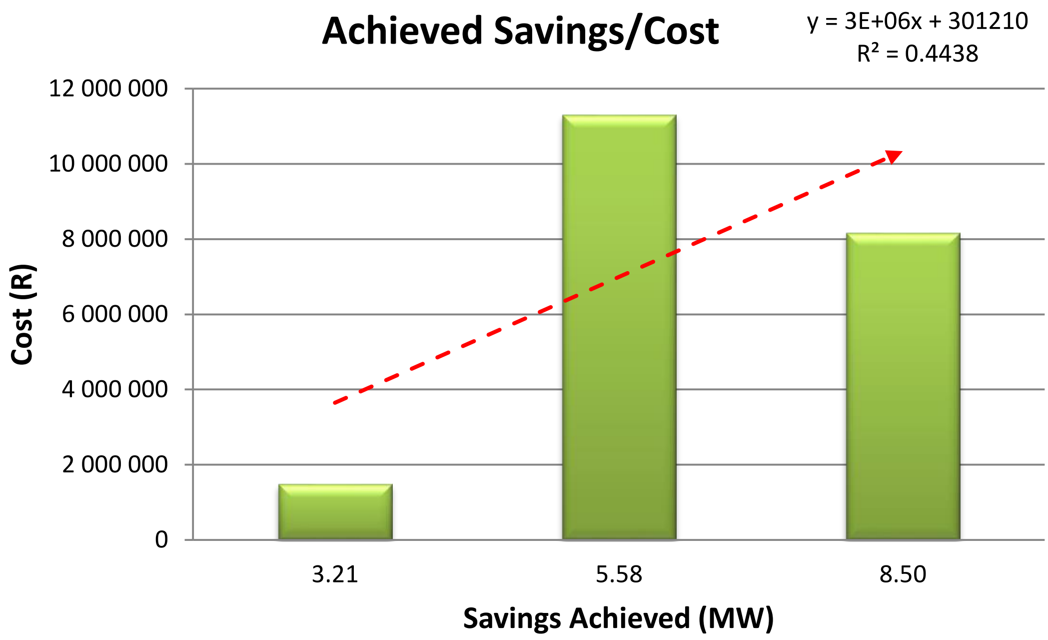


Figure 52: Pump load-shifting cost versus savings achieved

From the data it is clear that there is not a very strong correlation between the cost implication of these projects and the savings they achieved. The reason for this is that the savings potential of a load-shifting intervention on a mine dewatering system is mostly influenced by the storage capacity of the hot water dams and the amount of water that has to be pumped daily. This is further confirmed when taking into consideration that the automation costs per pump does not vary significantly.

Fridge plant automation costs

Four previously implemented fridge plant automation projects were analysed to get a better understanding of the cost implications of automating a fridge plant. Automation of a fridge plant system can become difficult due to the complexity of the fridge plant itself. Fridge plants can be shut off fairly easily, but all fridge plants have a very complex start-up procedure. The automation of a fridge plant also requires a relatively large amount of instruments that include temperature sensors, pressure sensors, vibration sensors, actuators and flow meters. Other pieces of equipment needed for automation include PLCs, valves and communication equipment. Most fridge plant systems have no form of automation installed and are only monitored through a SCADA system. Figure 53 shows the cost implication per pump for a few previously implemented fridge plant automation projects.

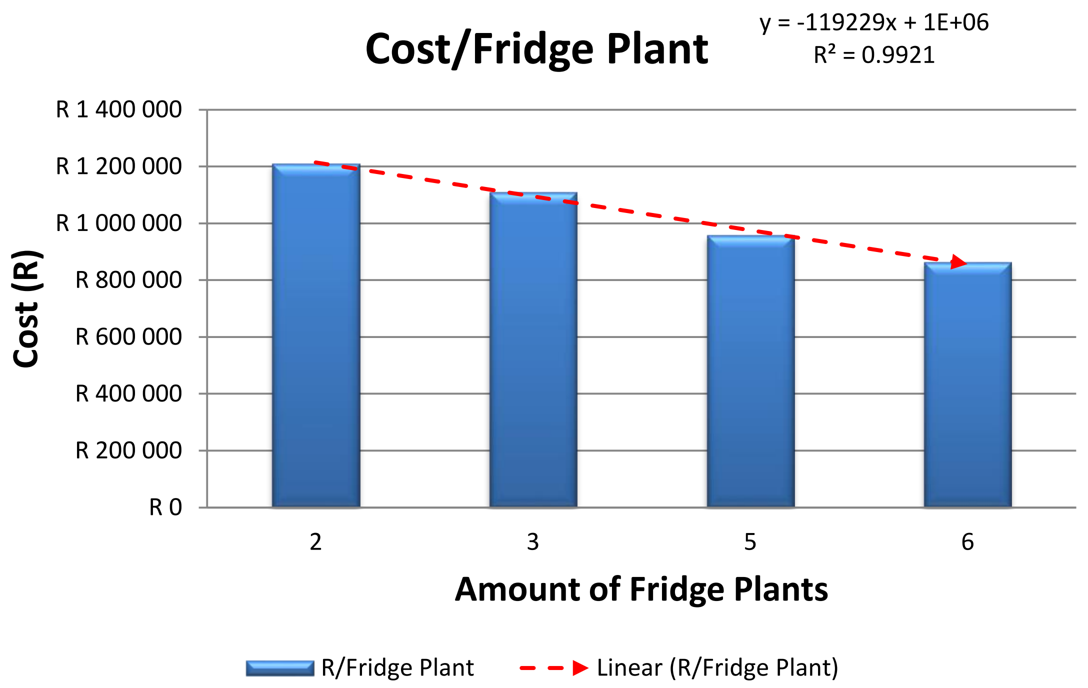


Figure 53: Previous projects fridge plant automation costs

From the data it is clear that there is about a 30% difference between the minimum and maximum cost implication per fridge plant. The difference in cost implication per fridge plant can be contributed to the location of the fridge plant to be automated, the size and layout of the fridge plant's piping system and to the age of the fridge plants. Older fridge plants are more complicated to automate and in some cases these fridge plants are not sufficiently monitored by SCADA systems; this results in more monitoring instrumentation needed for automation. From the data it is evident that the cost implication of automating a fridge plant system is between R800,000 and R1,200,000 per fridge plant. Similar to the automation of the dewatering system, the cost implication is severely influenced by the level of automation before the DSM intervention.

The same data was analysed in order to see if there was any correlation between the cost implication and the savings achieved by automating the fridge plant system. This data can be seen in Figure 54.

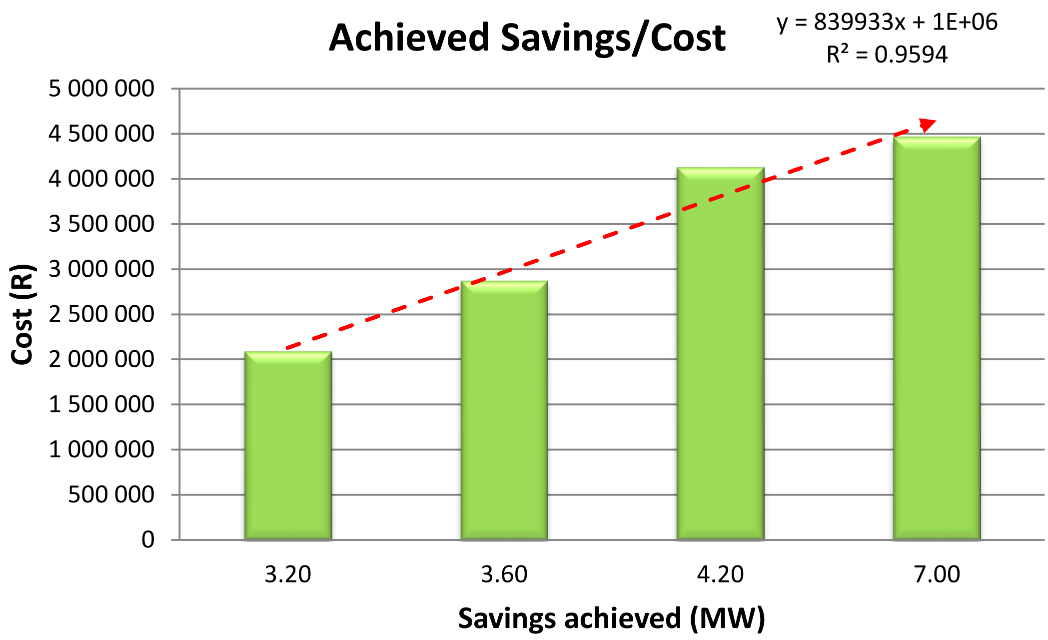


Figure 54: Fridge plant load-shifting cost versus savings achieved

From Figure 54 it seems that the higher the cost implication the larger the savings achieved. This can be contributed to the size of the fridge plants. Larger fridge plants are more expensive to automate but also have a higher savings potential when implementing load shifting.

Water System Optimisation costs

A few previously implemented WSO projects were analysed to get a better understanding of the cost implication of implementing an energy efficiency strategy on a mine water distribution system. When implementing a WSO project some of the most expensive equipment include valves and actuators. These actuated valves have to be installed on all mining levels where the supply of water needs to be controlled. The analysed cost implication data can be seen in Figure 55.

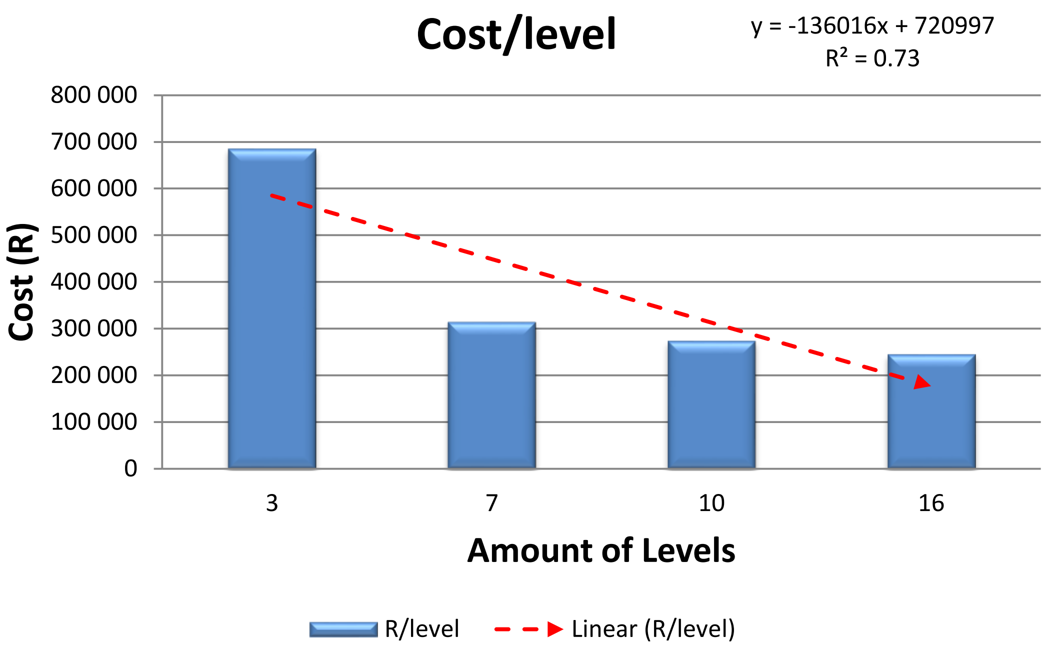


Figure 55: Previous projects cost per level optimisation

From the data above it seems that there is more or less a constant cost implication per level except for one previously implemented project. This can be contributed to the size of the valves and actuators that had to be installed and also to the lack of communication network on the mine. The cost of valves increases significantly as the diameter of a valve increases. Larger valves also require larger actuators which also increases the cost implication. In order to control the system communication to all components is required. On some mines there are not sufficient communication networks underground which also contributes to a larger cost implication.

The above data was analysed in order to see if any correlation between the cost implication and the savings achieved exist. This data can be seen in Figure 56.

