Demand Side Management on an Intricate Multi-Shaft Pumping System from a Single Point of Control

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ABSTRACT

Title: Demand side management on an intricate multi-shaft pumping system from a single point of control

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Key words: DSM, ESCO, Eskom, multi-shaft pumping system

Eskom, the sole supplier of electricity in South Africa is facing an energy crisis. This is due to the steady increase in demand for electricity in South Africa. Low electricity prices in South Africa have helped the energy intensive industries of South Africa to be more competitive. Unfortunately this has resulted in poor energy efficiency practices and has hampered incentives to save energy.

To address this problem, Eskom initiated a Demand Side Management (DSM) programme. DSM is beneficial to both Eskom and the client. However, due to the high cost of implementing such projects, it is feasible to implement it only on sites where the load shift potential is high enough for Eskom to benefit. The mining industry has been targeted for DSM programmes. This is due to the existence of a large mining sector in South Africa and to its energy intensive nature.

Most mining operations require large amounts of water which is used to cool the underground environment and so ensure productivity and the safety of the workers. Due to the large amounts of water needed for mining, the electricity usage of these pumping systems is very high. If the use of this electricity can be optimised by implementing DSM principles, this will result in the long term savings of costs for the mines involved.

The majority of pumping systems found on mines are single shaft systems. Individually these systems have a very high DSM potential. However, if multiple shaft systems can be used for DSM, the benefits will be far greater. Furthermore, combining several sites with an interconnected water pumping system will increase the potential for DSM and enable sites where individually the potential is too low to be feasible for a DSM project to raise their potential. This will result in more sites where DSM projects can be implemented and more clients who can benefit from the DSM programme.

The purpose of this study is to investigate and implement a DSM project on an intricate multi-shaft mine pumping system which will be controlled from a single point. The project required a detailed investigation of the pumping systems on each shaft and how the water system is interlinked between the shafts. This project was carried out on Beatrix Mine Shafts 1, 2 and 3. The pumping systems were analysed and simulated according to the specific constraints and requirements that were specified by the mine.

During the investigation and implementation of this project, possible efficiency improvements on certain pump stations were discovered and implemented. The improvements enabled both an increase in water flow to the surface and a decrease in power consumption. Due to this load reduction, the savings achieved were higher than those found in most load shifting projects.

Moreover, additional infrastructures were installed to ensure communication between pumping systems. Once the simulation and optimisation of the control system was completed, the pumping system network was automated. The load shift resulted in a ± 3.5 MW shift in the morning peak demand period and a ± 6.0 MW shift in the evening peak demand period.

This load shift has resulted in an average cost saving of R 80 000 per month during summer tariff period, and R 300 000 per month during winter tariff period. This saving result was calculated by taking load reduction into account. This project has shown that a DSM project can be implemented successfully, given the necessary historical data and expertise, on a pumping system that is interconnected between multiple shafts.

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ABBREVIATIONS

BAC	Bulk Air Coolers
Btu	British thermal unit
DDC	Direct Digital Controller
DSM	Demand Side Management
EMS	Energy Management System
ESCO	Energy Service Company
GDP	Gross Domestic Product
HVACI	Heating, Ventilation and Air Conditioning International
kW	Kilowatt
kWh	Kilowatt-hour
M&V	Measurement and Verification
MD	Maximum Demand
Ml	Mega litre
MW	Megawatt
PLC	Programmable Logic Controller
REMS	Real time Energy Management System
RTP	Real Time Pricing
SCADA	Supervisory Control And Data Acquisition
SMS	Short Message System
TEMMI	Transfer of Energy, Momentum and Mass International

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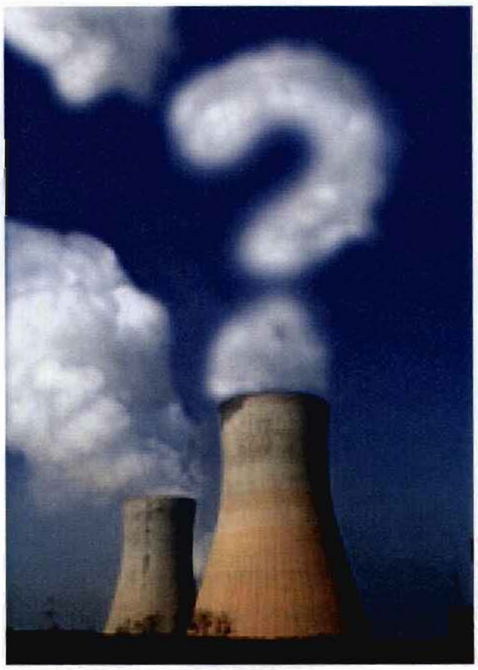
CHAPTER 1: INTRODUCTION AND BACKGROUND



1.1 Preamble

The worldwide need to conserve energy is becoming one of the crucial issues of this century. The time when abundant energy was readily available is over. Growing population and economies have led to an increased demand for energy. This increase in energy generation has led to increased costs and impacts on the environment, and political instability in the region may play a factor. The total energy demand worldwide has increased from 207 quadrillion British thermal units (Btu) in 1970 to 412 quadrillion Btu in 2002 [1]. It is estimated that from 2002 to 2025 the increase in world energy utilisation will grow by almost 2.5% per year [1].

It is only natural for growing and developing countries to proportionately use more energy then the growth of their economies and as living standards improve. However, there is also a continued rising energy demand in developed countries, and consequently there is tremendous pressure to supply the world's energy needs. It is therefore in everyone's interest, whether government, consumer or energy suppliers, for the available energy sources to be extended as far as possible.

The overall aim is to provide affordable energy needed for rapid economic growth and improved living standards, and also to satisfy the increasing energy demand of the developed countries. Achievement of this aim requires a combination of increased energy conservation, an expanded and increased variety of energy supplies, and increased energy efficiency.

1.2 Electricity demand growth and peak electricity demand problem

South Africa's industry is based largely on the extraction and processing of minerals which are energy intensive in nature. As a result, the Industrial and Mining Sectors are the heaviest users of energy, accounting for more than two-thirds of our national electricity usage [2].

If one compares the South African economy to those of developed countries, it is clear that South Africa uses a lot more energy for every Rand of economic output. South Africa had the 26th biggest gross domestic product (GDP) in the world in 2001, but was the 16th largest consumer of energy [2]. This is due to its economy being dominated by mining, minerals processing, metal smelting, the production of synthetic fuel (synfuel) which are naturally energy intensive enterprises and cheap electricity.

The figure below shows energy consumption in Petajoules per capita for some developed and developing countries. South African electricity consumption is currently estimated to be growing at 1 000 Megawatt (MW) per year [2]. As a result, the electricity demand is expected to exceed the generating capacity of Eskom during the peak demand periods in 2007 [3] [4], as shown in Figure 2. From Figure 2 it is clear that South Africa is getting closer to the developed countries in terms of energy intensity [2].

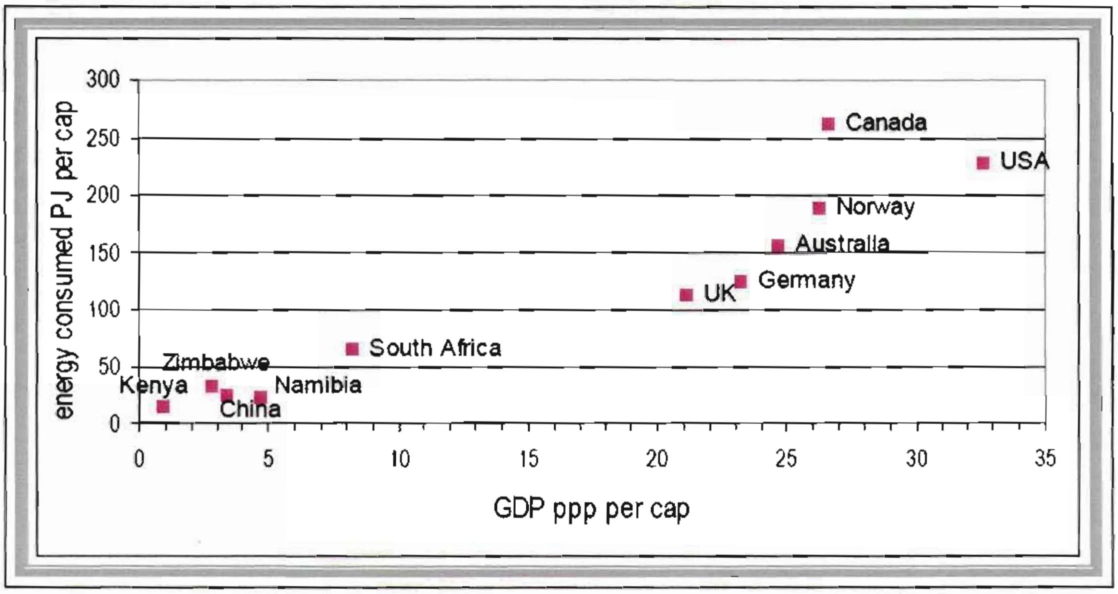


Figure 1: Energy demand per capita (2000) [2]

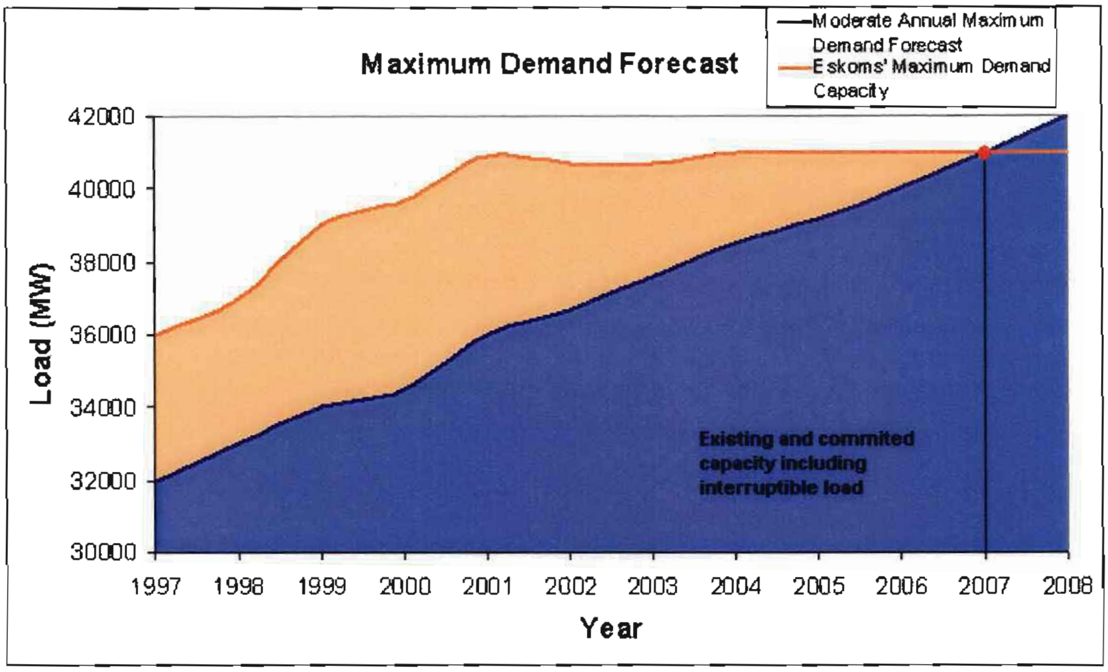


Figure 2: Eskom capacity status and maximum demand forecast [3]

This growth in electricity demand has led to research into ways to decrease the demand of large energy users during specific times of the day. In Figure 3, a breakdown of energy consumption per sector for South African is given. A study by Lane [5] shows that a 27% reduction of the peak load can be realised on a typical deep level South African mine. This could be achieved by managing and optimising the energy usage of the primary systems such as pumps, compressors, winders, fridge plants, etc.

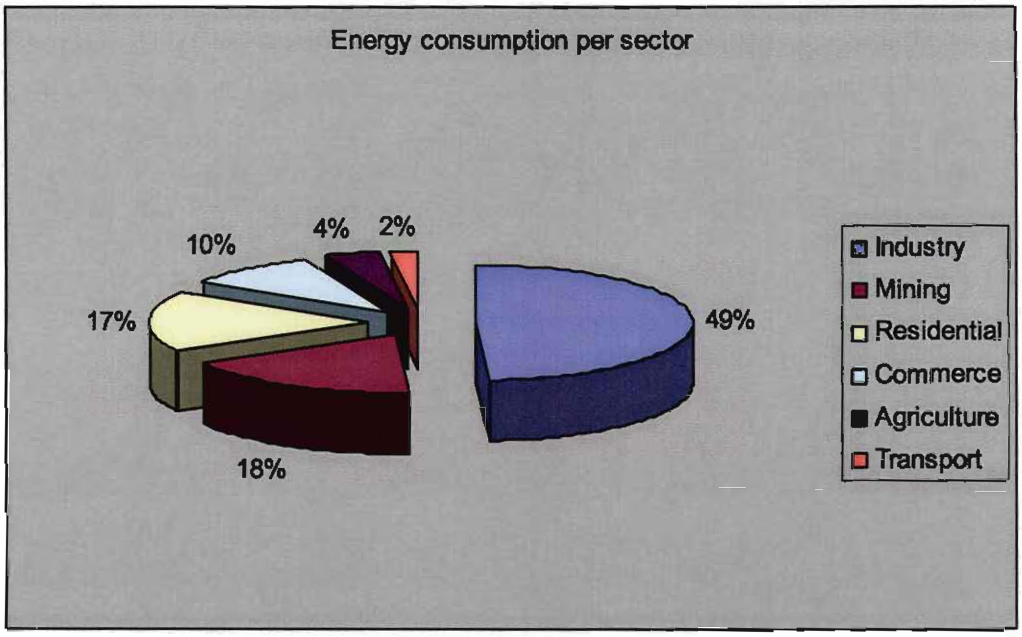


Figure 3: Energy consumption per sector (2003) [6]

To determine the trend of the electricity demand in South Africa, Eskom launched an intense investigation and realised the following factors:

- Season of the year: The demand curve rises during winter due to the additional energy that is required to power space heaters and geysers etc. (refer to Figure 5). This can easily be seen in the commercial sector, refer to Figure 4 (Townships and Municipalities). The main cause of this variation is clearly seen in the municipalities, townships and electrification.
- Time of day: During a normal day there are two main periods where the demand is high. The first period is between 07:00 and 10:00 and the second between 18:00 and 20:00.
- Day of week: Due to working hours during the week, the type of day strongly influenced the demand curve. The different types of days are identified as Saturdays, Sundays or Public Holidays and Weekdays. The two main peak periods found in a normal day are more easily identifiable on Weekdays than on the Weekend periods.

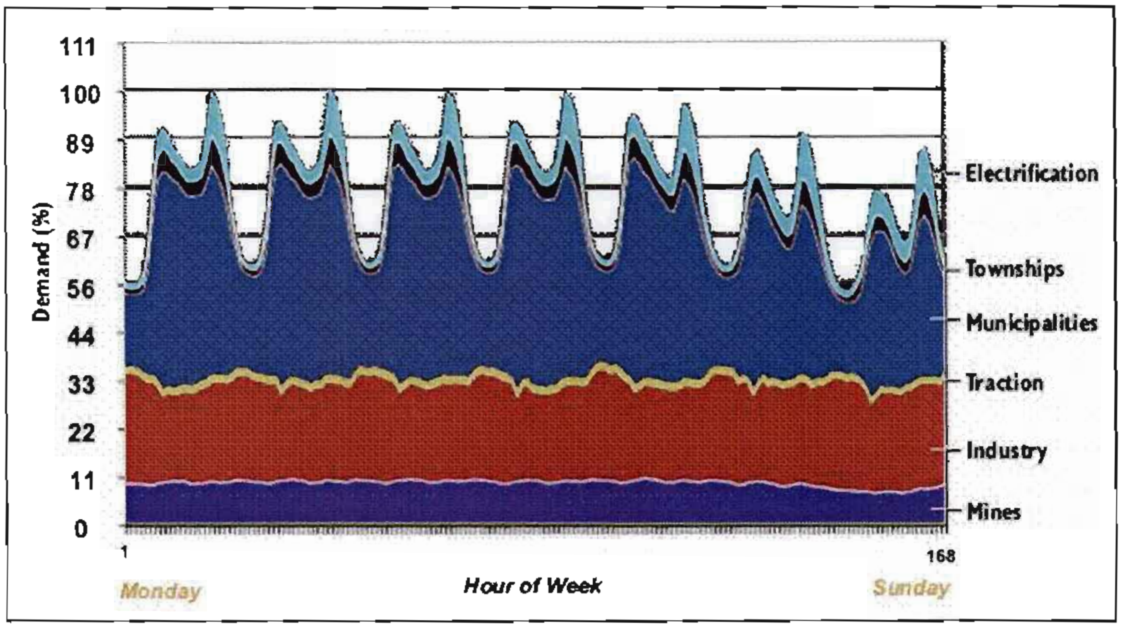


Figure 4: Weekly energy demand of different sectors

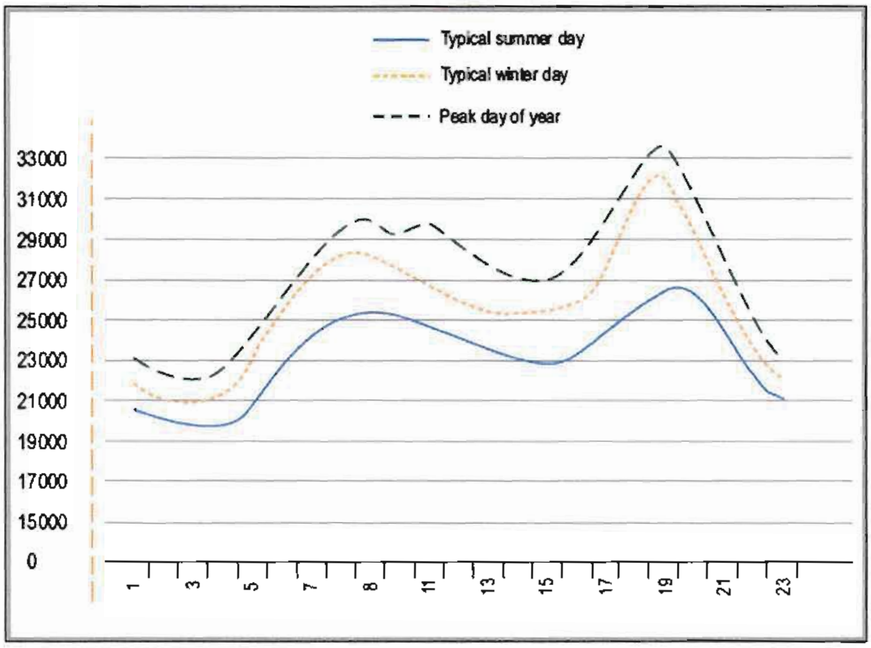


Figure 5: Typical weekday energy profile 2003 [7]

The figure above clearly indicates the factors that influence the energy demand profile of South Africa [7]. Fluctuations are caused mainly by the Residential, Commercial and small industry sectors. In an effort to reduce the demand peaks, Eskom introduced an electricity price structure that reflected the real cost of generation, called real time pricing (RTP). This price structure was intended to influence very large customers to use electricity more in off-peak periods and less in high-peak periods [8].

However, due to the ineffectiveness of RTP, Eskom later developed a simpler tariff structure. This tariff was called MegaFlex and it separated the 24 hour profile into three categories, namely peak, standard and off-peak. The price for each kWh differs according to these categories. The industry and mining sector (which is energy intensive) falls under the MegaFlex pricing structure. A comprehensive layout and conditions of Eskom's MegaFlex pricing structure can be seen in Tables 1 and 2 [9].

Table 1: MegaFlex-demand time periods

Defined time periods:	Weekdays	Saturday	Sunday
Peak	07:00 - 10:00 18:00 - 20:00	N/A	N/A
Standard	06:00 - 07:00 10:00 - 18:00 20:00 - 22:00	07:00 - 12:00 18:00 - 20:00	N/A
Off-peak	22:00 - 06:00	12:00 - 18:00 20:00 - 07:00	Whole day

Table 2: MegaFlex-season demand periods (2006)

High-demand season (June – August)		Low-demand season (September – May)
52,22c + VAT = 59,53c/kWh	Peak	14,82c + VAT = 16,89c/kWh
13,81c + VAT = 15,74c/kWh	Standard	9,20c + VAT = 10,43c/kWh
7,51c + VAT = 8,56c/kWh	Off-peak	6,52c + VAT = 7,43c/kWh

As shown in the tables above, the MegaFlex tariff divides the time of the week into three periods (Table 1) and also differentiates between demand seasons (Table 2). The three periods are categorised to reflect the way in which demand varies during the day. Due to the increase in demand during winter, the tariff for winter months is priced much higher than for summer months.

In recent times, the South African gold mines experienced operating financial losses and threatened to close down due to the impact of the strong rand and increasing input costs. In 2004, production in the gold sector decreased by 7.2%. On average, 450 000 workers were directly employed by the mines in 2004, with an estimated 200 000 workers employed in interrelated industries. Almost 6 million people were directly dependent on mining for their daily survival in 2004 [10].

Mines have played, and continue to play, a major role in the South African economy and infrastructure, and it would be devastating for the country if its mines had to close down. Therefore, there is continuous pressure to increase production while decreasing cost. This can be seen from the great number of mining companies that signed the Energy Efficiency Accord in 2005 [11].

Mines in South Africa use a significant amount of electricity [2]. This makes them an ideal target for the implementation of Demand Side Management (DSM). The implementation of DSM projects would benefit the mines by decreasing production costs, and also benefit Eskom as they would help with the energy crisis that it is facing.

1.3 Demand Side Management (DSM) and Energy Service Companies (ESCO)

Demand Side Management or also referred to as energy demand management, usually means actions that manipulate or control the quantity of energy consumed by the user. These actions include reducing energy demand during peak demand periods when energy supply systems are limited or reducing overall energy consumption through energy efficiency [12].

Since its conception, over 30 countries have successfully implemented DSM to:

- Increase energy savings [13].
- Decrease the need to build more energy generating facilities [13].
- Increased the reliability of power network operation [13].
- Improve ecological quality and decrease the cost of electrical energy [13].

DSM programs started during the 1970s in the United States of America as a result of the growing fear of the energy crisis and environmental concerns regarding the generation of electricity [14]. The primary objective of DSM is to encourage the stable and efficient use of electrical energy, which will result in a lower electrical energy demand during peak demand times. By managing the electrical energy demand in this manner, electricity suppliers will be able to more consistently meet the requirements of energy consumers and reduce costs for all concerned.

From this, one can deduce that the key benefit of DSM is the efficient use of electricity energy without interfering with consumer manufacturing or production and contentment levels. Further, DSM will result in significant cost savings for both consumers and suppliers of electricity. While the DSM concept has been around for some time, its implementation in South Africa is relatively new. Eskom, a major electricity supplier in South Africa, formally recognised DSM in 1992 and has led the way in promoting it since [15], [16].

The required change in the usage of energy on the consumer side can be either one of the two actions described next, or a combination of both. The first is to use less energy overall and is referred to as *energy efficiency*. The second is to move energy to different times of the day, called *load management*. In the case of energy efficiency the load curve or baseline is reduced uniformly which shows reduced energy utilisation due to improved energy efficiency.

The use of *energy efficient* technologies leads to the reduction of energy demand and greenhouse gas emissions, which are the consequences of decreased stress on power generating plants. Other benefits to energy efficiency include reduced maintenance and equipment replacement costs; fewer risks associated with generation, such as low energy demand and fluctuating interest rates and fuel prices; and decreased political and national security risks [11]. Figure 6 shows graphically how energy efficiency affects the load curve.

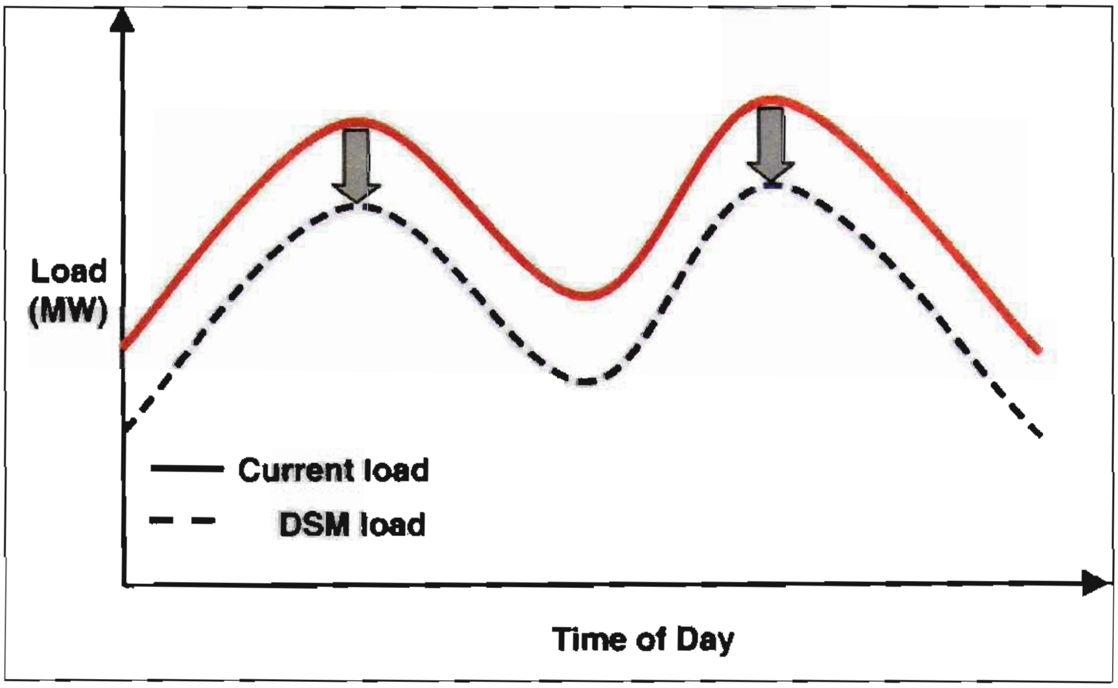


Figure 6: DSM by means of the energy efficiency principle [11]

The second option is *load management* which is achieved by manipulating time patterns and electricity usage. This is done in a way that will change the electricity load profile of the consumer without interfering with the customer's activities. Load management permits energy consumers to reduce electricity usage during peak demand periods by shifting some energy usage to periods of low demand.

Thus, optimisation of daily electricity usage means that the energy load can be shifted (not reduced, as in energy efficiency) to lower demand in the peak periods. Hence, the total energy usage remains the same. Figure 7 illustrates how the energy load profile will be modified as a result of load management.

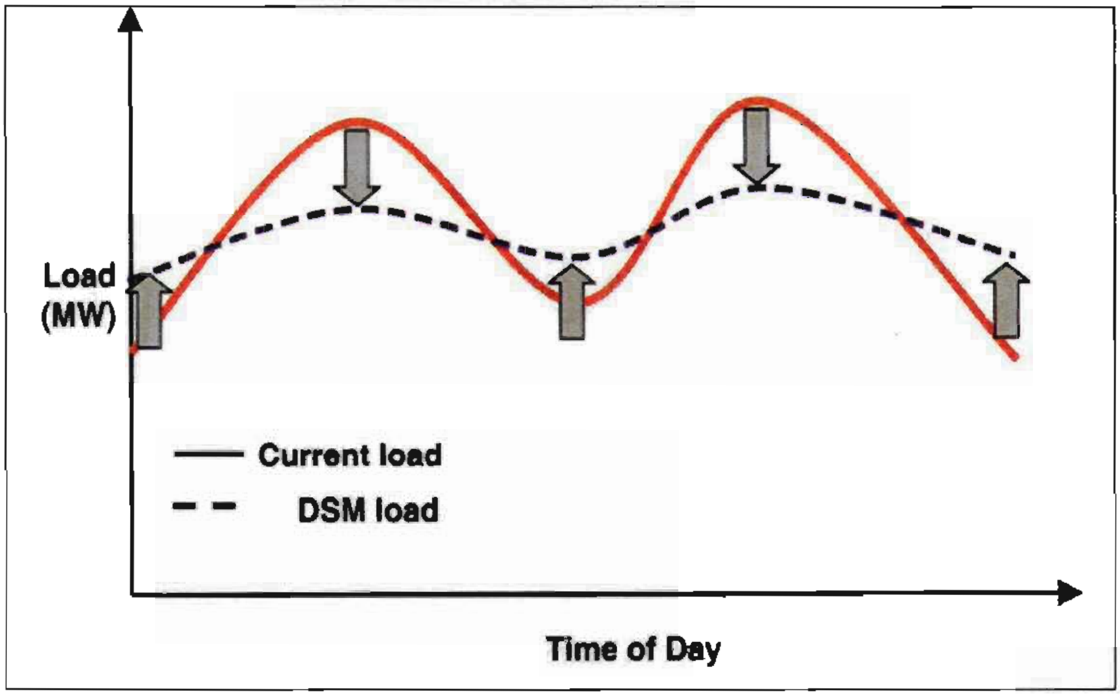


Figure 7: DSM by means of load shift [11]

The load management programmes have an enormous impact on peak load reduction. This helps to lower electricity rates and prolong the time where new power generation facilities are needed due to increase in demand. This time delay can than be used to build additional power generation facilities.

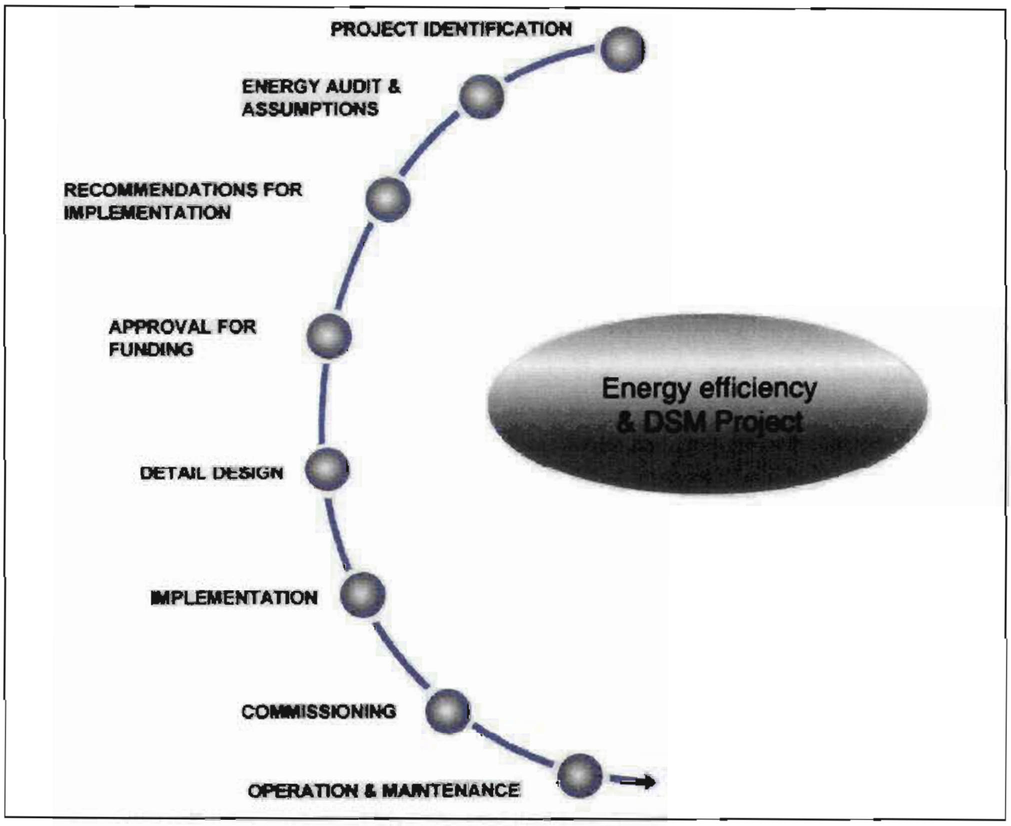


Figure 8: Energy efficiency and DSM project stages [11]

Figure 8 illustrates the different stages of an energy efficiency and DSM project. In this study, all the different stages will be discussed with the exception of the "approval for funding" stage as it is not relevant to this study. Energy Services Companies (ESCOs) are companies in the private sector that help to realise DSM objectives [17]. ESCOs generally act as project developers for a wide range of tasks and assume the technical and performance risks associated with the project. They operate in a three way partnership between themselves, an electricity supplier and the electricity consumer [18] [19].

The difference between ESCOs and other firms that offer energy efficiency or load management, like consulting firms and equipment contractors, is the concept of performance-based contracting. When an ESCO accepts a project, the company's compensation, and often the project's financing, is directly linked to the amount of energy that is actually saved or shifted [18][19].

In addition to the economic benefits realised by ESCO customers, this expanding industry has had a profound effect on the economy. New jobs have been created, not only within the ESCOs, but also though the use of contractors and through the many firms involved directly and indirectly in supporting energy efficiency and DSM projects.

The history of DSM is short and one can easily say that the energy service industry is relatively young. However, the future for ESCOs and for their customers is bright. This is due to the increasing global need to implement energy efficiency projects on an extensive basis.

1.4 Problem statement

In South Africa, gold mines are at times under enormous financial pressure. This is due to the increased cost of production, fluctuating gold prices, and the erratic exchange rate. These factors have resulted in many mining companies closing down uneconomical shafts, leading to the retrenchment of many workers, unemployment and social turmoil. While there are ongoing major efforts to reduce the costs of production, a significant area that has been overlooked is the potential savings from more efficient use of electricity.

Most mining operations require large amounts of water, necessary to cool the underground environment and to ensure the productivity and safety of the workers. The water is used in cooling, cleaning operations, drilling and mining operations, and many more. Most mines use water in a closed circuit, using additional water only to balance the loss arising from evaporation or other causes.

In order to close the circuit of water usage, and to prevent floods due to fissure water, pumping systems are used to return water to the surface. Fissure water is ground water that seeps through the rock face and ends up in the underground dams. The large amounts of water and high pumping head used mean that the electricity usage of these pumping systems is very high. The application of DSM principles to this electricity usage will result in long term cost savings for the mines. Furthermore, Eskom will benefit from the delay in their capital investment for additional capacity and the better utilisation of existing power stations, transmission and distribution systems.

In addition, some mines have inter-shaft water usage, i.e. water is sent to and received from multiple shafts which form an intricate network of water flow and usage. Accordingly, the total amount of water used by a multiple shaft system is greater than that used by most single shaft systems. If the electricity used by this intricate system can be manipulated in accordance with DSM principles, the benefits will be greater than those gained from single shaft systems. Moreover, the cost of implementation and maintenance of the DSM project will be reduced.

However, some mines do not have enough potential to implement DSM programmes. It would not be financially viable to invest in the infrastructure and skills required by DSM unless sufficient value can be gained from the electricity load that is shifted. Nonetheless, the potential can be increased if the mines in question form part of a bigger water pumping network. The implementation costs of a multiple shaft system would be high, but overall the costs would be less than the application of DSM on a single shaft system for each mine. In addition, this will provide new infrastructure for mines that would normally have been unable to afford the upgrade.

Implementation of DSM on a multiple shaft system can be achieved only through the utilisation of dynamic simulation models, a detailed study of the water networks and an optimisation of the pumping systems involved. Such research and studies have been carried out on pumping systems, but these studies concentrated on single shaft pumping and water usage systems only. This dissertation presents the methodology for the implementation of DSM for intricate multi-shaft pumping systems on mines.

1.5 Contribution of this study

The contributions of this study to the engineering community are as follows:

- Determination of the possibility of control on a multi-shaft pumping system.
- Calculation of the DSM potential of the multi-shaft pumping system by utilising integrated simulation and optimisation techniques.
- Implementation of DSM strategies to show the feasibility and sustainability of the project.
- Provision of more possibilities to implement DSM strategies where they may have been overlooked due to lack of potential.

1.6 Synopsis of this dissertation

Chapter 1 discussed the background to the energy problem; gave a brief history of DSM and ESCO; provided the problem statement which also described why multi-shaft networks may be more beneficial to DSM; and discussed the contribution made by the study.

An analysis of the water pumping systems on mines is provided in Chapter 2 which includes discussion of the use of water and pumping systems on the mines; a brief discussion of required and existing control systems on pumping systems; and an analysis of inter-shaft water usage. In addition, pump efficiency principles relevant to this study, as well as establishing a stable communication link between different shafts, are analysed.

Chapter 3 considers the steps taken to determine the DSM potential of multi-shaft pumping systems. The multi-shaft pumping system selected for this study, Beatrix 1, 2 and 3 shafts, is investigated in detail. The investigation includes determination of the water flow network, the necessary infrastructure, each individual shaft's clear water pumping system, analysis of the power consumption of each pumping system, and possible impacts on mining operations due to DSM.

Once the DSM potential of the multi-shaft pumping system has been determined, Chapter 4 considers the need for real time energy management software. This discussion includes mathematical calculations and the control and simulation models for the real time energy management system, together with the software and integrated control model of the simulation and control models. In addition, testing of the software and the control philosophy of the pumping systems as a whole are discussed and a target for the load shift value is set. Testing ensures that the efficiency principles discussed in Chapter 2 are taken into account.

Once the control system has been tested and optimised, implementation of the real time energy management system to manage the multi-shaft pumping system is discussed. This includes a description of the infrastructure and the process of installing the real time energy management system, necessary for the control of the multi-shaft pumping system. In addition, any problems encountered during the implementation stage and the expected savings from the simulation are discussed.

Chapter 5 discusses DSM results and financial results obtained after the implementation of DSM. Furthermore, a description is given of the verification method which confirms that the results reported are the actual results obtained.

Finally, Chapter 6 provides conclusions concerning the strategies, design, financial and contractual implications, as well as an overall summary regarding recommended further work on DSM on multi-shaft systems.

CHAPTER 2: ANALYSIS AND REQUIREMENTS OF WATER PUMPING SYSTEMS ON SOUTH AFRICAN MINES

2.1 Introduction

One of the major problems encountered by deep level mining faces is the high ambient temperature. This is caused by the underground rock face releasing a lot of heat. This causes great difficulty in maintaining working conditions in the mine within comfortable limits. Conventional cooling techniques that are currently available have failed to address this problem. The reason for this is best explained if some cooling methods are given as an example.

The cooling technique that is most well-known is air conditioning. The basic principle is that the air in a room is extracted into the air conditioner, where it is cooled to a certain temperature, and then the cooled air is then blown back into the room. Due to thermodynamics, the colder air mixes with the warmer air and in turn lowers the temperature of the air in the room. This cooler air is again extracted by the air conditioner and the process is repeated. This technique attempts to keep the air inside a room at the desired or specified temperature.

The problem with this technique when applied to the mining environment is that the area that needs to be cooled is far too large. In addition, the surface area of the rock face where the heat is emitted is too extensive. Therefore it is not cost effective or feasible to use it. Another cooling technique is gas cooling but due to gas being highly flammable, the danger of explosions and fires, it is not even considered as an option in the context of underground mines.

Due to the unique nature of the cooling requirements on mines, the best cooling technique - taking cost, reliability and safety into consideration - is to use refrigeration plants. Refrigeration plants or fridge plant uses water as a cooling medium and, when these are applied to mines, they require a large volume of water. There are two possible layouts for fridge plants, namely closed and open refrigeration cycles. The closed cycle uses only Bulk Air Coolers (BAC) to cool the air using the chilled water and the cold water is not sent underground but back into the fridge plants. The open cycle uses BACs to cool the air and also sends the chilled water down. The use of this water and the pumps involved in the process of this cooling technique are discussed in the following sections of this chapter.

In addition, pump efficiency principles relevant to this study are discussed. The requirements of a control system that is needed to implement DSM on inter-shaft pumping system as well as existing control systems are identified and considered. Furthermore, an analysis on inter-shaft water usage, with examples, is given. Lastly a stable communication link between shafts is discussed.

2.2 Use of water and pumping systems in the mining process

2.2.1 Typical water usage

The previous section stated that fridge plants make use of water as a cooling medium. These fridge plants are usually located on the surface. The temperature of the water that flows into the fridge plant is in the area of 20°C [20]. Once the water has been cooled down to below 5°C, it is used by the Bulk Air Coolers (BAC) to cool down the air [20]. The cooled air is then sent down the mine shafts [20]. The remaining water is then sent down the mine to lower levels where it is used for drilling, cleaning and further cooling operation such as in cooling cars and spot coolers.

Once the water has served its purpose, it flows down into (underground) settlers. These settlers are used to separate mud from water after it has been used in the mining operation. The separation procedure of mud from the muddy water is explained below:

The water flows towards the settlers in pipes containing flocculants which increase the density of the mud particles in the water. This causes the mud to gain weight and sink to the bottom. It must be noted that for this reaction to take place the water's PH level must be controlled around 8.5, which is an alkaline solution [20].

Water containing the heavy mud particles flows into the intake well. The intake well is a vertical pipe in the middle of the settler with the bottom end submerged to 2 metres below the water in the settler. This ensures that the turbulence of the inlet water flow is confined to the inlet well. In turn, this allows the mud particles in the water in the region of the intake well to be still causing the mud to sink to the bottom of the settler [20].

The clear, clean water on the surface of the settler is then pumped to the (underground) clear water dam by means of transfer pumps. In addition to the water used to cool the mine, natural underground water or fissure water seeps from the rock surfaces and is also collected in the clear water dam. The water in the clear water dam is then pumped back to the surface using the pump stations. When the water reaches the surface it flows again into the fridge plant to be cooled, and the process described above is repeated.

The typical water usage described above illustrates the closed loop system of the mine water cycle. When the total volume of the water cycle decreases it is replenished by adding external water from a local water supplier. The transfer pumps mentioned above are small compared to the pumps in the pump stations used to pump water back to the surface. For this reason the transfer pumps are not included in this study.

2.2.2 Clear water pumping system

In a typical mine approximately 30 % of the total energy usage is consumed by the pumping systems [20]. Previous studies indicate that it is feasible to do a detailed survey of the potential load shift on the clear water pumping system on a specific mine. With this in mind, it would be more beneficial and viable to do the survey on a pumping system that incorporates multiple shafts, and to include an efficiency survey, where applicable.

