A NEW APPROACH TO ENSURE SUCCESSFUL IMPLEMENTATION AND SUSTAINABLE DSM IN RSA MINES

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ABSTRACT

Title: A new approach to ensure successful implementation and sustainable DSM in RSA.

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Keywords: DSM, ESCo, load shift, clear water pumping system, Eskom, REMS.

In this study a new tool was developed that made new approaches possible for the successful implementation of Demand Side Management (DSM) projects. The new approaches are incorporated into a generic tool that makes it possible for Energy Services Companies (ESCos) to undertake DSM projects that were previously not possible with currently available technology. Through these new approaches, maximum results can be obtained on a sustainable basis on the clear water pumping systems of South African mines.

The author was responsible and participated in four different investigations and implementations of DSM projects. These were grouped into three case studies. Each of these studies required different new innovations.

The innovations described in this thesis include the adaptation of the Real-time Energy Management System (REMS) that was developed and marketed by HVAC International, to mines with intricate pumping systems, mines without any instrumentation and control infrastructure, as well as to mines that make use of a Three Pipe Water Pumping System.

The tool developed and applied in these projects was part of Eskom's DSM programme. In this programme, large electricity clients who wish to shift electrical load out of peak periods, are assisted by having the total costs of such projects funded by Eskom. The fact that the clients will most likely enjoy substantial electricity cost savings, (by not having to pay the high peak prices), is a major attraction of this programme. Nevertheless, the programme is not moving as fast as it should.

The National Energy Regulator (NER) has set an annual target of 153 MW load to be shifted since 2003. By the end of 2005, the accumulated target load to be shifted will be 459 MW. However, Eskom has indicated that an accumulated total of only 181 MW load will have been shifted by the end of 2005. This means that the Eskom DSM programme has actually only achieved 39% of its target.

The innovations described in this thesis will help ESCos to address this shortfall more effectively.

SAMEVATTING

Titel:	'n Nuwe benadering om suksesvolle implementering en volhoubare DSM in RSA te verseker.
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Promoter:	Prof. M. Kleingeld
Sleutelwoorde:	DSM, ESCo, las verskuif, myn waterpompstelsel, Eskom, REMS

In hierdie studie is 'n nuwe hulpmiddel ontwikkel om nuwe benaderings moontlik te maak vir die suksesvolle implementering van aanvraagkant elektrisiteitsbestuursprojekte (DSM projekte). Die nuwe benaderings is omvat in 'n generies hulpmiddel en sal Energie Diensverskaffer Maatskappye (ESCos) help om DSM projekte te onderneem, waar dit met die huidige tegnologie vir hulle voorheen nie moontlik was nie. Deur van hierdie nuwe benaderings gebruik te maak kan Suid-Afrikaanse myn waterpompstelsels maksimum resultate bereik en handhaaf.

Die outeur was verantwoordelik en het deelgeneem aan vier verskillende ondersoeke en implementasies van DSM projekte, wat in drie verskillende gevallestudies verdeel is. Elkeen van hierdie ondersoeke het nuwe en unieke innovasies geverg.

Die innovasies wat in hierdie tesis beskryf word, sluit die aanpassing in van die Intydse Energie Bestuur Stelsel (REMS), wat deur HVAC Internasionaal ontwikkel en bemark is, in myne met ingewikkelde water pompstelsels, myne sonder enige instrumentasie en beheer infrastruktuur en myne waar 'n Drie-pyp Water Pompstelsel tans gebruik word.

Die hulpmiddel wat hier ontwikkel en toegepas is, het deel uitgemaak van Eskom se DSM program. Hierdie program ondersteun groot elektrisiteitskliënte, wat elektriese las buite die piekperiode wil verskuif, deurdat Eskom die volle koste van sulke projekte dra. Die program is besonders aantreklik aangesien kliënte heel moontlik 'n aansienlike elektrisiteitsbesparing sal ondervind (deurdat hulle nie die hoë piektyd tarief hoef te betaal nie). Ten spyte hiervan het die program tot dusver nog nie groot byval gevind nie.

Die Nasionale Energie Beheerliggaam (NER) het sedert 2003 'n jaarlikse doelwit gestel om 153 MW las te verskuif. Die totale lasverskuiwing aan die einde van 2005 is dus 459 MW. Eskom het egter aangedui dat die totale lasverskuiwing slegs 181 MW sal wees, wat beteken dat die Eskom DSM program slegs 39% van die oorspronklike doelwit sal bereik.

Die innovasies wat in hierdie tesis ontwikkel is, sal ESCos help om hierdie tekortkominge meer effektief aan te spreek.

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- Finally, all thanks to my Creator, without whom none of this would have been possible.

PREAMBLE

This thesis describes the evolvement of a new approach to control clear water pumping systems in the mine industry. The progress of the new approach is described with the aid of actual case studies on four different gold mines in South Africa.

The case studies are grouped and described in three separate chapters. These chapters describe the clear water pumping systems of the case study mines, the short comings to the new approach and the new enhancements that were incorporated to the approach.

After the evolvement of the new approach is described it is evaluated to ensure that all clear water pumping systems in the mine sector in South Africa can be controlled consistently at an optimum point and contribute to the South African peak demand problem.

The thesis concludes with a final generic implementation procedure of the new approach as well as further work and recommendations.