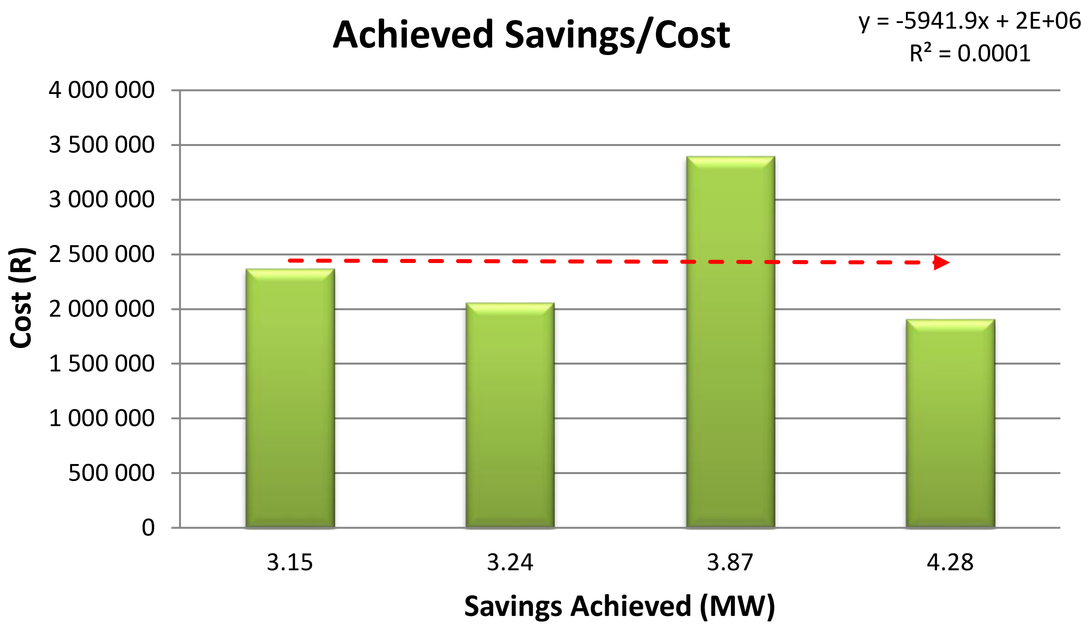


Figure 56: WSO cost versus savings achieved

From the data above it seems that there is no strong correlation between the cost implication and the savings achieved. The reason for this is that the saving potential of a WSO project is mostly influenced by the demand for water on the optimised levels. Some mining levels require less water than others and some mines require less water per level depending on production.

COOLING AUXILIARIES OPTIMISATION COSTS

In order to get a better understanding of the cost implication of a CA intervention a few previously implemented projects were analysed. When implementing a CA project the most expensive pieces of equipment are the VSDs. VSD prices increase significantly by size. The cost implication will thus mostly be influenced by the size of the VSDs that have to be installed. The analysed cost implication data of the previously implemented projects can be seen in Figure 57.

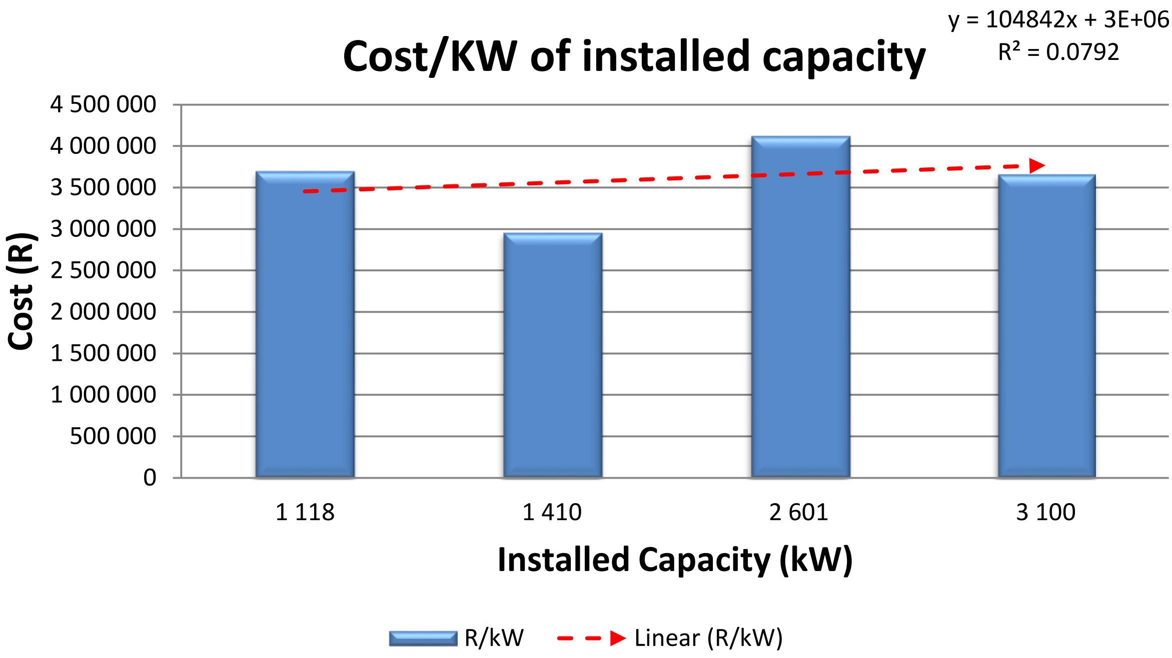


Figure 57: Previous projects cost of cooling auxiliaries optimisation

From the above data it seems that there is no correlation evident between the installed capacities of the cooling auxiliaries and the cost for implementation of such an intervention. This may be because of the difference in design of each refrigeration system's cooling auxiliaries. As mentioned previously some fridge plant systems are overdesigned to accommodate for further expansion in underground development. This data is not very conclusive on the cost implication for implementing CA interventions and it is thus suggested to do an in-depth investigation before attempting to implement such an intervention. The same data was then analysed to see if there was any correlation between the cost implication and savings achieved by optimising a mine's cooling auxiliaries. The analysed data can be seen in Figure 58.

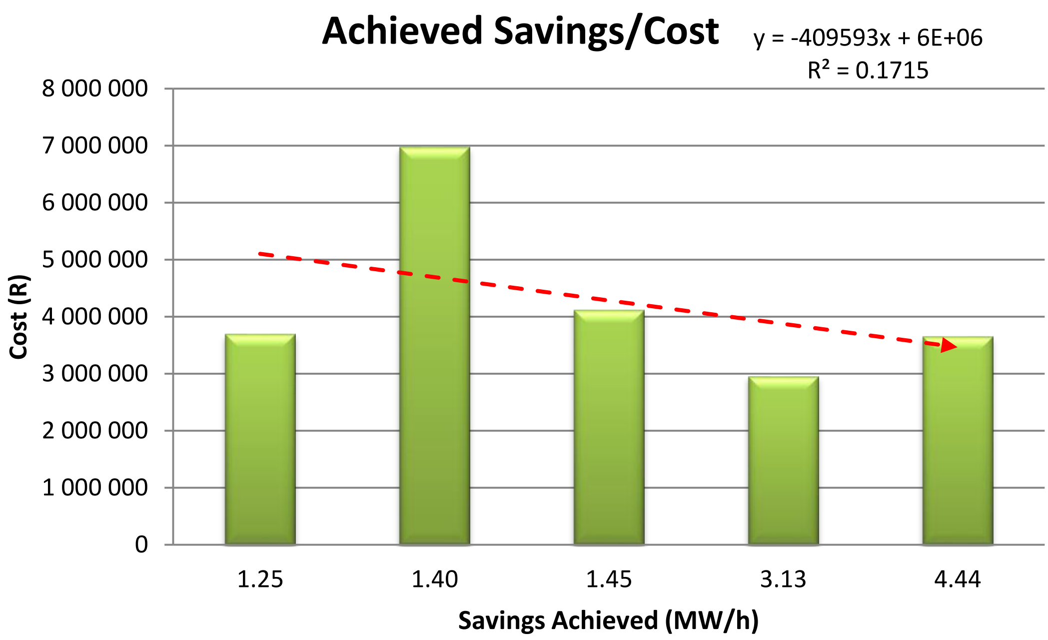


Figure 58: Cooling auxiliary optimisation cost versus savings achieved

From the data it seems that there is no correlation between the cost implication and the savings achieved. This can be contributed to the variable demand for chilled water in the mining industry. Some mines had a larger demand for chilled water at the time the refrigeration system was designed, but production might have decreased and with it the demand for chilled water. As mentioned previously the size of the VSD on a cooling auxiliary depends completely on the size of the motor on a specific auxiliary and this would have a direct effect on the cost implication. It is thus suggested that cost implication and savings achievable should be calculated using the fridge plant cooling auxiliary installed capacity.

Comparison between energy efficiency and load-shifting costs

All the data from Section 3.4 was analysed in order to establish the difference in the cost implication and possible cost benefit between energy efficiency interventions and load-shifting interventions. All cost implications and cost benefits were normalised to 1 MW in order to analyse the data efficiently. The results can be seen in Figure 59.

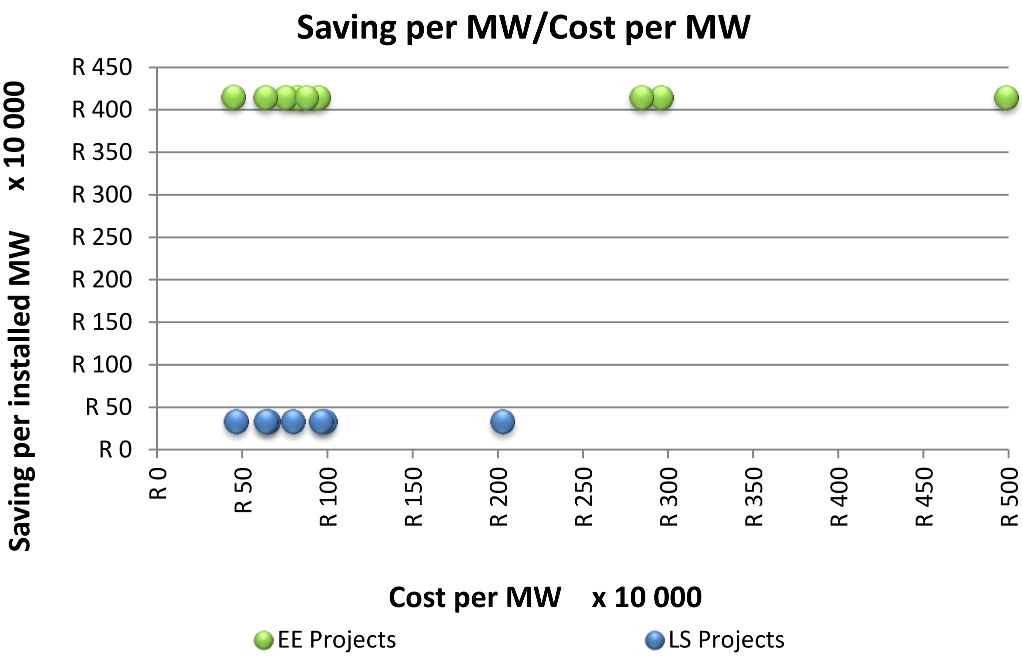


Figure 59: Saving achieved versus cost per MW comparison

From the data it is clear that there is a major difference between the cost implication and cost benefits of load shifting and energy efficiency interventions. This can simply be contributed to the differences between the two strategies. The load-shifting intervention's cost implication is mostly influenced by the number of pumps or fridge plants that have to be automated and not the size of the pump or fridge plant motors as is the case with energy efficiency interventions. The savings potential of load-shifting interventions is mostly dependent on the buffer capacity of the system and not of the variable demand for chilled water as it is for energy efficiency interventions.

3.5 SELECTION OF BEST STRATEGY FOR IMPLEMENTATION

When implementing DSM interventions on marginal mines the main focus should be on obtaining the largest savings with the smallest cost implications. In order to calculate this, each project's payback period should be calculated. The payback period is the time in which the initial cost implication of an investment is expected to be recovered from the cost benefit generated by the investment.

Because of the variable nature of mining operations it becomes difficult to determine the exact payback period of a project. Expected savings are dependent on the operation of an implemented DSM intervention. The payback period of a DSM intervention can be calculated using the following equation:

$$Payback\ period = \frac{Initial\ investment}{Cash\ inflow\ per\ period} \qquad \text{Equation 19}$$

Larger savings on a smaller initial investment will decrease the payback period. It thus makes sense that the payback period of a project will be the identifying factor of selecting the most cost-effective strategy for implementation.

3.6 CONCLUSION

A method for identifying and selecting possible water reticulation systems for DSM intervention was discussed in this section. It has become clear that identifying possible systems suitable for intervention can be simplified. After system component and operating procedure identification the saving potential and cost implication should be estimated.

By using previously implemented project data and information it was possible to create tools to assist in the preliminary investigation process. The tools created can assist in determining the saving potential, cost benefit, cost implication and payback period of each of the four selected DSM interventions. This information can then be used to prioritise the implementation of DSM interventions and a mine group's dewatering systems. Not all the tools created could deliver clear enough estimations and it is thus suggested that a thorough investigation be done on each component. The system should then be simulated by an expert in the relevant field to obtain accurate estimations for cost implication and saving potential.