It is evident that the clear water pumping system is a very important and intricate control system on any mine. The pumping systems are used to prevent flooding of the mine and to maintain adequate water levels to keep the cooling process constant. Problems within this control system could give rise to flooding which would cause inadequate water levels elsewhere in the system which, in turn, would interrupt the cooling process. This will result in a production shut down as ambient temperatures underground often exceed 50°C.

The pumping system is typically connected to a number of fridge plants and cooling towers on the surface of the mine. However, in deep mines there may be fridge plants underground. A basic layout of a typical underground pumping system at a gold mine is shown in Figure 9:

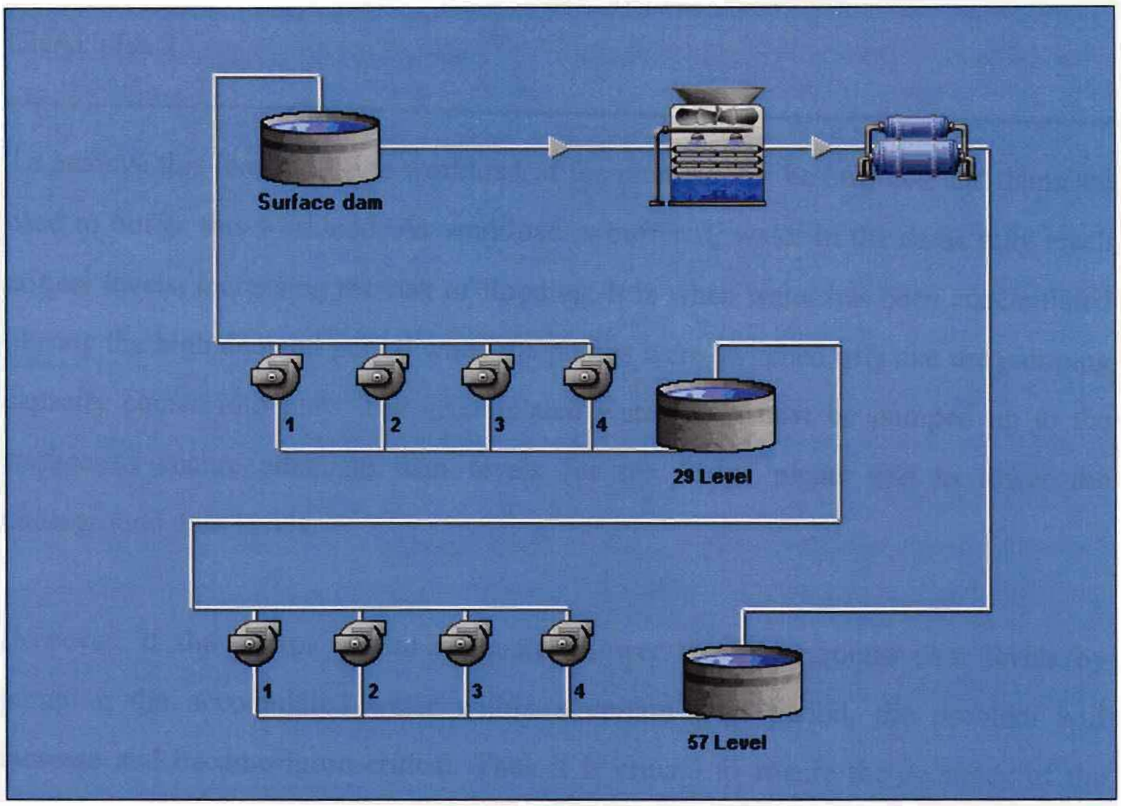


Figure 9: Basic layout of a typical underground pumping system at a gold mine

Due to the many constraints contained in the clear water pumping system, the load shifting can be realised only by using a control system that includes these constraints. When determining the achievable load shift potential of a clear water pumping system, certain physical properties must be taken into account. These properties comprise flow rates, pump capacities, pump static head, dam sizes, total amount of daily water pumped up to the surface, etc.

In order to maintain adequate dam levels the pumping system is regulated by switching the number of pumps on each level to match the inflow water into the dam. This is a simple task but difficulties creep in when the pumps are switched off for a certain period - to shift the electrical energy load from expensive, high demand periods to cheaper periods – in order to save electricity costs.

To achieve this load shift, the workload of the pumps must be buffered and dams are used to buffer this workload. As workload is buffered, water in the dams may reach critical levels, increasing the risk of flooding. It is when water has been accumulated (during the high demand period when the pumps were switched off) that the pumping capacity comes into play. The accumulated water must now be pumped up to the surface to ensure adequate dam levels for the fridge plants and to lower the underground dam levels.

However, if the pumps cannot adequately lower the underground dam levels by pumping the accumulated water within a certain time period, the problem will increase and become more critical. Thus it is crucial to ensure the accuracy of the simulation and optimisation of the system for DSM to be realised on the clear water pumping systems.

2.3 Pump efficiency principles

There are many principles and ways to increase the efficiency of a pump, although these will depend on its function and the system in which it operates. Because of this, the principles for pump efficiency discussed in this section will be of relevance to this study only.

It is evident that the clear water pumping system used by mines will require more than one pump to operate at the same time on the same system. To meet this need there are two arrangements which, given the operating characteristics of the different pumps, could deliver a single combined performance curve.

The first of these arrangement is called Series Operation and it requires one pump to discharge directly into the suction of a second pump, with both pumps delivering the same flow rate but sharing the combined pressure of the two pumps [21][22]. The following figure shows how the pumps are connected.

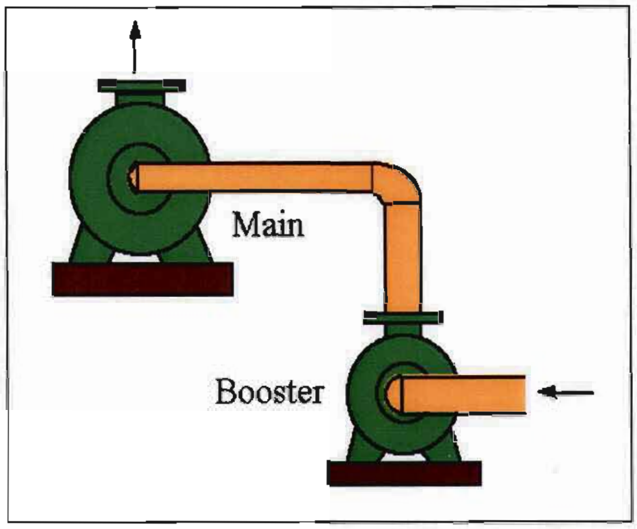


Figure 10 : Series operation of pumps [21]

The smaller pump is therefore installed upstream of the larger one to boost the suction pressure to the larger pump. This results in a larger head (i.e. vertical distance the pump can deliver) for the system but at the same flow rate. Figure 11 shows the performance curve of the each pump and of the two pumps in series.

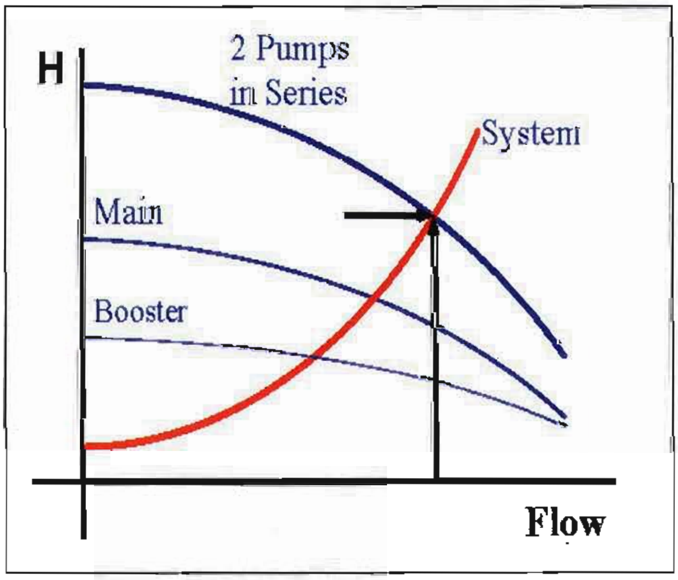


Figure 11: Performance curve for series operation of pumps [21]

However, due to the dynamic rate of flow into the clear water dams and flood controls in a clear water pumping system, it is not possible to use the series operation arrangement. For this reason the second arrangement, Parallel Operation, is used.

In the Parallel Operation arrangement two or more pumps takes its suction from a common header and discharges into another common header, consequently sharing the flow and operating at the same head [21]. The use of multiple pumps on the same system allows the pumps to be switched off and on to meet the varying demand. The figure below shows how the pumps are connected in a Parallel Operation.

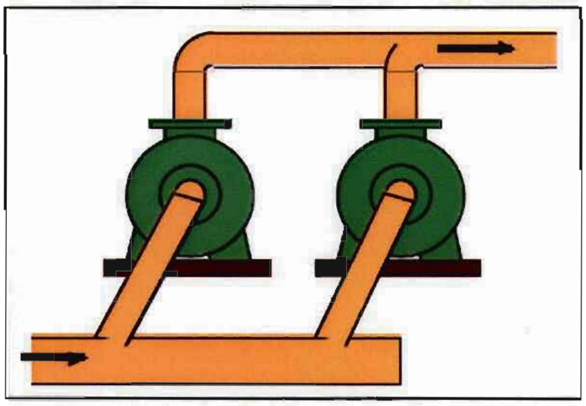


Figure 12: Parallel operation [21]

The following graphs illustrate how this arrangement will affect the system's performance:

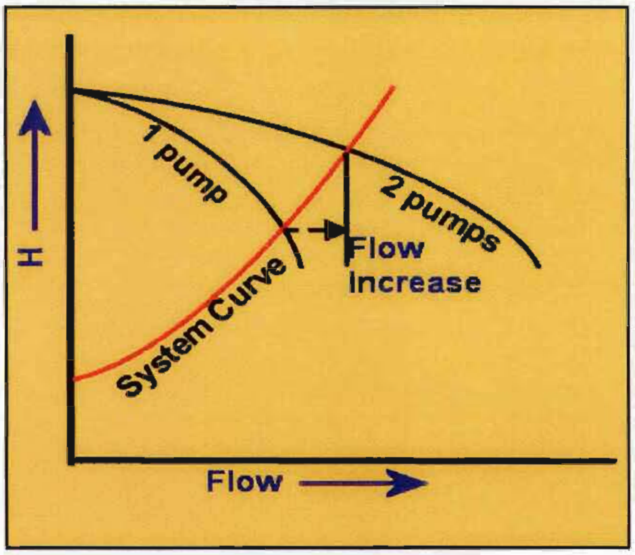


Figure 13: Characteristics of single vs. parallel operation [23]

Two identical pumps operating in parallel are capable of producing double the flow of a single pump at any given head. However, the actual flow rate realised in the system is determined at the intersection of the system curve with the pump curve. Therefore, the increase in the flow depends on the system curve. An additional factor influencing the change in flow arises when the systems' resistance is purely frictional, and fluctuates in proportion with the flow change. The flow will increase only to the point at which the system curve intersects the two-pump curve, as shown in Figure 14 [21][22][23].

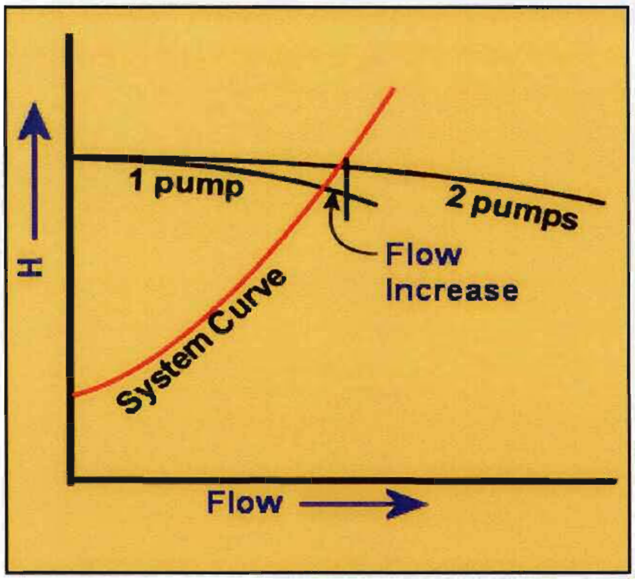


Figure 14: Flow increase due to parallel operation [23]

The amount of flow increase is affected not only by the system curve, but also by the steepness of the pump curves. Pumps with flat curves will have less head separation than pumps with steep curves and therefore will have less of a flow rate change. Each of the parallel pumps will operate at a lower flow rate, when operating together, than they would if they operate alone on the same system. This is particularly relevant to multi-pump arrangements and careful selection is required to ensure the most efficient and stable operation [21] [23].

Because of the lower flow rate when pumps operate together, a steady increase in the number of pumps will reduce the flow rate through each pump. This could result in the final pump adding only a fraction of its capability to the system output as is indicated in Figure 15.

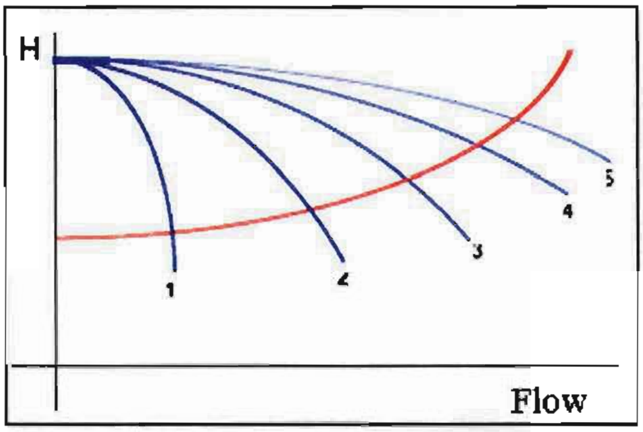


Figure 15: Performance curve for multiple pumps [21]

Another practical problem with parallel operation is when the two pumps with different performance curves operate together. These pumps can be of different sizes or of the same size but one pump worn while the other is new. The combination of head and capacity of both pumps becomes effective only after the shut-off head of the smaller or worn pump is reached. At that point only, the capacity from the slower or worn pump will be added to the capacity of the faster pump to provide a combined output [21] [23].

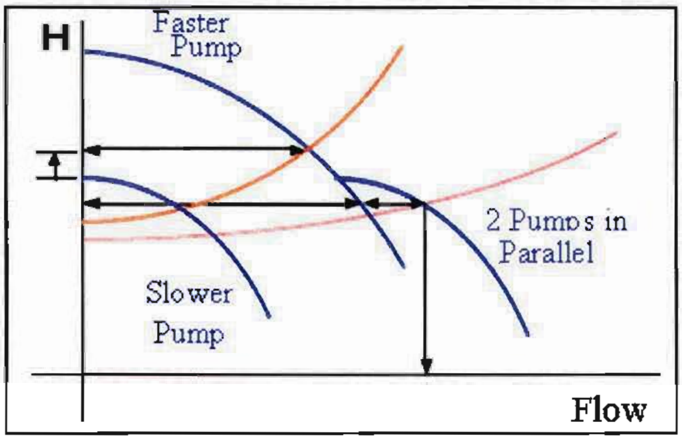


Figure 16: Different performance pumps in parallel [21]

However, if the system curve moves to a steeper slope and cuts the curve of the parallel pumps at a head higher than the shut-off head of the smaller pump, then the slower or worn pump will not contribute to the net flow rate of the system [21].

Most mines do not take these principles into account when operating pumps in parallel. For this reason, a quick survey of pump layout and usage can drastically increase efficiency of the pumping stations in a clear water pumping system.

2.4 Required and existing control systems

Due to the enormous financial benefits that are easily realisable in the industry, as well as the incentives given by Eskom in terms of funding, many systems have been developed in attempts to save electricity and to implement DSM principles. Despite all these attempts none of the systems could fulfil the following needs:

- Provide simulations that are accurate, efficient and fully integrated.
- Automated scheduling of electrical components of pumping systems.
- Real-time schedule that reacts and respond to any changes, whether it is foreseeable or unforeseen, to the system by constantly monitoring the live data and calculating the schedule accordingly.
- Schedules that ensure the shifting of load according to the price and demand periods.
- The fully automated control of all electrical components to ensure the system is controlled in accordance with the calculated schedule.
- The system must comply with all constraints to ensure that the control and calculated schedule do not contravene safety and operation policies.
- The system must be stable, reliable and able to measure and record its own performance in terms of the electrical load shifted.
- The system must be able to calculate the financial savings that result from this load shifting.

Previous studies [20] have shown that existing patented systems that help to shift load in some way cannot fulfil all the requirements given above.

An example of this is a system developed by *Mark A. Cascia [24]*, called *Digital controller for a cooling and heating plant having near-optimal global set point control strategy*. It uses a direct digital control or DDC controller to implement a control strategy that provides for near-optimal global set points. In other words, power consumption and consequently energy costs for operating a heating and/or cooling plant can be controlled and minimised at a precise point in time. The model is derived from a mathematical analysis using relations from fluid mechanics and heat transfer under the assumption of a steady-state load condition. The deficiencies of this and similar systems are given below:

- This system concentrates on optimisation of power consumption. Therefore it attempts to save electricity instead of shifting the energy load.
- A single interface that gives access to the control platform is not possible as control is achieved through individual controllers.

Another example is provided by the system developed by *William A. Irvin [25]*, called *Pump station control system and method.* This system provides a monitoring and control system with an interface method between the operator and the pump station controller. It focuses on the control of constant and variable speed pumps. In brief, this system takes into account the operating parameters of the pumps, calculates a real-time cost parameter, and displays this to the operator. In addition it can calculate a potential optimised cost parameter for the sensed parameter i.e. calculates the optimum combination of pumps that should be running, if valid, at a certain speed. The deficiencies of this and similar systems are given below:

- The optimised schedule calculated by this system cannot be relayed to the pump stations automatically and relies on a human operator to carry out the optimised schedule.
- The system calculates from real-time parameters, the instantaneous cost parameters and then calculates an optimised cost parameter. This process prevents the system from optimising the pump stations for a certain period of time.

The two systems developed by *Cascia* and *Irvin* respectively, are focused on cooling, heating or hoisting systems, and wastewater pumping systems, respectively, while other existing systems are focused on city water distribution. However, it must be emphasised that city water distribution and mine water pumping system have certain differences.

For instance, the water reservoirs used in mines are far smaller than their counterparts in city water distribution. The smaller dams trigger faster fluctuation of the water levels and the reaction or response of the control system must be able to cater for this. If the dam levels fluctuate too much and the system cannot keep up, it may result in pumps being switched on and off at short intervals (cycling).

The immense amount of water dispensed in a city water distribution system leads to the city's electricity bills being higher (comparatively) than those of a mine for the electricity used by its pump stations. Consequently the cost of the software to control the city water distribution is very high when compared to the potential savings that can be realised by implementing this same software on a mine's water pumping systems.

Some examples of the systems developed for city water distributions are *Derceto for water distribution* [26] [27] and *MISER-PS Pump Scheduling* by Tynemarch Systems Engineering Ltd [28] [29]. Both systems have fully automated control over all the components to ensure the systems are controlled according to the schedule calculated.

Derceto focuses on larger water distribution networks than *MISER-PS* and minimises energy costs by optimising valves and pump schedules throughout the water distribution network. It aims to shift energy usage to lower tariff times, run pumps more efficiently, and reduces the maximum demand required. It achieves its aims by choosing the minimum number of pumps required to run simultaneously. This is a very flexible system with a wide range of applications but it is expensive and requires a specialist to install and maintain it.

The second system *MISER-PS*, can calculate an optimisation schedule for pumps and valves on an hourly or half-hourly interval, taking into account pump efficiencies and energy tariff rates. This system can be used in two modes, on-line or off-line with the on-line mode having significant advantages. *MISER-PS* also allows for short-term production planning, maintenance planning and unforeseen emergency planning for the water distribution system.

2.5 Analysis of inter-shaft water usage

The most critical factor in a mine water pumping system is the amount of water sent down the shaft. When a particular mine is linked to nearby mines this factor becomes even more critical, as the water for each individual mine will materialise in the water systems of all the other mines, at some point in time.

Inter-shaft water usage usually occurs as a result of certain decisions made by the mining company when mines are to be developed. One of the reasons for inter-shaft water usage is due to certain mine shafts having a shorter life span i.e. the amount of reef available for extraction is small compared to the nearby shafts. Once the entire reef has been extracted, the shaft is converted into a service shaft to service all the nearby mines and to pump all the water used by the nearby mines back to the surface. Once the water reaches the surface it is transferred back to the shafts where it came from to be used again or is sent to evaporation dams.

The Harmony mines in the Free State, Harmony 3 Shaft and Masimong 4 Shaft – provide a good example of an inter-shaft water network. The layout of the network is shown in Figure 17.

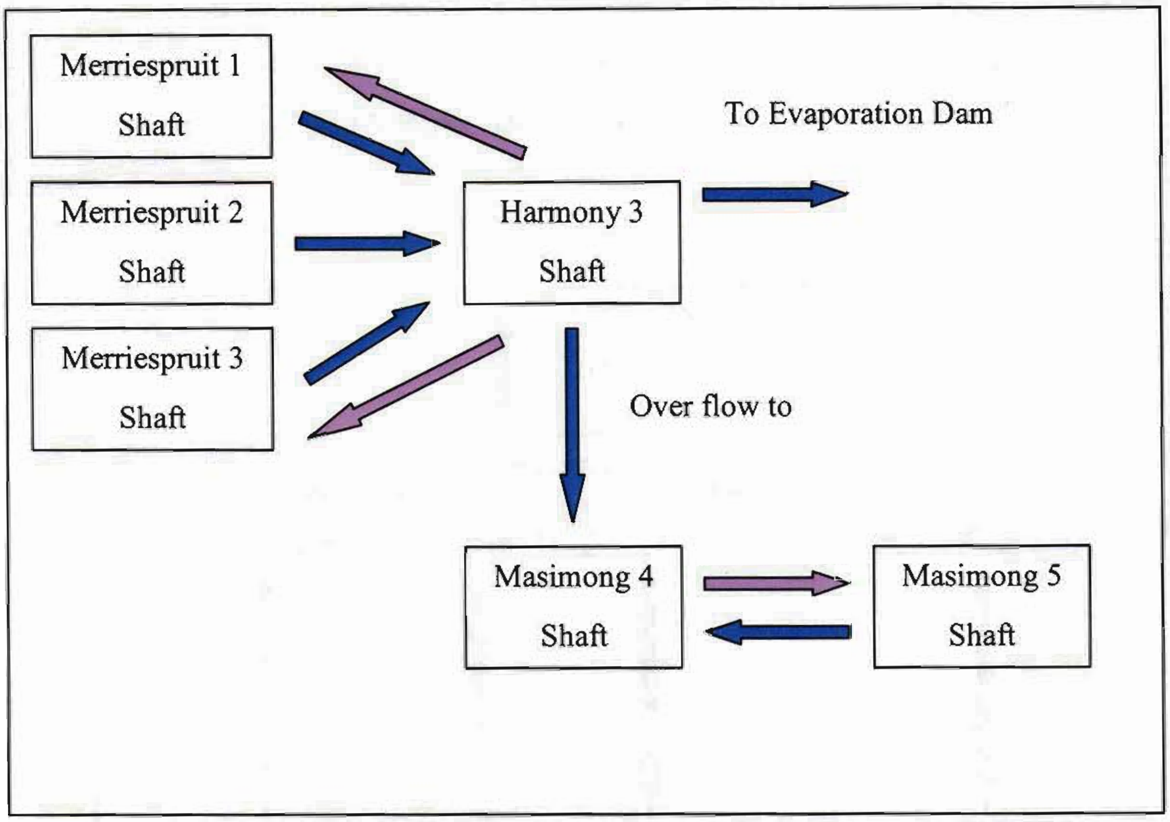


Figure 17: Inter-shaft water network layout 1

It is imperative that Harmony 3 Shaft and Masimong 4 Shaft keep the water table at a certain level. If the water levels reach a critical level it will affect the operations of all the shafts in the region especially Merriespruit 1, 2, 3 Shafts and Masimong 5 Shafts. These shafts do not having pumping systems of their own and rely on Harmony 3 Shaft and Masimong 4 Shaft to keep adequate water levels.

Another reason for inter-shaft water usage is when several mines share the same reef belt, which results in the mines becoming connected at different levels underground. This allows certain operations to become centralised, including water cooling facilities and clear water pumping, and this means that less infrastructure is needed on each separate shaft.

An example of this type of inter-shaft water network is the Goldfields mines in the Free State, Beatrix 1, 2 and 3 Shafts. The layout of the network is shown in the figure below.

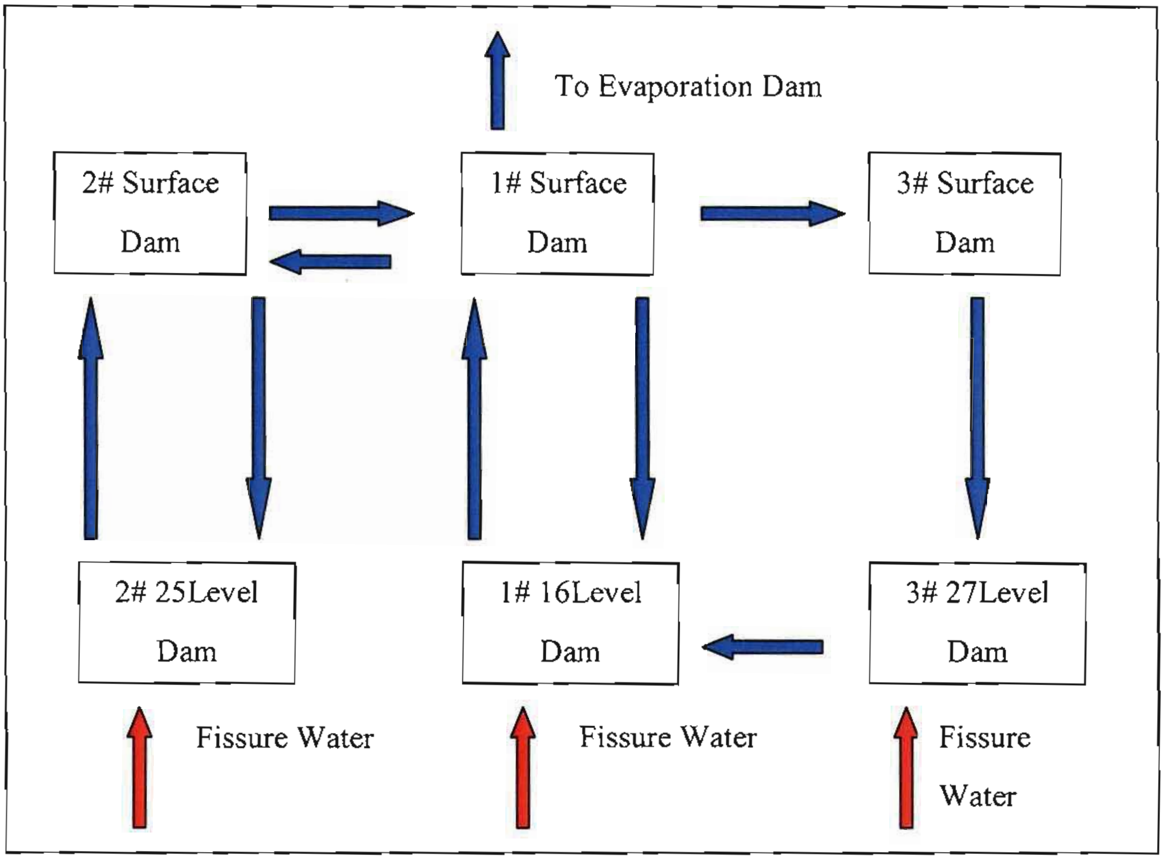


Figure 18: Inter-shaft water network layout 2

2.6 Stable communication link between shafts

Fast, accurate communication is essential to ensure safety and correct operation of pumps on a multi-shaft pumping system. Further, the successful implementation of a DSM programme on a multi-shaft pumping system requires stable communication. Accordingly, a medium for constant, stable and fast communication link between shafts was investigated.

In the past most communication and data transfer used copper wire as a medium for transmitting these signals. Since the development of photonic crystal fibres in the

1990s, the fibre optic cables have replaced copper wire in many industries. Fibre optics has many advantages over conventional copper wire, some of which apply to the mining industry. It is therefore more feasible to use fibre optics to ensure stable communication and data transfer links between shafts.

The advantages that fibre optics offers the mining industry are given below.

- **Less expensive** - Length for length, optical cable can be produced more cheaply than copper wire.
- **Thinner and lightweight** - An optical cable weighs less than an equivalent length of copper wire cable. Fibre-optic cables take up less space because the fibres can be drawn to smaller diameters than copper wires.
- **Low power** - Signals in optical fibres degrade less, so lower-power transmitters can be used instead of the high-voltage electrical transmitters needed for copper wires. This in turn saves money.
- **Digital signals** - Optical fibres are ideally suited for carrying digital information, which is especially useful in computer networks.
- **Light signals** - Unlike electrical signals in copper wires, light signals from one fibre do not interfere with those of other fibres in the same cable.
- **Non-flammable** - There is no electricity in optical fibres as only light is transmitted, so there is no fire hazard.
- **Less signal degradation** - The loss of signal in optical fibre is less than in copper wire.

In more advanced clear water pumping system, Programmable Logic Controllers (PLCs) that control the pumps are located underground near the pumps. These PLCs are connected via an Ethernet network and communicates with a server called Supervisory Control and Data Acquisition (SCADA) which is located on the surface in a control room. Fibre optics cables are used to ensure stable, fast and reliable communication between the PLCs. The different structures of the Ethernet and fibre optic cables require a switch to convert the signals between the two mediums. The figure below illustrates this communication.

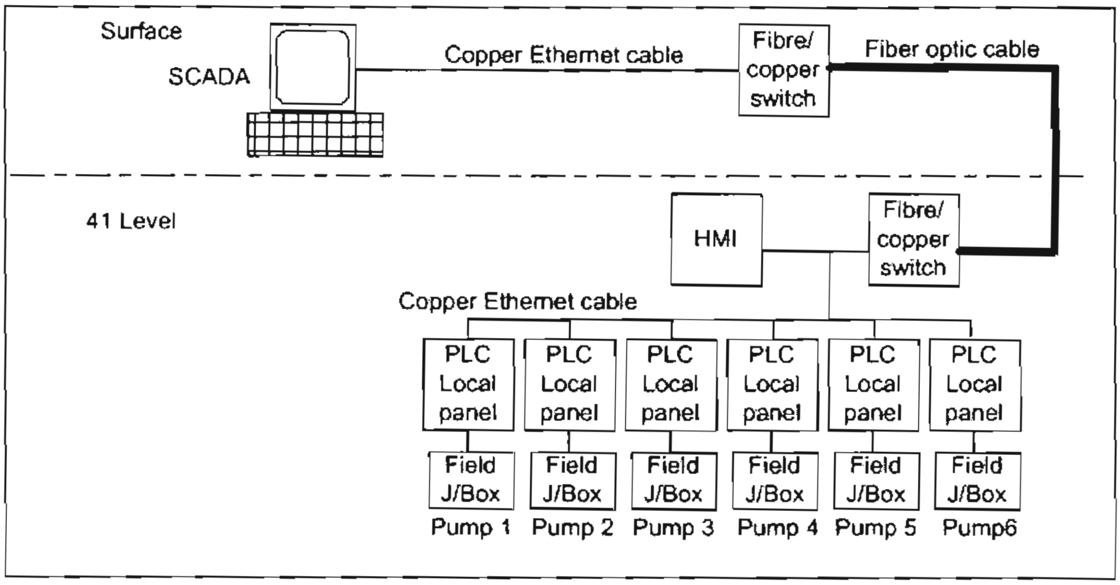


Figure 19: Typical network layout

Fibre optics cables are particularly suited to the considerable distances between shafts, making the advantages listed above even more beneficial. The use of fibre optics cables, guarantees the stability and reliability of communication between the multi-shaft pumping systems.

2.7 Conclusion

This chapter provides an analysis of water pumping systems, including the use of water on the mines, how pumping systems are used and how these systems are involved in the mining process. Furthermore, efficiency principles relevant to these pumping systems is analysed, water use between shafts is explained, and the origins of this intricate water network are described. In addition, requirements of the needed control systems and the existing control systems are discussed and the possibility of establishing stable, reliable communications between shafts is investigated.

CHAPTER 3: DETERMINING DSM POTENTIAL FOR MULTIPLE SHAFT WATER PUMPING SYSTEMS

3.1 Introduction

This chapter discusses the procedure of determining the Demand Side Management (DSM) potential for multiple shaft water pumping system. The initial steps taken during a DSM investigation will be considered together with a case study of a multi-shaft water pumping system. The Beatrix mine 1, 2 and 3 shafts were deemed suitable for the case study.

Further, a detailed investigation into Beatrix 1, 2 and 3 shafts, including the layout of the shafts, the inter-shaft water network, the layout of the pump stations, the infrastructure necessary to automate the pumping systems, and the installed capacity of the pumping systems will be conducted. In addition, a feasibility study to ensure that the inter-shaft clear water pumping system can be controlled, so as to accommodate load shifting and energy efficiency, will be described.

When the above aspects have been explored, the power consumed by the water pumping systems before the implementation of DSM, together with a prediction of power consumption after the implementation of DSM, will be analysed. Subsequently, a system to implement the control needed for DSM on the multi-shaft pumping system will be discussed, and any possible impacts that DSM may have on the mine and its operations will be considered.

3.2 Initial DSM investigation

The first step taken by a DSM investigation is to identify a project, and this usually entails an investigation into the systems and subsystems found on the majority of mines. These systems consume a large portion of the total electrical energy used by a mine. Examples of such systems are pumps, ventilation and cooling, winders and compressed air systems. Once these systems are identified, a potential for DSM and load shifting must be identified. This means that the systems must have sufficient storage and spare capacity to enable the implementation of DSM and load shifting strategies.

For this study, pumping systems on multiple shafts will be considered. If the mine concerned in the initial investigation is willing to implement the proposed strategies for a certain trail period, a detailed energy audit will be performed on the system concerned. This audit includes acquiring the following:

- Establishing the number of machines involved in the system as well as the electrical installed capacity.
- Determining the common/daily operations of the system.
- Detailing the system's layout
- Establish storage potential i.e. water dams.
- Determine the electrical energy consumption of the system.
- Develop an hourly energy consumption profile of the system for an average day.

Because this study involves multiple mine shafts, an audit will have to be performed on each shaft. Due to Eskom's MegaFlex pricing structure, load shifting will be implemented only on weekdays. The benefits and savings for both Eskom and the mine would be too low if load shift was implemented during weekends. This becomes evident when considering the price structure. The tariff structure is a major control criterion because it is the major reason why load shift is beneficial to the mine. The defined time periods and cost of each period are given in Table 1 and Table 2.

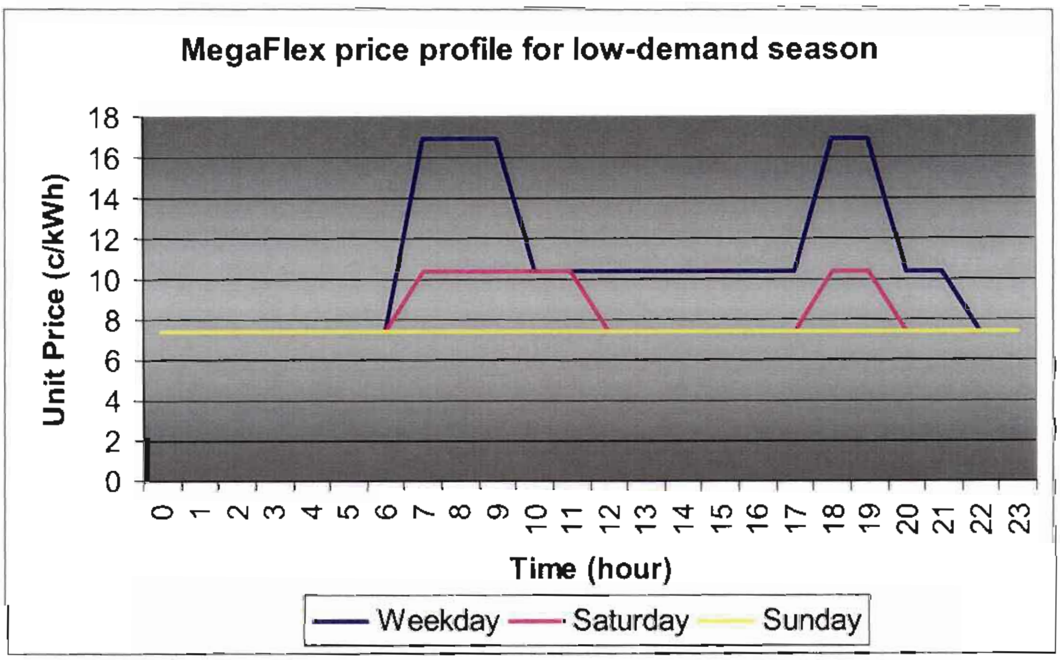


Figure 20: MegaFlex price structure – low-demand season

The low demand season is from September to May and the high demand season is from June to August. These figures explain why load shifting is concentrated on weekdays. Weekdays contribute 85% of the weekly tariff price [20]. It is also clear to see that the hourly rate in the high-demand season is significantly higher than in low-demand season.

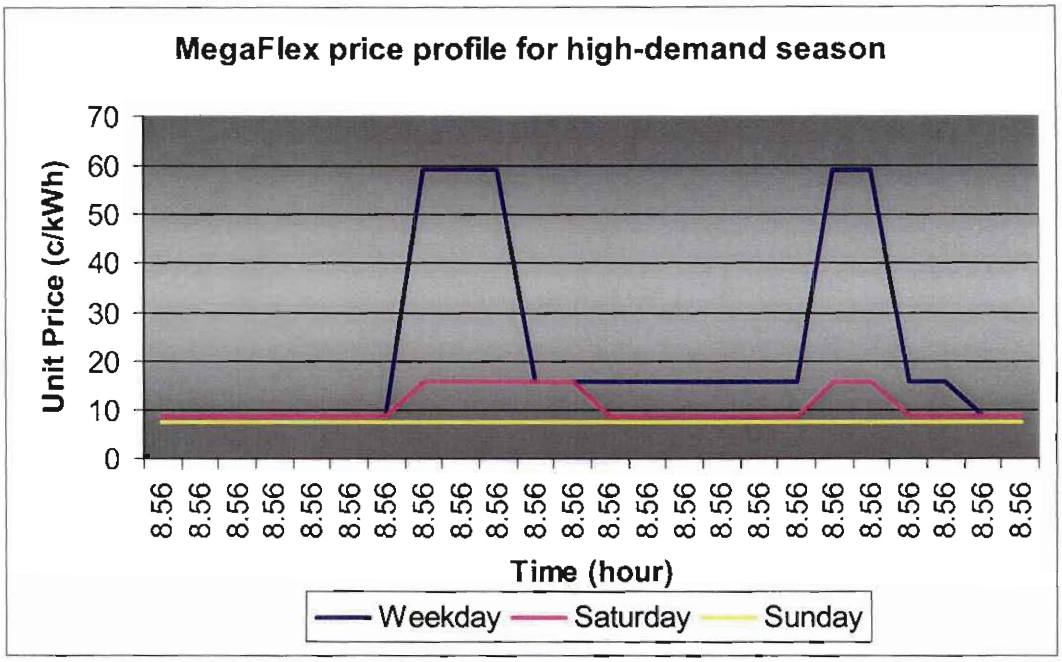


Figure 21: MegaFlex price structure - high-demand season

If any one of the multiple shafts involved has no potential for a DSM project then the proposed project will result in a failure. Thus it is imperative that the investigation is accurate and realistic.

3.3 Detailed investigation on Beatrix 1, 2 and 3 shafts

Beatrix Mine is located ±20 km south of the town of Virginia in the Free State Province. It is part of GFI Mining South Africa (Pty) Limited and is wholly-owned by Gold Fields Limited [30]. The infrastructure of the mine includes four shafts and two metallurgical plants. This study will investigate only 1, 2 and 3 Shafts, as 4 Shaft is not included in the inter-shaft water network.

Figure 22: Beatrix mine

During the 2005 financial year, Beatrix Mine milled 4.18 million tons of ore [31] with an average yield of 5.3 g/ton [31]. The total amount of gold produced was 19 418 kg [31]. In 2006, Beatrix Mine milled 3.551 million tons of ore [31] with an average yield of 5.3 g/ton [32]. This resulted in a total of 18 541 kg of gold produced in 2006 financial year.

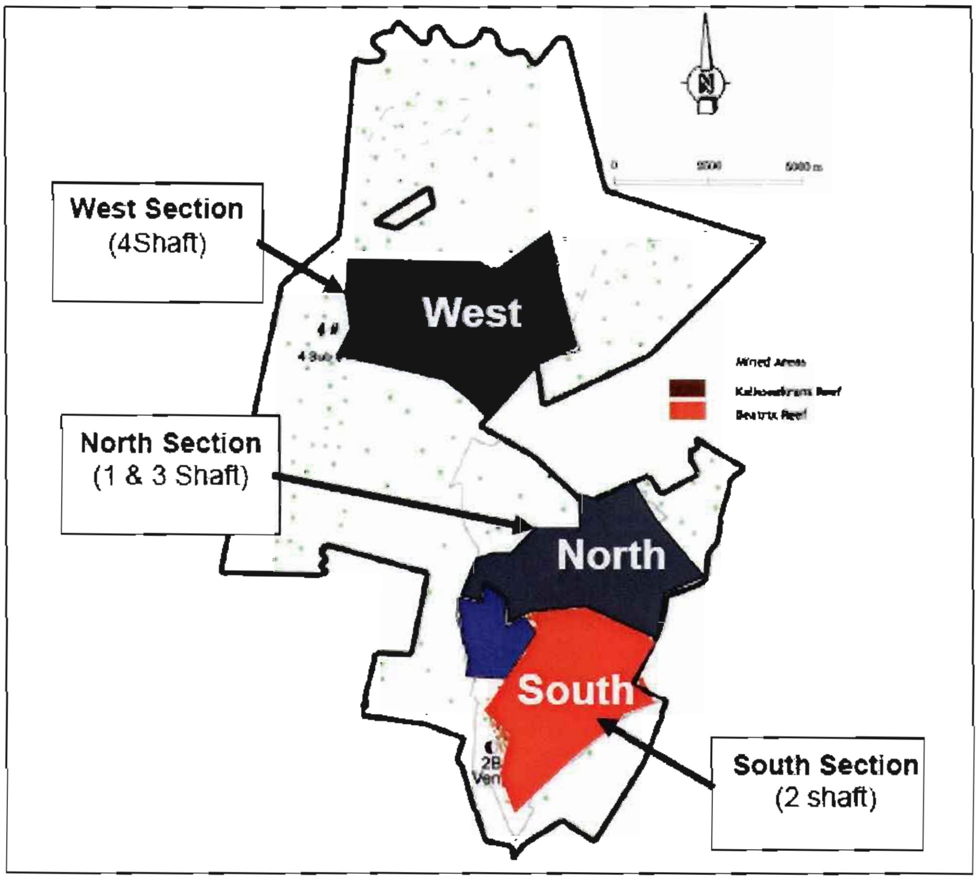


Figure 23: Area section for Beatrix mine

Figure 23 indicates how closely the three shafts are located, while Figure 24 shows the layout of the shafts and how they are connected (see Appendix A for enlarged version). As discussed in an earlier chapter, the major uses of water on most mines, including Beatrix, are for cooling and mining operations.