The four DSM interventions discussed in this chapter were analysed and compared differentiating between load shifting and energy efficiency interventions. Previous project data shows that load-shifting projects have a larger potential electricity cost saving when taking into consideration the capacity of the system's baseline. The data also shows that implementation of energy efficiency interventions are more expensive to implement per megawatt installed capacity. It is thus suggested that load-shifting projects take priority over energy efficiency projects. The best method for determining which intervention to implement is, however, to determine the payback period for each intervention. The intervention with the shortest payback period will take priority for implementation. This will ensure that the intervention with the highest saving potential and lowest cost implication is selected.

The following chapter will show a case study where the methods described in this chapter are implemented. The results will verify the method.

Chapter 4. IMPLEMENTATION OF COST-EFFECTIVE STRATEGIES

This chapter describes the implementation and verification phase of the techniques discussed in Chapter 3. The selection and implementation method was used to select the best DSM intervention on a mine group's marginal mines. The expected savings was calculated and verified.

4.1 INTRODUCTION

The aim of the case study is to reduce the client's electricity costs by implementing DSM interventions on the mine group's water reticulation systems. Production shafts will be investigated and shafts with the greatest potential for DSM intervention will be identified. The water reticulation systems will then be investigated to identify which components of each system can be optimised through DSM intervention. The most feasible cost-effective strategy will then be selected for implementation. Because funding is available from Eskom for evening peak periods, the focus will be on the evening peak for load-shifting investigations.

4.2 CASE STUDY OVERVIEW

SITE AND SYSTEMS IDENTIFICATION

The mining group considered for this case study is currently operating in South Africa and Papua New Guinea. The group consists of ten underground mines, one open pit operation and several surface sources in South Africa. The mining group employs more than 40 000 employees and has a market capitalisation of R33 billion as of June 2012. For the purpose of this study all ten underground mines will be considered marginal. From this group two marginal mining shafts were identified using the methods discussed in Chapter 3. The results from this investigation can be seen in Table 4.

Table 4: Mine group investigation results

Marginal Mineshafts	WSO	FP	CA	P	Score
Mineshaft A	✗	✗	✗	✗	0
Mineshaft B	✗	✗	✗	✗	0
Mineshaft D	✗	✗	✓	✗	1
Mineshaft E	✗	✗	✗	✗	0
Mineshaft F	✓	✗	✗	✗	1
Mineshaft G	✓	✓	✓	✗	3
Mineshaft H	✓	✗	✗	✗	1
Mineshaft I	✗	✗	✗	✗	0
Mineshaft J	✓	✓	✓	✓	4
Mineshaft K	✓	✗	✗	✗	1

The mining shafts considered in this case study are situated twenty kilometres north of Welkom and consists of three shafts. However, only Shaft 1 and Shaft 3 will be used since there are no production levels on Shaft 2. Shaft 1 is made up of a surface shaft, sub-shaft and a decline. In 2011, an acquired asset was incorporated into this operation and named Shaft 3. Both shafts are mechanised. Conventional mining techniques are used on the Basal, Elsburg and Dreyerskraal Reefs, with mining operations extending to a depth of some 2 350 metres. Figure 60 shows the satellite view of both shafts.

Figure 60: Satellite view of Shaft 1 and Shaft 3

SHAFT 1 WATER RETICULATION SYSTEM INVESTIGATION

Preliminary investigations were done on Shaft 1's water reticulation system. At Shaft 1 water is pumped from Level 67 hot water dams to Level 53 hot water dams using three 500 kW pumps. The water is then pumped to Level 30 hot water dams by using four 1 000 kW pumps. Finally the water is pumped to surface using three 1 100 kW pumps. Figure 61 shows a simplified layout of Shaft 1's pumps.

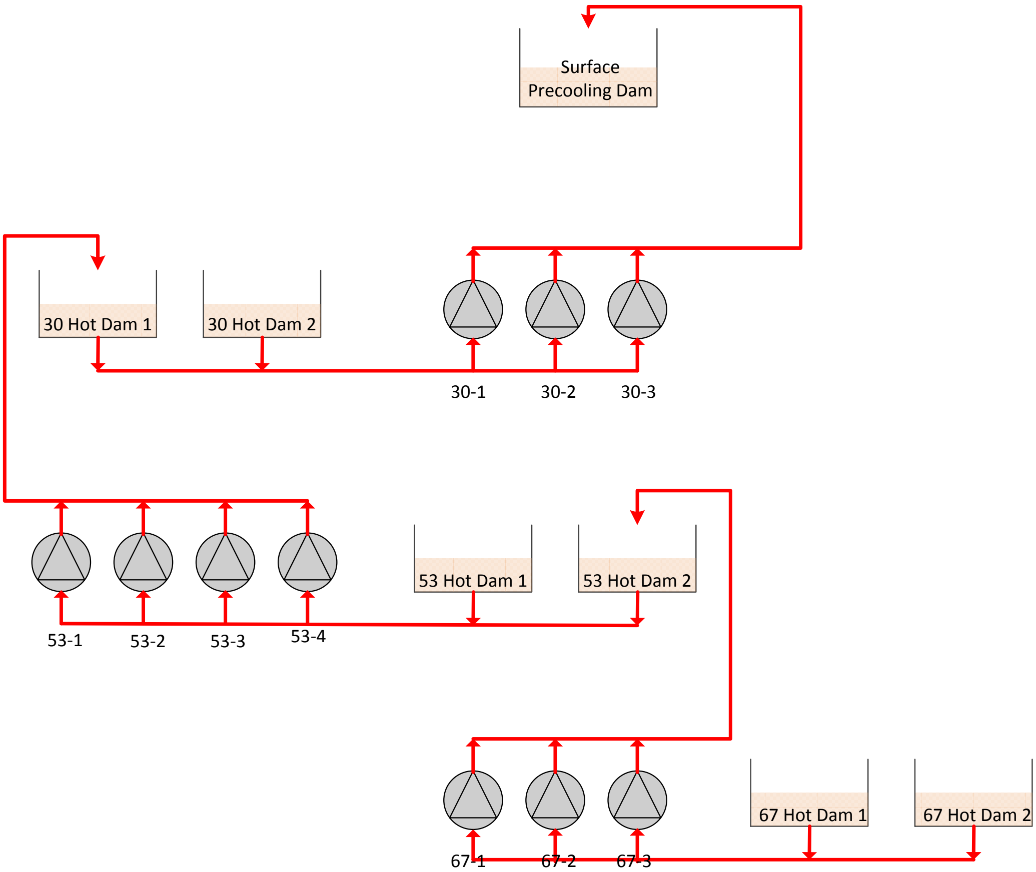


Figure 61: Simplified layout of Shaft 1 pumps

HVACI implemented a load-shifting pumping project in 2005 by using their patented REMS at Shaft 1. The system achieved a target load shift of 1.5 MW during the performance assessment period. The dewatering system was reinvestigated to identify additional savings opportunities that yielded that only a small 300 kW at most would be achievable.

Shaft 1's refrigeration system is situated underground on Level 225. The refrigeration system consists of two lead fridge plants (with 45 000 kW cooling capacity) and seven lag fridge plants. Six of these fridge plants have a cooling capacity of 3 000 kW and one fridge plant has a cooling capacity of 4 500 kW. The water for the fridge plants is stored in the hot water dam with a capacity of 4 Ml. The chilled water is stored in the chill dam with a capacity of 4 Ml. The chill dam feeds five chill ponds and several drilling machines. The hot dam receives makeup water, drilling water and water from the chill ponds. Figure 62 shows a simplified layout of Shaft 1's refrigeration system.

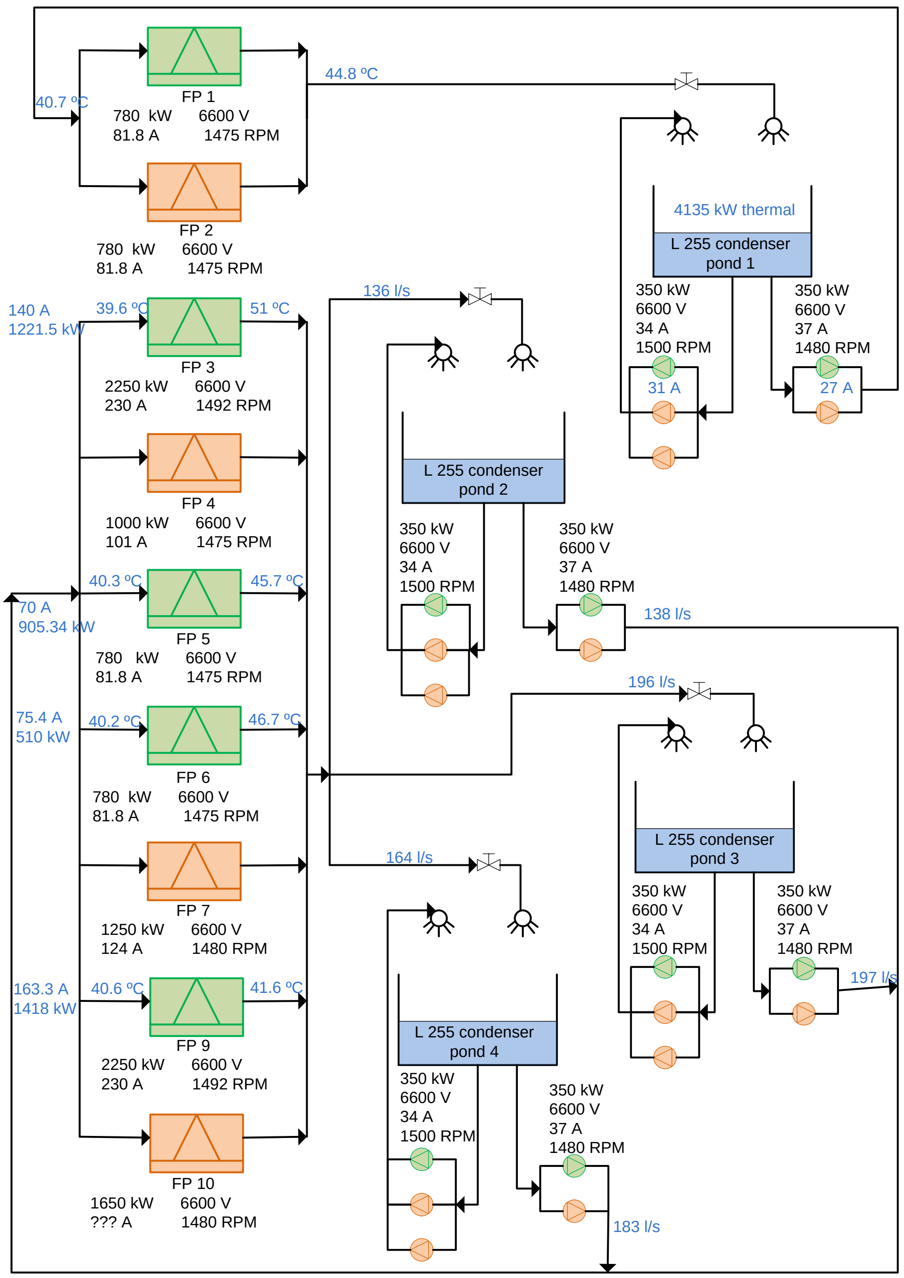


Figure 62: Simplified layout of Shaft 1's refrigeration system

There were two main constraints to determine load shift capability: the size of the hot and chill dams and the amount of cold water needed by the mine. A model representing the fridge plant, dam levels, flows and temperatures of the refrigeration system was built in Excel®. Simulations were run from this model and the results documented. The load value obtained from the model was compared to the baseline calculated from data obtained from the SCADA system.

The constraints used to govern the simulations were the following:

1. The dam levels not to exceed 95% or fall below 40%. This applies to both the hot and cold dams.
2. The cooling capacity of the lead plant not to exceed 4 500 MW.
3. The cooling capacity of the lag plant not to exceed 12 000 MW (not all the fridge plants are in working order).
4. The flows must be calculated that there is no back flow into dams or fridge plants (no negative flows).
5. The lead plant flow must be governed between 0 l/s and 170 l/s.
6. The bypass flow to the lag plant must be kept above 170 l/s (this will keep the cold dam from running dry and the hot dam from flowing over).

Shaft 1's fridge plant's hot and cold water dams have a sufficient storing capacity to make load shifting during peak times possible. The chilled dam can supply enough water during peak times to reduce the electricity used by the fridge plant by 1.2 MW during summer months. The simulation results can be seen in Figure 63.

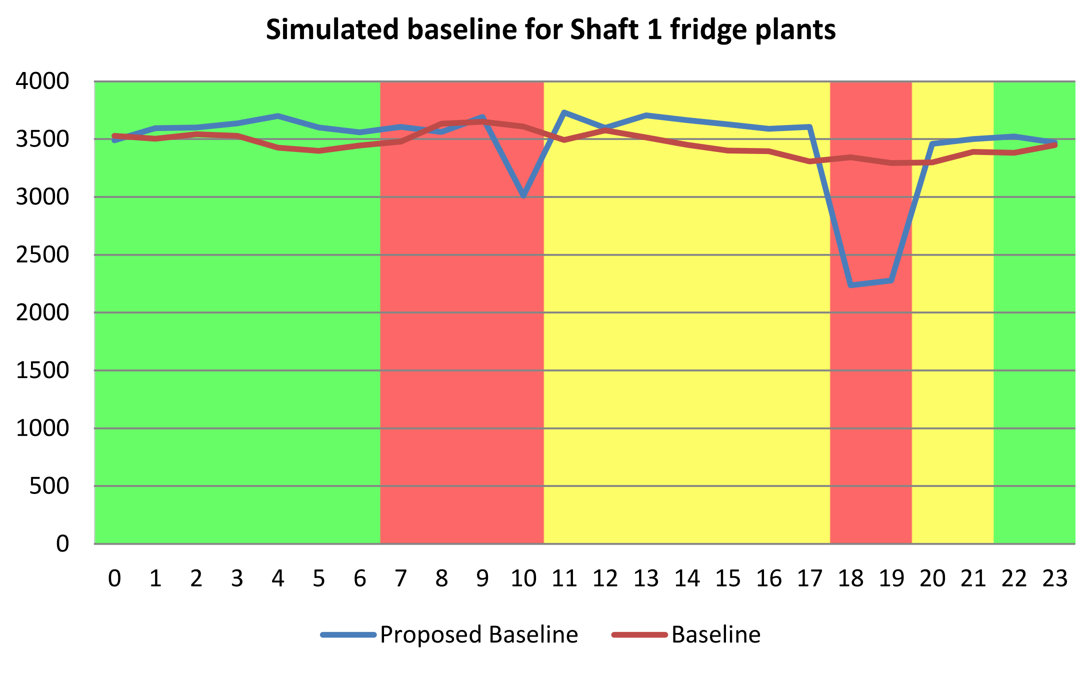


Figure 63: Shaft 1 fridge plant simulation results

The results obtained from the simulation show that there is load shift potential on the Shaft 1 fridge plant system. This data was presented to the mine, but the proposal to do a load shift on the fridge plant system was rejected. The reasons given were that the fridge plants were too old to automate and too expensive to replace. The mine was not willing to take the risk of manually switching the fridge plants on and off on a regular basis.

The underground refrigeration system was also investigated for a possible CA intervention. Data of the refrigeration system's cooling auxiliaries was collected from the mine. This data can be seen in Table 5.

Table 5: Shaft 1 fridge plant auxiliary system

	Quantity	kW	V	A	RPM	Running	Installed running kW
Evaporator							
Evaporator pump	2	350	6 600	38.9	-	1	350
Chill dam transfer pump	2	300	6 600	43	-	1	300
Chill pond 1							
Transfer pump	2	90	525	120.18	1 480	1	90
Respray pump	3	30	525	43	1 480	1	30
Chill pond 2, 3, 4, L284, L276							
Transfer pump	10	45	525	62.8	1 480	5	225
Respray pump	15	75	525	101	1 480	5	375
Condenser							
Condenser pump	6	350	6 600	37	1 480	4	1 400
Hot water respray pump	12	350	6 600	34	1 500	4	1 400
TOTAL INSTALLED RUNNING AUXILIARY POWER (kW)							**4 170**

The Excel® simulation used for the fridge plant load-shifting investigation was then used to calculate possible savings; this time taking the following into consideration:

- Install one VSD on the two fridge plant evaporator water pumps.
- Install three control valves on the three cooling tower outlet pipes downstream of the condenser pumps of Fridge Plants 3-10.
- Install required control and instrumentation to operate as specified in the following section

The system was then simulated using the following operational parameters:

- Operate Fridge Plants 3-10 at the current evaporator flow during the morning peak and the standard tariff periods.

- Operate Fridge Plants 3-10 at a 10% higher flow by increasing the evaporator pump VSD frequency during the off-peak tariff periods.
- Operate Fridge Plants 3-10 at a 40% lower flow by decreasing the evaporator pump VSD frequency during the evening peak-tariff period.
- Control the three condenser control valves to maintain a condenser water temperature difference of 9°C over the condensers of Fridge Plants 3-10 utilising proportional-integral-derivative (PID) control logic.

The simulation yielded a possible electricity reduction of 1.87 MW during the peak periods. The results from the simulation can be seen in Figure 64.

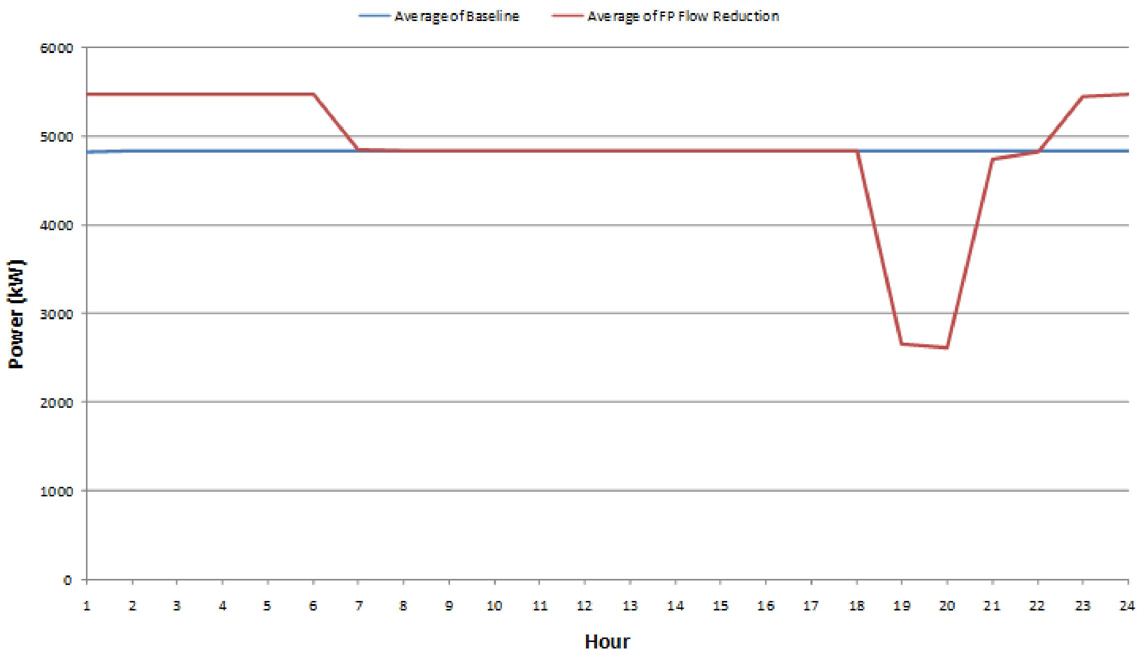


Figure 64: Shaft 1 cooling auxiliary flow reduction simulation results

An investigation on the water distribution system was not done due to the fact that the refrigeration system is underground. This significantly lowers the potential savings on the water distribution system because water does not have to be pumped to surface to be cooled.

SHAFT 3 WATER RETICULATION SYSTEM INVESTIGATION

Preliminary investigations were done on Shaft 3's water reticulation system. At Shaft 3 water is pumped from the Level 69/5 hot water dams to the Level 56/5 hot water dams by using two 1 200 kW pumps. Water is then pumped to surface by using two 1 200 kW pumps. On both levels one pump operates when needed while the second pump serves as a backup pump. The mine has a policy not to operate any dewatering pumps during the evening peak periods. After the investigation it was found that this policy is not enforced properly. A simplified layout of Shaft 3 pumps can be seen in Figure 65.

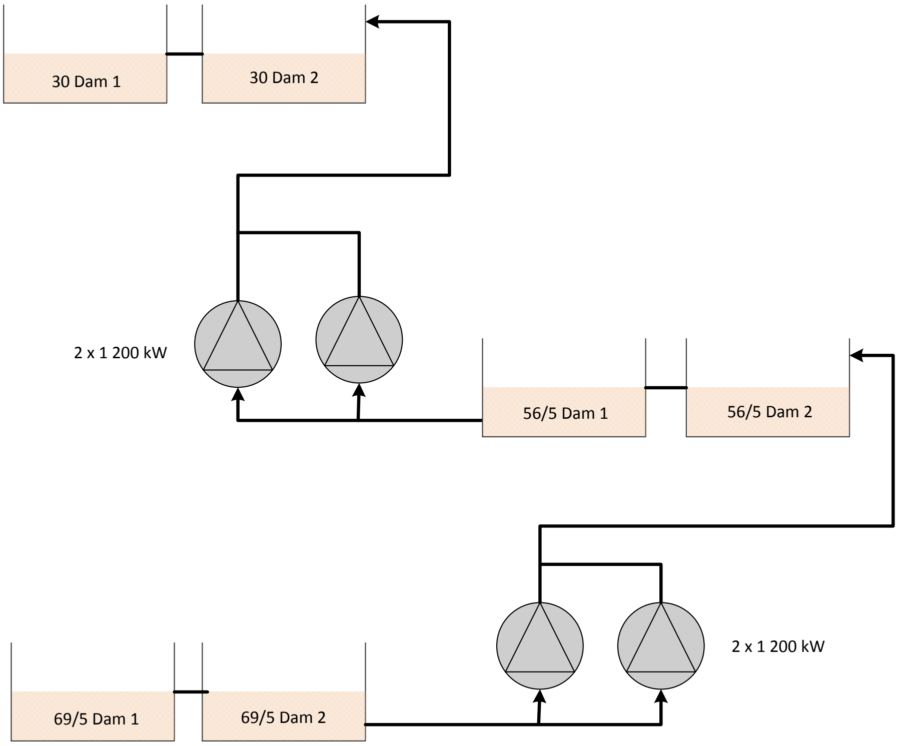


Figure 65: Simplified layout of Shaft 3 pumps

A baseline for Shaft 3's pumps was calculated using log sheets obtained from the mine. The running statuses of the pumps were then used to determine a baseline for Target 3# pumps. Figure 66 shows the baseline as well as the proposed profile for Shaft 3.

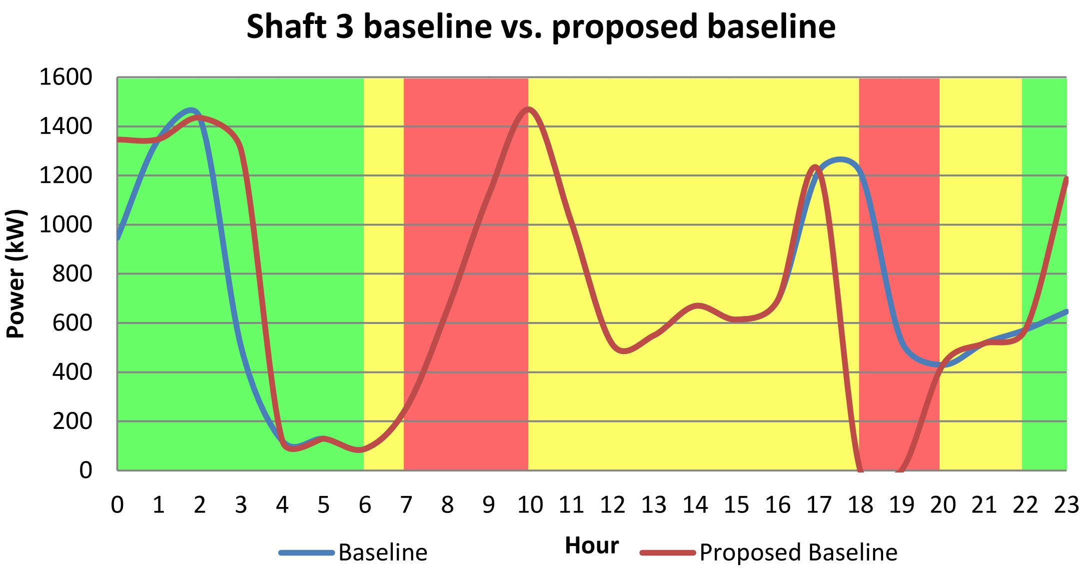


Figure 66: Shaft 3 simulation results

The results show that an average estimated evening load shift of 870 kW can be achieved. The underground dams also have sufficient storing capacity for a complete load shift during the evening peak. The dewatering system will have to be simulated to get an accurate calculation of possible savings.

The refrigeration system at Shaft 3 comprises two underground BACs supplied with water from two separate fridge plants. These are two closed loop systems. The fridge plant sizes are 780 kW and 1 400 kW respectively. The underground fridge plants operate 24/7. There are currently no hot water or chill water dams and thus the only storage capacity in the system is the BAC sump.