3.3.1 Investigation on the multi-shaft pumping system

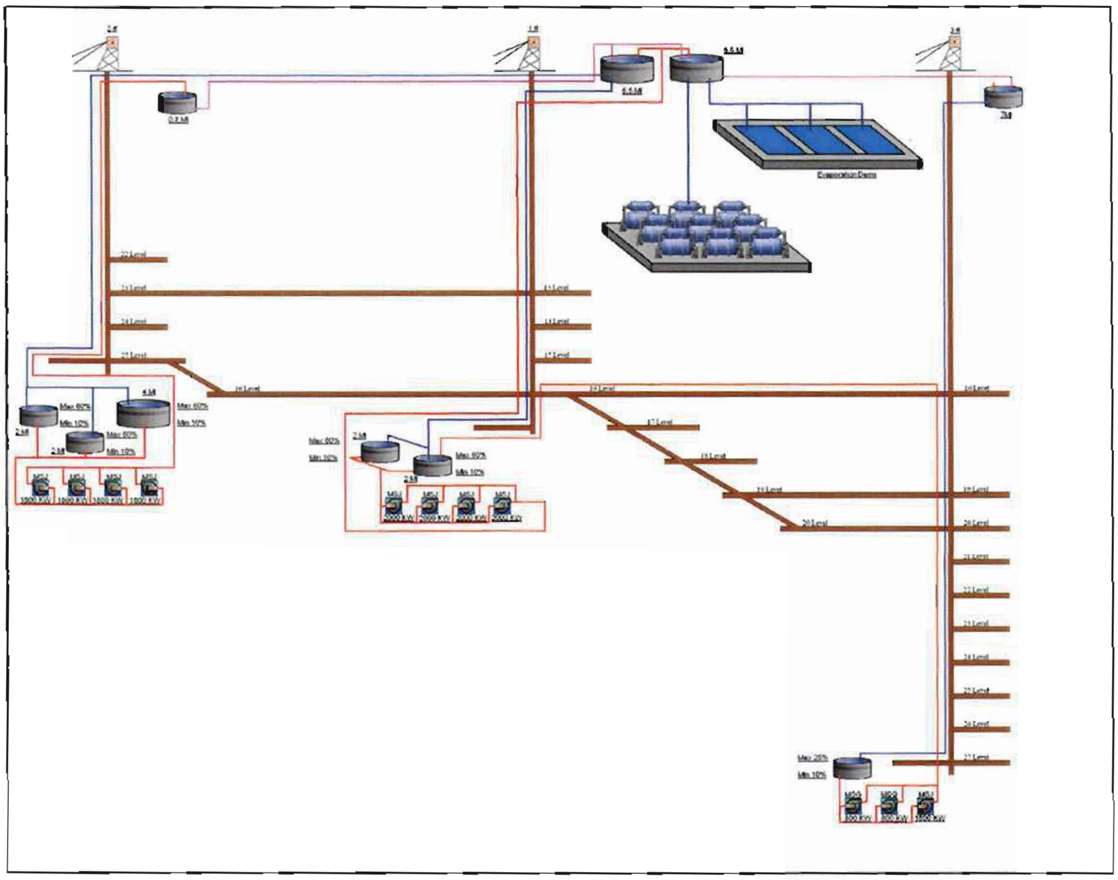


Figure 24: Beatrix 1, 2, 3 shafts layout

In September 2004 Beatrix Mine was identified as a possible candidate for the implementation of a DSM project. The involvement of pumping systems in multiple shafts made the project unique. Historical pump data was acquired and a detailed investigation was launched. The data was processed to obtain a 24 hour profile of how many pumps were operated. Drawing on this profile and the electrical load capacity of the pumps, for each individual shaft, three separate energy consumption baselines were realised.

From these baselines, the potential for load shift can be determined. This will be discussed in detail in section 3.5. An in-depth analysis of the current operations of the pumping systems, the layout of each pumping system, the current control systems in use, and the feasibility of the proposed project will be discussed in section 3.4.

Further, the inter shaft water network and average water usage for each individual shaft will be discussed. Variability in the amount of fissure water received by each shaft on a day-to-day basis is large. Consequently, the maximum amount of fissure water for each shaft will be used in this study. The fissure water is not easily measured and an estimated value from the mine personnel is used.

An average of 8.4 Mega Litres (Ml) per day must be pumped from 27 Level on 3 Shaft to the clear water dam at 16 Level on 1 Shaft. This figure includes 4.32 Ml/day of water sent down the shaft for cooling and mining operations, plus 4.08 Ml/day of fissure water. Then, from 16 Level on 1 Shaft, the water emanating from 3 Shaft is pumped back to the surface.

In future, 3 Shaft will pump an estimated 9 Ml/day from its 27 Level pump station to the new clear water dam at 16 Level on 1 Shaft, or this will be pumped back to the surface. Water will be transferred from the new dam to the mining operations, while excess water will be pumped back to the surface via the existing pump station at 16 Level on 1 Shaft.

The clear water pumping system at 25 Level on 2 Shaft pumps approximately 10.2 Ml per day to the surface. This figure includes 5.8 Ml/day of fissure water and 4.4 Ml/day of water sent down the shaft for cooling and mining operations. Other excess water will be transferred to the clear water pumping system on 1 Shaft, via transfer pumps from 25 Level on 2 Shaft to 16 Level on 1 Shaft.

The clear water pumping system at 16 Level on 1 Shaft pumps the water sent by 27 Level on 3 Shaft, the excess water sent by 2 Shaft, the water sent down 1 Shaft for cooling and mining operations, and fissure water. An estimated 20.5 Ml/day of water is pumped to the surface via the pump station at 16 Level on 1 Shaft. This figure includes 8.4 Ml/day from 27 Level on 3 Shaft, 5.6 Ml/day of water sent down the shaft for cooling and mining operations, and up to 6.5 Ml/day of fissure water, plus the excess water from 2 Shaft.

Figure 25 shows the water network with the values given in the above paragraphs to illustrate the system as a whole. The figure also includes the number of dams on each level and their capacities.

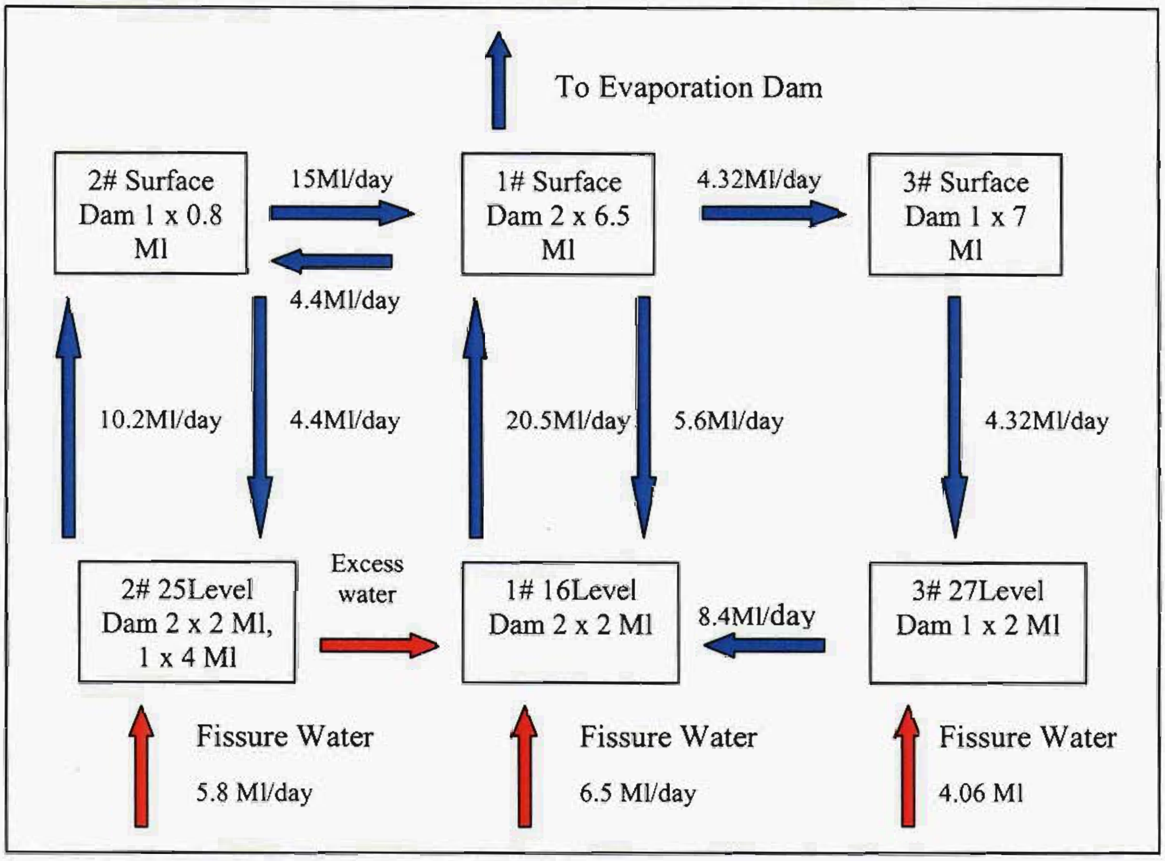


Figure 25: Beatrix 1, 2 and 3 shafts' water network

3.3.2 Investigation into necessary infrastructure

The infrastructure needed to implement the DSM project on the multi-shaft pumping system is discussed in this section. Investigation of Beatrix 1, 2 and 3 Shafts found that there was no existing infrastructure to accommodate automation of the pumps on any of the Shafts.

However, successful implementation of the DSM project on the multi-shaft pumping system necessitated automation of the pumping system. This infrastructure is divided into three categories, to make it easier to explain:

- Hardware installed on the pumping stations.
- Network and communication equipment.
- Software and additional equipment.

The hardware includes the following equipment:

- Automatic dam level indicators for each dam.
- Automatic control valves for each pump.
- Field instrumentation for each pump i.e. vibration transmitter, bearing temperature transmitter, flow switch, pressure switch and electric actuator.
- High-tension and instrumentation cables.
- Electrical switchgears.

The Network and communication equipment includes the following:

- A Programmable Logic Controller (PLC) for each pump station on each shaft.
- Fibre optic cables from each pump station to a single control point on the surface.
- A Supervisory Control and Data Acquisition (SCADA) system.

Software and additional equipment includes the following:

- A Real-time Energy Management System (REMS) to monitor and perform load shifting on the pumping systems.
- A Server to run REMS and store data for REMS.

The above infrastructure will have to be installed on Beatrix 1, 2 and 3 shafts in order to automate the pumping systems.

3.4 Beatrix 1, 2 and 3 shaft clear water pumping system

This section will give an in depth analysis of the current operations of the pumping systems. In addition, the layout of each pumping system, current control systems in use, and the feasibility of the proposed project will be analysed. Each individual shaft will be discussed in detail, including the benefits that will arise due to the new proposed control system.

3.4.1 Beatrix 1 shaft

It is clear that Beatrix 1 Shaft is the most important shaft in the network. All the water in the system ends up on the surface dams of 1 Shaft, including water pumped via the pump station at 16 Level or through transfer pumps on the surface from 2 Shaft. This is necessitated by the fridge plants being situated on the surface of 1 Shaft. This centralised cooling of the three shafts means that Beatrix 1 Shaft acts as the core shaft to the entire inter-shaft network.

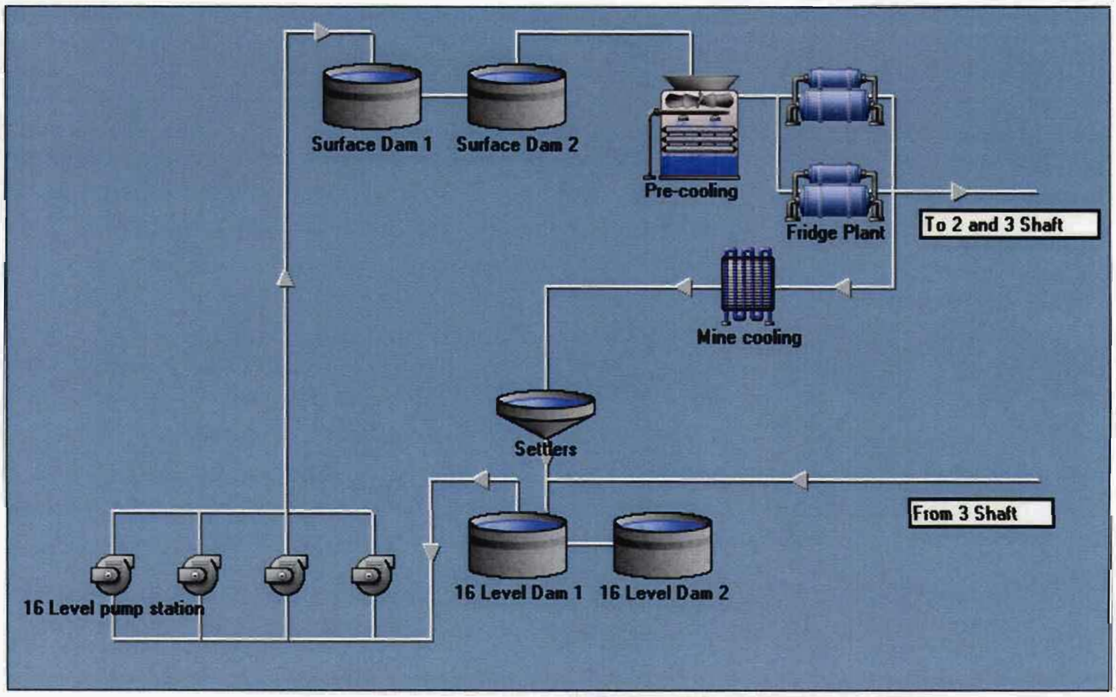


Figure 26: Beatrix 1 shaft pumping system layout

The pumping system on Beatrix 1 Shaft consists of the following; on the surface there are two hot water dams with a capacity of 6 500 000 litres (6.5 Ml) each. These hot dams feed the fridge plants located on the surface at Beatrix 1 Shaft. There is only one pumping station at this shaft which is located at 16 Level. It consists of two hot water dams with a capacity of 2 Ml each.

Of the two dams at 16 Level, one is used as a spare dam and is available for extra storage if emergency storage is needed [33]. A spare dam should be as empty as possible to allow maximum storage space if an emergency occurs [20]. If the dam that is used to store the hot water gets too full of mud and the capacity starts to decrease, the water is transferred to the spare dam and the mud filled dam is cleaned.

The pump station at 16 Level housed four pumps (2000 kilowatt each) installed during the investigation period. These four pumps operate into two columns that feed into the hot water dams on the surface. The mine will install a further two pumps of the same size as the currently operating pumps, with an extra column. The installation will be completed before the implementation of this project begins. The different layouts are illustrated in Figure 27 and Figure 28.

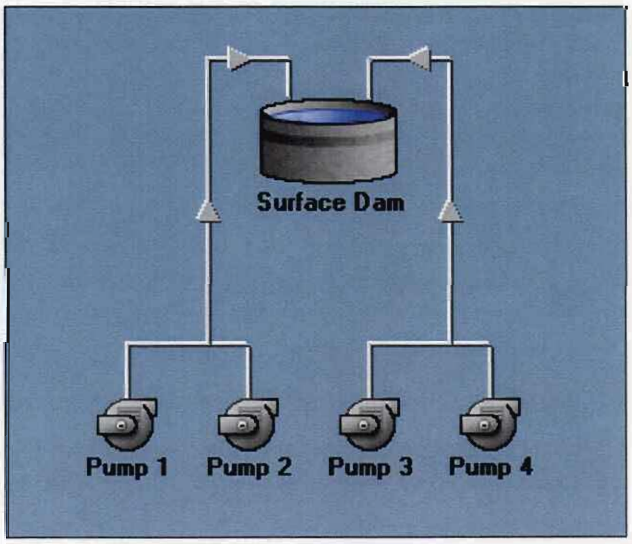


Figure 27: 4 pumps 2 columns layout (Layout A)

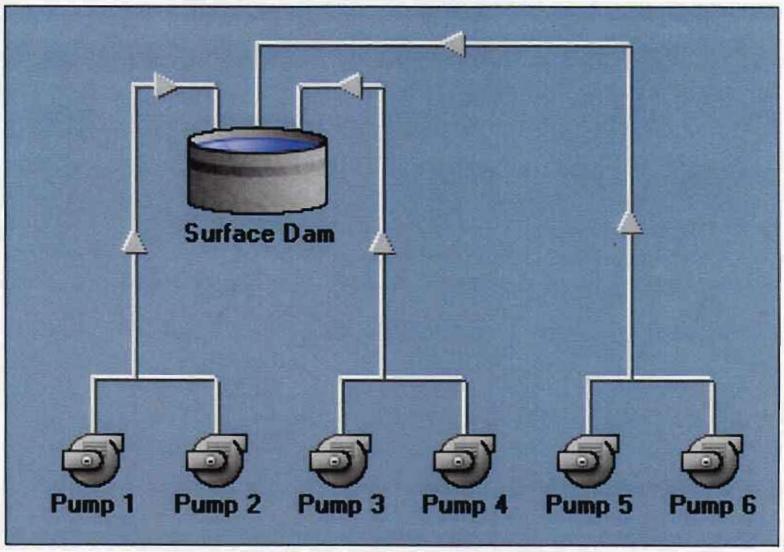


Figure 28: 6 pumps 3 columns layout (Layout B)

Operation of the pump station during the investigation period was as follows:

- One pump operates at all times.
- If the level of the hot water dam on 16 Level reaches 55-60% another pump is started.
- If the dam level drops below 30% one pump is switched off.
- If however two pumps are operating and the dam level continue to rise above 75% an additional pump is switched on.
- If the dam level drops below 15% all pumps are switched off.

When more than one pump was operating, it was standard practice to run pumps that fed into the same column. In other words, if pump 1 was operating and an additional pump needed to be switched on, pump 2 was started (refer to Figure 27). This is an inefficient way to operate pumps if one considers the parallel operation discussed in section 2.3.

The flow rate in the column when one pump is operating is ±120 litres per second (l/s). When two pumps operate in parallel i.e. pump into the same column, the flow rate is ±185 l/s. Clearly, selecting pumps that pump into different columns will result in an increased amount of water pumped (±240 l/s) for the same power consumption. A more efficient selection and management of (existing) pump operation will result in electrical load shift and also energy efficiency.

Further verification of this possibility was achieved by means of a mathematical simulation in Microsoft Excel, using the solver add-in. This simulation serves to verify the possibility of load shift while keeping to the normal operational constraints. The load shifting was performed according to Eskom's MegaFlex pricing structure, i.e. the load was shifted from peak periods to off-peak periods.

The simulation had to be conducted on all three shafts as a complete system. It must be noted that the number of pumps were averages taken over a period and are therefore not whole numbers. Figure 29 below shows the results of the simulation, and indicates that load shifting is possible on Beatrix 1 Shaft while adhering to the system's constraints.

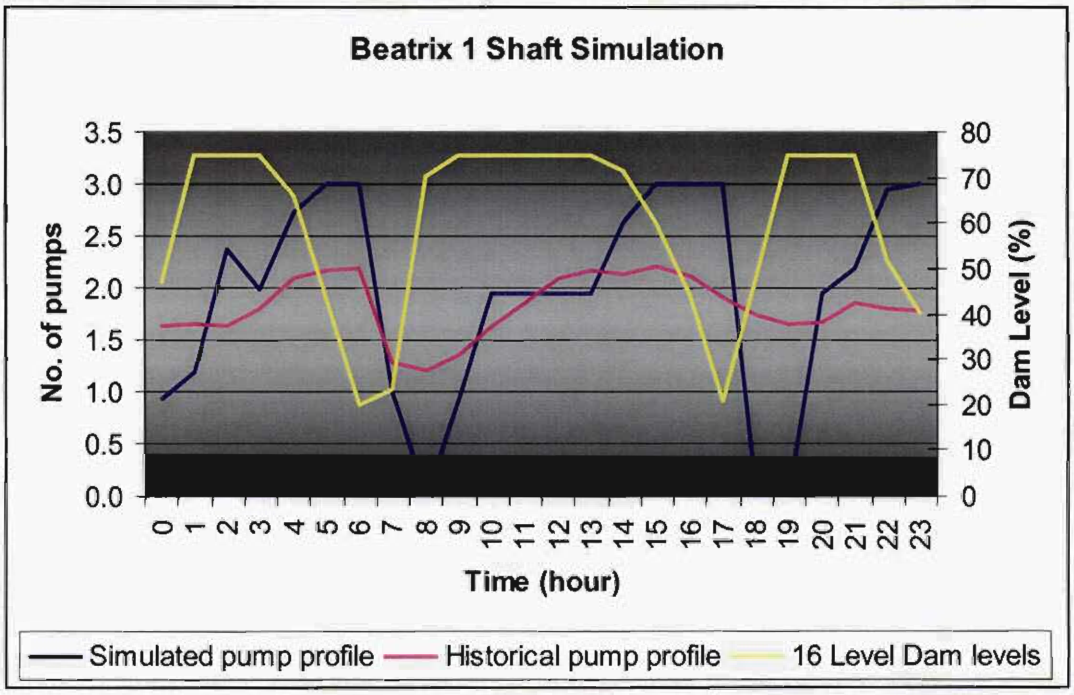


Figure 29: Beatrix 1 shaft mathematical simulation results

3.4.2 Beatrix 2 shaft

Beatrix 2 Shaft has a simple layout, as illustrated in Figure 30. The pumping system consists of a small surface dam with a capacity of 800 000 litres (0.8 Ml). Four pumps (1800 kilowatt each) and three hot water dams were found in the pumping station at 25 Level. Two of the three dams have a capacity of 2 Ml while the third has a capacity of 4 Ml.

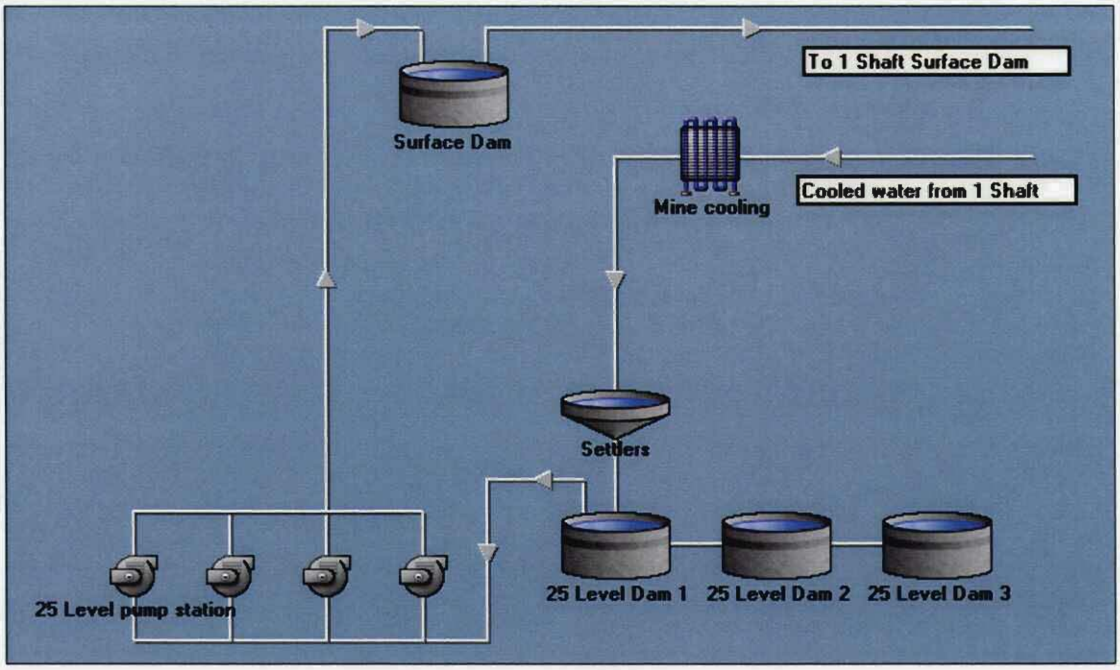


Figure 30: Beatrix 2 shaft pumping system layout

Beatrix 2 Shaft receives chilled water from Beatrix 1 Shaft and this is used to cool the mine. The hot water dams at 25 Level store water sent down the shaft plus any additional fissure water. The pump station at 25 Level pumps the hot water back to the surface, where it is pumped by transfer pumps to the surface dam at Beatrix 1 Shaft.

An additional two pumps will be installed in the pump station at 25 Level. The four pumps, two columns configuration is shown in Figure 27, while the future six pumps two columns configuration is shown in Figure 31.

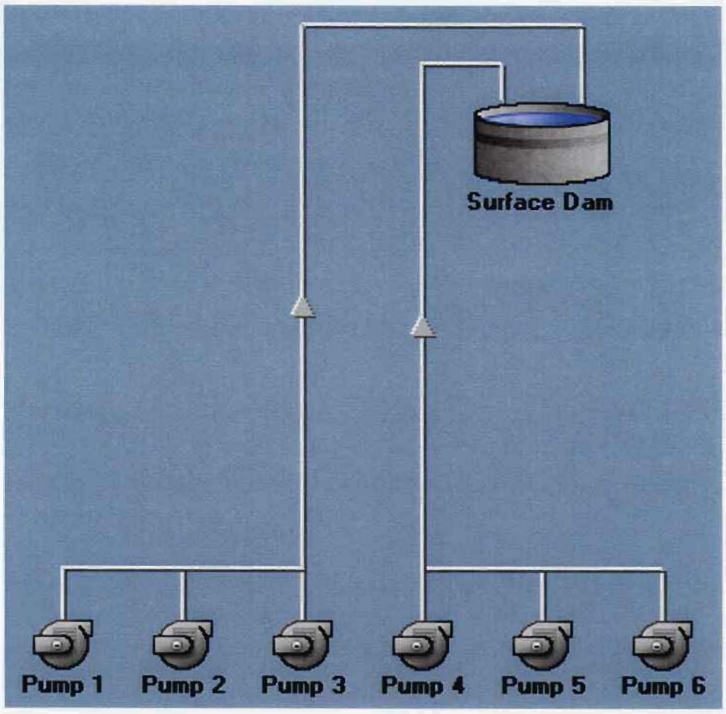


Figure 31: 6 pumps 2 columns layout

Operation of the pump station during the investigation period is as follows:

- One pump operates at all times unless the dam level drops below 20%.
- Once the dam level rises above 50-55% an additional pump is started.
- If the dam level rises above 75% another pump is started.
- If three pumps are running and the dam level drops below 55%, one pump is stopped.
- If two pumps are running and the dam level drops below 30%, one pump is stopped.

As mentioned in section 3.4.1, it is also standard practice at Beatrix 2 Shaft to run pumps in the same column before selecting a pump on a separate column. Improved selection and management of the pumps will achieve both load shift and energy efficiency on Beatrix 2 Shaft.

Further verification is provided by Figure 32 which demonstrates the results of the simulation discussed in section 3.4.1 for Beatrix 2 Shaft. This graph clearly indicates that load shift on Beatrix 2 Shaft is possible while adhering to the system's constraints.

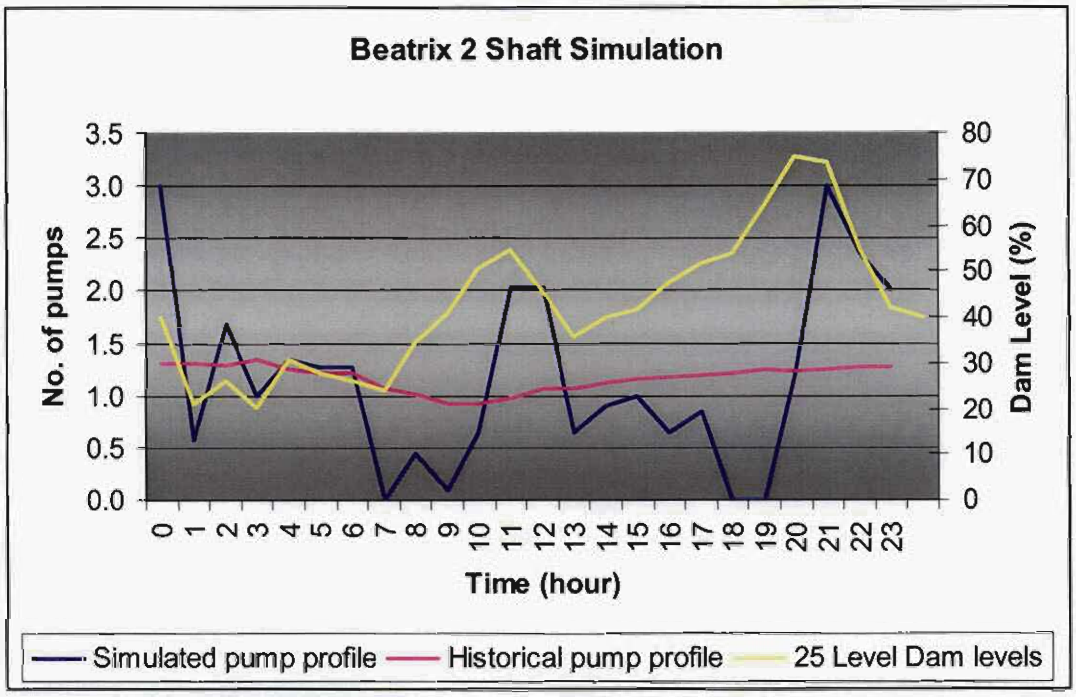


Figure 32: Beatrix 2 shaft mathematical simulation results

3.4.3 Beatrix 3 shaft

Beatrix 3 Shaft is a fairly new shaft compared to Beatrix 1 and 2 Shafts. This is the only shaft of the three that will have deepening projects in the future. The pumping system consists of a surface dam with a capacity of 7 Ml and a pumping station located at 27 Level. Currently there are three pumps installed on the station with a 2 Ml capacity dam.

The three pumps consist of two small pumps (800 kilowatt each) and one larger pump (1800 kilowatt). The 800 kW pumps are capable of pumping 85 litres per seconds (l/s) each and the 1800 kW pump can pump 112 l/s. Beatrix 3 Shaft receives chilled water from Beatrix 1 Shaft. Water that is sent down the mine and any additional fissure water are stored in the dam at 27 Level. The pump station then pumps the water to

Beatrix 1 Shaft where it is stored in the dam at 16 Level. The current layout is illustrated in Figure 33.

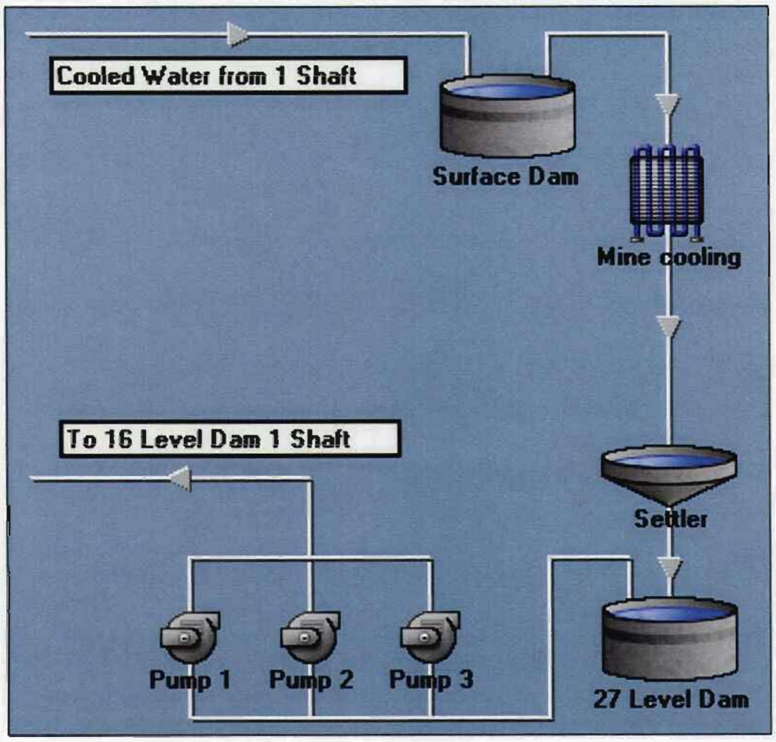


Figure 33: Beatrix 3 shaft pumping system layout

Arising from the new development on 3 Shaft, additional pumps and a new dam will be installed. Each of these pumps will be capable of pumping 120 l/s back to the surface. The new pumping layout will be the same as for Beatrix 2 Shaft, see Figure 31. In addition, an extra dam will also be prepared to cater for increased water usage in the future.

The pumping operation during the investigation period was as follows:

- One pump operates at all time, unless the dam level drops below12.5%.
- Once the dam level rises above 25%, an additional pump is started.
- If the dam level rises above 35% and two small pumps are operating, then one small pump is swapped for the bigger pump.
- The dam level is kept between 12.5% and 40% at all times.

Unlike the other two shafts, Beatrix 3 Shaft currently has one column only. However it is standard practice to pump a smaller and larger pump into the same column. This is inefficient because the smaller pump adds only a small contribution to the net flow rate. This can be verified by considering the flow rates of the different configurations.

If two 800 kilowatt (kW) pumps are operating the net flow rate is 120 l/s. If the 1800 kW pump and one of the 800 kW pump are operating, the net flow rate is 130 l/s. However the power consumption of the former configuration is 30% less then the latter and the net flow rate difference is only 10 l/s.

Efficient pump selection and better management of the control system would result in load shift and energy efficiency. Further verification is provided by Figure 34 which demonstrates the results of the simulation discussed in section 3.4.1 for Beatrix 3 Shaft. This graph clearly indicates that load shift on Beatrix 3 Shaft is possible while adhering to the system's constraints

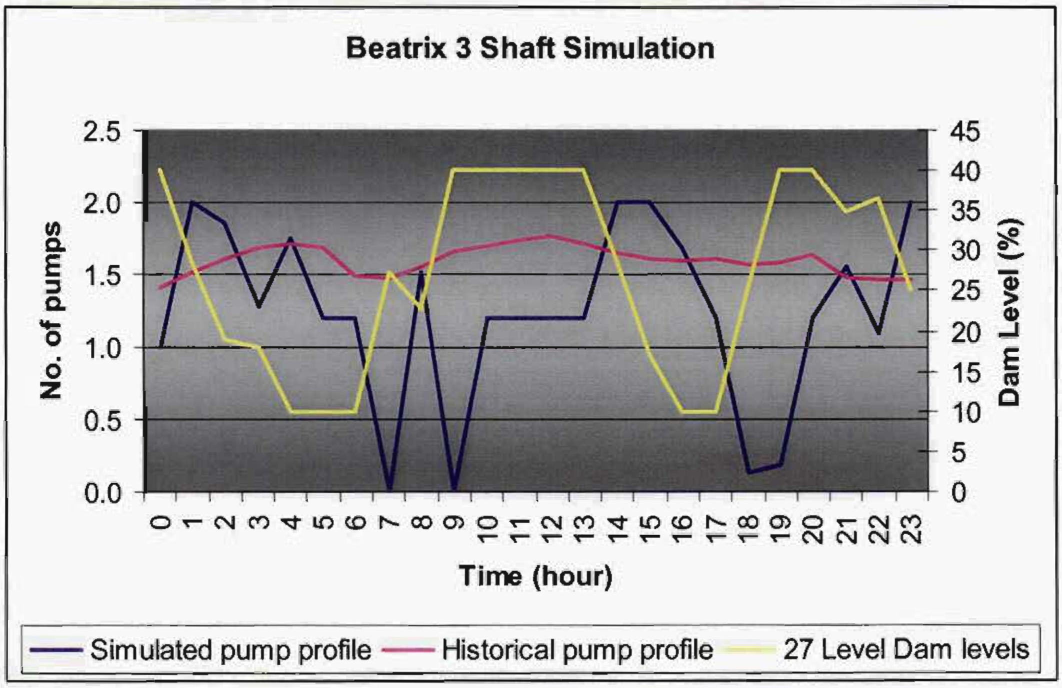


Figure 34: Beatrix 3 shaft mathematical simulation results

3.5 Analysis of current power consumption of the pumping systems

To analyse the power consumption of the multi-shaft pumping system, the power consumption of each individual shaft had to be determined. The first step was to verify the installed capacity of the pumping stations for each shaft. The next step was to use historical data of the pump operation to determine a power consumption baseline for each shaft.

It was necessary to draw up separate power consumption baselines for Weekdays, Saturdays and Sundays. This was due to the decrease in mining operations during Sundays and the different pricing structure of Eskom's MegaFlex pricing category. Diminished mining operations during weekends mean that less water is needed underground and therefore that less water is pumped back to the surface. Consequently, less energy (electricity) is used.

Calculation of the baselines for each of the three shafts enables the potential load shift of the pumping systems per shaft to be established. In addition, the potential load shift of the entire multi-shaft pumping system can be calculated when the baselines are combined. Due to the large amount of water on 1 Shaft its power analysis will be considered first, followed by 2 Shaft and 3 Shaft, respectively. Thereafter the power analysis for the overall system will be discussed.

3.5.1 Beatrix 1 shaft power analysis

The pumping system situated at 16 Level on Beatrix 1 Shaft currently has four pumps with an installed capacity of 2000 kilowatts (kW) per pump. Prior to the implementation of the new energy management system, a further two 2000 kW pumps will be installed, with an additional column. Accordingly, the total installed capacity on 1 Shaft will be 12000 kW.

Using historical data for the pumping operation, baselines were obtained for 1 Shaft on Weekdays, Saturdays and Sundays. Then, from these baselines, the potential load shift of the pumping system on 1 Shaft was ascertained. Figures 35, 36 and 37 show the power baseline of Beatrix 1 Shaft for Weekdays, Saturdays and Sundays, respectively. These baselines represent the average amount of energy that was used over the three month investigation period.