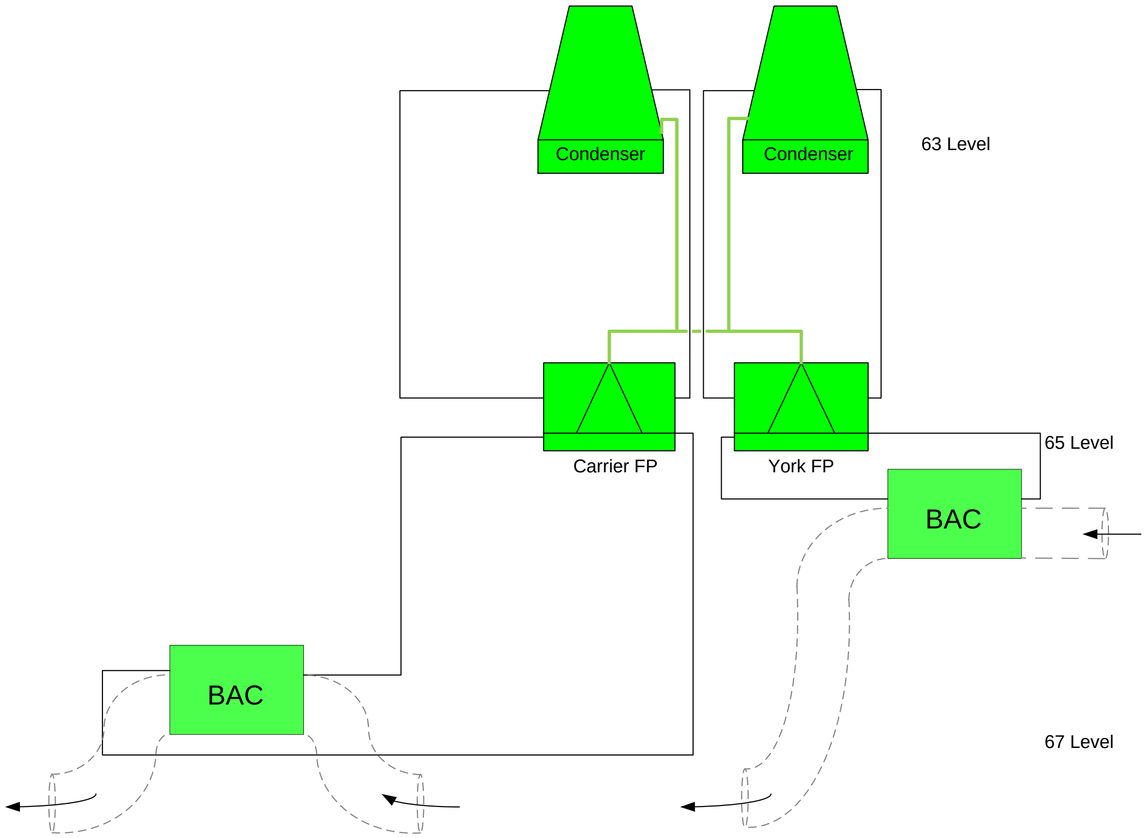


Figure 67: Shaft 3's underground refrigeration system

Because Shaft 3's refrigeration system has no buffer it was decided to do manual shutdown testing. The proposed test is to shut down the fridge plants, but to keep water circulating through the BAC. The result is that the BAC will continue to deliver cooled air; the effect will, however, diminish as the water in the sump gets warmer. When the plants are started up again, the plant will run on full load until the water reaches the required design temperature.

The primary concern with this intervention was the effect on underground temperatures. The aim of the experiment was to emulate the planned load shift by stopping the plant for one hour and measuring the effects. The results could then be extrapolated to estimate the impact on underground temperatures. Two underground levels were identified that would most severely be affected by the shutdown testing. Layouts of these levels were obtained and can be seen in Figure 68.

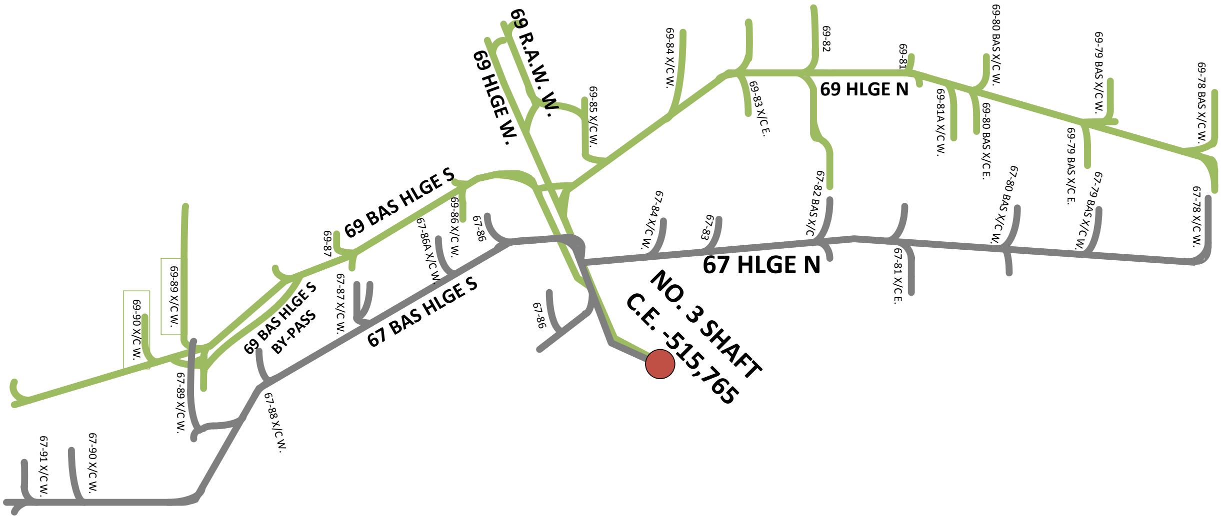


Figure 68: Layout of two underground levels

Portable temperature loggers were installed at selected working areas to measure the effects on the underground temperatures. The experiment was scheduled for a Saturday evening during the evening peak period. On that specific weekend the mine experienced many electrical problems that resulted in the fridge plants being switched off much longer than planned. Data from this event was used instead of the planned experiment. The results temperatures can be seen in Figure 69.

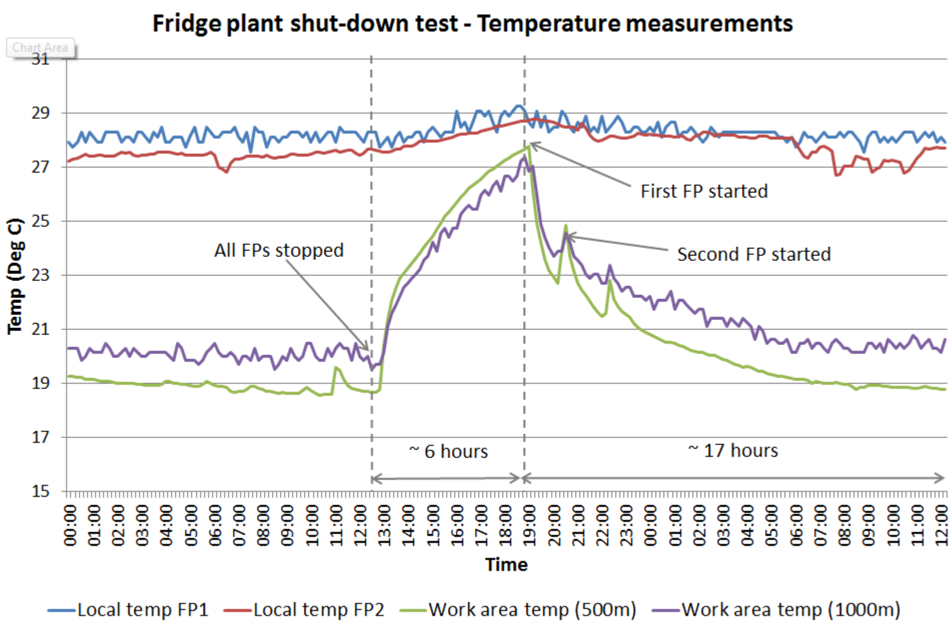


Figure 69: Refrigeration plants shutdown test results

The abovementioned data was used to create a regression model to determine the rate of temperature change during the periods the fridge plants were on or off. This regression model can be seen in Figure 70. These results have been published by Booysen [89].

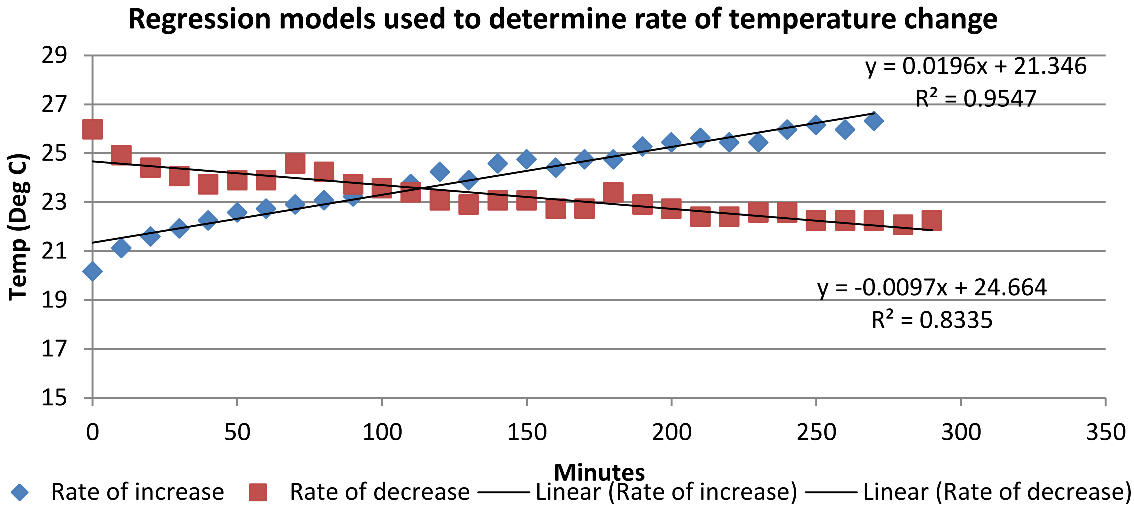


Figure 70: Regression model of temperature change rate

Booysen used the regression models to estimate the impact of a two-hour shutdown. Figure 71 shows the results. The experimental results showed that a load shift would be possible. The data used was for a full-plant stop where the project planned to keep the BAC circulation running. The rate of temperature change was also calculated with the plant start-up staggered [89].

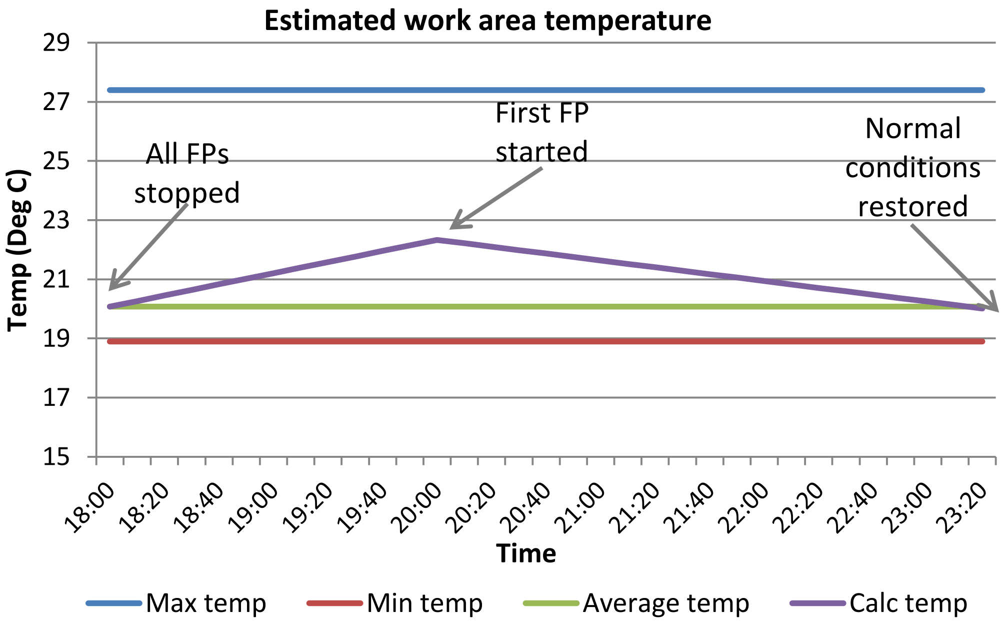


Figure 71: Estimated impact of load shifting on underground temperatures

Booysen then concluded that the results from this experiment showed that load management on this particular setup would be feasible [89]. This then indicates that a further evening load shift of 2 180 kW would be possible.

A preliminary water flow investigation into Shaft 3's water distribution system and cooling auxiliaries showed little potential for large electricity savings and were halted due to time constraints. A decision was made to implement an evening load shift intervention on both the dewatering and refrigeration system of Shaft 3. Even though funding would be available through Eskom the cost implication and cost benefit would have to be calculated before implementation.

Log sheets for Shaft 3's dewatering and refrigeration system were obtained and the baseline average calculated was 2 900 kW. Using the data from Figure 47 it was estimated that there is a load shift potential of between 2.57 MW and 3.85 MW. The obvious constraint is the installed capacity and baselines of the systems and thus it is safe to expect an evening load shift of between 2.57 MW and 3.1 MW. In order to determine the cost implication the site would have to be investigated, but using the previous project data from Section 3.4 the cost implication can be estimated. It is important to note that this only includes automation costs and not the costs of the energy management system. The cost implication estimation can be seen in Table 6.

Table 6: Cost implication for Shaft 3

Shaft 3 cost implication			
Equipment	**Qty.**	**Min cost**	**Max cost**
Pumps	4	R2,000,000.00	R2,400,000.00
Fridge plants	2	R1,600,000.00	R2,400,000.00
Total		**R3,600,000.00**	**R4,800,000.00**

Both systems were simulated using Excel® and REMS and showed that a total evening load shift of 3.1 MW can be expected. The baseline and optimised simulated profile can be seen in Figure 72.

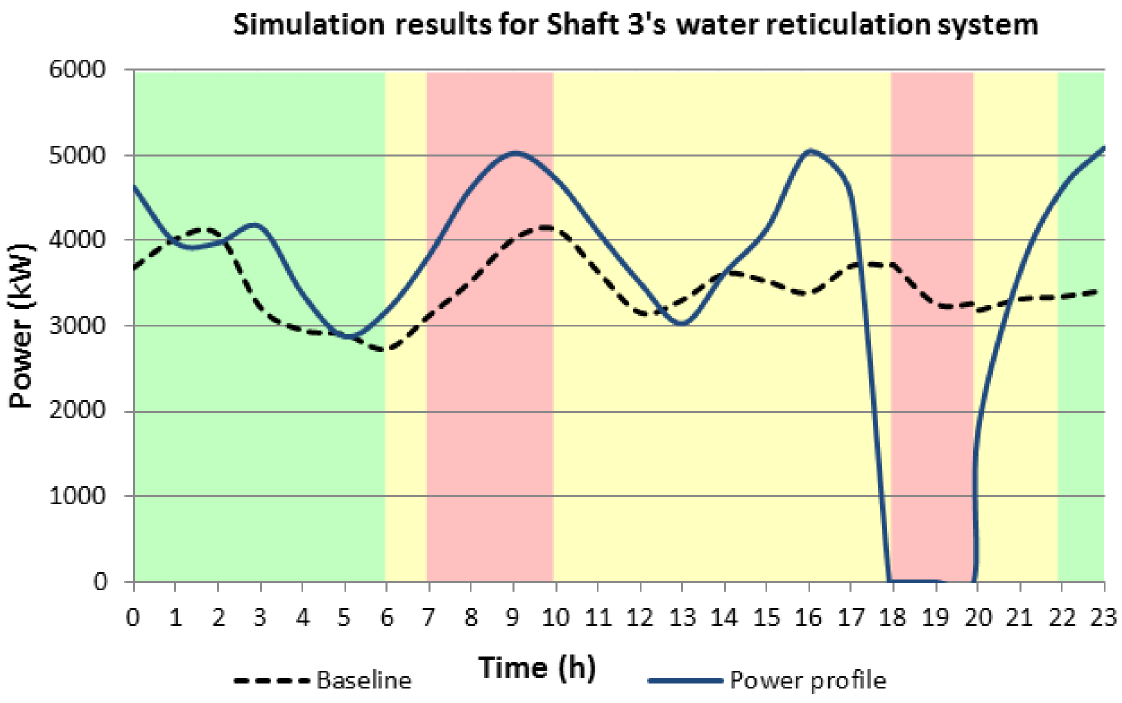


Figure 72: Shaft 3’s baseline and optimised profile

This information was discussed with both clients and it was decided to implement an evening load shift intervention on both the fridge plant system and the dewatering system. Both systems were investigated onsite to determine the automation that would have to be implemented. The fridge plant system was being automated during investigation. The dewatering system was completely manually operated. A decision was made to fully automate the dewatering system and to only implement an early warning system on the refrigeration system to make it safe to remotely start and stop the fridge plant system. The proposed layouts for both systems can be seen in Figure 73 and Figure 74.

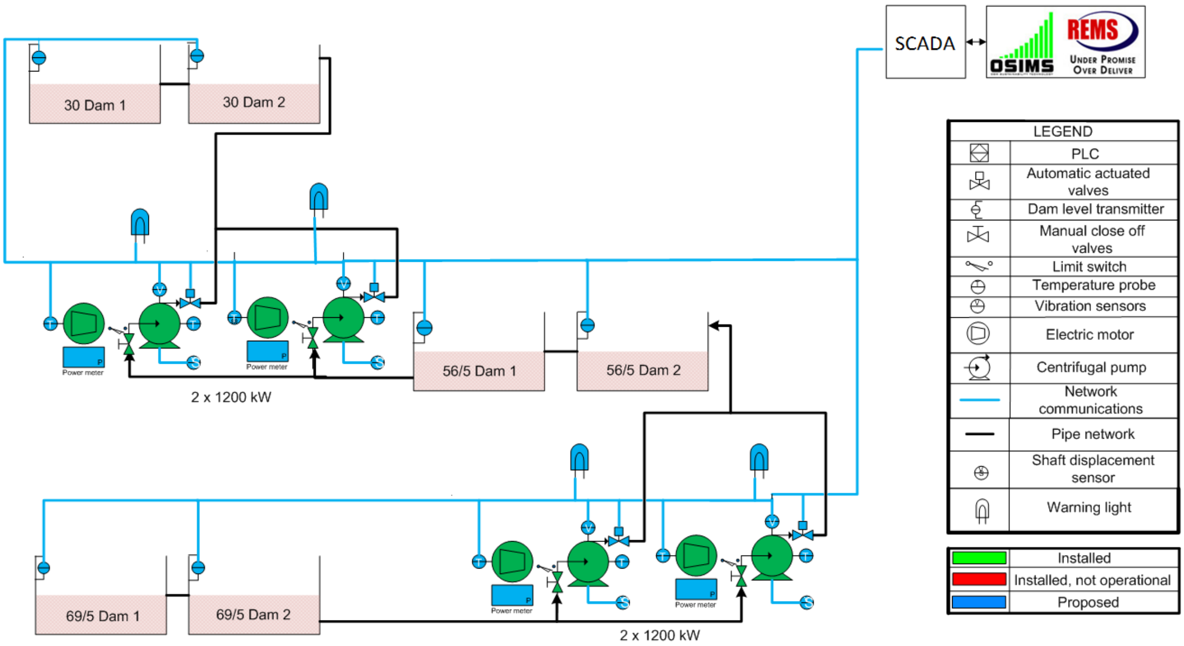


Figure 73: Proposed layout for Shaft 3's dewatering system

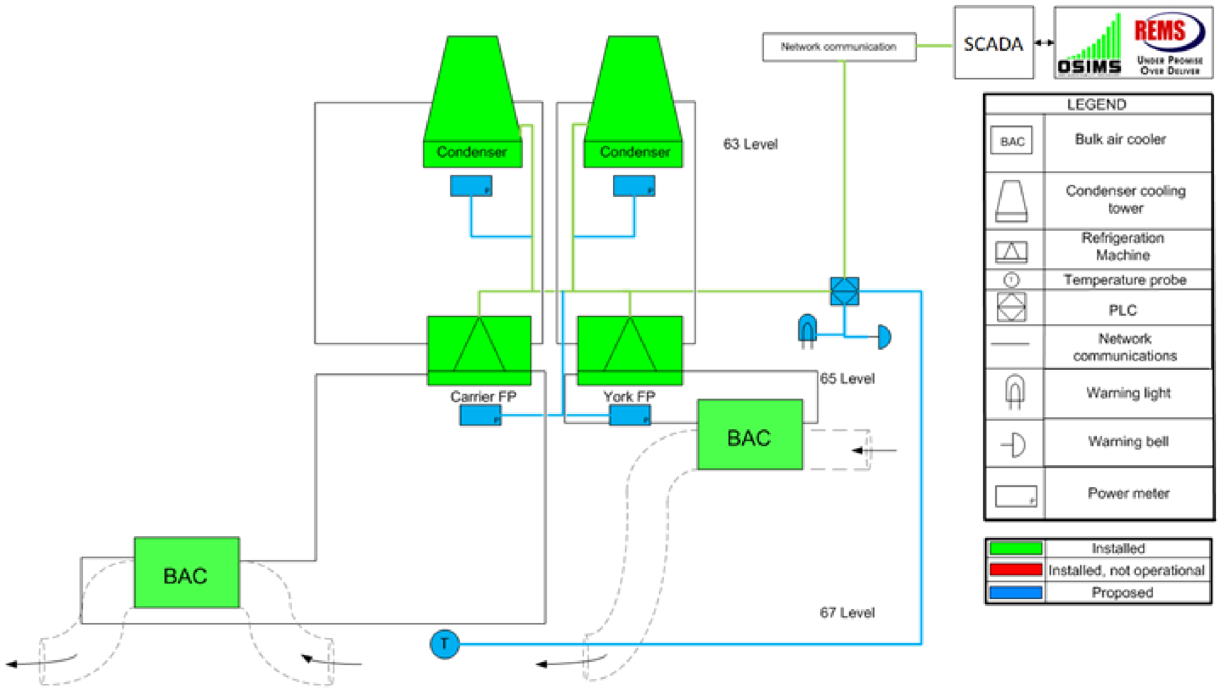


Figure 74: Proposed layout for Shaft 3's refrigeration system

As a result of the refrigeration already being automated the estimated cost implication declined severely. The payback period also decreased substantially. The resulting cost implication, average daily saving and payback period can be seen in Table 7.

Table 7: Payback period for Shaft 3's DSM intervention

Shaft 3 cost implication			
Equipment	**Qty.**	**Min cost**	**Max cost**
Pumps	4	R2,000,000.00	R2,400,000.00
Fridge plants	2	R10,000.00	R10,000.00
Total		R2,010,000.00	R2,410,000.00
Average daily saving		R4,133.69	
Payback period (years)		1.3	1.6

These savings were calculated using the average between the summer and winter tariffs that results in a smaller expected daily saving that in turn results in a longer payback period. The reason for this is to compensate for days when load shifting would not be possible due to breakdowns or operator errors.

4.3 RESULTS

The load-shifting interventions were monitored over a consecutive three-month performance assessment period during which the energy management system was set to operate on automated control. Both systems were monitored for errors and the control philosophies were adapted and optimised. An automated alarm system made it possible to safely monitor and manage the systems. The savings for each day were calculated using the data obtained from log sheets.

The data was then converted into a 24-hour electricity usage profile for each day to be compared to the baseline. The baseline for each day was scaled accordingly and the resulting savings were calculated. The resulting average electricity profiles for the performance assessment period of Shaft 3's water reticulation system can be seen in Figure 75.