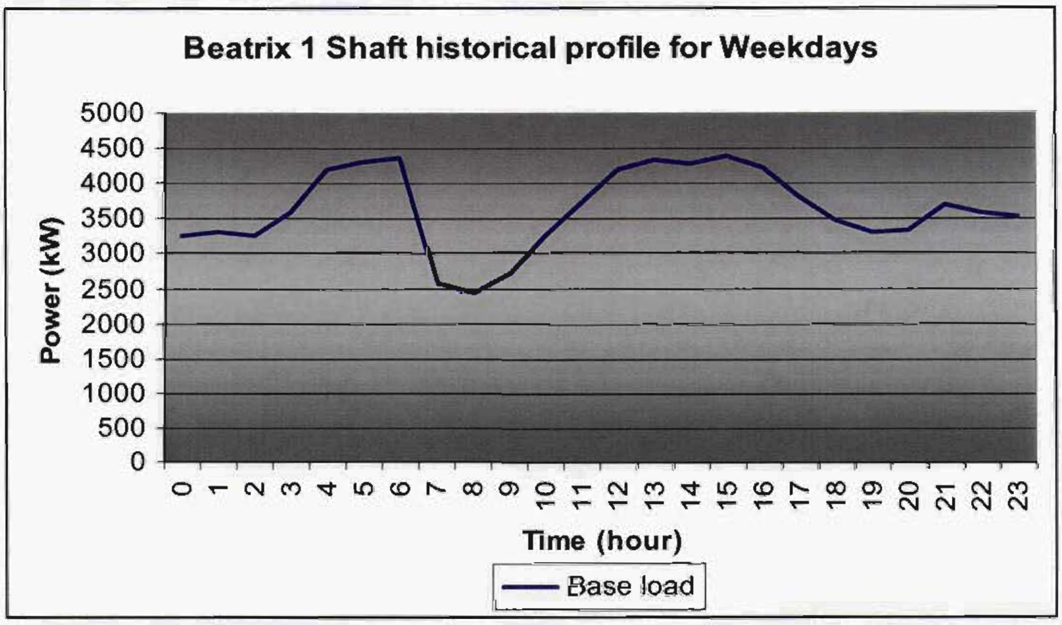


Figure 35: Beatrix 1 shaft baseline for weekdays

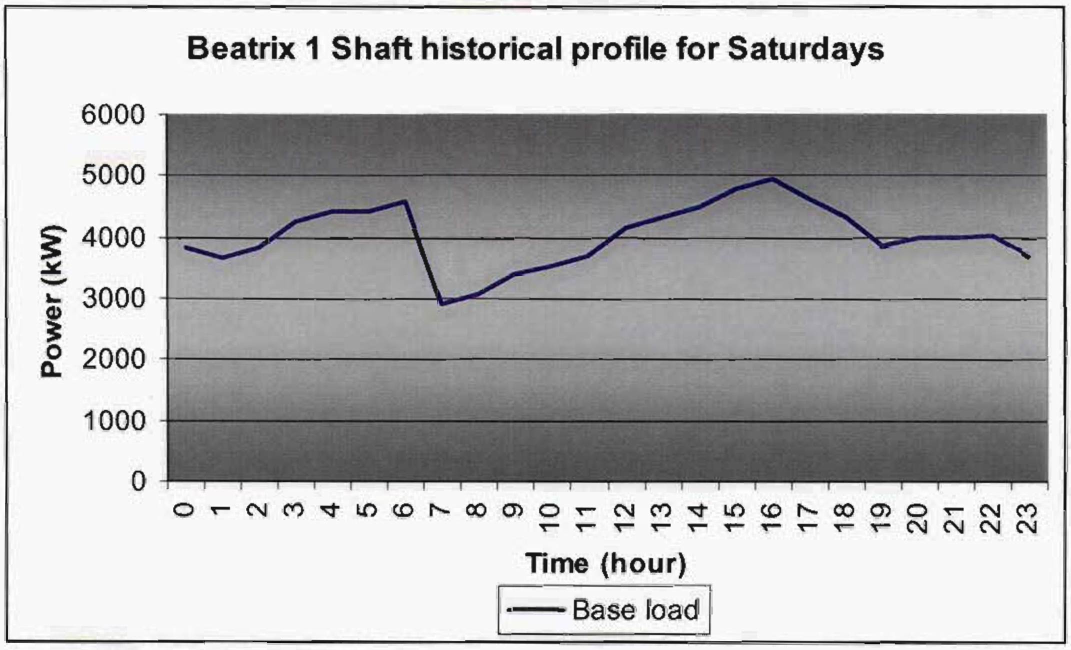


Figure 36: Beatrix 1 shaft baseline for Saturdays

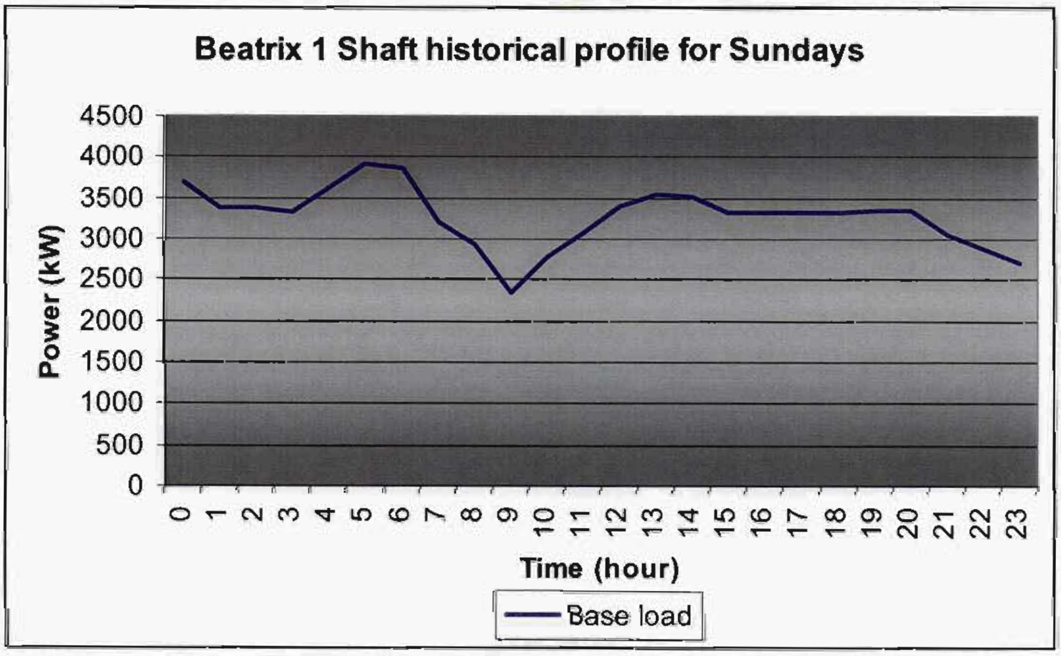


Figure 37: Beatrix 1 shaft baseline for Sundays

Figure 35 demonstrates that the maximum possible load shift potential during the evening peak period between 18:00 and 20:00 during weekdays is 3.4 MW. It has already been established, in section 3.4.1, that load shift on Beatrix 1 Shaft is possible.

However, only after an accurate simulation that considers certain system dynamics and realistic pump operation can a load shift *value* be set. The mathematical simulation in section 3.4.1 did not consider these dynamics, which include column operation, fluctuations in water usage, and water flows in and out of dams, etc.

3.5.2 Beatrix 2 shaft power analysis

The pumping system situated at 25 Level on Beatrix 2 Shaft currently has four pumps with an installed capacity of 1800 kilowatts (kW) per pump. Again, prior to the implementation of the new energy management system, a further two 1800 kW pumps will be installed. This will provide a total installed capacity on 2 Shaft of 10 800 kW.

Using historical data for the pumping operation, baselines were obtained for 2 Shaft on Weekdays, Saturdays and Sundays. Following this, the potential load shift of the pumping system on 2 Shaft was established. Figures 38, 39 and 40 depict the power baseline of Beatrix 2 Shaft for Weekdays, Saturdays and Sundays, respectively. These baselines represent the average amount of energy that was used over the three month investigation period.

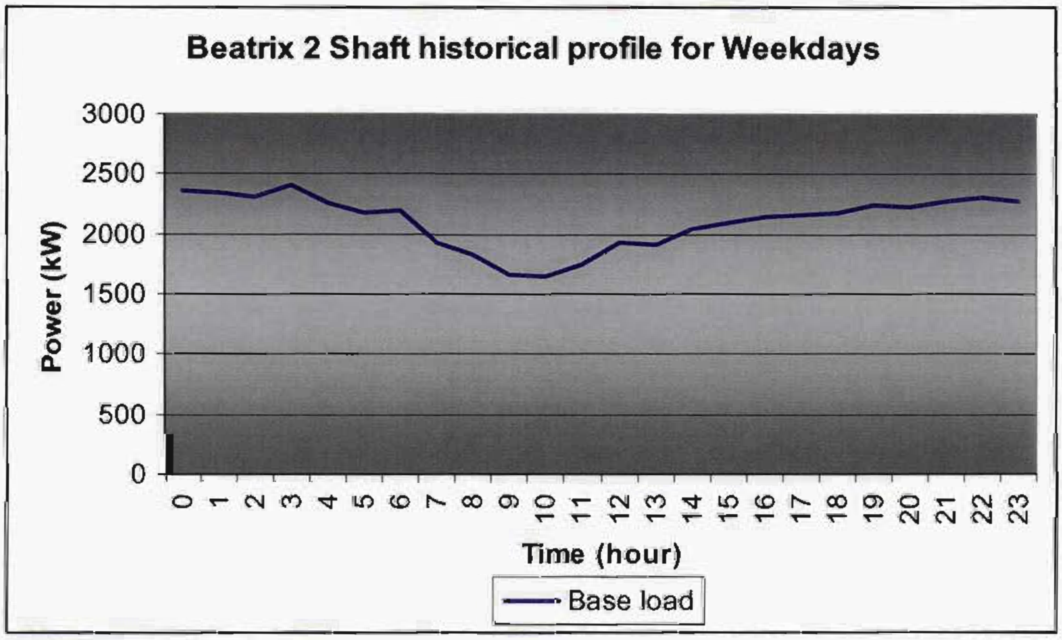


Figure 38: Beatrix 2 shaft baseline for weekdays

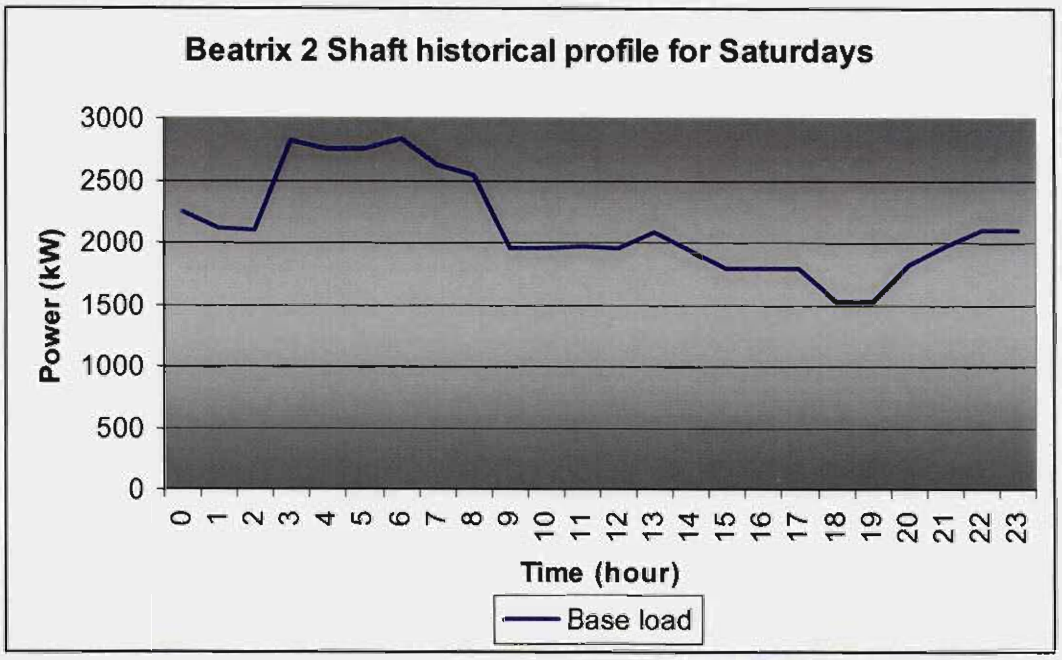


Figure 39: Beatrix 2 shaft baseline for Saturdays

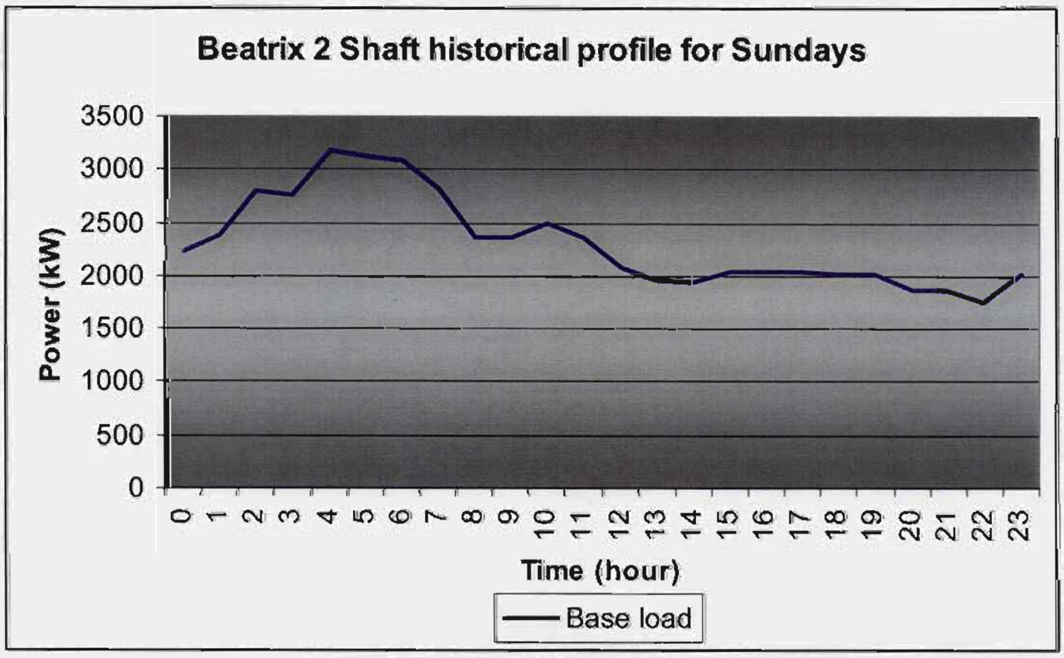


Figure 40: Beatrix 2 shaft baseline for Sundays

Figure 38 indicates that the maximum possible load shift potential during the evening peak period between 18:00 and 20:00 during weekdays is 2.2 MW. It was established earlier, in section 3.4.2, that load shift is possible on Beatrix 2 Shaft but, as mentioned in section 3.5.1 more dynamics have to be considered before a load shift value can be determined.

3.5.3 Beatrix 3 shaft power analysis

The pumping system situated at 27 Level on Beatrix 3 Shaft currently has three pumps with an installed capacity of 800 kilowatts (kW) for two MSG pumps, and 1800 kW for one MSJ pump. However, 3 Shaft is still being developed and six new pumps and an additional dam will be installed. Although this development is scheduled for completion in the near future, it is the current system characteristics that will be analysed in this study. Consequently, the figure for the total installed capacity on Beatrix 3 Shaft is 3400 kW.

Using the historical data of the pumping operation, baselines were obtained for Weekdays, Saturdays and Sundays. Thereafter, the potential load shift of the pumping system on Beatrix 3 Shaft was realised. Figures 41, 42 and 43 indicate the power baseline of Beatrix 3 Shaft for Weekdays, Saturdays and Sundays respectively, and represent the average power used over the three month investigation period.

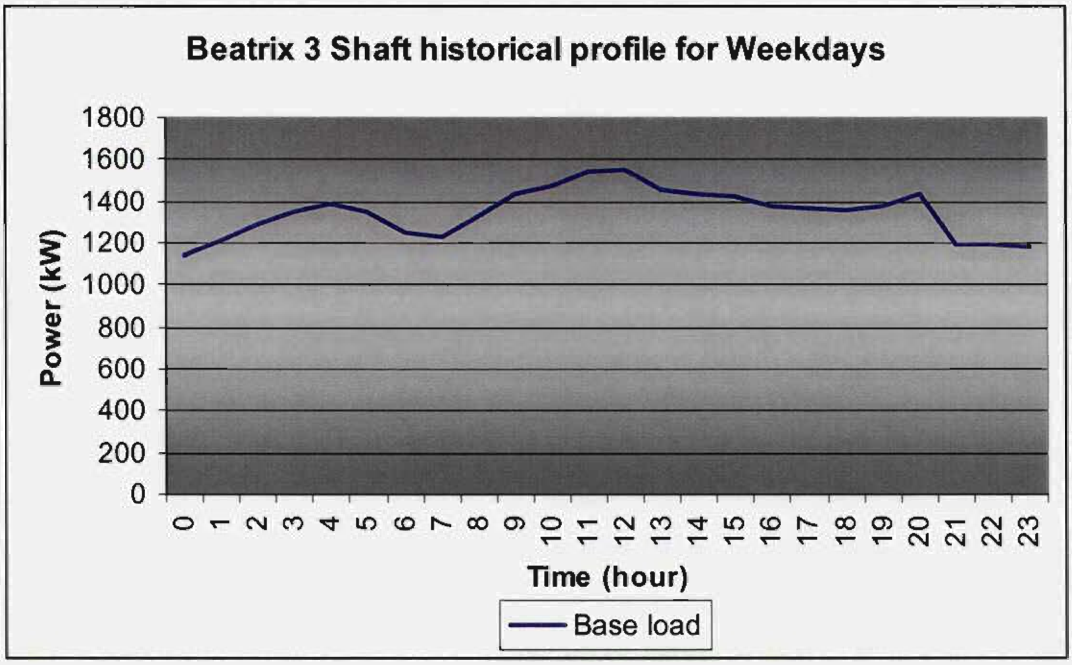


Figure 41: Beatrix 3 shaft baseline for weekdays

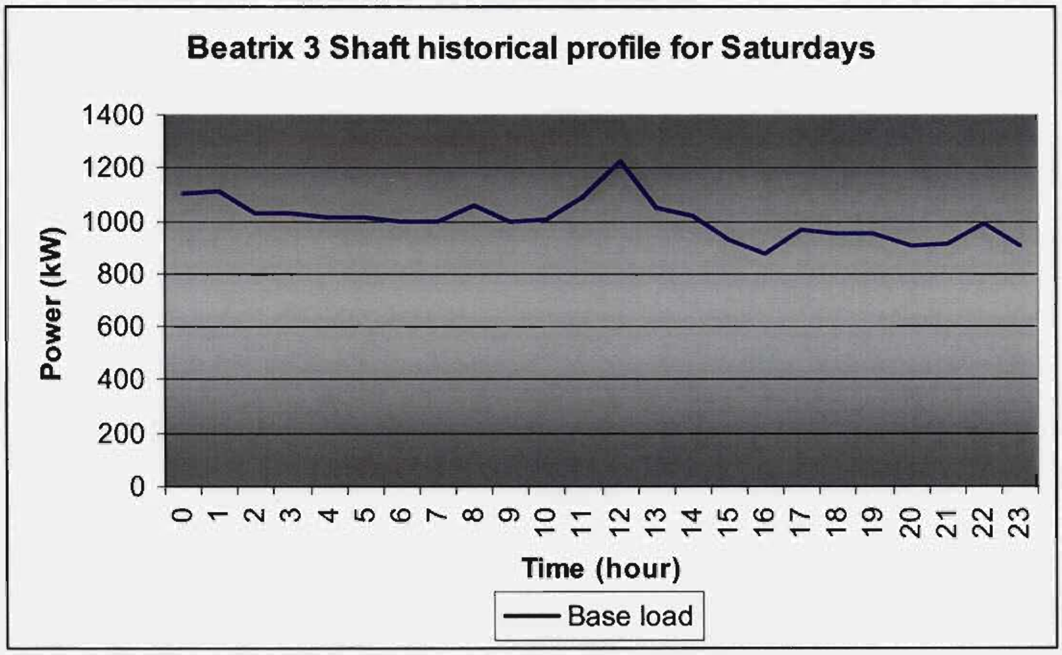


Figure 42: Beatrix 3 shaft baseline for Saturdays

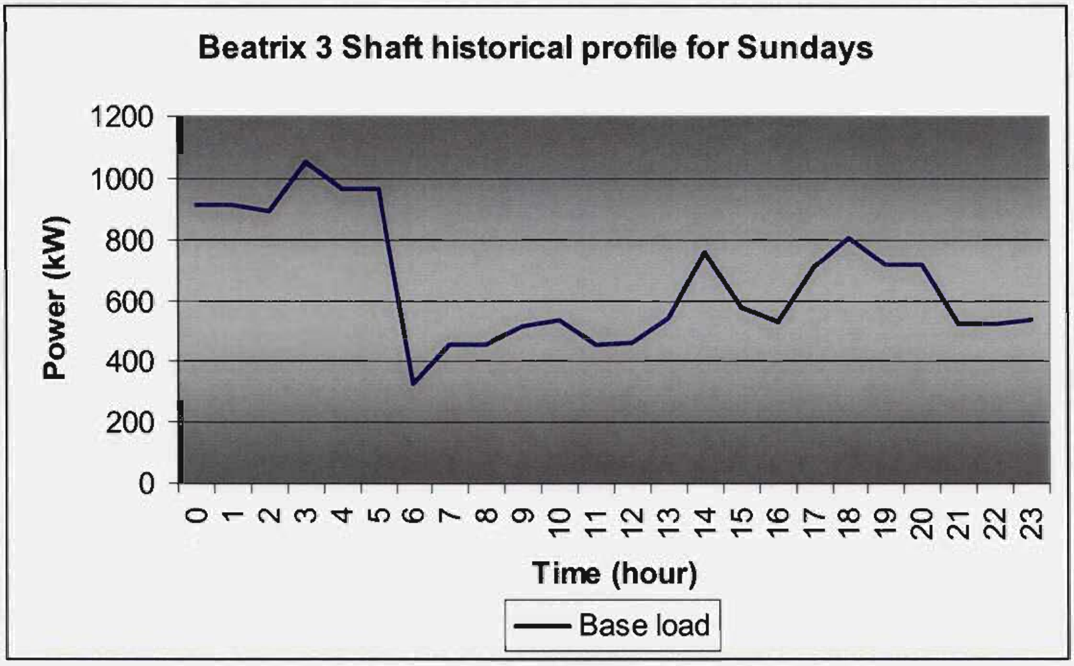


Figure 43: Beatrix 3 shaft baseline for Sundays

Figure 41 demonstrates that the possible load shift potential during the evening peak period is 1.36 MW. It was determined earlier, in section 3.4.3, that load shift on Beatrix 3 Shaft is possible. However, as pointed out above, more dynamics have to be considered before a load shift value can be attained.

3.5.4 Overall system power analysis

In total, the pumping system for Beatrix 1, 2 and 3 Shafts has an installed capacity of 26200 kW. Combining the historical data and the calculated baseline enabled overall baselines for Weekdays, Saturdays and Sundays to be determined, which, in turn, allowed calculation of the overall load shift potential of the multi-shaft pumping system. Figures 44, 45 and 46 present the power baseline of the overall system for Weekdays, Saturdays and Sundays, respectively.

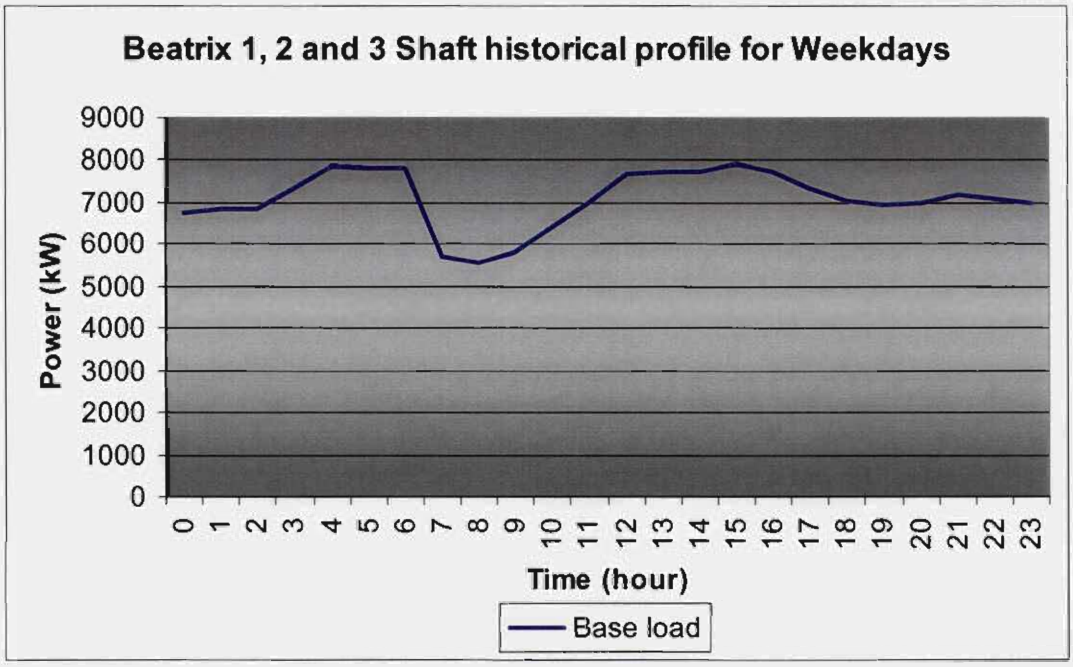


Figure 44: Beatrix 1, 2 and 3 shaft baseline for Weekdays

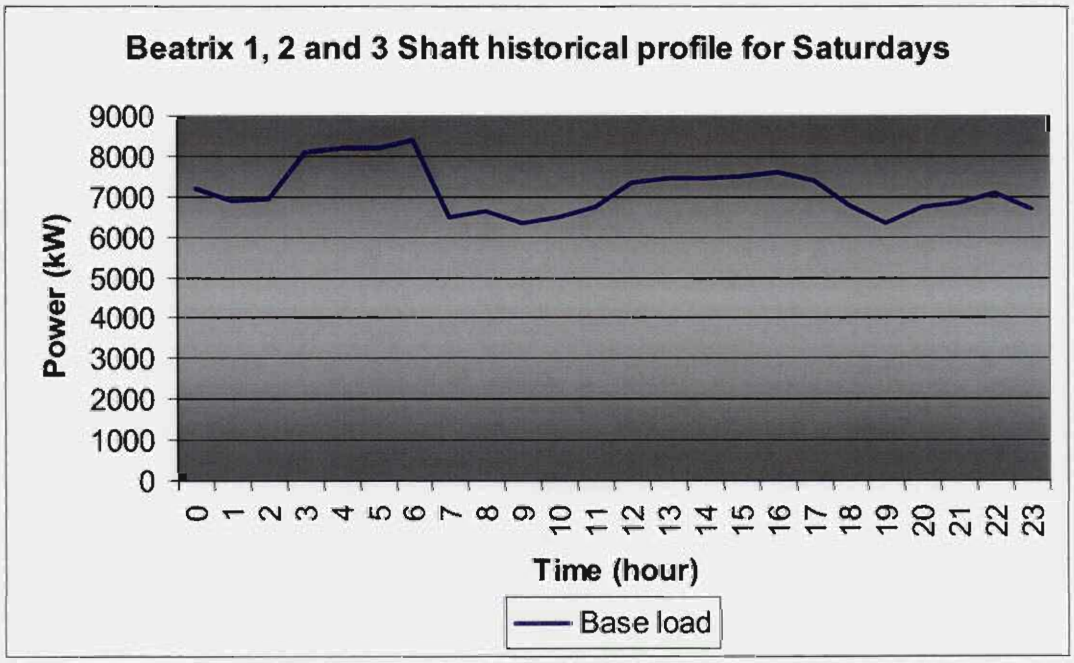


Figure 45: Beatrix 1, 2 and 3 shaft baseline for Saturdays

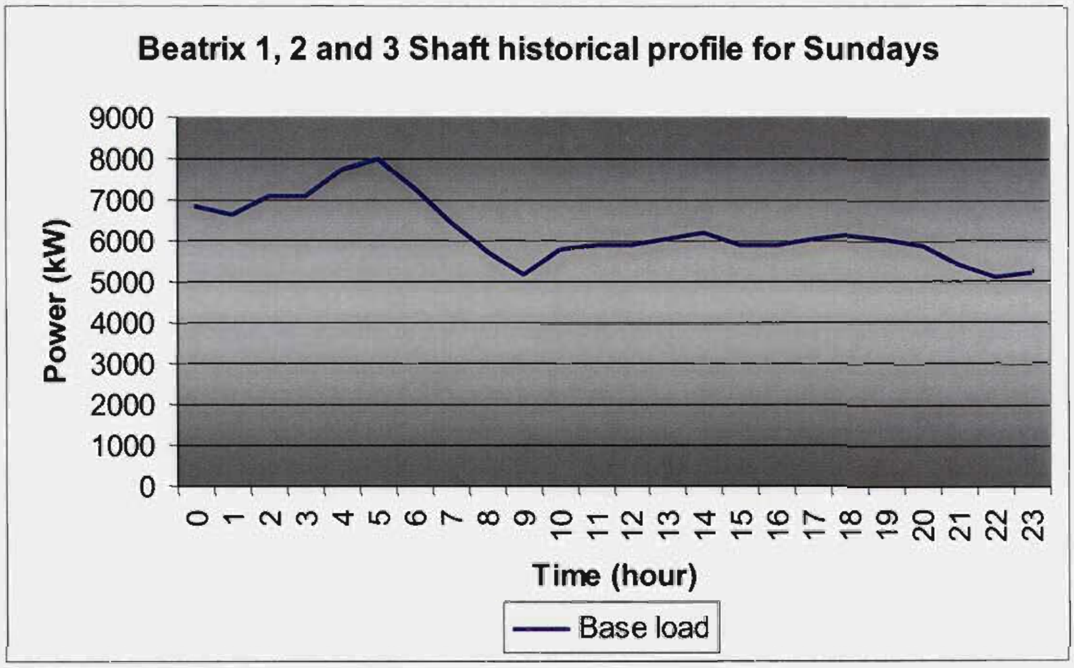


Figure 46: Beatrix 1, 2 and 3 shaft baseline for Sundays

Figure 44 indicates that the potential load shift from the multi-shaft pumping system at Beatrix 1, 2 and 3 Shaft is 7.0 MW. Sections 3.4.1 to 3.4.3 have already established that load shift is possible on all three Shafts and that more dynamics have to be considered before a load shift value can determined.

3.6 Need for real time energy management

Detailed investigation of the multi-shaft pumping system revealed the need for an automated Energy Management System (EMS). This EMS will have to accommodate all the requirements stipulated in section 2.4, and must ensure that the mine will change its current operation schedule only if there is a high level of confidence that safety and production will not be affected.

For this to be achieved the EMS will have to be able to simulate the fully integrated operation of the mine in detail. This simulation must be verified by using the detailed operational data from previous years. It was found that Transfer of Energy, Momentum and Mass International or TEMMI's patented system called Real Time

Energy Management System (REMS) provides such a system. The figure illustrates the flow chart of how REMS operate.

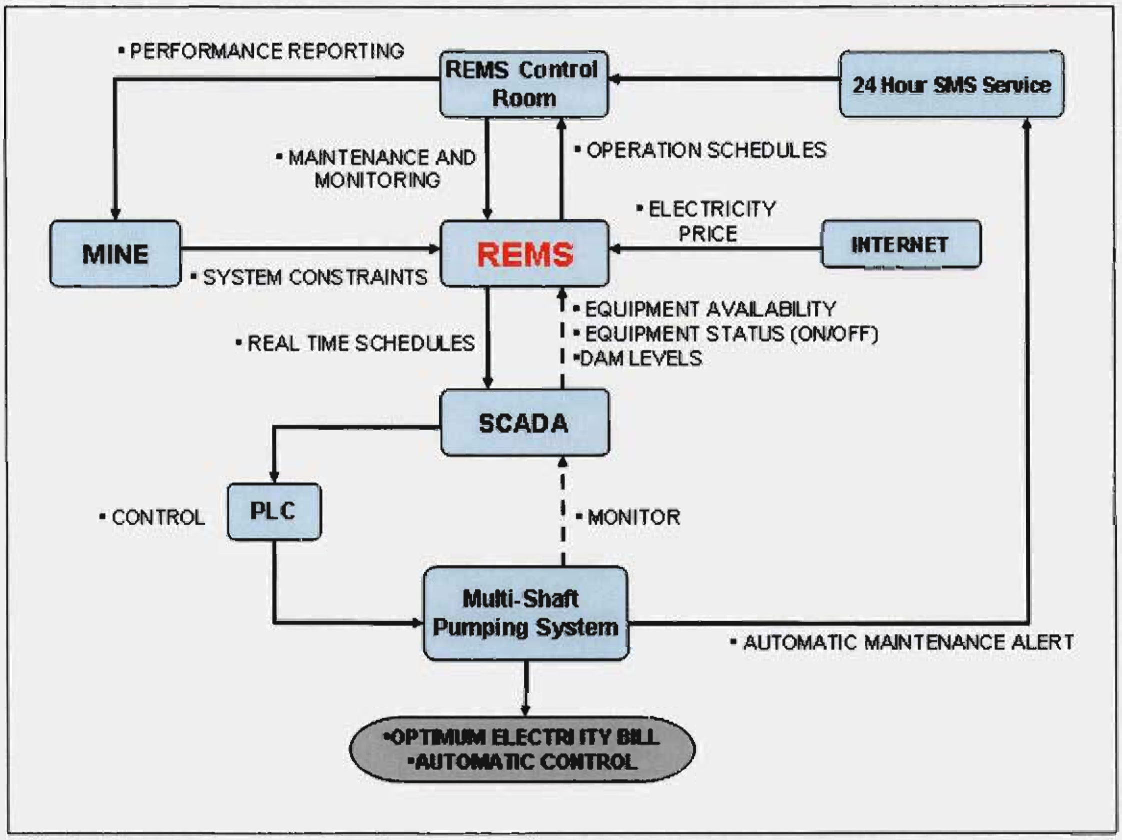


Figure 47: Flow chart of REMS operations

With REMS, the requirements needed for the automated control for the multi-shaft pumping system on Beatrix 1, 2 and 3 shafts are fulfilled. This automated control ensure load shift and energy efficiency to successfully implement DSM on the multi-shaft system.

3.7 Possible impacts on mining operations due to DSM

While DSM programmes have been implemented successfully on a number of South African mines, the many dynamics and uniqueness of the pumping systems on individual mines influence the impact of DSM on each mine. Moreover, there have not yet been any DSM projects implemented on a multi-shaft pumping system.

Nevertheless it can be assumed that the impact will be similar to DSM on single shaft pumping systems, but on a larger scale.

Case studies have been conducted to determine the possible impacts DSM will have on mines, and have established that these are:

- Financial impacts.
- Infrastructure impacts.
- Sustainable issues.

3.7.1 Financial impact

There are four possible financial impacts that a DSM programme can have on a mine. The first financial impact would be through actual electricity cost savings due to load shifting and energy efficiency. Previous case studies have shown that the average monthly electricity cost saving for a mine ranges from 5% (during the low-demand season) to 16% (during the high-demand season) [34].

Table 3 shows the results of the case study done on six mines with DSM programmes [34].

Table 3: Electricity cost savings due to DSM [34]

MINE	INSTALLED CAPACITY (MW)	MONTHLY OPERATIONAL COST BEFORE DSM		EVENING LOAD SHIFT POTENTIAL (MW)	AVERAGE MONTHLY COST SAVINGS DUE TO DSM (ACTUAL)			
		LOW DEMAND SEASON	HIGH DEMAND SEASON		LOW DEMAND SEASON	% SAVING	HIGH DEMAND SEASON	% SAVING
Kopanang	26.0	R 341,811	R 626,942	4.5	R 16,971	5%	R 103,812	17%
Elandsrand	27.2	R 642,961	R 1,196,637	3.5	R 14,556	2%	R 102,137	9%
Bambanani	23.8	R 714,061	R 1,398,010	7.0	R 32,407	5%	R 160,263	11%
Masimong 4#	18.8	R 237,218	R 430,104	4.0	R 20,405	9%	R 111,964	26%
Harmony 3#	24.2	R 318,309	R 605,802	3.8	R 15,651	5%	R 72,801	12%
Mponeng	47.2	R 984,241	R 1,878,697	11.0	R 46,641	5%	R 448,971	24%
Average	**27.9**	**R 539,767**	**R 1,022,699**	**5.6**	**R 24,439**	**5.0%**	**R 166,658**	**16.4%**

The second financial impact would be to achieve labour cost savings arising from the automatic control system replacing the duty of the human factor [34]. While the labour cost savings have already been demonstrated, the uniqueness of each pumping system means that the labour cost savings will vary per mine. Table 4 below shows the results of a labour cost savings case study [34] on three different mines.

Table 4: Labour cost savings as a result of DSM [34]

MINE	TOTAL NUMBER OF PUMP ATTENDANTS		MONTHLY COST PER PUMP ATTENDANT	TOTAL LABOUR COST SAVING (MONTLY)	PERCENTAGE CUT DOWN ON LABOUR COST
	BEFORE DSM	DUE TO DSM			
Kopanang	6	0	R 4,550	R 27,300	100%
Masimong 4#	12	6	R 3,800	R 15,300	50%
Harmony 3#	18	12	R 3,650	R 21,900	33%
Average	**12**	**6**	**R 4,000**	**R 21,500**	**61.1%**

The replaced pump attendants have been re-trained and successfully relocated to fill other vacant positions on the mine. Another possibility is that a DSM programme may require additional labourers. If a mine did not have any automated systems before DSM was implemented, an artisan will have to be employed to maintain the new automated control equipment [34].

The third financial impact would be the operating life of the pumps. Load shift projects implemented on pumping systems often require pumps to be stopped and started more frequently. This decreases the operating life of a pump. A rule-of-thumb indicates that the oil in the bearings should be replaced after every 80 start-up actions [34]. It is also concluded that frequent switching of industrial pumps contributes between 15% and 25% of the overall maintenance cost of a pump [34].

Extra heating due to the high start-up current could also shorten the life of the motor insulation system. Another rule-of-thumb indicates that for every 10°C rise above the limit of the motor, insulation life is halved [35].

Figure 48 illustrates the more frequent switching of pumps in order to do load shifting and compares this with the old method of running the duty pumps for long periods without stopping. The blue lines indicate the running status of the pumps prior to the

DSM project; green lines indicate the status of the pumps while doing load shifting; and the red blocks indicate Eskom's two peak demand periods, being the most expensive time in which to consume electricity [34].

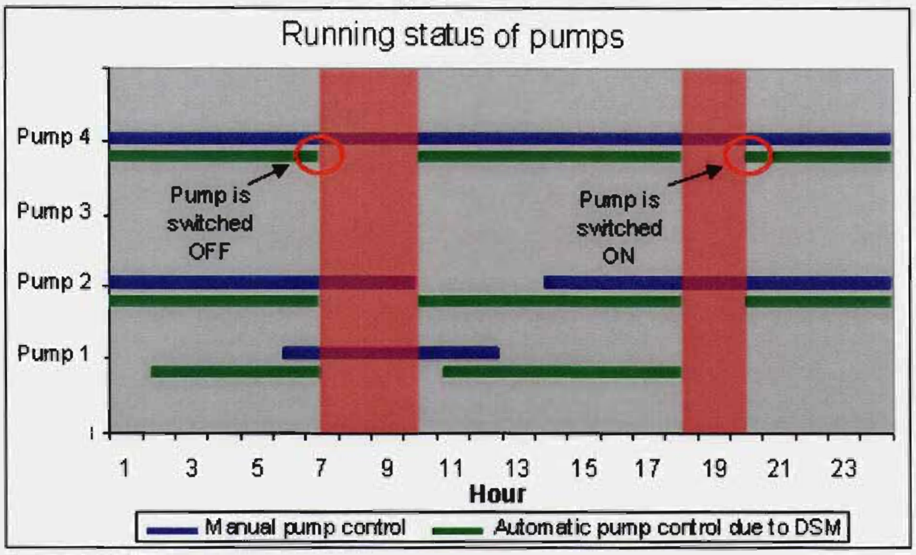


Figure 48: Frequent switching of pumps due to DSM [34]

The increased frequency of switching means that the maintenance cost of the pumps will be higher. However there are also instances where DSM may reduce the frequency of switching the pumps. A case study of the Tau Tona mine [34] showed that the DSM programme caused a reduction in the frequency of the switching of the pumps. For a more in-depth discussion of this case study please refer to reference [34].

The fourth financial impact is the risks the mine must take when implementing a DSM project, i.e. the penalties payable to Eskom for underperforming during the MW load shift savings and the possible early termination of the DSM project. The mine will have to pay penalties if its performance is less than 90% of the contractual load shift savings, and, if a DSM project is terminated before the contractual period has passed, the mine has to pay penalties to Eskom. The information needed to calculate the penalty payable to Eskom is given in Table 5.

Table 5: Information required for calculating the termination cost of a project [34]

DESCRIPTION	PROJECT RELATED INFORMATION
Total cost of DSM measures (T) (Infrastructure cost funded by Eskom)	R 3,000,000
Contractual duration of DSM project (Years)	5
Contractual date when project started	1 August 2005
Contractual date when project terminates	31 July 2010
Date of early termination	31 December 2006
Number of days falling short of the 5 year period (D)	1260

Taking into account the following information, and by using the termination penalty (TP) formula, the penalty to be paid to Eskom can be calculated as follows:

Equation 1

$$(TP) = \left(\frac{\text{Total cost of DSM measures (T)}}{\text{365 days} \times 5 \text{ (contractual period) years}} \right) \times$$

$$(\text{Number of days falling short of the 5 year period (D)})$$

$$= \left(\frac{3000{,}000}{365 \times 5} \right) \times 1260$$

$$= \text{R2,071 million}$$

Clearly it is important for any mine to be aware of the hidden costs associated with a DSM programme before taking on a project of this magnitude. Having all the necessary information to hand should enable the mine to moderate costs by diligent maintenance of the system, or by entering into a maintenance contract with an Energy Service Company (ESCO).

3.7.2 Infrastructure impact

DSM load shifting projects require the system to be automated in order to ensure sustainable results. The pumping system should be automated so that it assumes the control activities previously performed by pump attendants on the pump station, and, to accommodate automatic control of the pumps, control infrastructure should be installed.

The benefits of an infrastructure upgrade vary depending on the existing installed infrastructure found at each mine. Table 6 below illustrates the results of a case study performed on six different mines where each mine received an infrastructure upgrade arising from a DSM programme [34].

Table 6: Infrastructure installed due to DSM [34]

MINE	HARDWARE INSTALLED				NETWORK COMMUNICATION EQUIPMENT			SOFTWARE INSTALLED	
	Automatic dam level indicators	Automatic control valves	Field instrumentation	New switchgear	PLC equipment	Instrumentation cable	Fibre optic cable	SCADA computer	REMS system
Kopanang									x
Elandsrand									x
Bambanani			x				x		x
Masimong 4#	x	x	x	x	x	x	x	x	x
Harmony 3#	x	x	x	x	x	x	x	x	x
Mponeng			x	x	x	x			x

3.7.3 Sustainable issues

The DSM initiative has many advantages but in order to reap these benefits completely sustainability must be ensured. When the REMS assumes the pumping responsibilities, the physical human related work is reduced by approximately 90%, and the remaining 10% workload is shifted from the pump attendant to the control room operator who monitors the system from a central point on site [34].

The 10% workload assumed by the control room operator includes control responsibility for the pumps during a breakdown situation, to ensure sustainable load-shift results. If the control room operator receives the warning message and can respond to the problem quickly, a possible missed opportunity can be turned into a load shift saving.

A previous case study has shown that DSM projects with control room facilities perform 39% and 63.4% better in low-demand and high-demand seasons respectively

[34]. Thus it is imperative that control room operators are on duty and able to assume the system control during breakdowns.

3.8 Conclusion

In this chapter the DSM potential for the multi-shaft pumping system on Beatrix 1, 2 and 3 Shafts was determined. It was established that a potential load shift of 7.0 MW is possible during the evening peak period, but this value requires further verification using REMS to ensure that the load shift value is achievable once the project is implemented.

Furthermore, detailed investigation into the pumping system of each shaft was conducted and the overall system behaviour and constraints were established. These results will be of assistance during the verification simulation to determine the exact load shift value. A system to control the multi-shaft pumping system was identified, being TEMMI's Real time Energy Management System (REMS). The possible impacts of a DSM programme for a mine were also discussed.

CHAPTER 4: IMPLEMENTATION OF A REAL TIME ENERGY MANAGEMENT SYSTEM ON MULTIPLE SHAFTS

4.1 Introduction

This chapter realises the aim of this study by implementing DSM on an intricate multi-shaft pumping system from a single point of control. The chapter will fully describe how REMS was used to build a control system capable of fulfilling the objective of this analysis. This control system will comply with all the constraints and parameters of an intricate multi-shaft pumping system.

The information gathered in Chapter 3 will be used to understand and test a Real-time Energy Management System (REMS). Once this is achieved, the multi-shaft pumping system will be integrated into REMS and an optimised control system will be built through simulations. This ensures that there will be no repercussions if the system becomes unstable. Furthermore, the load shift value for the system will be verified, and the automation of the pump stations involved and the setup and installation of REMS will be discussed.

This chapter includes a discussion of any problems encountered during and after the implementation stage, together with the control philosophy for the complete control system for a multi-shaft pumping system. The control philosophy describes how the system will react according to the dam levels and time of day.

4.2 Research and design of control system

This section discusses the research and design of the REMS control system to be used in the DSM project for the multi-shaft pumping system on Beatrix 1, 2 and 3 Shafts. This discussion will cover only the general principles of the control system of REMS. For an in-depth discussion of the REMS approach, please refer to Rautenbach J.W. *Engineering a novel automated pump control system for the mining environment.* This study only required the understanding and utilisation of the REMS control system.

4.2.1 Mathematical and control module

The control module of REMS receives information from the Supervisory Control And Data Acquisition (SCADA) tags and utilises the mathematical module to calculate the schedule of the pumps in real time. The mathematical equations used to model the water pumping system of the mine are designed to be as accurate a representation of the actual system as possible [37]. The information that the control module receives from SCADA is as follows:

- Dam levels (upstream and downstream dams)
- The number of available pumps on a pump station
- The number of pumps operating on a pump station
- The time of day

In addition, internal tags in the control module can be programmed by the user to further customise the behaviour of the system.

The SCADA system is the backbone of the entire control system on a mine. The control operators monitor all the mining systems on SCADA and send instructions via the SCADA system to the Programmable Logic Controllers (PLCs) of the intended system. The SCADA system communicates with the PLCs by means of tag values. The PLCs register the values of connected components, for example, pumps, valves and dam level indicators, etc. in each tag.

If the control operator changes the values of the tags on SCADA, the SCADA system will alert the PLCs of the changes. Subsequently, the PLCs will execute the change on the components to which they are connected. However, REMS also connects to SCADA and this replaces the decision-making function of the control room operator. REMS calculates the optimised schedule and prompts SCADA to change the values of the necessary tags, which SCADA then sends to the PLCs. The PLC then executes the necessary changes and updates the system.

Each pump station has a controller in REMS and each controller monitors both upstream and downstream dams to ensure these dam levels are kept within their limits, as illustrated in Figure 49. The default position is for the downstream dam to have control privileges, and therefore the constraints of the downstream dam are the deciding factors in the calculations.

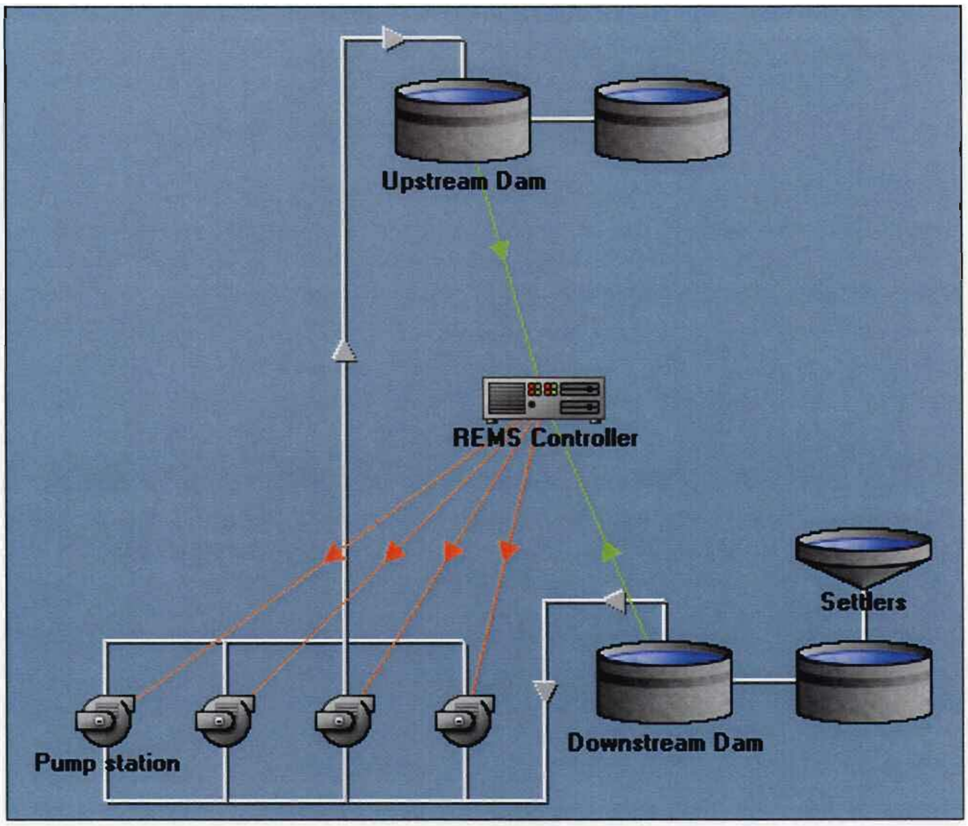


Figure 49: Upstream and Downstream dam illustration

Due to patent restrictions an in-depth discussion of the REMS controller cannot be given but a brief high level analysis will be discussed. The REMS Pump Group Controller consists of two sections: the upstream controller and the downstream controller. Each is responsible for the water level in the upstream (US) and downstream (DS) dams respectively.

The DS controller checks the DS dam boundaries and will stop the first of any running pumps in the pump group as soon as the DS dam level reaches the specified

DS Maximum dam level. If the DS dam level continues to rise, all the pumps that are still running will be turned off one by one.

The US controller works by using an upper bound control parameter, referred to as the Upperbound. The Upperbound is a profile consisting of 24 values. Each of the 24 values corresponds to an hour of the day. When the upstream dam level exceeds the Upperbound for a specific hour, the US controller will start an additional pump in the pump station. If the US dam level exceeds the Upperbound plus the US Offset, the US controller will start another pump in the pump station.

When the US dam water level drops below Upperbound minus the US Control Range, the controller will stop a running pump on the pump station. If the US dam level drops below the Upperbound minus the US Control Range minus the US Offset, another pump in the pump station will be stopped.

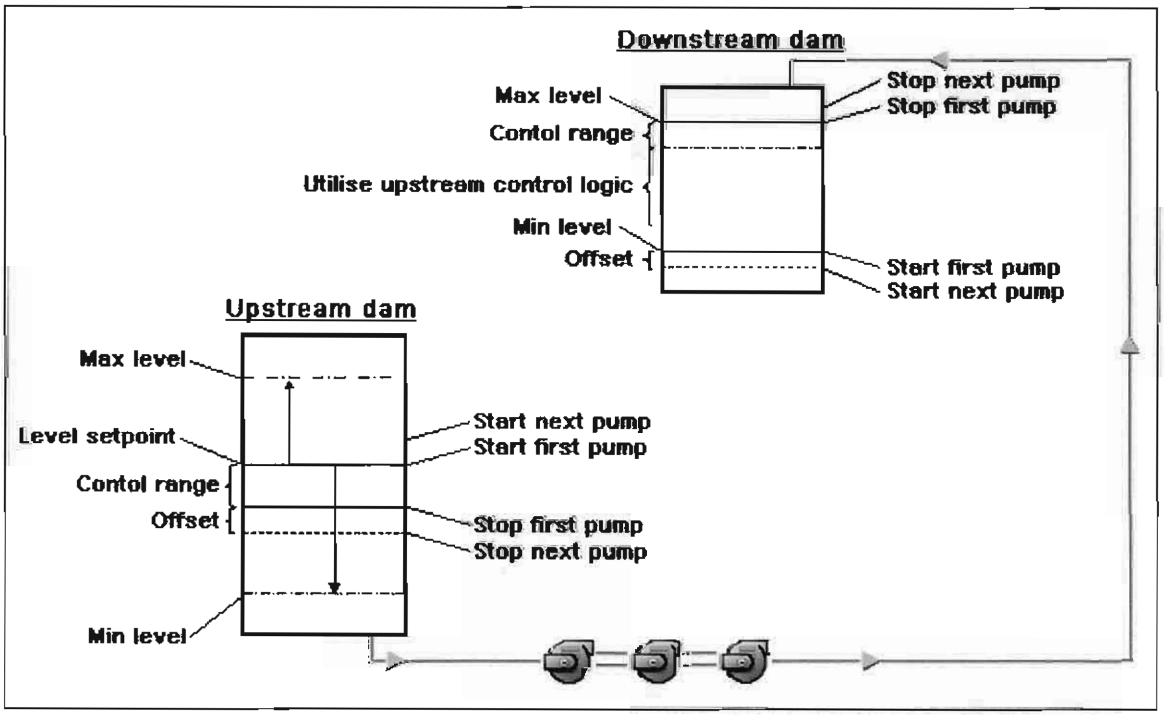


Figure 50: REMS Pump Group Controller control philosophy

The control range and system constraints (i.e. Dam levels) incorporate certain safety factors. They are set lower and higher than the extreme maximum and minimum, respectively, of the specific dam. This is to ensure that appropriate measures can be taken should the control system experience problems. Possible problems are the loss of communication with the SCADA system, pump breakdowns, column bursts, etc.

The occurrence of problems when dam levels are high could lead to the loss of lives due to flooding, and major damage to mining operations could be caused. Therefore REMS controls the pumps without compromising the safety and control specifications set by the mining industry [38] [39]. In addition, REMS has a control strategy built into its control system. It ensures that a given number of pumps are allowed to pump into a column simultaneously, which will provide an increased mean time between the failures of columns.

Furthermore, the life of a pump can be extended by ensuring that all the start-up and shut-down procedures are executed correctly. Therefore REMS has start-up and shut-down lag times for each pump which ensures that the PLCs have enough time to carry out these procedures. It must be noted that these start-up and shut-down times differ on each mine.

While the controller discussed previously uses the maximum and minimum dam levels from US and DS dams, the grid schedule - another controller available in REMS - specifies a schedule for each hour of the day according to different dam levels. The schedule specified is the preferred number of pumps that should be operating. Table 7 provides an illustration of a possible grid schedule. The hours shown in red are peak times.

Table 7: Example grid schedule

Level	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
50%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60%	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	1	0	0	1	1	1	1
70%	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1
80%	2	2	2	2	2	2	2	1	1	1	2	2	2	2	2	2	2	2	0	0	2	2	2	2
90%	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	2	2	2	2
100%	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

4.2.2 Simulation module

The simulation module in REMS can be used to replicate operations such as pumping, fridge plants, winders and compressed air systems. The values used in the simulation were gathered during the detailed investigation on Beatrix 1, 2 and 3 Shafts. This means that the necessary values for a specific make and model of the equipment can be derived from data acquired during measurements or from the manufacturer's data sheets.

The simulation module behaves exactly as the system would in real time. The software was developed in such a way that the simulation could be reused in the control of the actual system after installation on the mine. This ensures that the results of the simulation reflect closely the results that will be achieved from implementation of the system. The models of the system are fully component-based and allow replication of an extensive range of operating conditions.

During the project investigation, the simulation element is used to simulate the pumping system. While the control module is applied to this simulated system. This indubitably results in data that can be used to assess the performance of the system over a simulated time-period. The results of the simulation session are processed in the same way the real-world control data is analysed. This will help to ensure the success and verification of the potential of the given project.

Simulations can be done in faster-than-real-time. A month of simulated data can be generated in under an hour, speeding up the investigation process considerably [36].

The simulation of a system can start with either the status of the real world system as start values, or values specified by the user. If for any reason the simulation model does not reach an answer, the problem can be resolved in a simulated environment without any repercussions for the actual system.

In section 4.3.2 the simulation for the multi-shaft pumping system will be built and optimised using the simulation module on REMS. Following the simulation, the results will be analysed to verify the potential load shift value for this project.

4.2.3 Integrated control and software model

This section describes REMS as a whole system. The control, mathematical and simulation modules are integrated and developed into a software package. This provides a practical, automated control product focused on controlling pumps, winders, fridge plants and compressed air systems in the industrial sector.

This project will focus on the control of pumping systems. As discussed earlier, REMS is a component-based application which allows a dynamic range of operating conditions. A typical REMS display can be seen in Figure 51.

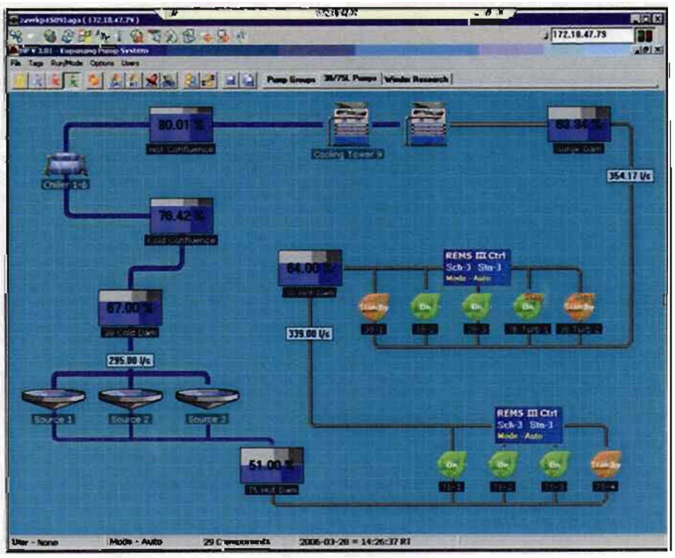


Figure 51: Typical REMS display

The components of REMS operate in an environment known as the Platform. A combination of components can be added to the Platform and set up to interact with each other. There are four operating modes: edit, idle, manual and auto. These are represented on the tool bar by yellow, blue, red and green icons, respectively, as shown in Figure 52.

Figure 52: REMS toolbar

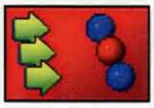
The additional settings of the Platform include

- Run mode (simulation or real time)
- OPC options
- Internal tags used for advance calculations and manipulation of certain values
- Alarms and warnings
- SMS notification for alarms and warnings
- User administration
- Save and backup project files

For the purpose of this study only the pump components of REMS will be discussed. Table 8 below shows the components used in REMS for the pumping system with a short description for each component.

Table 8: Components in REMS

	Dam	The dam image displays the dam levels and present it to the Controller for scheduling calculations
	Settler	Provide visual representation that certain dams contain settlers
	Pump	The pump component displays the pump status

	Valve	The valve component displays valve status
	REMS Controller	The REMS controller calculates the schedule for the pump station according to the dam levels
	REMS Grid Controller	The REMS grid controller schedules the pump station according to the dam levels and time of day
	Valve Controller	The REMS valve controller controls the valves according to the dam levels
	Pump Group Logger	Logs the pump group and all individual pumps statuses, schedules and dam levels for each controller.
	Generic Data Logger	Logs any additional information required
	Data Extractor	Used in the simulation mode to extract data from all the components involved in the simulation

The next step is to determine the effects that each component will have on the system as a whole. This is achieved by simulating each component separately to investigate the effects of its operations. Once this has been achieved, the components can be integrated into a system, and, once integrated, the feasibility of controlling the system as a whole is realised.

Subsequent to this realisation, the multi-shaft pumping system can be built in the REMS Platform environment according to its system constraints and parameters. The next section discusses implementation of the system within the simulation to verify the load shift value for the multi-shaft pumping system. The discussion also includes the control philosophy for the multi-shaft pumping system and problems encountered during and after the implementation of the DSM project.

4.3 Implementing the system

This section discusses the implementation stage of the DSM project on the multi-shaft pumping system. This will include detailed system constraints and the parameters needed to control the multi-shaft pumping system in accordance with mine regulations. These parameters and constraints will be used during the simulation of the multi-shaft system.

Once the simulation has been optimised to give the best results possible, the software control philosophy for the system will be documented so as to explain in detail how the system will behave. The next step will be to implement it on the mine and then analyse all the problems encountered during and after the implementation.

It must be noted that the new installation of dams and pumps on 27 Level at Beatrix 3 Shaft will be completed only after implementation of the REMS control system. Accordingly, the simulation and the results of implementation that will be discussed in this study will exclude the new pumping infrastructure. However, the new infrastructure will be selected with DSM principles in mind, and this will ensure the sustainability of the DSM project on the multi-shaft pumping system.

4.3.1 System constraints and parameters

The system constraints and parameters used in this study match the criteria used by the mine for each pumping system involved, and include:

- dam sizes and levels for both upstream and downstream dams
- maximum number of pumps allowed to operate simultaneously
- maximum number of pumps available
- number of available columns
- maximum number of pumps allowed to operate into a column simultaneously
- each individual pump's electrical consumption
- each individual pump's flow rate

Each of the parameters and constraints will be given for each pump station involved in the multi-shaft pumping system. It must be noted that all necessary precautionary measures have been incorporated into these values.

First, the constraints and parameters for the controller of the pump station on 16 Level will be given.

Table 9: 16 Level constraints and parameters

16 Level controller constraints	
Maximum number of pumps utilised	4
Maximum number of pumps available	6
Number of columns available	3
Number of pumps for each column	2
Each pump's electrical demand	2000 kW
Each pump's flow rate	± 120 l/s
Upstream	
Dam size	2 x 2Ml
Maximum dam level	80%
Minimum dam level	20%
Download	
Dam size	2 x 6.5 Ml
Maximum dam level	90%
Minimum dam level	40%

Second, the constraints and parameters for the controller of the pump station on 25 Level will be given.

Table 10: 25 Level constraints and parameters

25 Level controller constraints	
Maximum number of pumps utilised	4
Maximum number of pumps available	6
Number of columns available	2
Number of pumps for each column	2
Each pump's electrical demand	1800 kW
Each pump's flow rate	± 110 l/s
Upstream	
Dam size	2 x 2Ml 1 x 4Ml

Maximum dam level	80%
Minimum dam level	20%
Download	
Dam size	1 x 0.8 Ml
Maximum dam level	90%
Minimum dam level	40%

Last, the constraints and parameters for the controller of the pump station on 27 Level will be given

Table 11: 27 Level constraints and parameters

27 Level controller constraints	
Maximum number of pumps utilised	2
Maximum number of pumps available	3
Number of columns available	1
Number of pumps for each column	2
Each pump's electrical demand	2 x 800 kW 1 x 1800 kW
Each pump's flow rate	2 x ± 85 l/s ± 112 l/s
Upstream	
Dam size	1 x 2Ml
Maximum dam level	40%
Minimum dam level	12.5%
Downstream	
Dam size	2 x 2Ml
Maximum dam level	80%
Minimum dam level	20%

4.3.2 Calculating, building and optimising the simulation

Calculating the simulation

The first step for any simulation is to calculate the expected results. The results of the mathematical simulations performed in section 3.4 indicate the feasibility of the control on the multi-shaft pumping system. In addition, power usage based on the amount of water that must be pumped to the surface must be calculated. This calculation must be done for each shaft.

For Beatrix 1 shaft:

Amount of water pumped out daily	=	20.5 Ml
Water pumped hourly	=	20.5 Ml / 24 hours
	=	0.854 Ml/hr
Flow rate needed to achieve this	=	0.854 Ml/hr*(1x10^6liters/3600 seconds)
	=	237.27 l/s
Pump capacity on 16 Level	=	120 l/s
Average number of pumps needed	=	237.27 l/s / 120 l/s
	=	1.98 pumps

Daily number of hours pump operates	=	1.98 x 24
	=	47.45 pump hrs /day
The power used to pump 20.5 Ml/day	=	2000kW x 47.45
	=	**94 900 kWh per day**

For Beatrix 2 shaft:

Amount of water pumped out daily	=	10.2 Ml
Water pumped hourly	=	10.2 Ml / 24 hours
	=	0.425 Ml/hr
Flow rate needed to achieve this	=	0.425 Ml/hr*(1x10^6liters/3600 seconds)
	=	118.05 l/s
Pump capacity on 25 Level	=	110 l/s
Average number of pumps needed	=	118.05 l/s / 110 l/s
	=	1.07 pumps

Daily number of hours pump operates	=	1.07 x 24
	=	25.7 pump hrs /day
The power used to pump 10.2 Ml/day	=	1800kW x 25.7
	=	**46 260 kWh per day**

For Beatrix 3 shaft:

Amount of water pumped out daily	=	8.4 Ml
Water pumped hourly	=	8.4 Ml / 24 hours
	=	0.350 Ml/hr
Flow rate needed to achieve this	=	0.350 Ml/hr*(1x10^6liters/3600 seconds)
	=	97.22 l/s
Pump capacity on 27 Level	=	85 l/s or 112 l/s or average of 94 l/s
Average number of pumps needed	=	97.22 l/s / 94 l/s
	=	1.03 pumps or 0.868 l/s
Daily number of hours pump operates	=	1.03 x 24
	=	24.82 pump hrs /day
The power used to pump 8.4 Ml/day	=	1133kW x 24.82
	=	**28 129 kWh per day**

Therefore the total theoretical value for electricity usage for the multi-shaft pumping system is **169 289 kWh per day**

The next step is to calculate the financial benefits the mine can expect from the DSM project. From the simulation in section 3.4 it was theoretically possible to switch off all the pumps during the evening peak periods, but only some pumps during the morning peak period. Consequently, it is necessary to consider the multi-shaft system as a whole system to be able to calculate the potential savings.

This calculation requires comparison of the load shifted power baseline with the historical power baseline and, using the tariff structure, calculation of the savings can be obtained. The two baselines are shown in the table below:

Table 12: Historical and load shifted baselines

Hour	Historical Baseline (kW)	Load Shift Baseline (kW)
1	6656	7983
2	6761	5113
3	6761	9584
4	7241	5000
5	7740	9519
6	7721	9504
7	7694	9504
8	5650	2000
9	5502	2087
10	5724	2017
11	6298	6128
12	6910	8906
13	7567	8906
14	7596	6128
15	7636	8682
16	7806	8600
17	7615	8628
18	7235	8671
19	6925	150
20	6826	150
21	6900	7240
22	7073	11600
23	6976	11471
24	6898	10136

This gave a load shift result of 3.59 MW in the morning peak period and 6.72 MW in the evening peak period. The electricity cost for a specific hour is calculated as follows:

For hour 19 the energy use in the past was 6925 kW. The hourly tariff for hour 19 is 16.89 c/kWh in summer and 59.53 c/kWh during winter.

Therefore in summer = 6925 kW x 16.89 c/kWh

= R 1 169.60 per hour

In winter = 6925 kW x 59.53 c/kWh

= R 4 122.59 per hour

To determine the daily energy cost this process is repeated hourly and summated. To calculate the savings due to the load shift, the difference in total daily cost between the two power baselines is established. However, the total power used between the historical baseline and the load shift baseline must be the same per day. As the load shift baseline differs from day to day, the historical baseline must be scaled accordingly to provide accurate saving results.

Energy efficiency from the more efficient pumping schedule on Beatrix 1 Shaft necessitated calculation of the relationship between power usage and the amount of water pumped. Analysis of this relationship entailed the historical water data and the power consumed by the pumping stations for the same period. The amount of water pumped daily was plotted against the power used on that day, using the equation.

The amount of water pumped daily was plotted against the power used for that day. The graph of this result including the trend line and trend equation is shown in Figure 53.

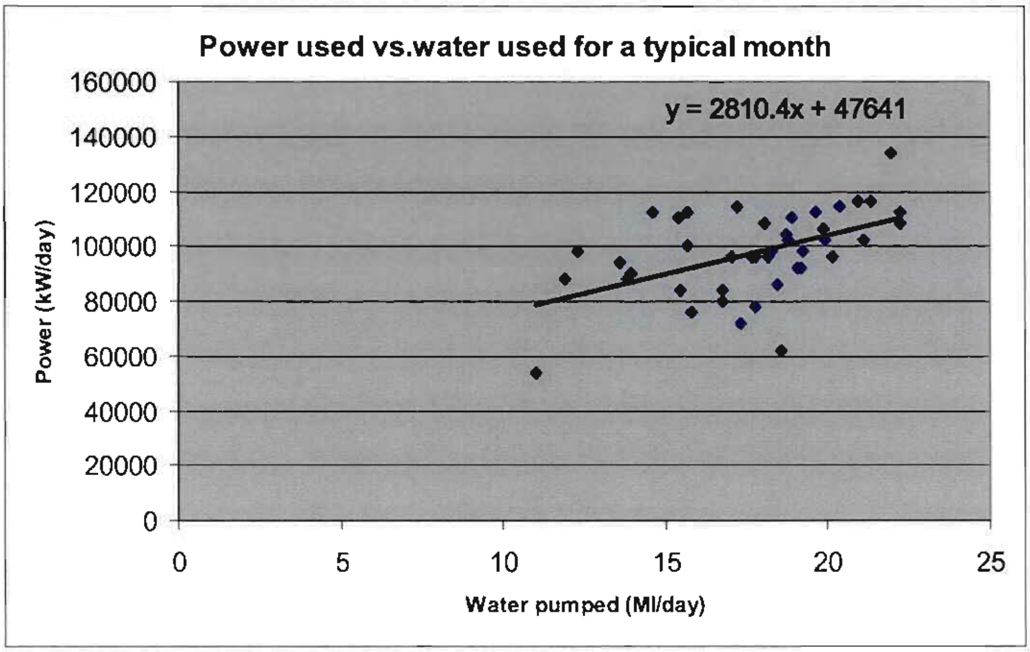


Figure 53: Beatrix 1# water pumped vs. power used and trend line equation

By using the equation:

$$y = 2810.4x + 47641$$

Where $y =$ power used to pump x amount of water and $x =$ amount of water pumped in Ml.

The power consumption that would have been used to pump a certain amount of water can be calculated and compared to the power consumption used during the more efficient scheduling of pump operation. From this, the overall load reduction due to the energy efficiency principles implemented on Beatrix 1 Shaft can be calculated.

On Beatrix 3 Shaft it was standard practise to run one MSG (800kW) and one MSJ (1800kW) pump together. The baseline used to calculate the load shift potential was acquired during this period of inefficient use of power.

- On Beatrix 3# mine, running one MSG and one MSJ pump together uses 2600 kW to pump 130 l/s.
- Running two MSG pumps together uses 1600 kW to pump 112 l/s.
- It is therefore much more efficient to run two MSG pumps, than running an MSG and an MSJ pump together.

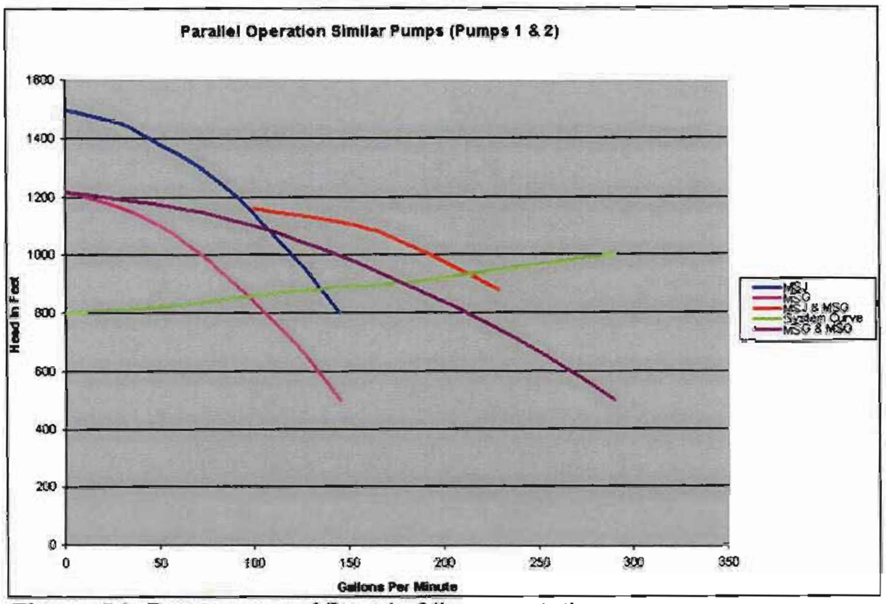


Figure 54: Pump curve of Beatrix 3# pump station

Figure 54 indicates the change in pump curve when:

- an MSJ pump runs on it's own
- an MSG pump runs on it's own
- an MSJ and an MSG pump runs together
- two MSG pumps run together

At Beatrix 3 Shaft it is only possible for a maximum of two pumps to run together. Three pumps running together will increase the risk for the column to burst.

The efficiency of a multistage pump is calculated as follows:

$$eff = P_{hydro} / P_{electric}$$

Where P_{hydro} is the output power of the pump and $P_{electric}$ the input power of the electrical motor.

$$P_{hydro} = \rho \times g \times Q \times H$$

Where Q is the flow rate and H the head of the pump.

On Beatrix 3 Shaft, according to the flow rate, if two MSG pumps (combined: 112l/s, 1600kW) runs the efficiency is:

$$eff = (\rho \times g \times Q \times H) / P_{electric}$$

$$eff = (1000 \times 9.81 \times 0.117 \times 500) / 1600kW$$

$$eff = 35.8\%$$

If one MSG- and one MSJ- pump runs (combined 130l/s 2600kW) the efficiency is:

$$eff = (\rho \times g \times Q \times H) / P_{electric}$$

$$eff = (1000 \times 9.81 \times 0.13 \times 500) / 2600kW$$

$$eff = 24\%$$

Note that all units for the equations given above are metric units.

Building and optimising the simulation

In this section the building and optimisation of the simulation for the multi-shaft pumping system on the REMS Platform will be discussed in detail. After this simulation has been completed the load shift value for the multi-shaft pumping system can be accurately specified.

The simulation for the multi-shaft pumping system in the REMS Platform is given in Figure 55. The simulation included the load shift and energy efficiency principles discussed in Chapter 2. The results of the simulation were verified and efforts were made to optimise the control system to give the best possible results.

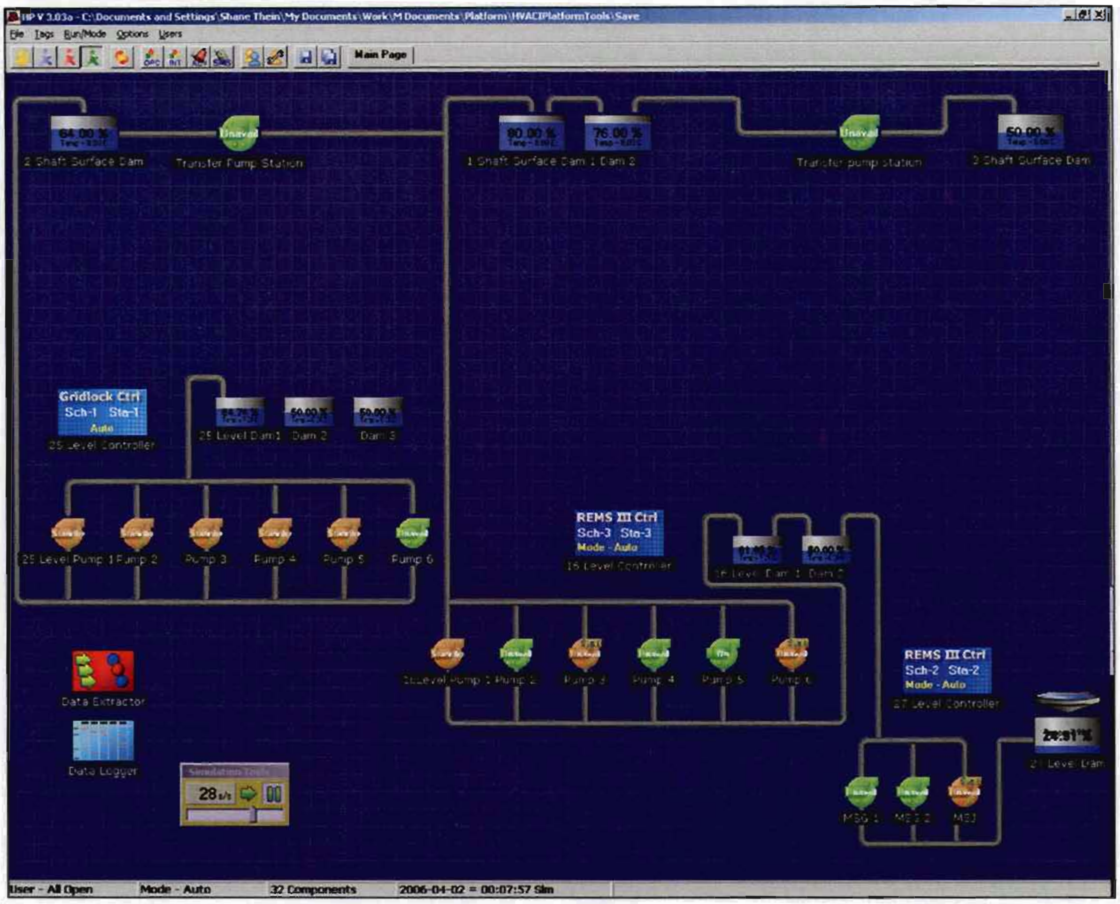


Figure 55: REMS simulation for Beatrix 1, 2 and 3 shaft pumping system

After a number of iterations optimising the control system, the best possible scenario was achieved, whilst keeping within the system constraints and parameters. The following load shift result was attained: a load shift result of 6.2 MW during the evening peak period was achieved, with an average of 4.0 MW during the morning peak period. The power baseline of the REMS control system for the multi-shaft pumping system is given in Figure 56, together with the historical power baseline. It shows the different power usage according to the time of day.

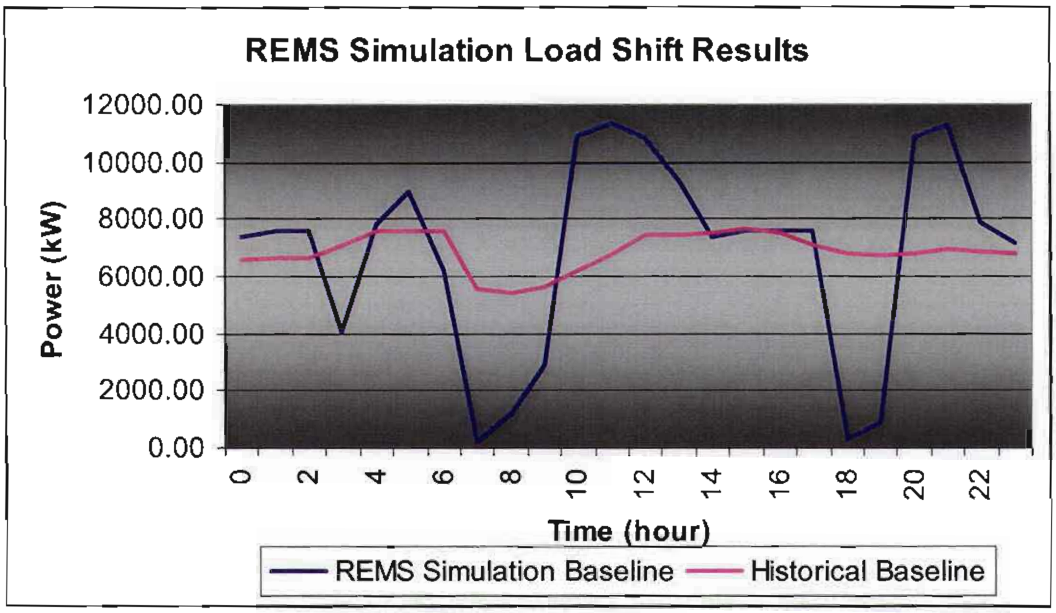


Figure 56: REMS simulation baseline vs. historical baseline

The simulation included the energy efficiency principles discussed earlier to reduce the load needed to pump a certain amount of water. However, the load shift value calculated from the simulation results did not incorporate the energy efficiency value. This is due to the energy efficiency value varying with the amount of water pumped each day, and the availability of the appropriate pumps needed to implement the efficiency principles.

This result allows the conclusion that the target load shift value is 6.0 MW during the evening peak, and takes into account some dynamics in the system such as non-constant water usage and flow rates. In international context the load shift value for the morning peak is not important but the evening load shift is of critical value for Eskom and for DSM programmes in South Africa.

Further, the dam levels were monitored to ensure that the simulation achieved the desired result while complying with constraints and parameters. Dam levels for the up and down stream dams for each of the pump stations are shown in Figure 57, Figure 58, Figure 59.

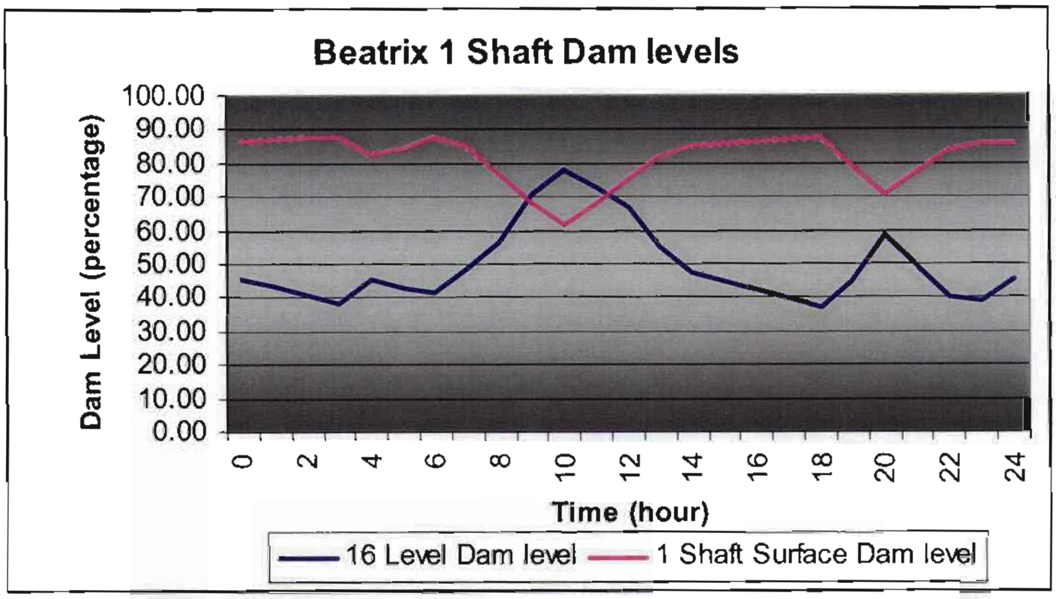


Figure 57: Beatrix 1 Shaft simulated dam levels

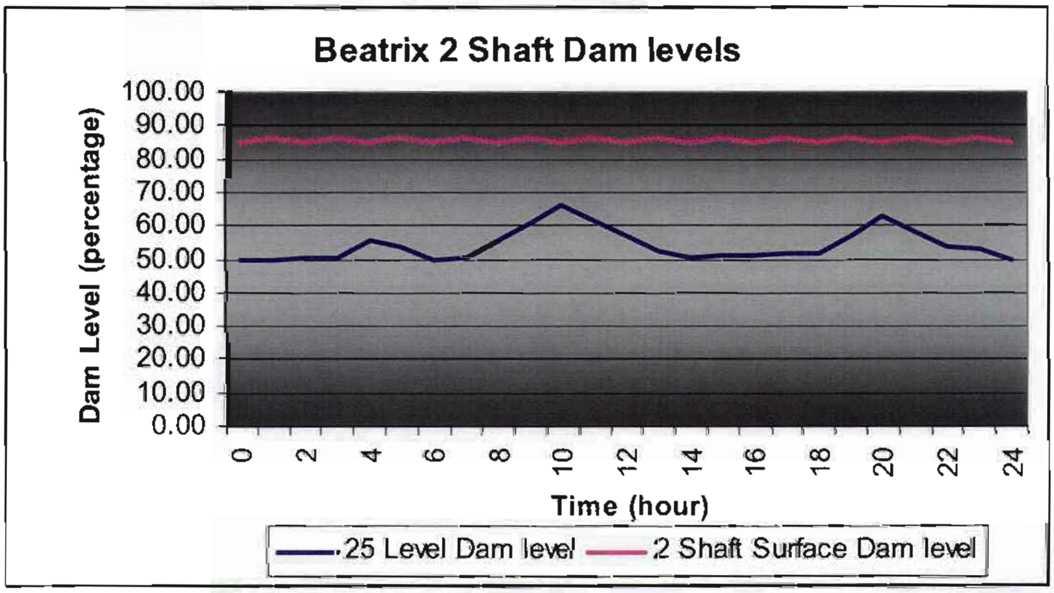


Figure 58: Beatrix 2 Shaft simulated dam levels

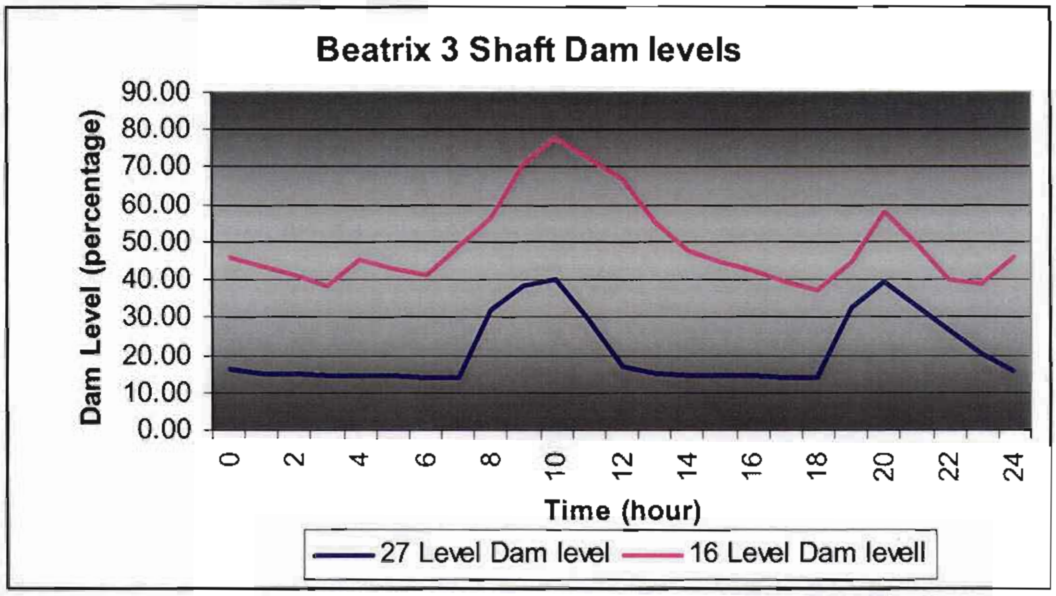


Figure 59: Beatrix 3 Shaft simulated dam levels

This verified that the result achieved was acquired safely and complied with the parameters and constraints of the system.