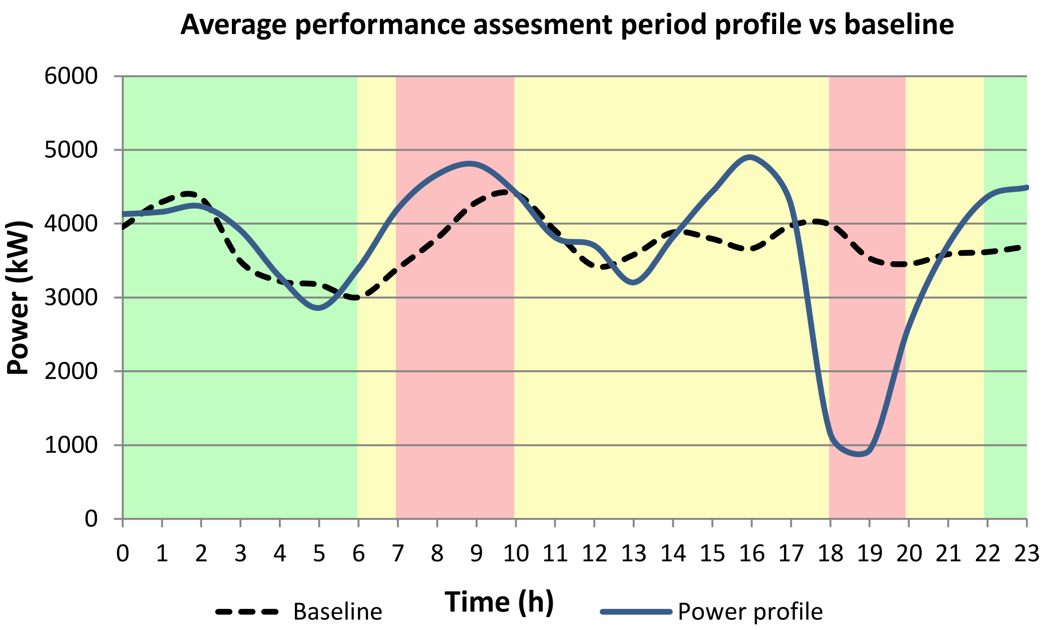


Figure 75: Average performance assessment load profile

From the above figure it is clear that not all the expected load was shifted out of the evening peak period. The reason for this is that during the performance assessment period a number of unexpected problems occurred. These problems included the following:

- Evening load shift was not possible due to electrical breakdowns earlier in the day
- Fridge plant breakdowns and gas leaks
- Maintenance on refrigeration system
- Control room operator errors
- Communication failures

These unforeseen errors resulted in a smaller average evening load shift than expected. A summary of the load shifted each month on Shaft 3 can be seen in Table 8.

Table 8: Monthly load shifted on Shaft 3's dewatering system

Performance assessment savings	
Month	**Savings with condonable days (kW)**
March	2 765
April	2 725
May	2 654
Average savings	**2 715**

Due to confidentiality agreements the exact contractor cost cannot be disclosed. It can, however, be said that the estimated cost implication and payback period is in range of what was expected. The intervention thus had a resulting cost benefit of R235,000 in the summer months and R395,848 in the winter months which would resulted in an annual yearly cost benefit of R631 000. There is, however, potential in the system to achieve a larger cost benefit should less unforeseen breakdowns occur. It is thus crucial that maintenance on these systems is done regularly.

4.4 CONCLUSION

In this case study a mine group's marginal mines were investigated to identify possible DSM intervention opportunities on the group's water reticulation systems. Two mines were identified for further investigation and one mine water reticulation system showed greatest potential for DSM implementation.

Shaft 3's water reticulation was investigated in detail to get a better understanding of system components and operating procedures. It was then decided to implement DSM interventions on both the dewatering and refrigeration systems. The systems were simulated and showed a possible combined load shift potential of 3.1 MW. The total cost implication was estimated to reach between R2,010,000 and R2,410,000 which resulted in a payback period of between 1.3 years and 1.6 years.

After implementation a three-month period was used to assess and monitor the implemented DSM interventions. The intervention resulted in an average combined load shift of 2.7 MW. The reason for not achieving the target can be attributed to unforeseen breakdowns and unscheduled maintenance on the fridge plant system. The 2.7 MW load shift intervention showed that a possible annual cost benefit of R631 000 is achievable with a possibility of more savings if maintenance is performed regularly.

Chapter 5. CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Because of a continuous increase in the demand for electricity in South Africa the country's largest electricity utility (Eskom) has been under strain to provide electricity. An expansion programme is underway to relief some of the strain, but this has caused a continuous increase in utility costs. Steep electricity tariff increases have forced large electricity consumers, for example the mining industry, to focus on energy efficiency and DSM.

More recently large industrial action has affected the marginality of the mining industry in such a way that mining groups were forced to cut down on production cost and even sell mining shafts. In order to improve the marginality of these mines a solution had to be found.

DSM intervention on mine water reticulation systems has shown great promise in the past and has been implemented on many South African mines with great success. Many mines with smaller systems have not been optimised because the priority for DSM intervention was to achieve the largest savings. Therefore, larger systems enjoyed priority over smaller systems. This only added to the increasing financial pressure on already marginal mines.

In this study the operation of a mine water reticulation system was studied to identify the most efficient DSM interventions to implement. DSM intervention on dewatering-, refrigeration and water distribution system were investigated to get a better understanding of the operation of these strategies. Previous project data was collected and analysed in order to create tools that would assist in the decision-making process for DSM intervention regarding saving potential, cost benefit and cost implication. This data would ultimately assist in determining a project's payback period that is used to prioritise DSM intervention applications.

A mining group was analysed and a marginal mining shaft's water reticulation system was chosen for further investigation. It was then decided to implement an evening load shift on both the mine's dewatering and refrigeration systems. After implementation the systems were monitored for a three-month period. This is the performance assessment to verify simulated results. It was then concluded that a combined average monthly load of 2.72 MW could successfully be shifted during the evening peak period. The cost implication of implementation of this project was within the expected amount obtained from the tools created by the previous project data. This resulted in a payback period of less than two years.

This study thus concludes that it is financially feasible to implement DSM interventions on marginal mines' dewatering systems. This would in turn assist in decreasing the marginality of some of these mines and would continue to do so for as long as these implemented systems are maintained.

5.2 RECOMMENDATIONS

The following is a list of recommendations that are made regarding the implementation of future DSM intervention on this marginal mine water reticulation system.

1. More historical data should be collected to refine the tools created in Chapter 3.
2. Further measurement and verification processes of the historic data should be implemented to assure historic project data stays up to date.
3. Investigations should be conducted to determine if some of the other mentioned dewatering strategies could be implemented. This includes water system optimisation and cooling auxiliary optimisation.
4. It was proven that both systems could successfully shift load out of the evening periods, thus the mines should always ensure that they have trained staff on hand to monitor the energy management system to prevent failure to shift load every day. These systems should also be investigated further for possible morning load shift opportunities.
5. A DSM intervention on a mine air system should also be investigated.
6. A study should be carried out to determine the effect of maintenance and breakdowns on the daily electricity savings of these interventions.

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Appendix A Daily performance assessment data

	Average monthly saving	Weekday	Weekend		Weekday					Weekend	
Hour		2013/03/01	2013/03/02	2013/03/03	2013/03/04	2013/03/05	2013/03/06	2013/03/07	2013/03/08	2013/03/09	2013/03/10
0		4211	2051	2251	3011	3651	4411	5011	4411	5011	3011
1		5611	3451	2851	3611	4411	4411	3011	3011	3011	3011
2		5611	3451	2751	5611	4211	3611	3011	3611	4211	5611
3		5011	2851	2051	5611	4211	5611	4211	5611	4211	5611
4		3011	851	1451	3011	3011	5011	4211	4411	3611	3611
5		3011	851	2051	3011	3011	3011	3011	3011	3011	3011
6		3011	851	851	3011	3011	3011	3011	3011	3011	3011
7		2251	1451	1451	3011	3011	3011	4411	4211	5011	4211
8		2251	3451	3451	3011	5611	5611	5611	4211	4211	4211
9		4851	3451	3451	5611	5611	5611	5611	4211	5611	5611
10		5611	851	851	5611	5611	5611	4211	4411	5611	4411
11		5611	851	851	5611	3011	3011	3011	4411	3611	3011
12		3611	851	1611	2251	3011	3011	3011	4211	3011	3011
13		3011	1451	2811	2251	1611	3011	3011	4211	1611	3011
14		3011	3451	4211	3611	4211	4211	4211	3011	2811	5611
15		2251	3451	5611	4211	4211	4211	5611	3011	2811	5611
16		4411	1551	3011	5611	5611	5011	5011	4411	3611	3611
17		3611	851	3011	4411	4411	4411	4411	4411	3011	3011
18		3451	851	2251	851	851	851	851	851	851	851
19		2051	851	851	851	851	851	851	851	851	851
20		851	2051	2051	2851	1451	851	1451	1611	1611	3611
21		851	2051	5611	4211	4211	4211	4211	4211	2811	5611
22		851	1451	5011	4211	4211	5611	5611	5611	4211	5611
23		851	851	4411	4251	5611	5611	5611	5611	5611	5611
Total		78864	44124	64764	89304	88624	93784	92184	90544	82944	94344
Saving (kW)	2 428	566	1 019	1 179	2 901	2 873	3 088	3 021	2 953	2 636	3 111

Weekday					Weekend		Weekday			Holiday	Weekday
2013/03/11	2013/03/12	2013/03/13	2013/03/14	2013/03/15	2013/03/16	2013/03/17	2013/03/18	2013/03/19	2013/03/20	2013/03/21	2013/03/22
1611	3011	5611	4411	5611	5611	5611	4211	5611	5611	2811	5611
2211	3011	4211	3011	3011	4411	4411	4211	4411	5611	4211	5611
4211	4411	4211	3011	5011	3011	4411	1611	3011	3611	4211	3011
4211	5611	4411	3011	5611	4411	3011	3011	3011	3011	3011	3011
2211	4211	3011	3011	4211	4411	3011	3011	3011	3011	3011	3011
1611	3011	3011	3011	3011	3011	3011	3011	3011	3011	3011	3011
1611	3011	3011	3611	3011	3611	4211	4211	3611	3611	3611	4211
2811	4211	3011	4211	3011	4211	5611	4211	4211	4211	4211	4211
2811	4211	4211	4211	3611	4211	5611	4211	4211	5611	4211	4211
4211	5611	5611	4211	4211	4211	3011	5011	5611	5011	4211	4411
5011	3451	5611	5611	4211	5011	3011	4411	4411	5611	5011	4411
3011	851	3011	4411	5611	4411	3011	4411	4411	4211	4411	5611
3011	1611	3011	4411	5011	3011	3011	3011	3011	3011	4411	4211
3011	1611	3011	3611	4411	4211	4211	3611	3011	3011	3011	3011
4211	5011	4411	5611	3611	4211	5611	4211	3011	3011	3011	3011
5611	5611	4411	5611	5611	5611	5611	4211	4211	3011	4211	4211
5611	5011	3011	3611	5611	4411	3611	5011	5611	5611	4211	5611
3011	3011	3011	3011	3011	3011	3011	4411	5611	5611	5611	5611
3011	3011	851	851	851	851	851	851	1451	3451	3451	851
3011	3011	851	851	851	851	851	851	851	851	851	851
3011	3011	851	851	3011	851	851	3011	3011	851	3011	3011
5611	3011	4211	4211	3611	4211	1611	4211	3011	851	3011	3011
5611	4911	5611	5611	4211	4211	2811	4211	3011	851	4211	5011
5611	5611	5611	5611	5611	4211	4211	4211	4211	2051	4211	5611
85864	89044	87784	89584	95544	90184	84184	87344	88544	84304	89144	94344
598	731	2 838	2 913	3 161	2 938	2 688	2 820	2 570	1 393	1 595	3 111

Weekend		Weekday				Holiday	Weekend	
2013/03/23	2013/03/24	2013/03/25	2013/03/26	2013/03/27	2013/03/28	2013/03/29	2013/03/30	2013/03/31
4211	4211	4211	4211	4211	4211	4411	Data loss	Data loss
4211	3011	3611	4211	3011	4211	3011	Data loss	Data loss
4411	4411	4411	5611	4411	5611	4211	Data loss	Data loss
4411	3011	4411	4411	3011	4411	4211	Data loss	Data loss
3011	3011	3011	3011	3011	3011	3011	Data loss	Data loss
3011	3011	3011	851	3011	3011	3011	Data loss	Data loss
3611	3611	851	3011	3711	3011	Data loss	Data loss	Data loss
4211	4211	3611	3611	5611	3711	Data loss	Data loss	Data loss
5611	5611	5611	4211	4211	5611	Data loss	Data loss	Data loss
5611	5611	4211	5611	4211	5611	Data loss	Data loss	Data loss
3011	3011	3011	5611	2811	4411	Data loss	Data loss	Data loss
4411	3011	4411	3011	4411	3011	Data loss	Data loss	Data loss
3011	3011	4411	3011	4411	3011	Data loss	Data loss	Data loss
3011	3011	3011	1611	3011	3011	Data loss	Data loss	Data loss
3011	3011	3011	1611	4211	3011	Data loss	Data loss	Data loss
5611	3611	3611	2211	4211	3711	Data loss	Data loss	Data loss
5611	5611	5611	4211	5611	5611	Data loss	Data loss	Data loss
4211	5611	5611	4211	4411	5611	Data loss	Data loss	Data loss
851	851	851	1451	851	1551	Data loss	Data loss	Data loss
851	851	851	851	851	851	Data loss	Data loss	Data loss
3011	3011	3011	851	851	851	Data loss	Data loss	Data loss
3011	3611	3011	3611	3011	4411	Data loss	Data loss	Data loss
5611	5611	4411	5611	4411	5611	Data loss	Data loss	Data loss
5611	5611	5011	5611	5611	5611	Data loss	Data loss	Data loss
93144	**89144**	**86784**	**82224**	**87084**	**92684**	**Data loss**	**Data loss**	**Data loss**
3 061	2 895	2 796	2 306	2 809	2 692	Data loss	Data loss	Data loss