4.3.3 Software control philosophy

The control philosophy used for the multi-shaft pumping system will be discussed in this section and the individual control philosophy if each shaft will be given in detail. There are two main factors which determine how the pumps on each shaft should be scheduled: the first is the tariff according to the time of day - this was discussed in section in 3.2 and the tariffs can be seen in Figure 20 and Figure 21; and the second is to ensure safe dam levels at all times.

Beatrix 1 shaft

Following is a description of the control philosophy for the REMS pumping system on Beatrix 1 Shaft. It gives a detailed explanation of how the system will behave depending on the water levels and time of day.

Morning Peak: 07:00 - 10:00

Evening Peak: 18:00 - 20:00

Off-Peak: 00:00 - 07:00, 10:00 - 18:00, 20:00 - 00:00

- The duration of the morning peaks is longer than evening peaks, so there are usually a greater number of pumps scheduled for the morning peaks.
- The dam level mentioned in this document is the level of the active dam – this could be either dam 1 or 2.

At 16 Level, the REMS controller gives the 16 Level Dam priority over the 1 Shaft Surface Dam. The minimum and maximum levels as well as the top and bottom offsets for the 16 Level Dam are given in Table 13.

Table 13: 16 Level dam levels

16 Level Dam	Max	75%
	Min	35%
	Offset	7%

The control range is the range within which the dam level can fluctuate before a pump is stopped or started, and the range differs with the time of the day. Table 14 shows the control range with its corresponding time.

Table 14: 16 Level control range

Control Range	Time (hour)	Range
Off-Peak	0-5	20
Before Peak	5-7	10
Morning Peak	7-10	20
Off-Peak	10-15	20
Before Peak	15-18	10
Evening Peak	18-20	20
Off-Peak	20-0	20

Using all the above values, the system will behave in the following way:

Table 15: 16 Level system behaviour

Evening Peak		Off-Peak		Before Peak		Morning Peak	
Start 3	87%	Start 3	69%	Start 3	59%	Start 3	83.40%
Start 2	80%	Start 2	62%	Start 2	52%	Start 2	76.40%
Start 1	73%	Start 1	55%	Start 1	45%	Start 1	69.40%
Stop 1	35%	Stop 1	35%	Stop 1	35%	Stop 1	35%
Stop 2	28%	Stop 2	28%	Stop 2	28%	Stop 2	28%
Stop 3	21%	Stop 3	21%	Stop 3	21%	Stop 3	21%

Beatrix 2 shaft

Following is a description of the control philosophy for the REMS pumping system on Beatrix 2 Shaft. It gives a detailed explanation of how the system will behave depending on the water levels and time of day. As stated in Beatrix 1 Shaft:

Morning Peak: 07:00 - 10:00
Evening Peak: 18:00 - 20:00
Off-Peak: 00:00 - 07:00, 10:00 - 18:00, 20:00 - 00:00

- The duration of the morning peaks is longer than evening peaks, so there are usually a greater number of pumps scheduled for the morning peaks.
- The dam level mentioned in this document is the level of the active dam.

At 25 Level the REMS controller gives the 25 Level Dam priority over the 2 Shaft Surface Dam. However, this is overridden when the down stream dam (i.e. the Surface Dam at 2 Shaft) is above 100% - which means that no pumps will operated. Table 16 shows the grid schedule of the grid controller on Beatrix 2 Shaft.

Table 16: Beatrix 2 Shaft grid schedule

Dam Level	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
30%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40%	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	1	0	0	1	1	1	1
45%	2	2	2	2	2	2	2	0	0	0	2	2	2	2	2	2	2	2	0	0	2	2	2	2
50%	2	2	2	2	2	2	2	0	0	0	2	2	2	2	2	2	2	2	0	0	2	2	2	2

60%	3	3	3	3	3	3	3	1	1	1	2	2	2	2	2	2	3	3	1	1	3	3	3	3
65%	3	3	3	3	3	3	3	2	2	2	3	3	3	3	3	3	3	3	2	2	3	3	3	3
70%	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
75%	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
80%	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

Beatrix 3 shaft

Following is a description of the control philosophy for the REMS pumping system on Beatrix 3 Shaft. It gives a detailed explanation of how the system will behave depending on the water levels and time of day. As stated in Beatrix 1 Shaft:

Morning Peak: 07:00 - 10:00

Evening Peak: 18:00 - 20:00

Off-Peak: 00:00 - 07:00, 10:00 - 18:00, 20:00 - 00:00

- The duration of the morning peaks is longer than evening peaks, so there are usually a greater number of pumps scheduled for the morning peaks.
- The dam level mentioned in this document is the level of the active dam.

At 27 Level, the REMS controller gives the 27 Level Dam priority over the active dam at 16 Level on 1 Shaft. The minimum and maximum levels as well as the top and bottom offsets for the 27 Level dam are given in Table 17.

Table 17: 27 Level dam levels

27 Level Dam	Max	40%
	Min	12.5%
	Offset	5%

The control range is the range within which the dam level can fluctuate before a pump is stopped or started, and the range differs with the time of the day. Table 18 shows the control range with the corresponding time.

Table 18: 27 Level control range

Control Range	Time (hour)	Range

Off-Peak	0-5	15
Before Peak	5-7	10
Morning Peak	7-10	15
Off-Peak	10-15	15
Before Peak	15-18	10
Evening Peak	18-20	15
Off-Peak	20-0	15

Using all the above values, the system will behave in the following way:

Table 19: 27 Level system behaviour

Evening Peak		Off-Peak		Before Peak		Morning Peak	
Start MSJ + MSG	40%	Start MSJ + MSG	40%	Start MSJ + MSG	37.5%	Start MSJ + MSG	40%
Start 2 MSG	37.5%	Start 2 MSG	37.5%	Start 2 MSG	32.5%	Start 2 MSG	37.5%
Start 1 MSG	32.5%	Start 1 MSG	32.5%	Start 1 MSG	27.5%	Start 1 MSG	32.5%
Stop 1 MSG	17.5%	Stop 1 MSG	17.5%	Stop 1 MSG	17.5%	Stop 1 MSG	17.5%
Stop 2 MSG	12.5%	Stop 2 MSG	12.5%	Stop 2 MSG	12.5%	Stop 2 MSG	12.5%
Stop MSJ	32.5%	Stop MSJ	32.5%	Stop MSJ	27.5%	Stop MSJ	32.5%

4.3.4 Implementation and problems encountered

This section discusses the implementation of the control system on the multi-shaft pumping system on Beatrix 1, 2 and 3 Shafts. It will include infrastructures installed on the mine with some graphical illustrations, and the installation of REMS software for the control system. In addition, problems encountered during and after the implementation of the DSM project, plus the expected savings, are discussed.

Implementation

In section 3.3 the necessary infrastructure needed for the successful implementation of the DSM project on the multi-shaft pumping system on Beatrix 1, 2 and 3 Shafts were discussed. Firstly all hardware necessary for the automation of the pumps are installed. The following figure shows a pump on 27 Level at Beatrix 3 Shaft.

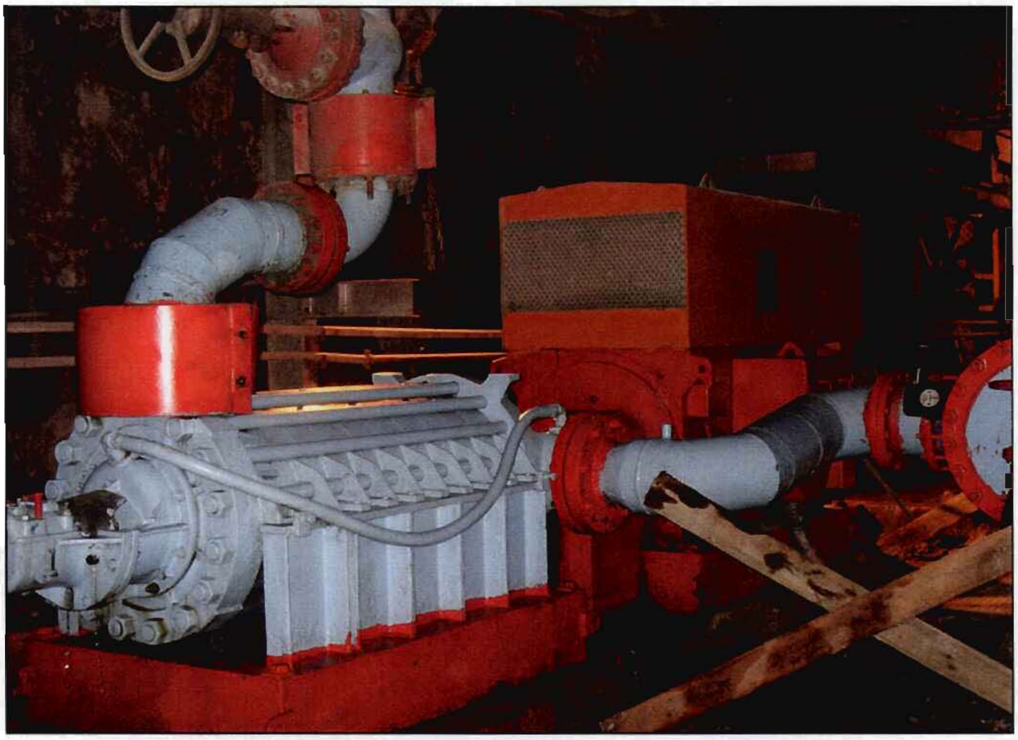


Figure 60: Pump on 27 Level Beatrix 3 Shaft

Following the completion of the hardware installation, network and communication equipment had to be installed to ensure the feasibility of control from a single point. The layout of the communication network installed on Beatrix 1, 2 and 3 Shaft is given in APPENDIX B: Communication Network Layout. The control room is situated on Beatrix 3 Shaft, from where the entire system is monitored and controlled.

The SCADA system that was installed for the multi-shaft pumping system was Intouch 9.5. The following figures illustrate the SCADA system on Beatrix 1, 2 and 3 Shaft pumping system.

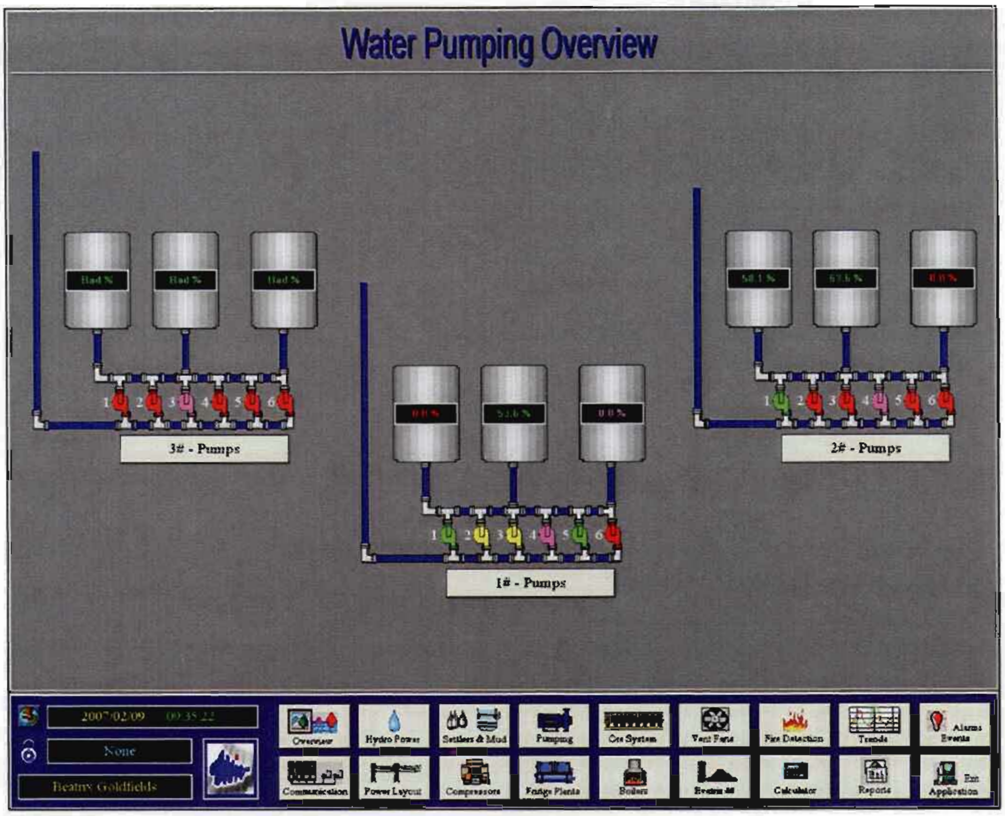


Figure 61: Beatrix 1, 2 and 3 Shaft water pumping overview

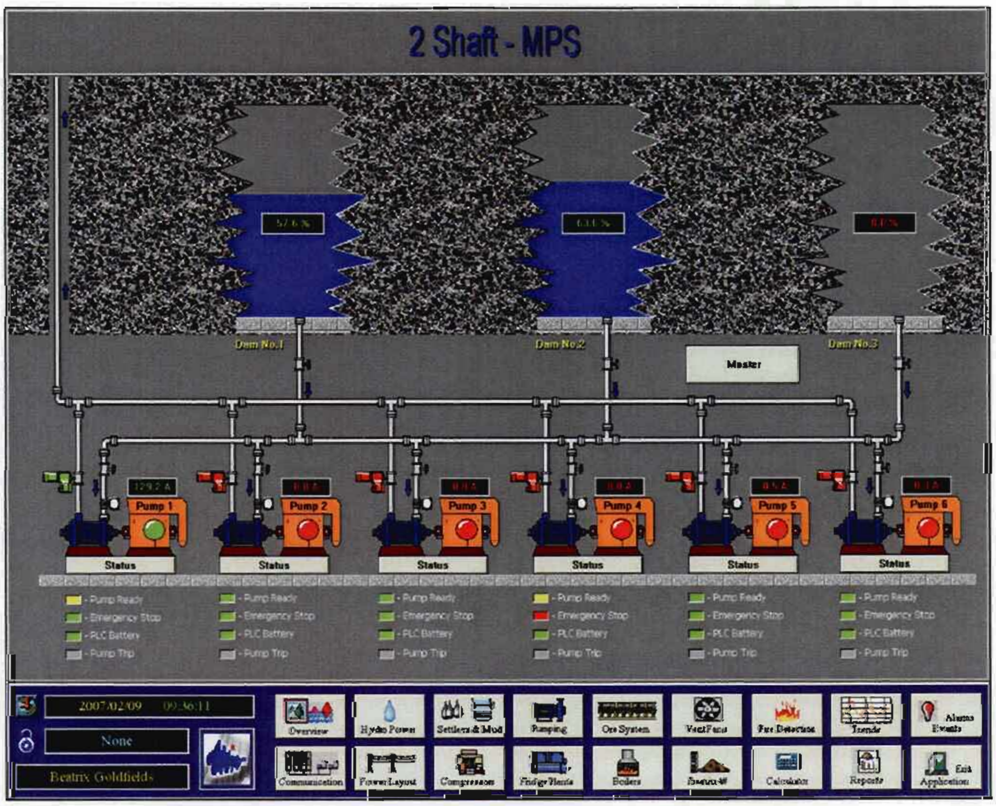


Figure 62: Beatrix 2 Shaft pump station overview

Figure 61 shows the water pumping overview of the multi-shaft system, and Figure 62 shows the pump station overview for each shaft. Figure 63 shows a pump and all the values of the SCADA monitors. The communication monitoring section of the SCADA system is shown in Figure 64. If the icon is green, it shows that the communication link is working, if red, that the communication link is down.

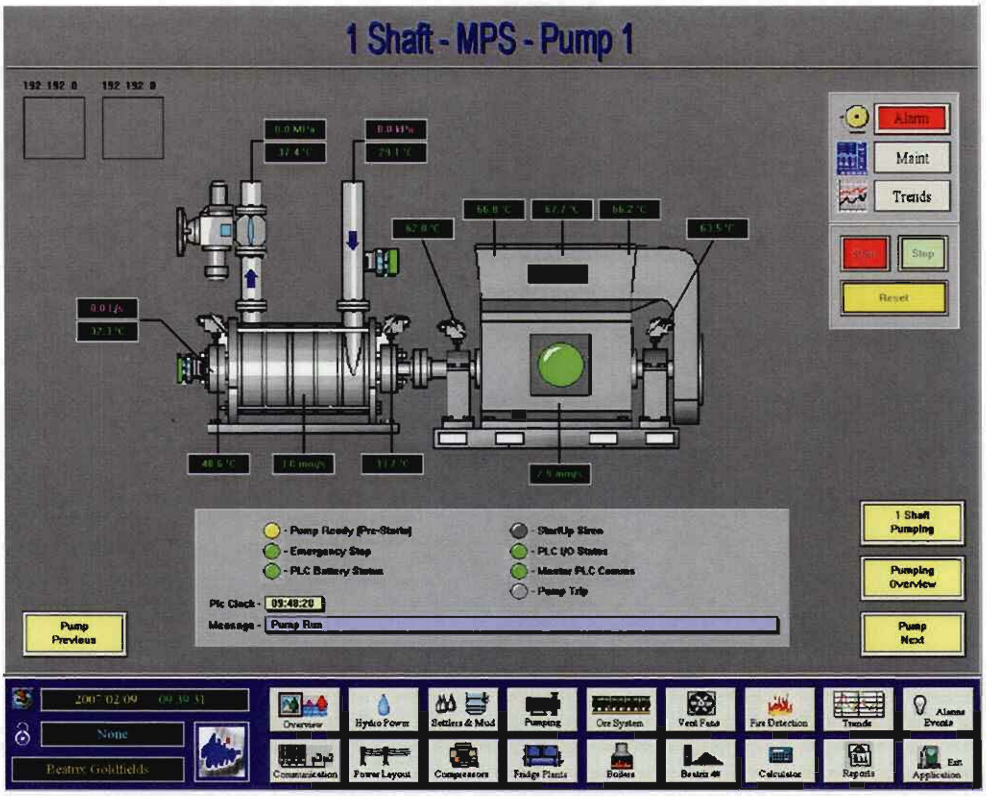


Figure 63: Typical pump in SCADA

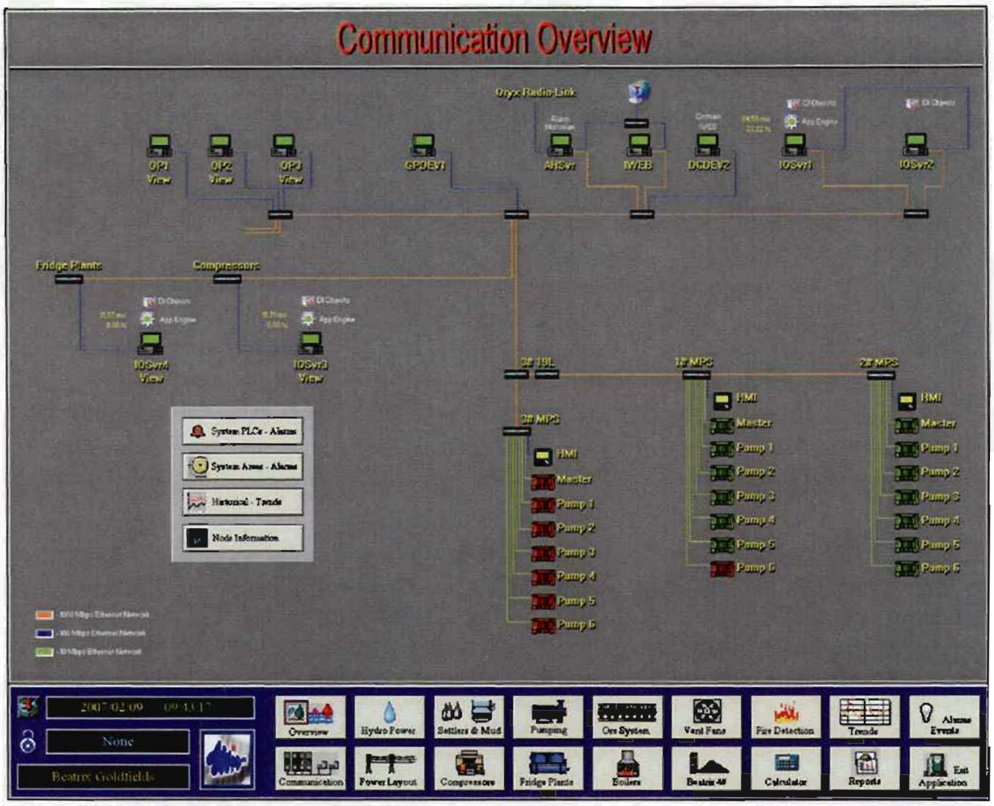


Figure 64: Communication overview

After the installation of the hardware and the communication network, the servers from which REMS operate on is installed in the control room and REMS is installed on the server. Figure 65 shows the complete REMS system of the multi-shaft pumping system of Beatrix 1, 2 and 3 Shafts. The monitor on the left in Figure 65 is the REMS system on Beatrix 4 Shaft. It is monitored via a radio link and enables overall supervision of both projects.

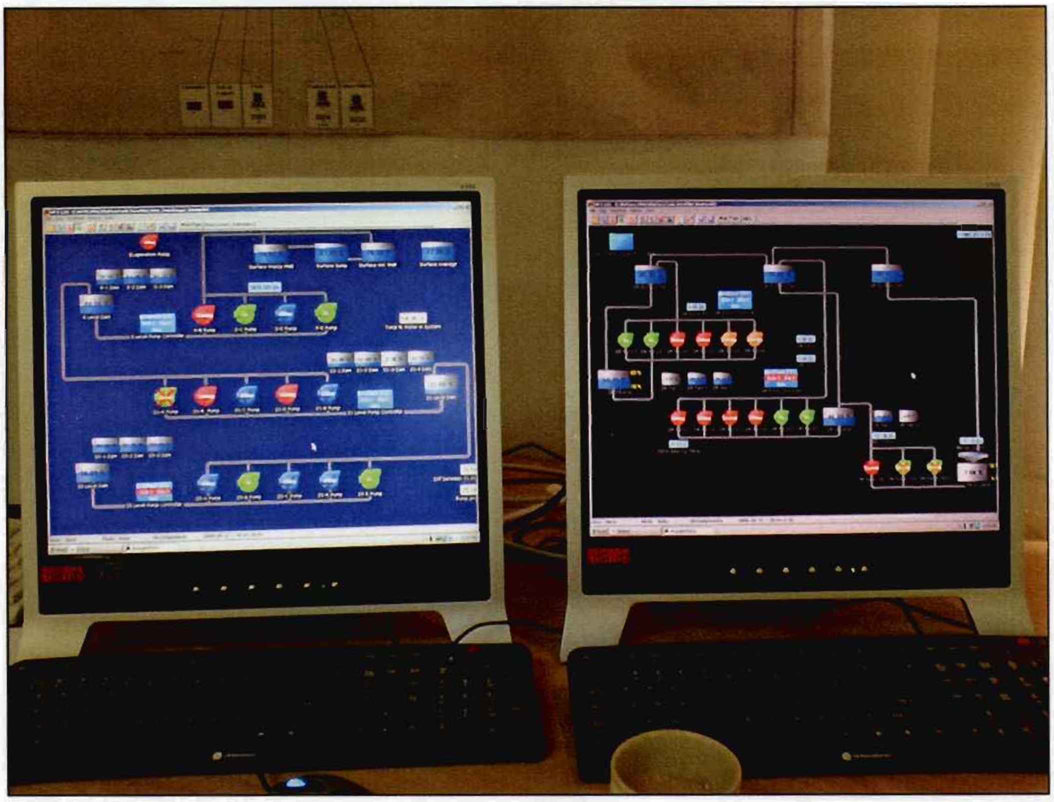


Figure 65: REMS system for Beatrix 1, 2 and 3 shafts

Problems encountered

The first and most problematic issue for the DSM project implemented for the multi-shaft pumping system on Beatrix 1, 2 and 3 Shaft is the pumping system layout changes on Beatrix 3 Shaft. The current layout used in this study will be changed to accommodate more water usage and storage, and it was not feasible to install automated infrastructure on pumps that are to be replaced.

The plan was to complete the installation of the new pump station by the end of the automation period of both 1 Shaft and 2 Shaft but the new pump station project was delayed. As a result, Beatrix 3 Shaft is kept on manual control for the pumps, while the scheduling for the operation of the pumps is calculated by REMS. The control room operators on Beatrix 3 Shaft will operate the pumps according to the REMS schedule. REMS will alert the operators every time the schedule changes to ensure that changes in the schedule are followed.

The installation of SCADA and the automated infrastructure for this project have accommodated changes expected in respect of the new pump station. In addition, all necessary equipment has been made available to the mine. This can be seen on the SCADA system as shown in Figure 66. This figure indicates that there is no communication link because none of the equipment had been installed.

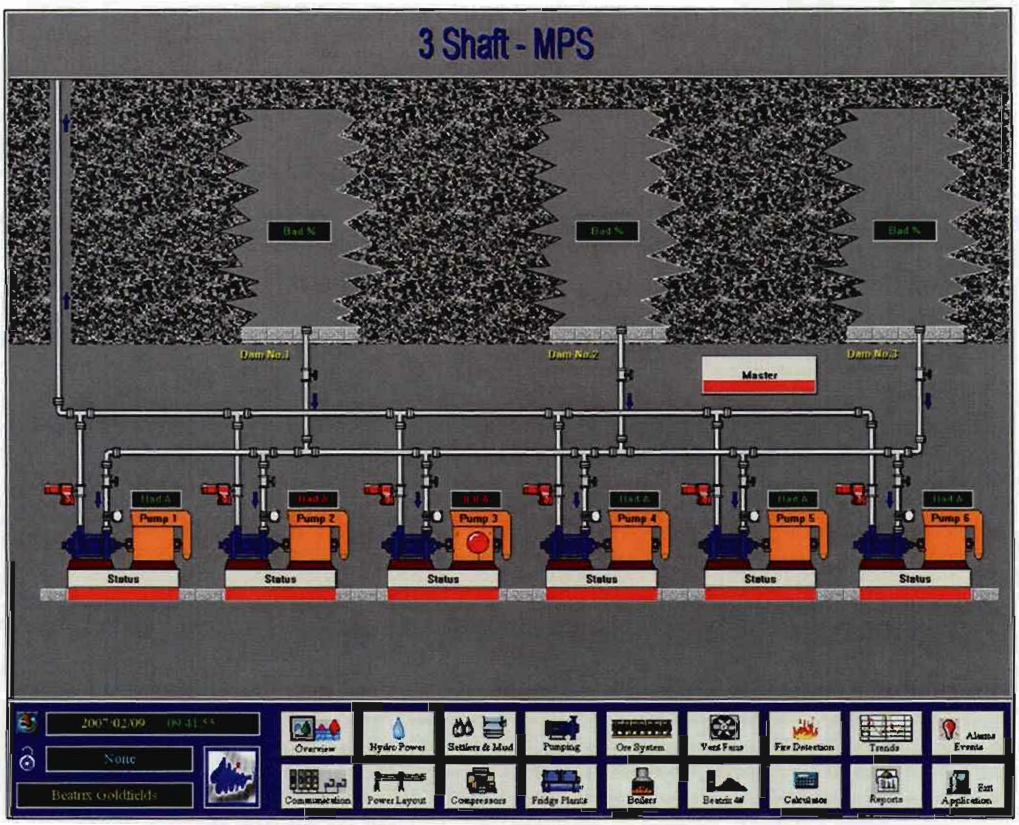


Figure 66: Beatrix 3 Shaft new pump station on SCADA

The human factor involved with the control system on Beatrix 3 Shaft gives rise to the expectation that performance of the load shifting will be affected negatively. This will be further verified in Chapter 5 which discusses the actual results of the control system. Once the installation of the new pump station is complete, an investigation will be launched to determine the new power consumption. This will establish the power consumption required to pump the same amount of water, and the baseline will be increased or decreased accordingly.

The second problem involved the poor state and old age of the pumps which meant that the automation stage of the pumps was considerably delayed. This included old solenoids and broken valves that needed to be fixed or replaced. The third issue was to do with pumps tripping on start-up or after a short time period due to electrical and PLC failures caused by the cycling of pumps. This resulted in reduced pump life, increased maintenance costs, and an inability to prepare dams for the peak periods which, in turn, resulted in reduced load shifting.

The last problem was the increased inflow of water into 27 Level dam on Beatrix 3 Shaft. This is due to the unpredicted increased water usage by miners, cooling and drilling operation. This made the dam level too high for load shifting during the evening peak and, consequently, no pumps could be switched off at the 27 Level pump station. This caused the 16 Level dam on Beatrix 1 Shaft to receive additional water during the evening peak. As a result, the pumps on 16 Level pump station will need to be started earlier and hence, less load shifting.

The high inrush of water starts after 10:00 am and continues until 03:00 pm and the flow rate is usually around 130 l/s. Due to the limited selection of pumps in the 27 Level pump station it is impossible to pump enough water before the evening peak period and at the same time implement energy efficiency principles on 27 Level pump station. Accordingly, the inefficient configuration of the MSG and MSJ pump had to be used to compensate for the increased flow rate during 10:00 am to 03:00 pm.

Use of the inefficient configuration meant that the load shift result during the evening peak increased from 500 kW to 1.3 MW. The historical baseline for Beatrix 3 Shaft was determined during use of the inefficient configuration, so the mine will still save on average R120.00 per day during summer and R1 000 per day during winter. The figure below shows the power profiles of the two different pump configurations.

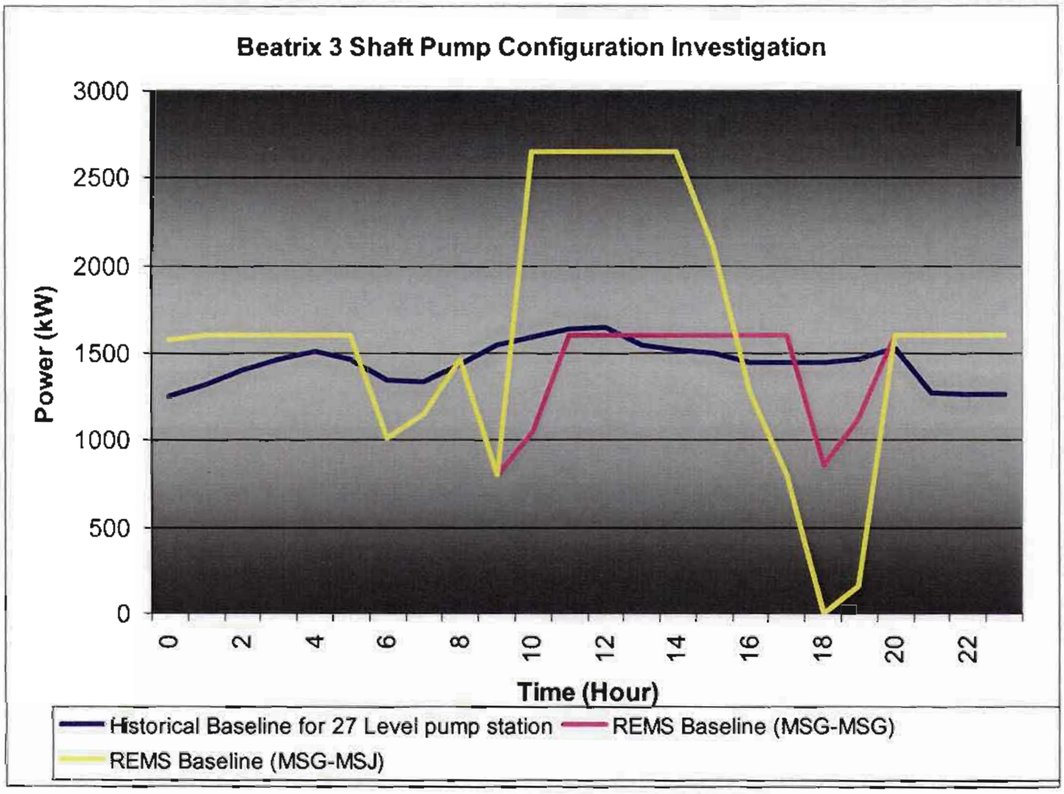


Figure 67: Power profile difference between the two pump configurations

Expected results

Results of the simulation determined the target load shift value in MW, and confirmed that the optimised load shift baseline can be used to calculate expected savings for the project. Calculation of the expecting savings was attained by using the two baselines in Table 12 and the MegaFlex tariff structure. The project anticipated savings of a 6.7 MW load shift, please note that the actual savings will be less then the results shown in Table 20.

Table 20: Expected savings

Average winter monthly savings	R 257 585
Average summer monthly savings	R 44 232
Yearly expected savings	R 1 170 848

4.4 Conclusion

This chapter discussed the implementation of the control system for the multi-shaft pumping system in REMS, as well as the steps taken to automate the pumping stations. Further, the load shift target for the multi-shaft pumping system was set at 6.0 MW for the evening peak period, and the implementation of the project, the problems encountered, and the expected savings were discussed.

Determining whether or not the implementation was successful requires analysis and verification of the results of the implemented system. Chapter 5 will discuss the results of the implementation and only if the results are satisfactory can this implementation be considered successful.

CHAPTER 5: RESULTS

5.1 Introduction

This chapter discusses the results of the energy management system on the multi-shaft pumping system. The results were derived over a four month period after implementation of the system. The aim of this study was to successfully implement DSM on a multi-shaft pumping system. Verification of the success of this study depends on the implemented system reaching the specified load shift target.

The verification methods used to analyse the results will be discussed and the validated results will be shown. Furthermore, the financial savings that resulted from the DSM project on the multi-shaft pumping system will be calculated.

5.2 Load shift achieved

An essential part of the DSM programme is the work of a Measurement and Verification (M&V) team that is independent of all parties involved (i.e. Eskom, ESCO and the mines). The M&V team must quantify the impacts and sustainability resulting from the DSM programmes [40] and ensures that all necessary steps are taken to guarantee the completion of the project. A post-implementation report is issued by the M&V team to certify that the project has reached the completion stage.

The next step is the performance assessment stage which delivers a monthly report over a three-month period. This ensures that the project did, in fact, deliver on the promised load shift value. Following the performance assessment stage, the performance tracking phase, aimed at ensuring the sustainability of the DSM project, will begin. For more information on M&V methods please refer to [40]

The DSM project on the multi-shaft pumping system on Beatrix 1, 2 and 3 Shafts was commissioned in July 2006. The results of the performance assessment period (for the three months from July to September 2006) and the performance tracking phase (in October 2006) are discussed.

In July 2006, a load shift value of 5.24 MW was achieved during the evening peak. Figure 68 shows the average load profile for July 2006 and Figure 69 shows the morning and evening load shift values for July 2006.

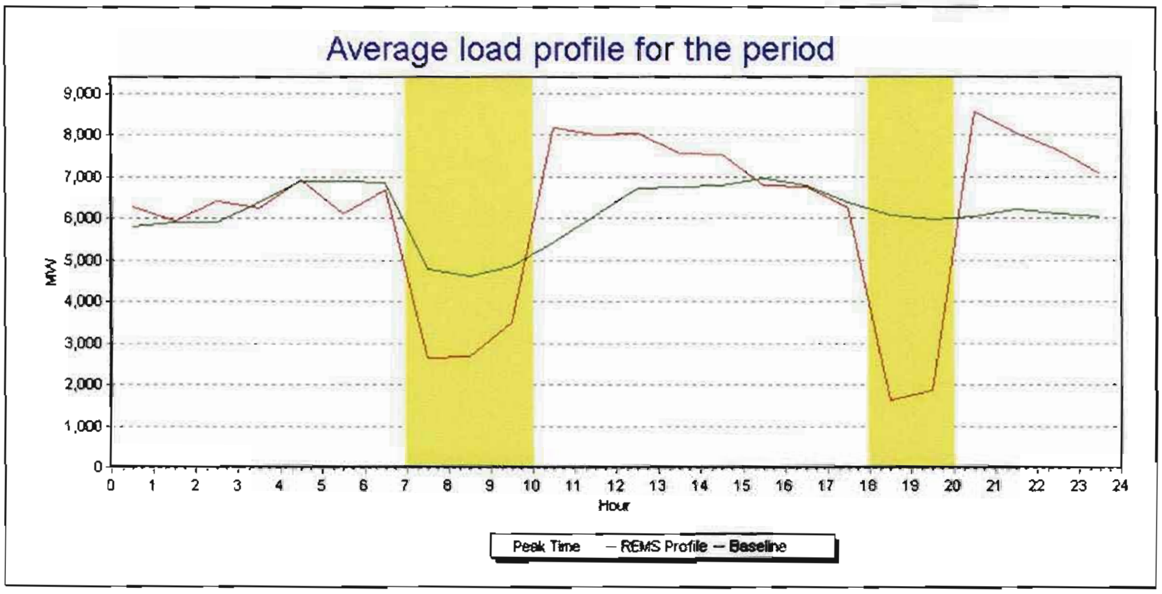


Figure 68: Average load profile for July 2006

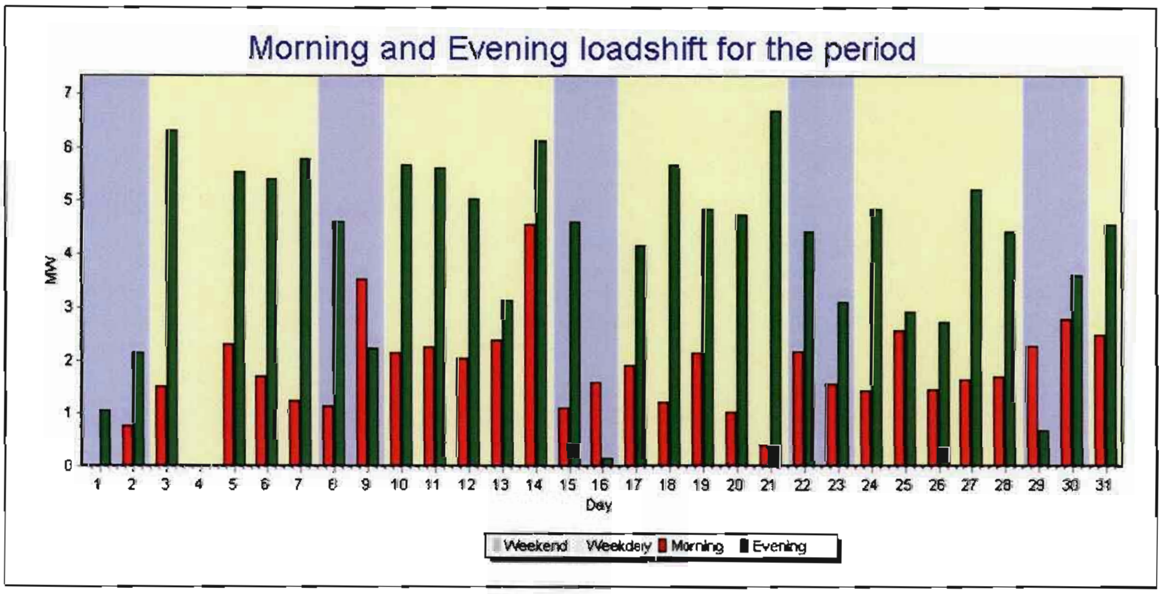


Figure 69: Morning and evening load shift values for July 2006

In August 2006, a load shift value of 4.68 MW was achieved during the evening peak. Figure 70 shows the average load profile for August 2006 and Figure 71 shows the morning and evening load shift values for August 2006.

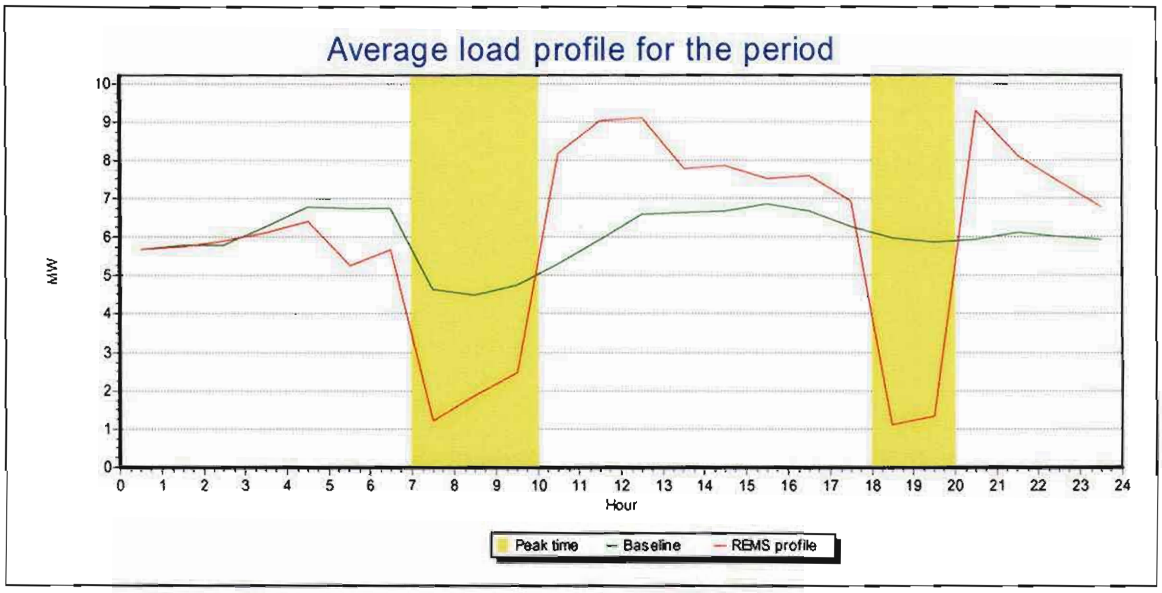


Figure 70: Average load profile for August 2006

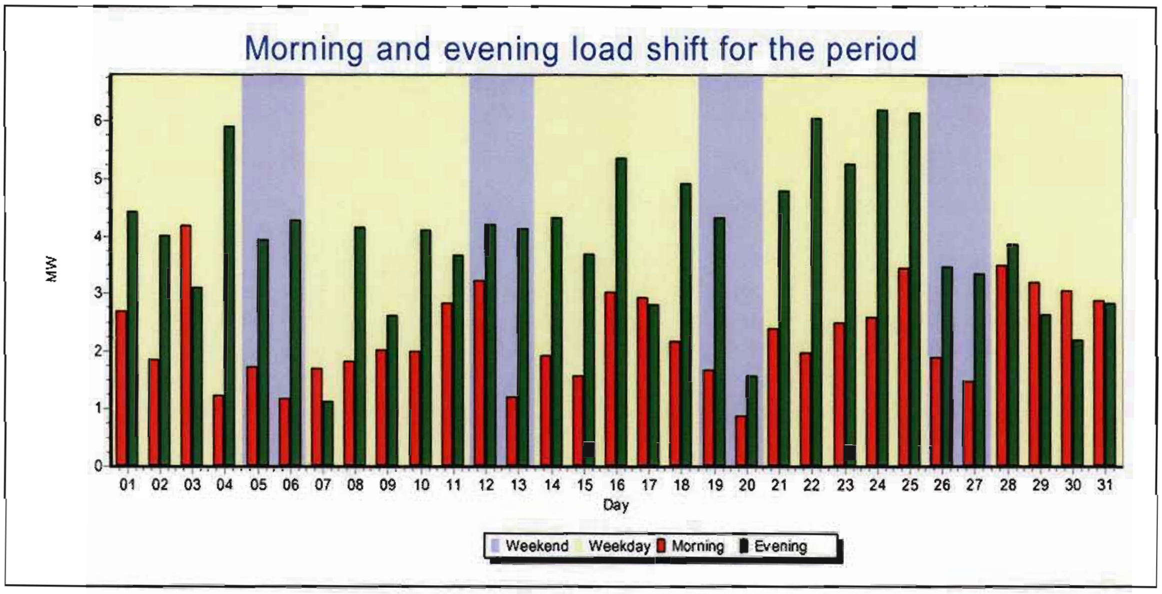


Figure 71: Morning and evening load shift values for August 2006

In September 2006, a load shift value of 5.46 MW was achieved during the evening peak. Figure 72 shows the average load profile for September 2006 and Figure 73 shows the morning and evening load shift values for September 2006.

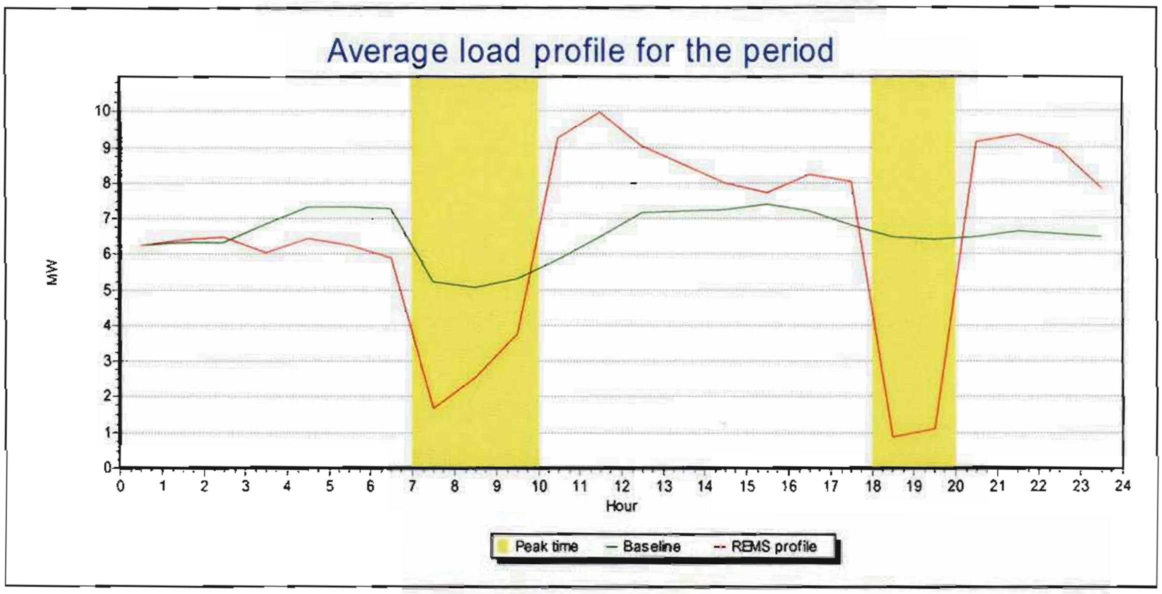


Figure 72: Average load profile for September 2006

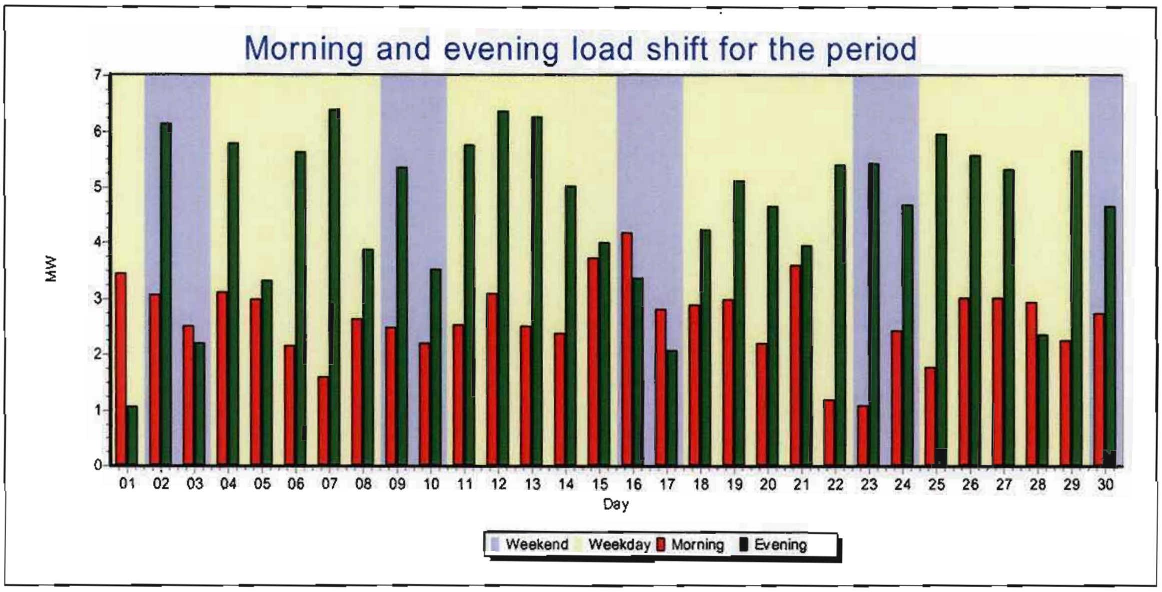


Figure 73: Morning and evening load shift values for September 2006

In October 2006, a load shift value of 5.05 MW was achieved during the evening peak. Figure 74 shows the average load profile for October 2006 and Figure 75 shows the morning and evening load shift values for October 2006.

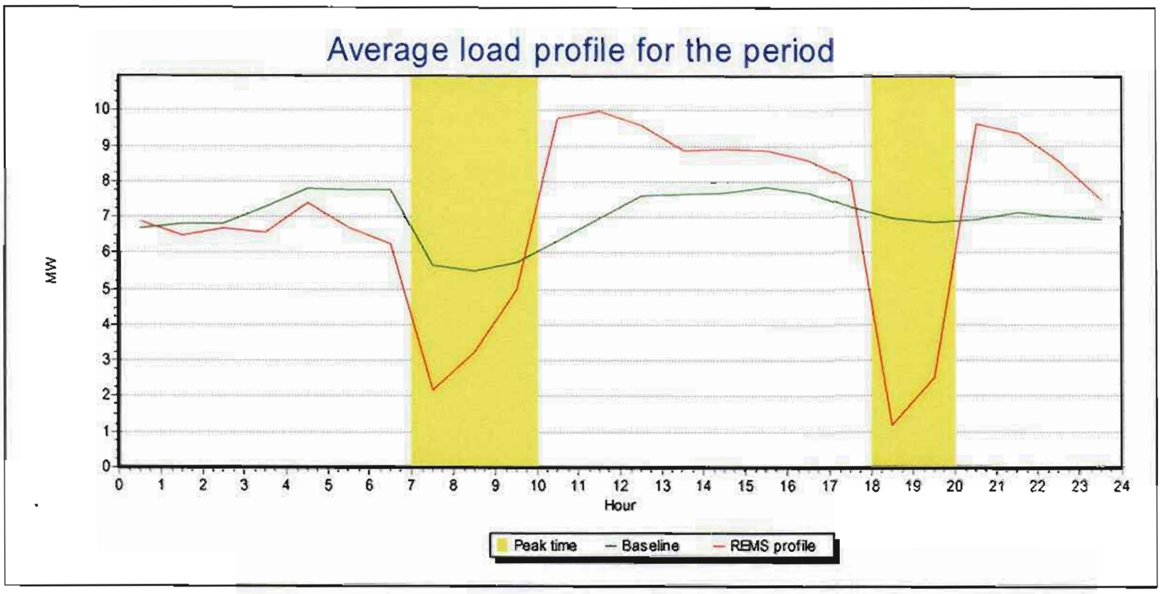


Figure 74: Average load profile for October 2006

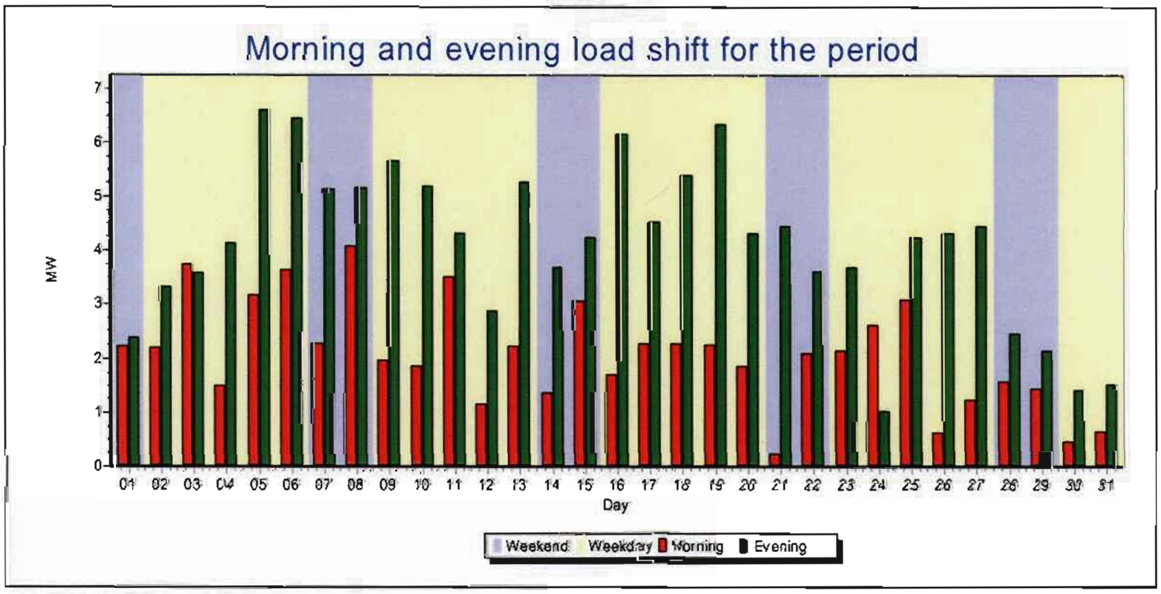


Figure 75: Morning and evening load shift values for October 2006

In summary, the MW value shifted during July to October 2006 is given in Table 21.

Table 21: Summarised load shift results

Evening load shift value	
July 2006	5.24 MW
August 2006	4.68 MW
September 2006	5.46 MW
October 2006	5.05 MW

These results show that the load shift target value was not reached over the four month period. This is attributable to the manual operation of the pump station on Beatrix 3 Shaft. Figure 68, Figure 70, Figure 72 and Figure 74 show that the target of 6 MW is reachable on certain days but, due to the late response of pump operators, the load shifted values during the peak periods were reduced.

In addition, the energy efficiency principles implemented in the 16 Level pump station on Beatrix 1 Shaft have not been taken into account. The power usage to water pumped relationship described in section 4.3.2 was reviewed by the M&V team and was deemed satisfactory and accurate for use in the calculation of the results.

Hence, having considered the energy efficiency, the MW value shifted during July to October 2006 is given in Table 22.

Table 22: Summarised load shift results after considering energy efficiency

Evening load shift value	
July 2006	6.30 MW
August 2006	6.13 MW
September 2006	6.02 MW
October 2006	5.92 MW

These results show that, by taking the energy efficiency into account, the load shift target of 6.0 MW is reachable. This conclusion acknowledges the late responses of the pump operators on Beatrix 3 Shaft, which also confirms that, if the pump station at 27 Level was automated, the load shift result would be higher.

5.3 Financial benefits

This section discusses the financial savings due to the DSM programme on the multi-shaft pumping system and calculates the financial savings, with and without considering the energy efficiency.

In July 2006, the savings achieved for the 5.24 MW load shift were calculated to be R129 019. The month of July falls under the winter tariff structure and after taking the energy efficiency into account, the savings for July were calculated to be R240 254.

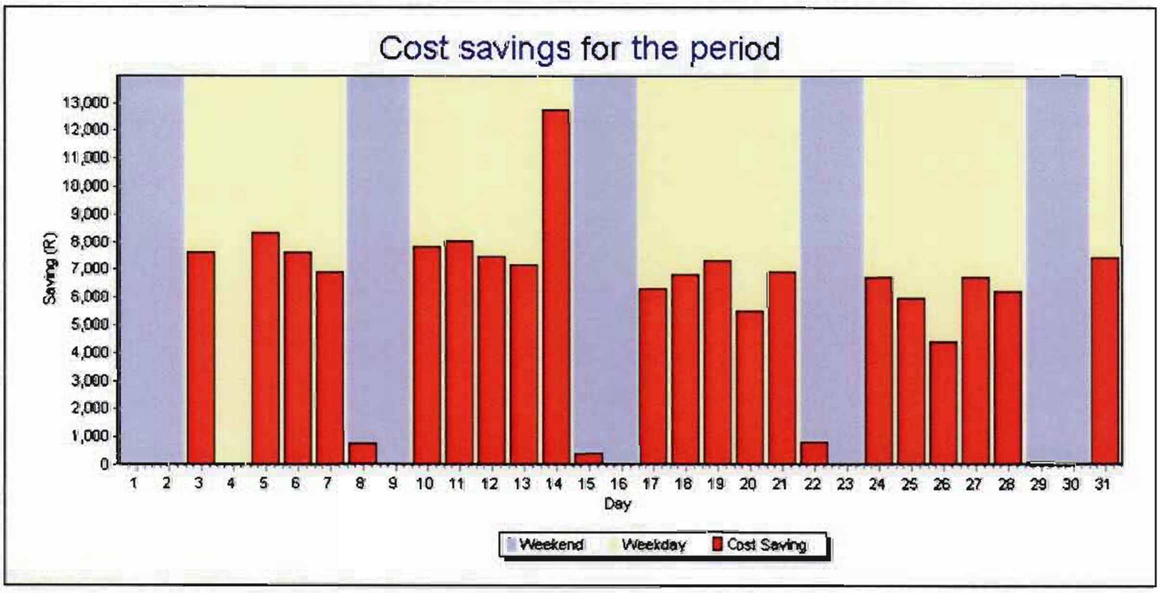


Figure 76: Rand savings for July 2006 without energy efficiency

In August 2006, the savings achieved for the 4.68 MW load shift is calculated to be R137 459. The month of August falls under the winter tariff structure. After taking the energy efficiency into account the savings for August was calculated to be R367 928.

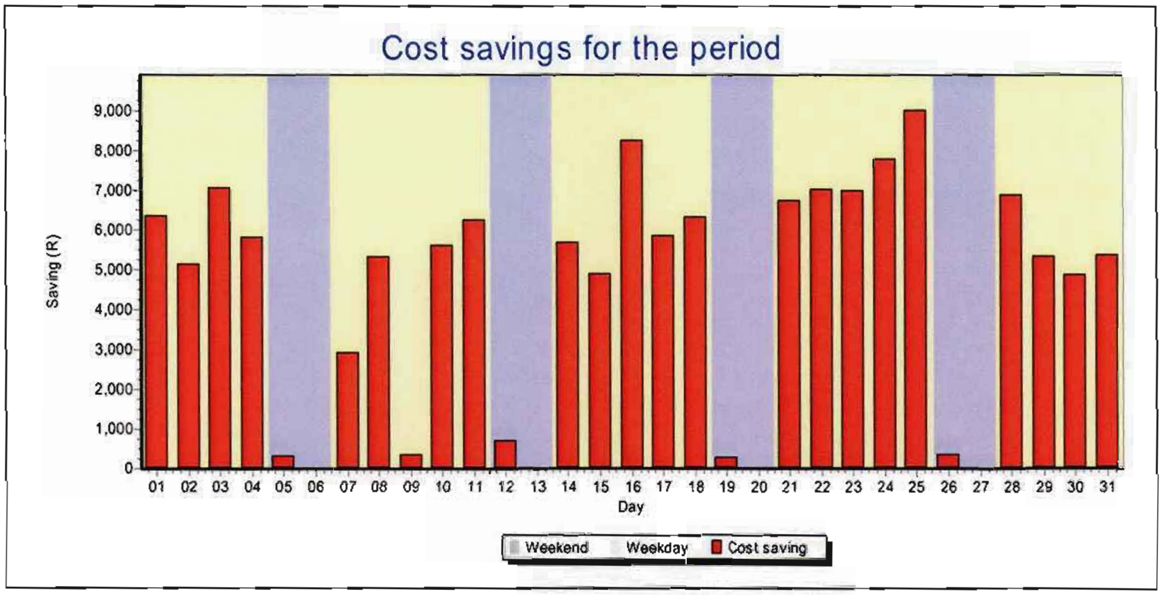


Figure 77: Rand savings for August 2006 without energy efficiency

In September 2006, the savings achieved for the 5.46 MW load shift is calculated to be R22 192. The month of September falls under the summer tariff structure. After taking the energy efficiency into account the savings for September was calculated to be R 73 867.

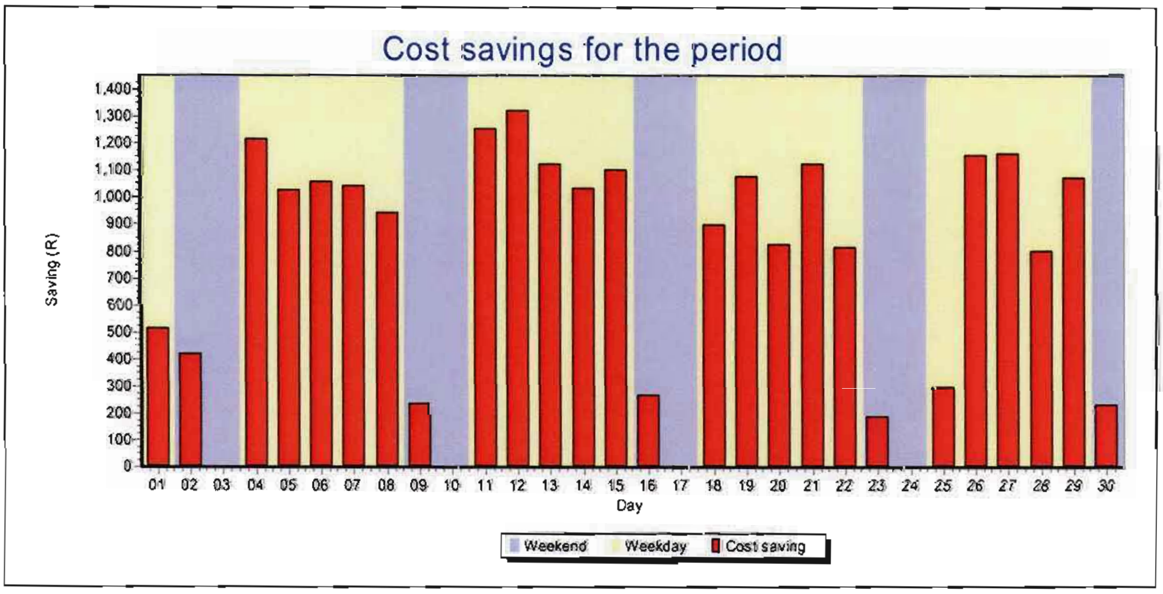


Figure 78: Rand savings for September 2006 without energy efficiency

In October 2006, the savings achieved for the 5.05 MW load shift is calculated to be R18 354. The month of October falls under the summer tariff structure. After taking the energy efficiency into account the savings for October was calculated to be R89 950.

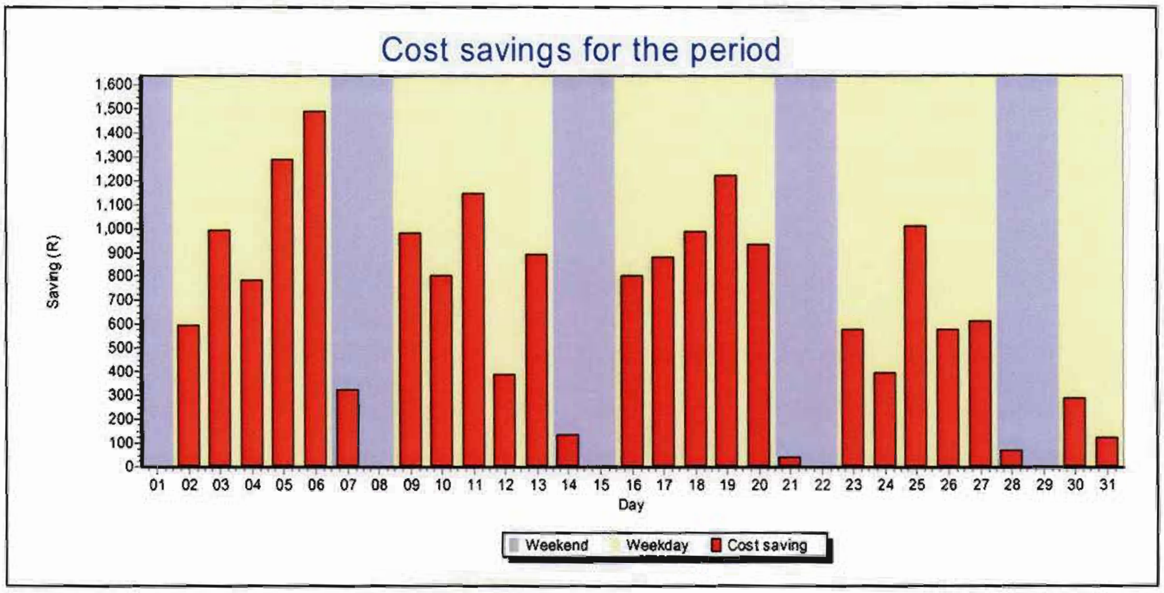


Figure 79: Rand savings for October 2006 without energy efficiency

The increased savings achieved once energy efficiency is taken into account is the result of the overall power consumption being less than the power consumption had energy efficiency principles not been implemented at Beatrix 1 Shaft. To illustrate this, a power profile of the load shifted profile with energy efficiency is plotted against a power profile before load shifting or energy efficiency was implemented on Beatrix 1, 2 and 3 Shaft's multi-shaft pumping system. This is shown in Figure 80.

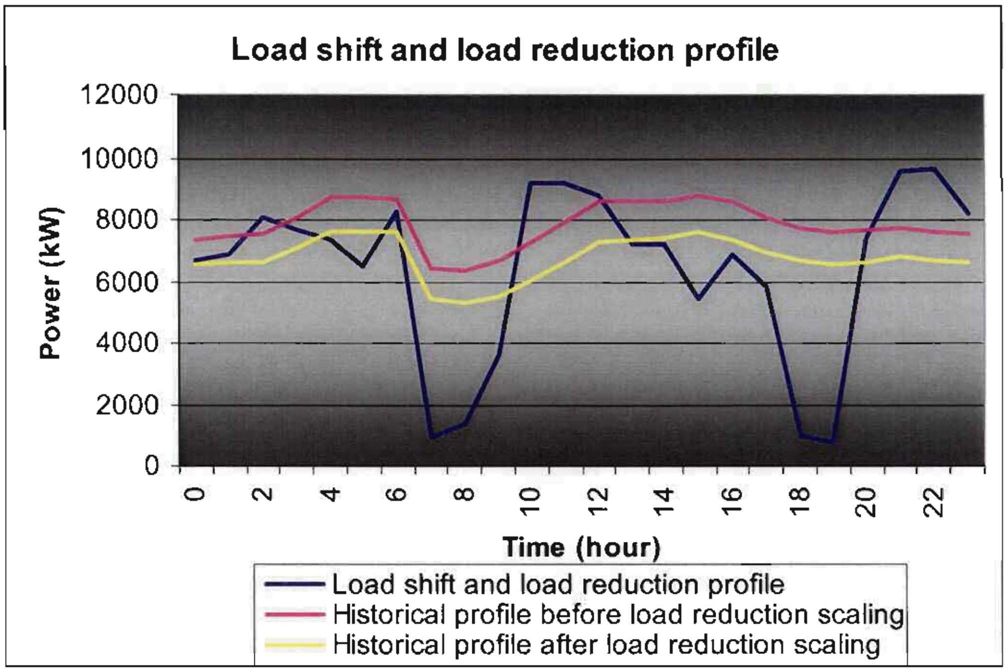


Figure 80: Load shifted and energy efficiency profile vs. historical profiles

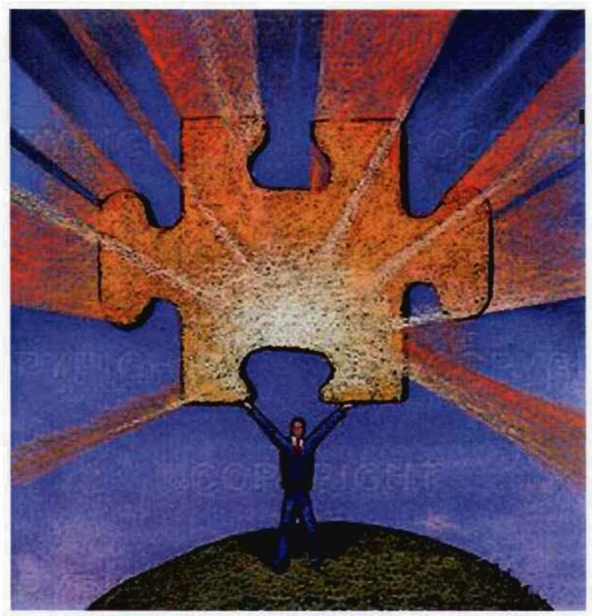
5.4 Conclusion

Results achieved from the DSM project implemented on the multi-shaft pumping system of Beatrix 1, 2 and 3 Shaft were calculated and discussed in this chapter. The results show that by taking energy efficiency into account, the target of 6.0 MW load shift was achievable despite manual operation on one of the pump stations.

It is difficult to see the effects of energy efficiency because the power is consumed after the energy efficiency is introduced. This makes it difficult to calculate and measure the energy savings achieved. If the entire system can be automated without any human error factor, the potential for a positive outcome will be greater.

The results discussed in this chapter confirm the conclusion that the DSM programme can be successfully implemented on an intricate multi-shaft pumping system, from a single point of control.

CHAPTER 6: CONCLUSION AND FURTHER RECOMMENDATIONS



6.1 Introduction

Due to the potential mutual benefits for both Eskom and the client, it is possible to find many strategies for DSM projects on South African mines. Once the multi-shaft pumping system on Beatrix 1, 2 and 3 Shaft was identified as a possible candidate for the first DSM multi-shaft pumping system project, a detailed survey of the mine was executed.

This chapter will discuss the summary of this study and the final conclusion regarding the success of the study. In addition, recommendations for further work on this study will be presented.

6.2 Summary

From the detailed survey it was clear that a load shift value of 6.0 MW during the evening peak period can be attained. In addition, an energy efficiency of ±600kW per hour, depending on the amount of water pumped to the surface, can be obtained. A simulation model was built which provided a safeguard that the system would operate within previously specified parameters and constraints, and this was implemented on the mine. The load shift results are given below. These have been separated to show the effects of the energy efficiency.

Evening load shift value without energy efficiency	
July 2006	5.24 MW
August 2006	4.68 MW
September 2006	5.46 MW
October 2006	5.05 MW
Average	**5.10 MW**

Evening load shift value with energy efficiency	
July 2006	6.30 MW
August 2006	6.13 MW
September 2006	6.02 MW
October 2006	5.92 MW
Average	**6.09 MW**

The financial savings due to the load shift and energy efficiency are given below. The results are separated to show the effects of the energy efficiency.

Evening load shift value without energy efficiency	
July 2006	R 129 019
August 2006	R 137 459
September 2006	R 22 192
October 2006	R 18 354
Total	**R 307 024**

Evening load shift value with energy efficiency	
July 2006	R 240 254
August 2006	R 367 928
September 2006	R 73 867
October 2006	R 89 950
Total	**R 771 999**

The financial savings increased drastically when the energy efficiency was taken into account.

6.3 Recommendations for further work

Some important recommendations for further work have resulted from this study. Investigation of other inter-shaft mining systems, e.g. underground conveyor belt systems, demonstrates that the DSM programme can be implemented on more multi-shaft systems and will increase the benefits for Eskom and the client.

This will allow mines that have small DSM potential individually but which are part of a network of multi-shaft systems to benefit from the DSM programme. Furthermore, the increased implementation of DSM programmes on multiple shaft systems means that Eskom will benefit from load shifting, whereas earlier this was not feasible.

In addition, the maximum demand (MD) for each shaft can be managed by controlling the electrical components on that particular shaft. By so doing, the MD can be controlled so that the set value is not exceeded, and this will save money on penalties. Another control mechanism is to implement the energy efficiency and load shift principles in the design of new mining shafts that will have multi-shaft systems.

6.4 Closure

As the demand for electricity increases Eskom's peak generating capacity is running low. Projections confirm that, by 2007, the peak demand will be higher than Eskom's current generating capacity. Eskom has launched a DSM programme to control this growth in electricity demand.

The main purpose of this programme is to reduce electrical energy usage during the evening peak periods. To achieve this, the electrical load must be shifted to other times of the day, or mines could implement energy efficiency principles to reduce the overall power usage. While the industrial and mining sectors are the largest consumers of electrical energy in terms of the amount of energy consumed per site, the implementation of DSM on these sectors will show the most impact.

Implementation of the DSM programme on multi-shaft pumping systems will realise a new sector for energy management in the mining industry. This will benefit the mines where the potential for DSM on a single mine alone is low. Combining the multiple shafts involved in the pumping system means that the potential is increased. Furthermore, the costs of implementing a DSM project are decreased in terms of the number of shafts per project.

Due to the success of this study, verified by the results, a new sector has been identified where DSM can be implemented successfully. This will benefit not only Eskom, as more DSM potential is found, but will enable mines that have low DSM potential individually to reap the rewards of DSM.

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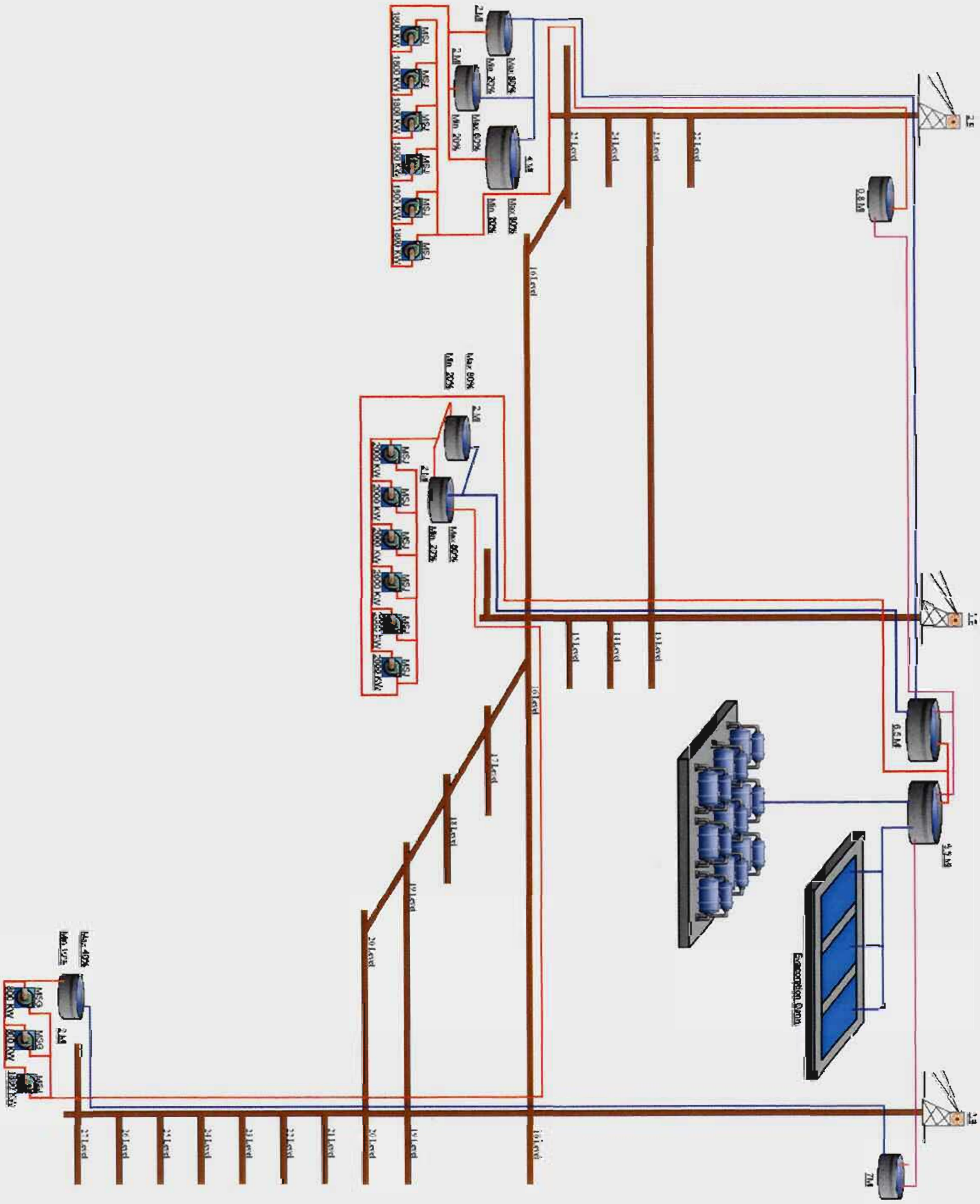
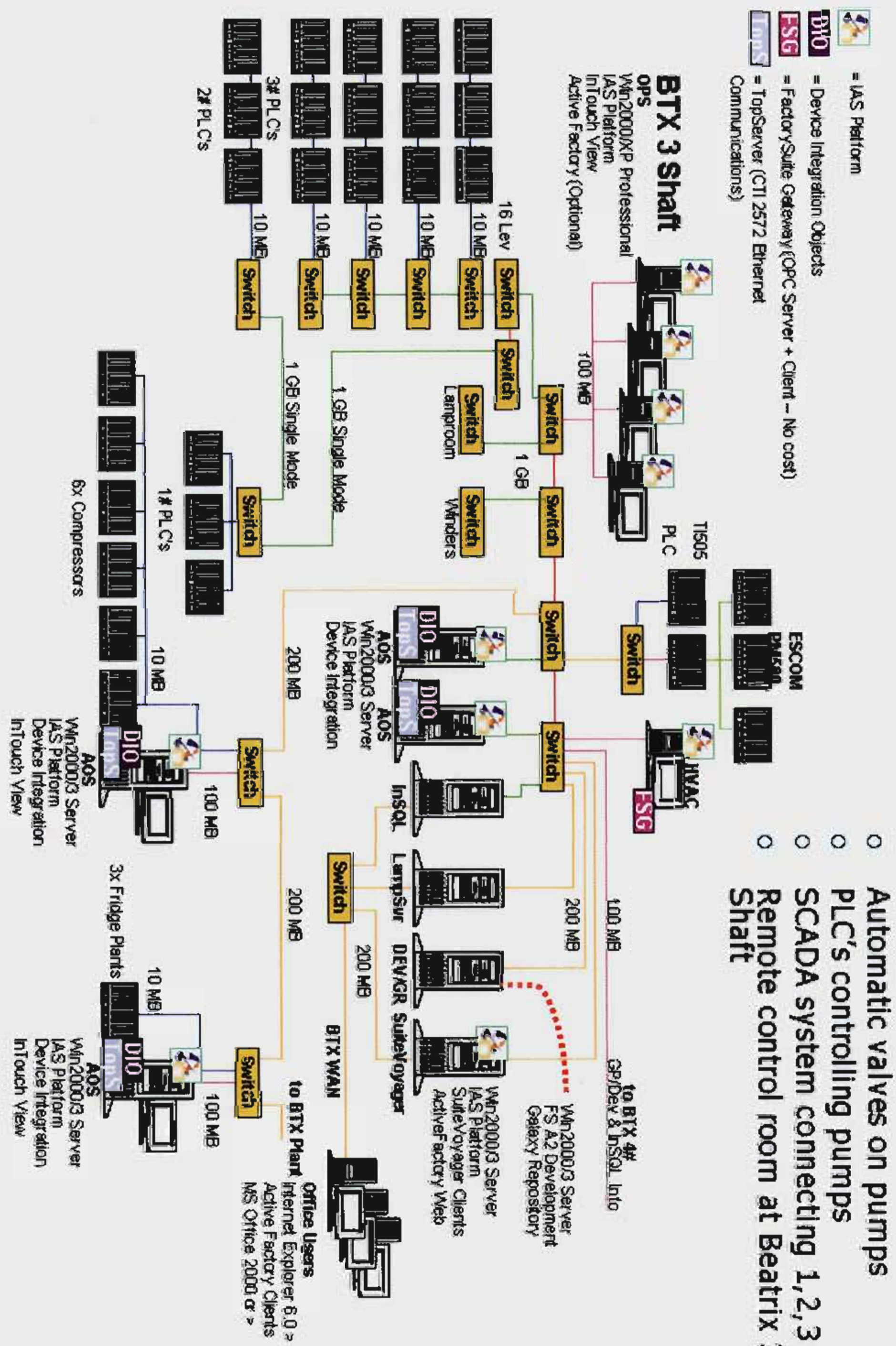
APPENDIX A: Beatrix 1, 2 and 3 Shaft Layout



APPENDIX B: Communication Network Layout



APPENDIX C: Performance-tracking report for Beatrix 1, 2 and 3 Shafts

Performance-tracking report for Beatrix 1, 2, 3 Shafts

September 2006

GOLD FIELDS

Introduction

This monthly report gives the savings generated by the REMS system controlling Beatrix 1, 2, and 3 Shafts. The savings period covered is from 01 September 2006 to 30 September 2006. Detailed analyses are included to explain the under-performance on specific days. This information could be used to improve the availability of pumping equipment in order to increase savings.

Performance over project lifetime

The REMS system has been operational for two months. See Table 1 below for the savings achieved.

Month	Proposed saving	Saving achieved	Unrealised potential / Over performance R/c (%)	Accumulated proposed savings possible	Accumulated actual savings	Accumulated unrealised potential / over performance
July 2006	R 189 843	R 99 971	R-89 872 (-47%)	R 189 843	R 99 971	R-89 872
August 2006	R 198 661	R 137 459	R-61 202 (-31%)	R 388 504	R 237 429	R-151 075
September 2006	R 28 957	R 22 192	R-6 765 (-23%)	R 417 461	R 259 621	R-157 840

***Table 1:** Actual savings*

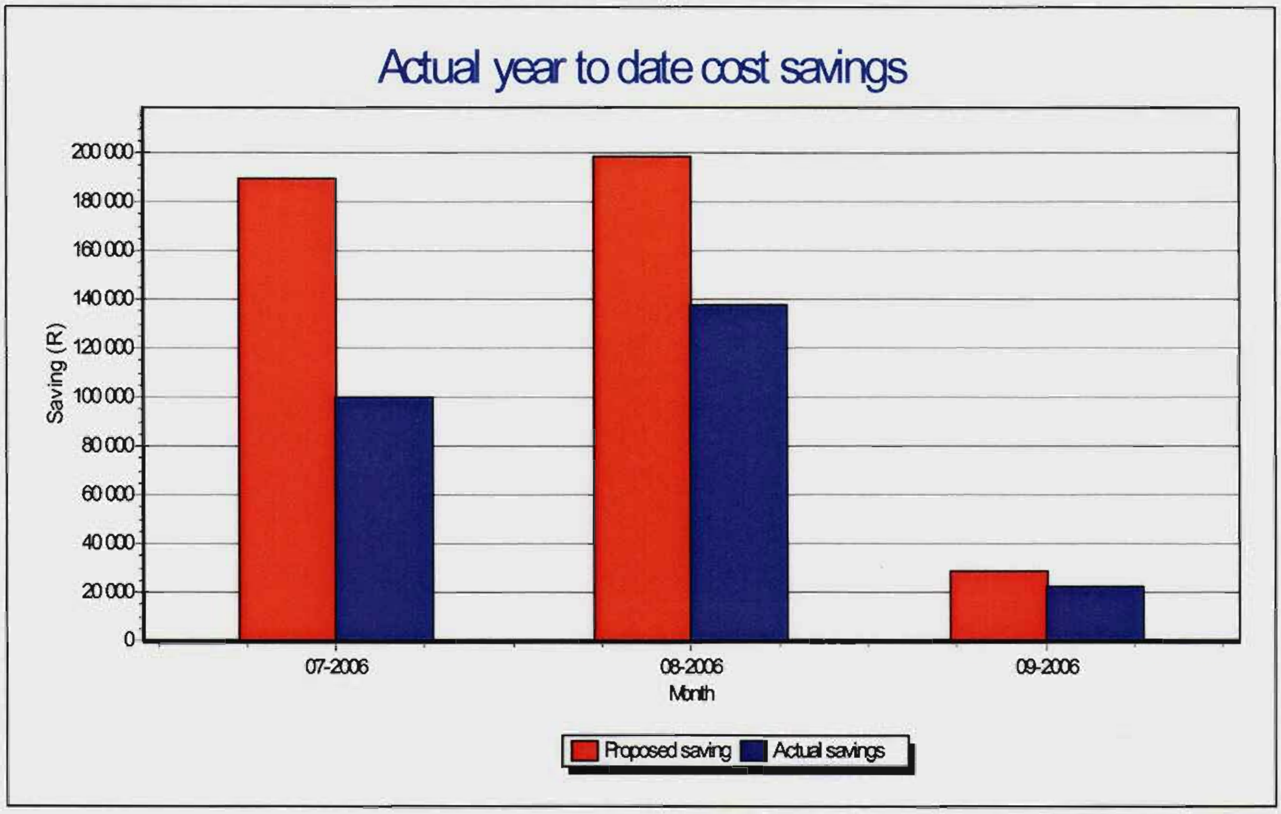


Figure 1: *Actual and proposed savings for the duration of the project*

REMS Savings

The total saving for the period from 1 September 2006 to 30 September 2006 is R 22 192. The average load reduction for the evening peak, excluding condonable days, is 5.46 MW. The figure below shows the daily cost savings.