Holiday	Weekday				Weekend		Weekday					Wee
2013/04/01	2013/04/02	2013/04/03	2013/04/04	2013/04/05	2013/04/06	2013/04/07	2013/04/08	2013/04/09	2013/04/10	2013/04/11	2013/04/12	2013/04/13
Data loss	4211	3611	3611	5011	5611	4411	2051	2051	5611	4211	4211	4211
Data loss	4211	4411	4411	4411	5611	3011	3451	4211	3011	4411	5611	5011
Data loss	5611	4411	5011	3011	3011	3011	3451	5611	3011	4411	5611	4411
Data loss	5611	3011	4211	3011	3011	3011	851	3011	3011	3011	3011	3011
Data loss	4211	3011	3611	3011	3011	3011	1611	3011	3011	3011	3011	3011
Data loss	4211	3011	3011	3011	3011	3011	1611	3011	3011	3011	3011	3011
851	1611	4211	3011	3611	4211	4411	3011	3011	4211	3011	3611	3011
851	3011	4211	3011	4211	5611	4411	5611	3011	5611	4211	5611	3011
851	3611	4211	4211	5611	5611	3011	5611	4411	5611	5611	5611	4411
2251	5611	5611	5611	5611	4211	3011	5611	4411	3011	5611	4211	5611
2251	5611	4411	5611	3011	3011	4411	4211	4211	3011	4411	3011	4211
2211	4211	3011	4211	4411	3011	4411	3011	4211	3011	3011	3011	4211
2811	3011	3011	3011	3011	3011	4411	4411	3611	3011	3011	4411	3611
2811	3011	3011	3011	3011	3011	3011	4411	3011	4411	3011	4411	3011
4211	3611	4211	3011	3611	4411	4411	3011	4411	4411	3011	4211	4411
4211	4211	4211	4211	4211	4411	4411	5611	4411	4211	3611	4211	4411
5011	5011	5611	5611	4411	3011	3011	4211	4211	4211	5611	5611	3011
4411	4411	4411	4411	4411	3011	3011	2051	4211	4211	5611	4411	3011
3011	3011	851	851	851	851	851	851	2051	851	2051	3011	851
3011	3011	851	851	851	1451	851	851	851	2251	851	851	851
3011	3611	3611	3011	3011	4211	4411	2251	3011	4411	3011	2251	3011
3011	4211	4211	4211	3011	4211	4411	2251	3011	3011	3011	4411	5011
3011	4211	4211	4211	4211	5611	4211	851	5611	4211	3011	5011	5611
3611	4211	4211	4211	4211	4411	2051	2051	5611	4211	3011	4211	4211
51398	**97264**	**89544**	**90144**	**86744**	**90544**	**82184**	**72904**	**88184**	**88544**	**86744**	**96544**	**88144**
-838	1 073	2 911	2 936	2 795	2 653	2 605	2 218	2 255	2 170	2 195	2 123	2 853

kend	Weekday					Weekend		Weekday					Wee
2013/04/14	2013/04/15	2013/04/16	2013/04/17	2013/04/18	2013/04/19	2013/04/20	2013/04/21	2013/04/22	2013/04/23	2013/04/24	2013/04/25	2013/04/26	2013/04/27
3611	3611	3611	4211	3611	3011	4211	Data loss	3611	3011	4211	4911	851	4211
3011	4211	3011	3011	3011	4411	4211	Data loss	4411	4411	5611	5611	2251	5611
3011	4211	4411	4411	4411	4411	5611	Data loss	4411	4411	5611	4411	851	4411
4411	3611	4411	4411	4411	3011	4411	Data loss	3011	4411	3011	3011	851	3011
4411	3011	3011	3011	3011	4211	3011	Data loss	3011	4411	3011	3011	851	3011
3011	3011	3011	3011	3011	4211	3011	Data loss	3011	3011	3011	3011	851	3011
3011	3011	3011	3011	3011	4211	Data loss	3011	4211	4211	3011	3011	851	3011
3011	4411	4211	4411	3611	4211	Data loss	4411	5611	4211	4411	5611	851	4211
3011	4411	5611	4411	5611	4411	Data loss	4411	5611	4211	4411	5611	851	5611
3011	4211	5611	4211	3451	4411	Data loss	3011	3011	4211	4211	4211	2811	5611
3011	4211	4211	4211	2051	4211	Data loss	3011	4211	4411	2051	3011	4211	4211
3011	4211	3011	4211	851	4211	Data loss	4211	4211	4411	2051	4211	4211	3011
3011	3611	3011	4211	3011	4211	Data loss	4211	3011	3011	1451	4211	2811	4411
3011	4411	3011	4411	3011	3011	Data loss	5611	3011	3011	3611	4411	1611	3011
3011	4411	4411	3011	4411	4411	Data loss	5011	4411	4411	4211	4411	3011	3011
3011	4211	5611	3011	4411	5611	Data loss	3011	5611	5611	4211	4211	5611	5611
3011	4211	4211	5611	3011	4211	Data loss	1611	4211	4211	3011	4211	5611	4211
3011	4211	4211	4211	3011	4211	Data loss	1611	3611	4211	3011	3011	4211	4211
851	851	851	851	851	851	Data loss	851	851	1451	3011	851	3011	851
851	851	851	851	3011	851	Data loss	851	851	851	3011	851	3011	3451
3011	3011	3011	3011	3011	3011	Data loss	5611	4411	4411	3711	4211	3011	4211
3011	5011	4411	5011	4411	4411	Data loss	5611	5611	4411	3711	5611	4411	5611
3011	5611	5611	5611	4411	4411	Data loss	5611	5611	3011	3011	5611	5611	3011
3011	5611	5611	5611	4411	5611	Data loss	4211	4211	3011	4211	4211	4211	3011
71344	92144	91944	91944	81024	93744	24466	65878	93744	90944	84784	95444	66424	93544
2 153	3 020	3 011	3 011	1 476	3 086	Data loss	Data loss	3 086	2 670	553	3 157	-212	1 778

Holiday	Weekday		Weekend		Weekday					Weekend		
2013/05/01	2013/05/02	2013/05/03	2013/05/04	2013/05/05	2013/05/06	2013/05/07	2013/05/08	2013/05/09	2013/05/10	2013/05/11	2013/05/12	2013/05/13
3011	4211	3011	4211	4211	3011	851	4211	5611	4211	4211	1611	3011
4411	4211	4411	5611	5611	4411	851	3011	5611	5611	1611	2211	3611
5611	4211	5611	5011	5011	4211	4211	5611	3611	5011	1611	2811	5611
5611	3011	5611	3011	3011	4211	5611	4211	3011	3011	2211	4211	4911
3011	3011	3011	3011	3011	2811	5611	1611	3011	3011	2811	1611	2211
3011	3011	3011	3011	3011	1611	3011	1611	3011	3011	2211	1611	1611
3011	2811	4211	3011	3011	1611	3611	3011	3011	3011	2211	2811	4211
4211	2811	4211	3011	4211	1611	4211	4411	5611	4211	4211	4211	5611
4211	2811	4211	5611	5611	3011	4211	4411	5611	5611	3011	3611	5011
4211	4211	5611	5611	4411	3611	4211	4211	4211	5611	1611	1611	3011
4211	5011	5011	4211	3011	4211	3011	5611	5611	3011	1611	1611	4211
3011	3011	1611	4211	3011	4211	3011	5611	4411	3011	4211	2811	5611
3011	3011	3011	3011	3011	3611	4411	3011	3011	3011	4211	2811	5611
3011	3011	3011	4211	4211	4411	1611	3011	3011	5611	4211	4211	3011
4211	5611	5611	5611	4211	5011	4211	4211	5611	5611	1611	3611	4211
3451	5611	5611	5611	5611	4211	4211	5611	4211	4211	3011	4411	4211
4211	4211	4211	3011	4211	4211	4211	4851	4211	2211	1611	3011	5611
3011	3011	3011	3011	3011	3611	1611	3011	3011	1611	1611	3011	4411
851	3011	851	851	851	2251	851	3011	3011	3011	1611	1611	851
851	3011	851	851	851	2251	851	3011	4411	3011	2811	2211	851
3011	3011	3011	3011	3611	851	3011	4411	3011	1611	4211	4211	3011
4211	5611	4411	4411	5611	851	4211	3011	3011	2211	2811	2811	4211
4211	5611	5011	5011	5611	851	5611	3011	3611	2811	2211	2811	4211
3011	4211	4211	4211	3611	851	5611	4211	5611	4211	3011	3011	4211
84584	91264	92344	92344	91544	71504	82824	91904	98064	87464	64464	68464	93044
2 705	823	3 028	3 028	2 995	760	2 631	850	406	665	506	973	3 057

Weekday				Weekend		Weekday					Weekend		
2013/05/14	2013/05/15	2013/05/16	2013/05/17	2013/05/18	2013/05/19	2013/05/20	2013/05/21	2013/05/22	2013/05/23	2013/05/24	2013/05/25	2013/05/26	2013/05/27
5611	5611	4851	3611	4211	5611	2211	4211	4211	5611	5611	4211	5011	5011
4411	4411	4851	3011	5011	4411	4211	3011	4211	5011	4211	4211	4411	4411
3011	3011	2251	3011	4411	3011	4211	5611	4411	3011	3011	4411	4411	5011
3011	3011	2251	1611	3011	3011	2211	5611	4411	3011	4411	4411	3011	4211
3011	3011	3011	1611	3011	3011	1611	3011	3011	3011	4411	3011	3011	4211
3011	3011	3011	1611	3011	1611	1611	3011	3011	3011	3011	3011	3011	3011
4211	4851	5611	4211	3011	4211	1611	3011	4211	4211	3611	4211	3611	4411
5611	4851	5611	4211	5611	4211	3011	3611	4211	4211	4211	4211	4211	4411
5611	3451	4211	5611	5611	2811	5611	5611	5611	5611	4211	4211	4211	5611
2811	2251	3611	5011	4211	2811	5611	5611	5011	4411	4211	5011	5611	4211
1611	3451	3451	3611	3611	2811	4211	4211	3011	3011	3711	4411	4411	4211
5611	4851	4211	4211	3011	2211	3611	3011	4211	3011	4411	4411	4411	3611
5611	4851	5611	4211	3011	1611	3011	3011	4211	3011	4411	4211	3011	4411
1611	2251	3011	3011	4211	2211	4411	3011	3011	3611	3011	4211	3611	4411
2211	2851	2851	4411	4211	2811	4411	3711	3011	4211	3611	5611	5611	3011
5611	5611	5611	5611	4211	2811	4211	5011	5011	5611	4211	5011	5611	4211
5611	4211	4211	4211	3011	1611	4211	5611	5611	4211	4211	3011	3611	5611
3011	3011	3011	4211	3011	1611	4211	4211	4211	2211	4211	3011	3011	5611
3011	2251	851	3011	3011	1611	3611	3011	4211	1611	3611	3011	3011	4411
3011	2251	851	3011	3011	1611	3011	3011	3011	1611	3011	3011	3011	3011
3011	2251	3011	3011	4411	3011	3011	3011	3011	1611	4411	3011	3011	3011
4411	3651	5611	4411	5611	4211	5611	4411	3011	1611	4411	4211	4211	3011
4211	3451	5611	5611	4211	2811	5611	4411	4211	3011	4411	4211	4211	3011
4211	3451	4211	4211	4211	2811	4211	3611	4211	4211	4211	4211	4211	3611
93064	85864	91384	90264	93864	68464	89264	95564	96264	83664	96764	96464	95464	99664
898	1 358	2 988	781	931	1 273	440	1 002	431	1 906	752	1 040	998	473

Weekday			
2013/05/28	2013/05/29	2013/05/30	2013/05/31
5611	4211	5611	5611
5611	4211	5611	4411
5011	4411	4411	3011
3011	4411	4411	4411
3011	4411	3011	3011
3011	3011	3011	3011
3011	3011	3011	3011
4211	4211	4211	3611
5611	4211	4211	4211
5611	5611	5611	5611
5011	5011	5611	5611
3011	3011	3011	5011
4411	4411	3011	3011
3011	3011	3011	3011
3011	3011	3011	3011
4211	4211	4211	4211
5611	5611	5611	5611
5611	5611	5611	5611
2251	851	851	851
851	851	851	851
3011	3011	3011	3011
3011	3011	3011	3011
5011	3611	4211	3011
5611	4211	4211	3011
97344	91144	92344	88744
2 536	2 978	3 028	2 878