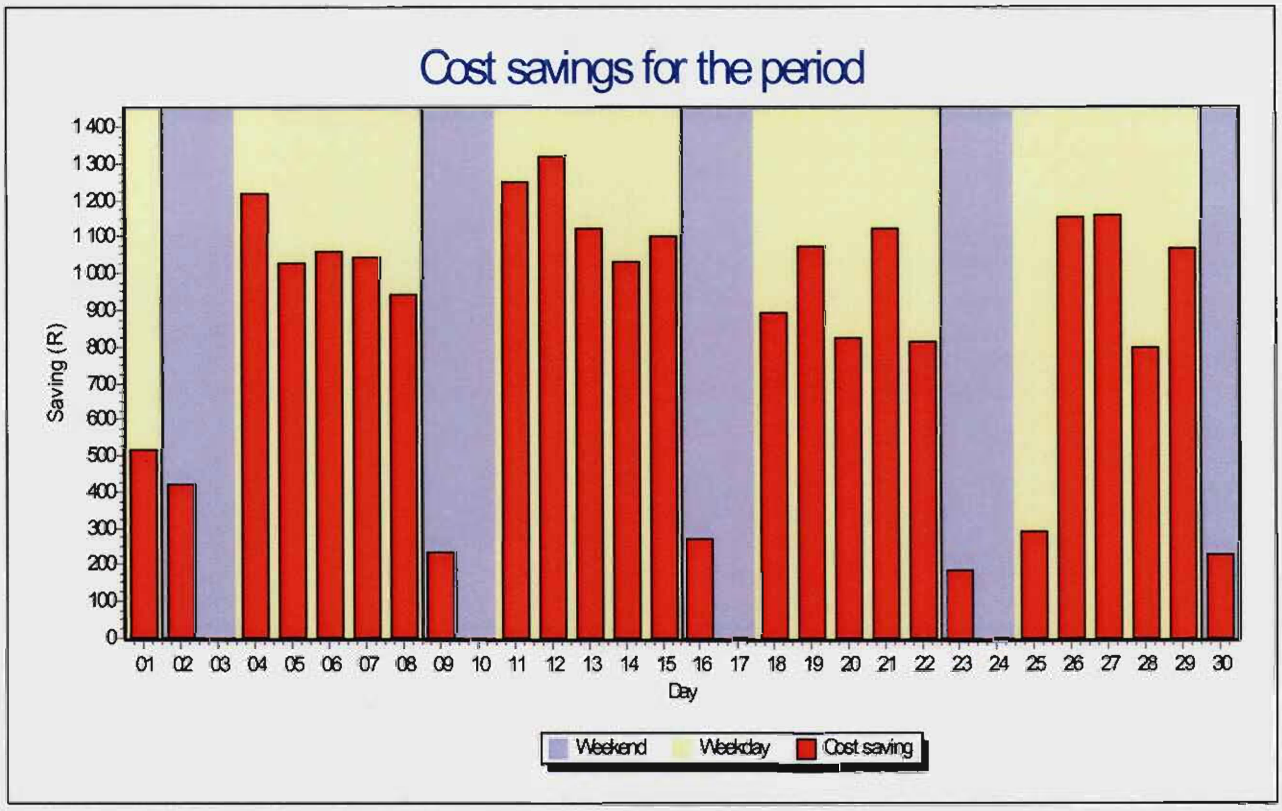


Figure 2: *Cost savings from 1 September 2006 to 30 September 2006*

Energy used and peak time load shift

Figure 3 shows the average load and baseline (MW) for 1 September to 30 September 2006. Please note that the baseline is scaled according to standard Measurement and Verification (M&V) practises. The morning and evening load shift (MW) for the same period is indicated in Figure 4.

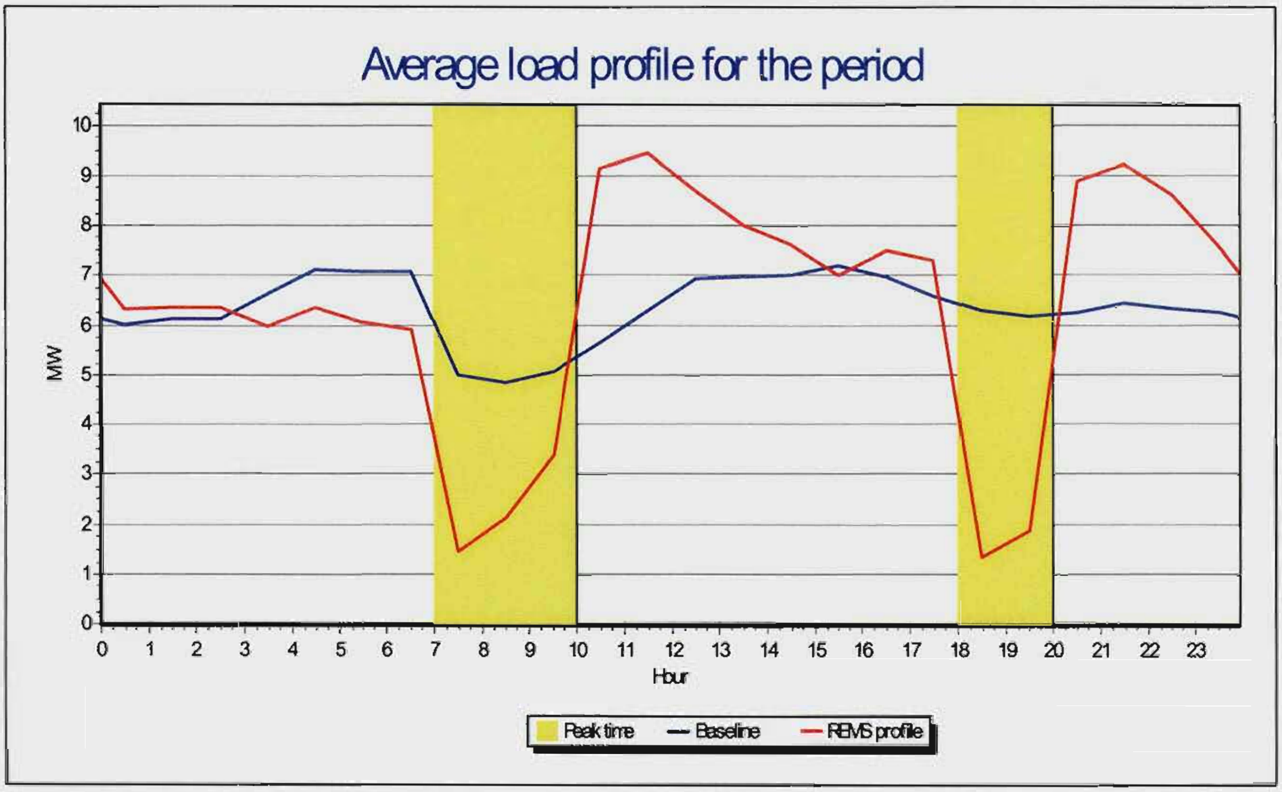


Figure 3: *Average load profile and baseline from 1 September 2006 to 30 September 2006*

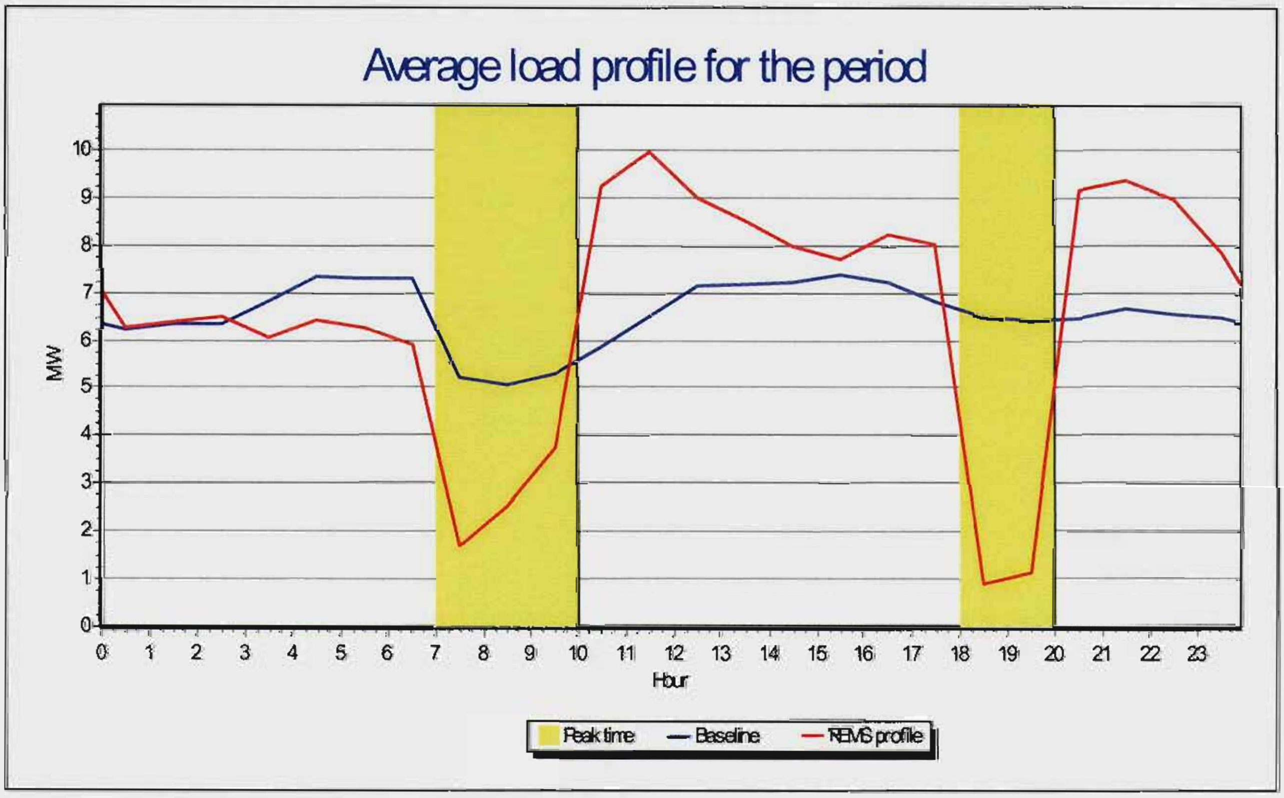


Figure 3: *Average load profile and baseline from 1 September 2006 to 30 September 2006*

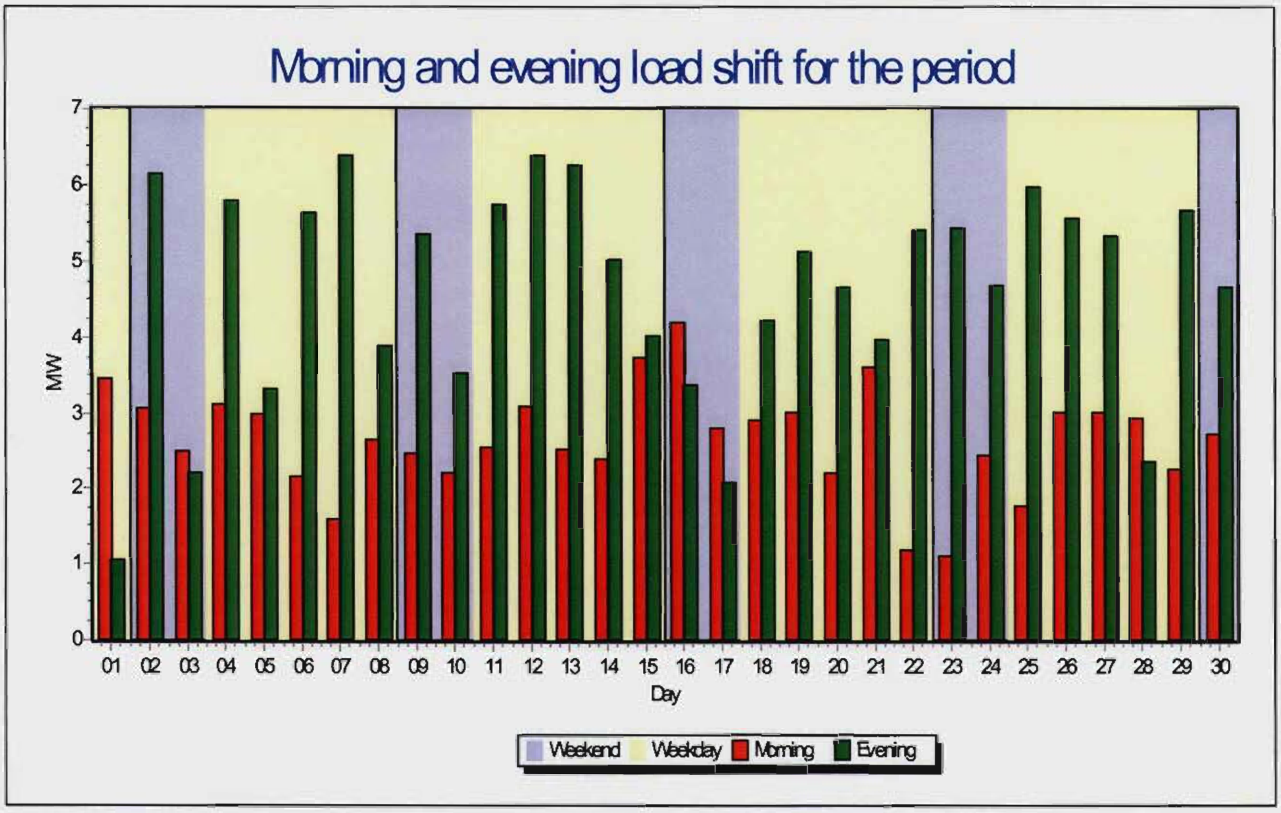


Figure 4: Morning and evening load shift from 1 September 2006 to 30 September 2006

Daily performance

The table below shows the breakdown of all the days in the period: 1 September to 30 September 2006.

Day	Actual saving	Missed opportunity	Reason/Condon able	System switched to manual [% of day]	Energy consumptio n [MWh]
1 September	R 515	R 660	In rush of water before peak time.	0	154.04
2 September	R 421			0	154.99
3 September	R 0			0	127.75
4 September	R 1 219	R 40		4	162.27
5 September	R 1 028	R 90	1# pump	0	148.27

			availability problems		
6 September	R 1 062	R 80		2	150.26
7 September	R 1 043	R 150		0	156.21
8 September	R 942	R 200	Power failure 1#	0	149.98
9 September	R 235	R 50		0	134.39
10 September	R 0			0	129.44
11 September	R 1 253			0	160.14
12 September	R 1 321			0	161.35
13 September	R 1 123	R 70		0	155.25
14 September	R 1 034	R 100		0	149.90
15 September	R 1 103	R 230		0	170.26
16 September	R 269	R 110		0	164.24
17 September	R 0			0	115.28
18 September	R 896	R 270		0	152.38
19 September	R 1 076			0	142.09
20 September	R 823	R 510		0	170.91
21 September	R 1 124	R 140	Maintenance on 3#	0	163.80
22 September	R 813	R 420		0	159.69
23 September	R 189	R 120		0	143.25
24 September	R 0			0	124.38
25 September	R 291	R 40		0	148.45
26 September	R 1 153	R 10		0	152.44
27 September	R 1 161	R 80		0	160.41
28 September	R 799	R 650	Electrical failure	1	182.96
29 September	R 1 069	R 270		0	170.92
30 September	R 230	R 140		0	161.97
Total/Average	**R 22 192**	**R 4 430**		**0**	**4 577.65**

Table 2: *Day performance for the period*

If the missed opportunities had been achieved, the extra cost savings would have been R 4 430. The system could only achieve 83.36 % of the maximum possible savings as a result of the reasons demonstrated in Table 2.

Conclusion

During the period 01 September to 30 September 2006, REMS saved **R22 192** on Beatrix 1, 2, 3 Shafts, with an average evening peak load reduction of **5.46 MW**. If all the missed opportunities had been realised, the cost savings would have increased to R **26 622**.

APPENDIX D: Daily Report for Beatrix 1, 2, 3 Shaft

REMS Daily report for Beatrix 1, 2, 3 Shafts

2006-08-22

Load shift results for Beatrix 1, 2, 3 Shafts for 22 August 2006

Parameter	Value
Morning peak	1.97 MW
Evening peak	6.06 MW
Average evening peak for month	4.68 MW
Contractual MW	6.00 MW
Cost saving for this day	R 7 015
Energy usage for this day	156.39 MWh
System on manual	0 % of the day

***Table 1:** Summary of day*

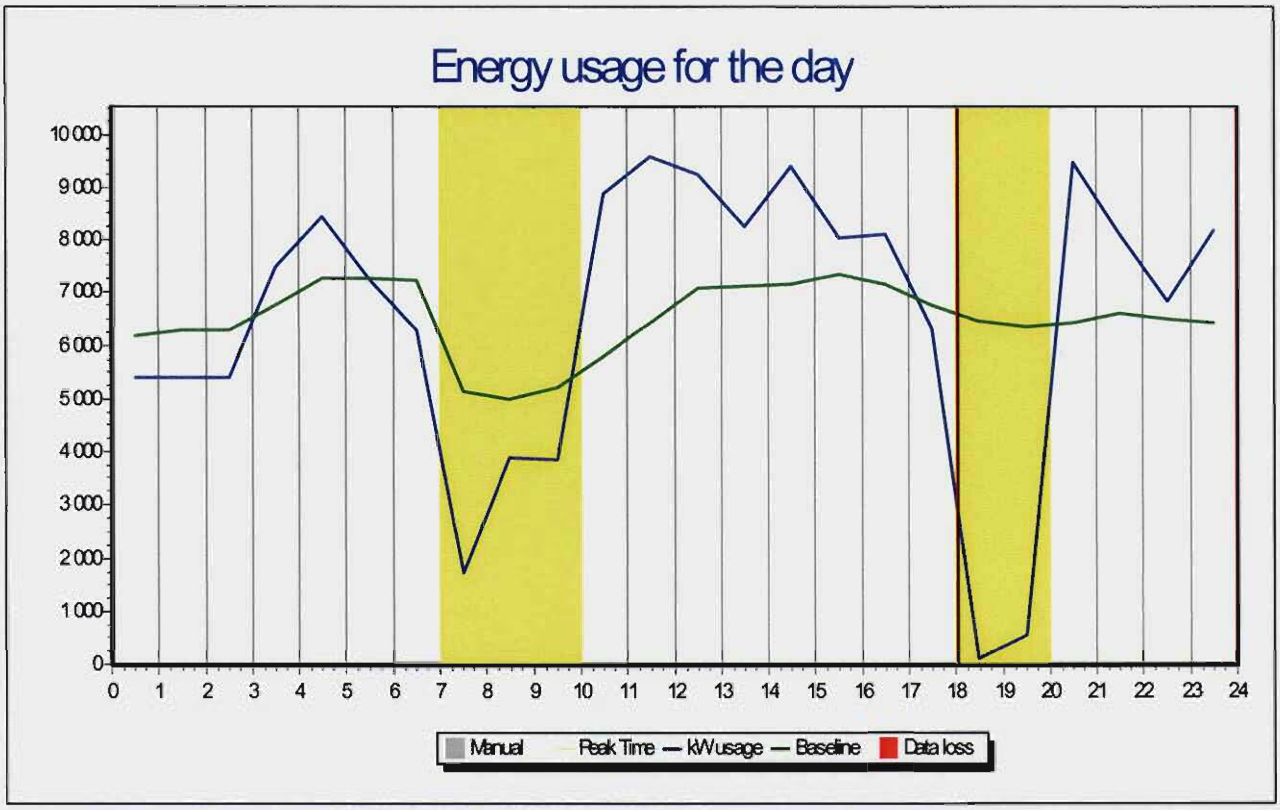


***Figure 1:** kW usage profile*

The above graph shows the energy usage profile for the day, indicating manual overrides (in gray) and data loss (in red) shown.

Summary for 1 Shaft Pump Controller

The figure below shows a detailed description of the 1 Shaft Pump Controller for the day. The status is the actual number of pumps running, and the schedule is the amount of pumps requested by REMS.

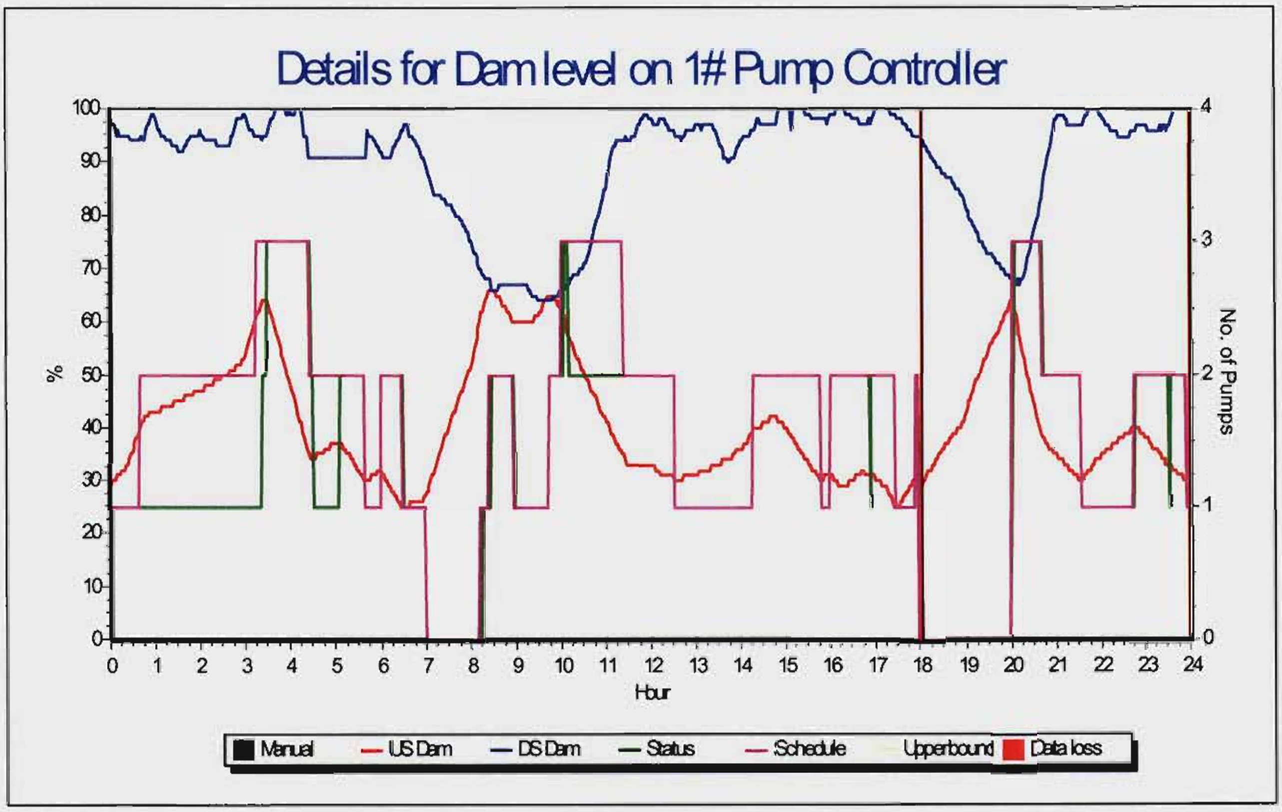


Figure 2: Dam levels, status and schedule for 1Shaft Pump Controller

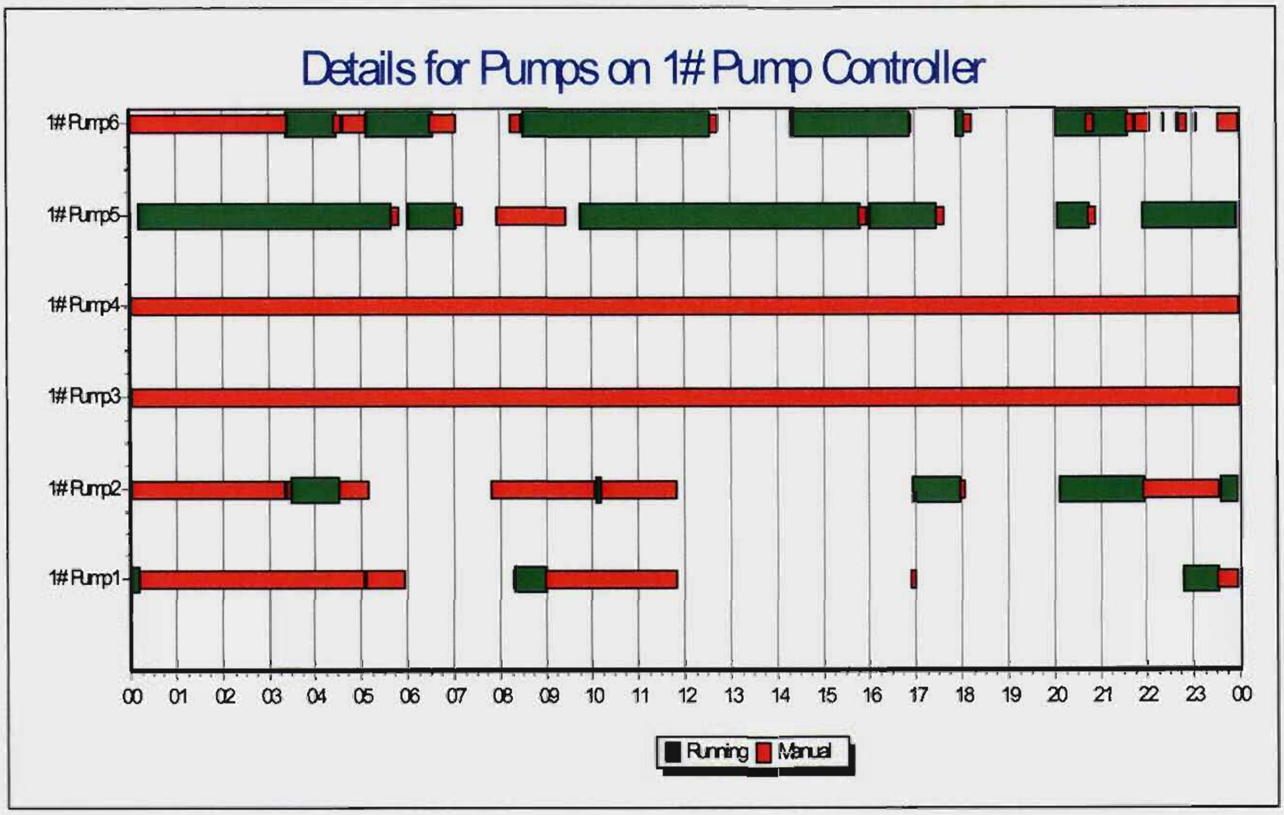


Figure 3: Runtimes for 1Shaft Pump Controller

The above figure shows the actual runtimes for the pumps on this level. The green bars indicate periods when the pump was running. The red bars indicate periods where REMS did not have control of the pump.

Summary for 2 Shaft Pump Controller

The figure below gives a detailed description of the 2 Shaft Pump Controller for the day. The status is the actual number of pumps running, and the schedule is the amount of pumps requested by REMS.

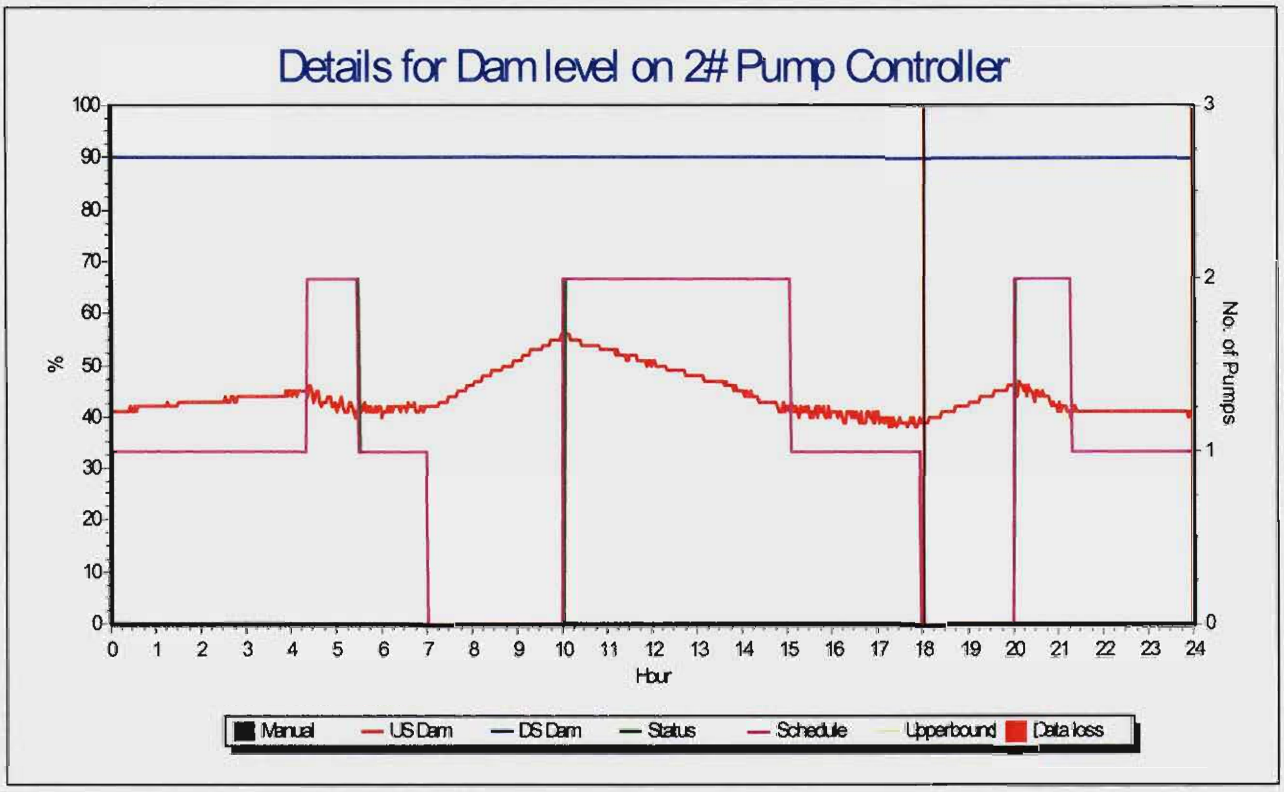


Figure 4: Dam levels, status and schedule for 2# Pump Controller

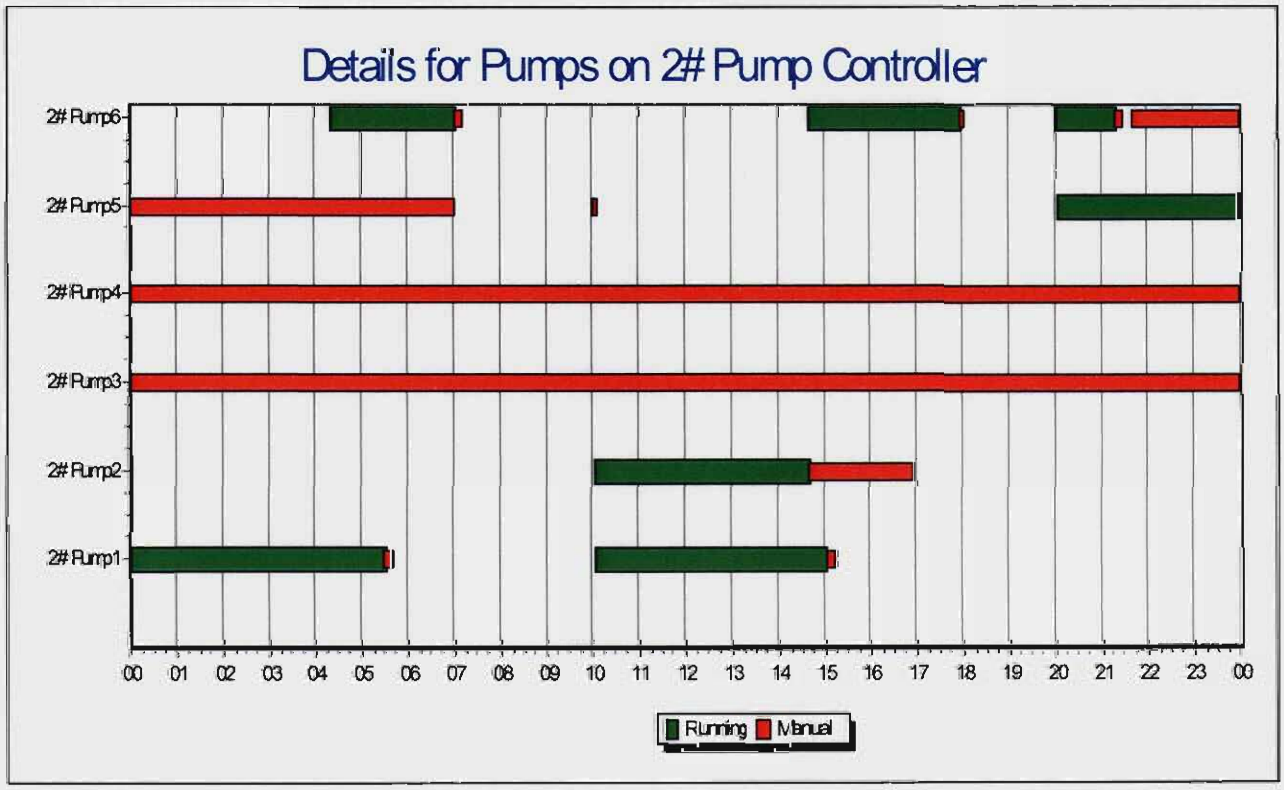


Figure 5: Runtimes for 2# Pump Controller

The above figure shows the actual runtimes for the pumps on this level. The green bars indicate periods when the pump was running. The red bars indicate periods where REMS did not have control of the pump.

Summary for 3 Shaft Pump Controller

The figure below shows a detailed description of the 3 Shaft Pump Controller for the day. The status is the actual number of pumps running, and the schedule is the amount of pumps requested by REMS.

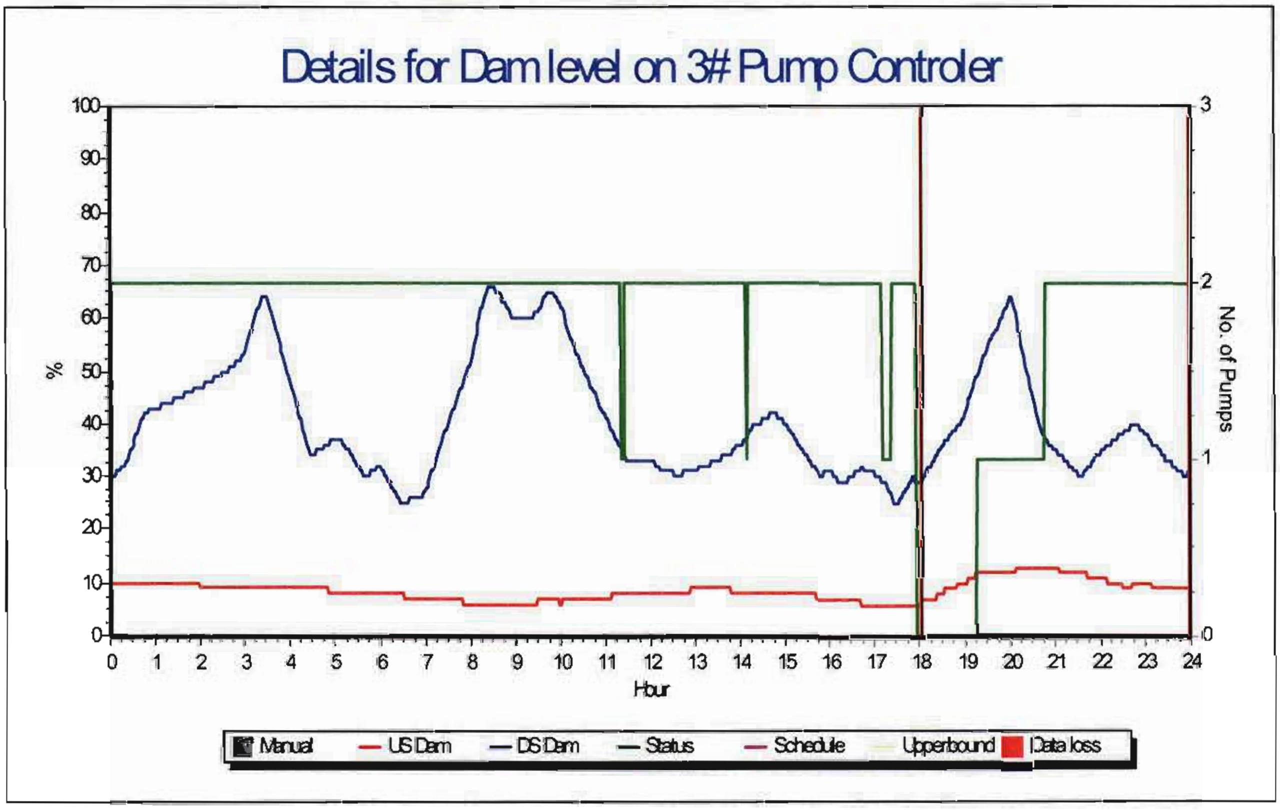


Figure 6: Dam levels, status and schedule for 3 Shaft Pump Controller

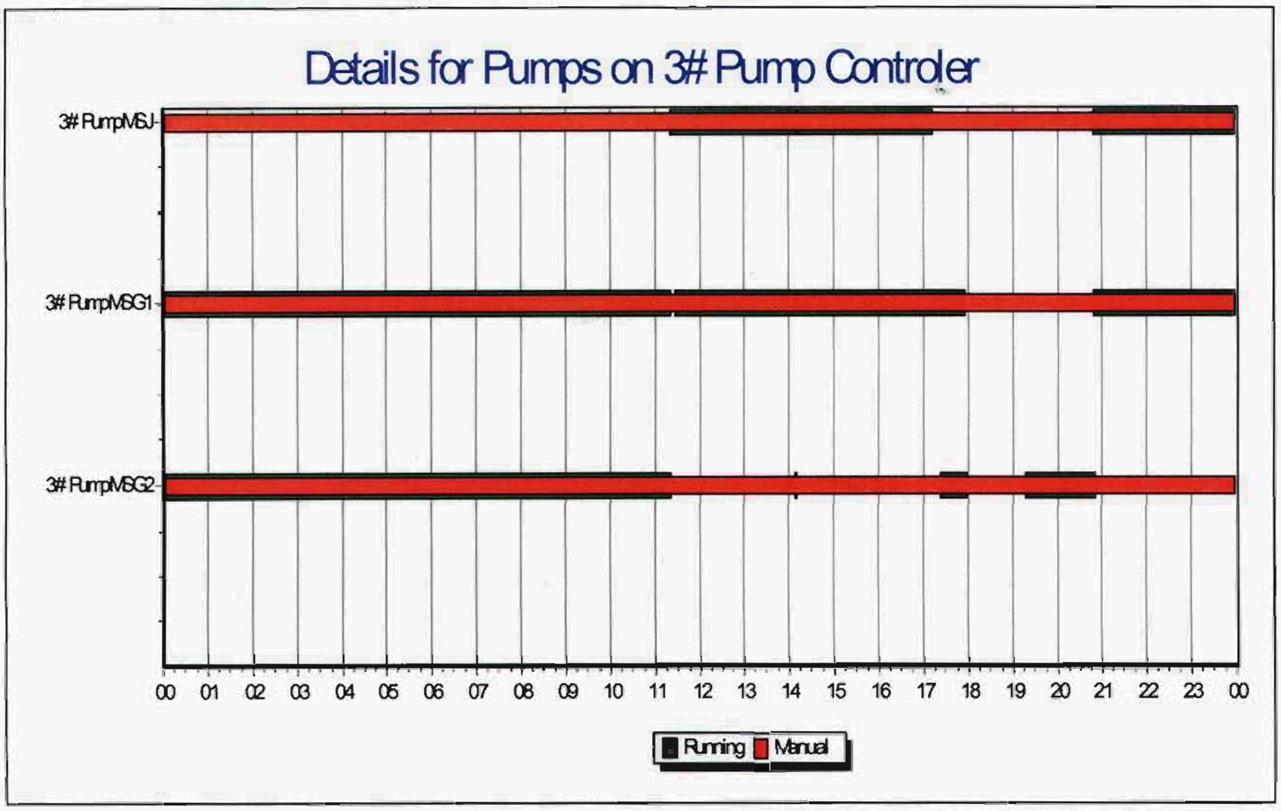


***Figure** 7: Runtimes for 3 Shaft Pump Controller*

The above figure shows the actual runtimes for the pumps on this level. The green bars indicate periods when the pump was running. The red bars indicate periods where REMS did not have control of the pump.