LIST OF ABBREVIATIONS

3CPFS	Three Chamber Pipe Feeder System
BTU	British Thermal Unit
CBL	Customer Base Line
CFL	Compact Fluorescent Lamp
DME	Department of Mineral and Energy
DSM	Demand Side Management
EE	Energy Efficiency
EE-DSM	Energy Efficiency Demand Side Management
EMS	Energy Management System
ESCo	Energy Services Company
EST	Energy Saving Trust
GDP	Gross Domestic Product
GWh	Giga Watt Hours
HMI	Human Machine Interface
HT	High Tension
IEP	Integrated Energy Planning
IRP	Integrated Resource Planning
kW	Kilowatt
kWh	Kilowatt-hour
l/s	Litres per second
LT	Low Tension
M&V	Measurement and Verification
Ml	Mega Litres
MVA	Mega Volt Ampere
MW	Megawatt
NER	National Energy Regulator
PC	Personal Computer
PLC	Programmable Logic Controller
RDP	Reconstruction and Development Programme
REMS	Real-time Energy Management System
RTP	Real-time Pricing
SCADA	Supervisory Control and Data Acquisition
SSM	Supply Side Management
TOU	Time-of-Use
TWh	Terra Watt Hour
VCB	Vacuum Circuit Breaker
VCP	Ventilation, Cooling and Pumping
WEP	Wholesale Electricity Pricing

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CHAPTER 1

INTRODUCTION

South Africa is fast running out of electricity supply. New ways have to be found to supply to the growing electricity demand as well as to replace base load capacity. New generation projects are in progress, but the results will arrive too late. DSM is one of the solutions that will be able to extend the point when demand will exceed supply. Pumping systems on mines are large electricity consumers and are ideal to achieve load shift out of peak demand periods. But there exists no technology in the mine industry today to achieve maximum, sustainable DSM results.

GOLD MINE	TYPE 1 Pumps can be controlled from surface control room	TYPE 2 Pumping systems that include 3CPFS	TYPE 3 No control infrastructure and/or no 24h control room	PEAK LOAD REDUCTION POTENTIAL (MW)
Bambanani	√			5.8
Tshepong		√		3.2
Masimong 4#			√	3.9
Harmony 3#			√	3.8
Kopanang	√			3.9
Great Noligwa	√			2.7
Tau Lekoa			√	1.6
Mponeng			√	6.5
Tau Tona			√	5.4
Savuka			√	2.4
Elandsrand	√			3.0
Target			√	1.5
Evander 7#			√	3.9
Evander 8#			√	3.0
Cook 1 - 3 #			√	3.0
Joel			√	0.5
Unisel	√			2.3
Brand			√	0.5
Elandskag			√	0.5
Njala			√	0.5
Doornkop			√	0.5
Kudu			√	0.5
St Helena			√	0.5
Orkney 1- 7 #			√	4.0
Beatrix 1,2,3			√	6.3
Beatrix 4			√	5.1
Kloof 7#			√	12.6
Driefontein		√		6.0
South Deep (S)			√	6.1
Randfontein 4 #			√	6.5
Blyvooruitzicht			√	3.0
Buffelsfontein			√	3.0
Hartbeesfontein			√	1.0
			TOTAL	113.0

Table 8: Mines which could benefit from the new procedure.

6.6 THE POSSIBLE NATIONAL AND ENVIRONMENTAL IMPACT

The following assumptions were made for the determination of the national peak load reduction potential on clear water pumping systems in South African mines:

- The list of gold mines in Table 8 is fairly comprehensive, but it can be said with certainty that there will still be other gold mines in South Africa that have peak load reduction potential. It is assumed that the table lists only 75% of such gold mines.
- Gold mining constitutes 18% of the industrial electricity energy consumption in South Africa, or two-thirds of the mining electrical energy consumption [32] [47]. The rest of the mining

industry combined consumes only one-third of the mining electrical energy consumption. Therefore the peak load reduction potential in gold mines contributes two-thirds of the total mine industry potential. The other third is contributed by other forms of mining i.e. platinum, coal, diamonds, etc.

Therefore the national peak load reduction potential for pumping systems on mines in South Africa is estimated to be as follows:

	113 MW	→ Gold mines listed in Table above = 75%	} Two-thirds
	37 MW	→ Other gold mines not listed = 25%	
	75 MW	→ One-third contributed by other forms of mining	
TOTAL	**225 MW**		

In a previous study on the national load shift potential on VCP systems on mines in South Africa it was estimated that a total of 550 MW was available [74]. This calculation was based on the average load shift potential of four case study mines and the assumption that this average can be achieved on every second mine in South Africa. When taking into consideration that the 225 MW estimated in this thesis is only for pumping systems, it seems to be a fairly good estimation.

In Chapter 1 it was seen that pumping systems on mines contribute about 2 300 MW of the peak load in South Africa [17] [18]. It is therefore apparent that peak load reductions on pumping systems could reduce this figure by almost 10%.

In Appendix E a calculation is given that arrives at a ball park figure of R 150 000 savings annually for 1 MW in peak load reduction. Applying this factor to the 225 MW estimated above, the savings that can be achieved by mines by merely scheduling the clear water pumps by means of REMS, is approximately R 34 million per year.

Electricity supply utilities, like Eskom, and other users of electricity will soon have to internalise the external costs of pollution and gas emissions and this will have to be reflected in the price of electricity. Most of the external costs cannot be quantified precisely but have environmental and social costs attached to it. The environmental implications of using 1 kWh of power are as follow [75]:

- 1,21 litres of water used;
- 0,49 kg coal burnt;
- 130 g ash produced;

- 0,35 g ash emitted;
- 7,95 g SO_2 emissions;
- 3,56 g NO_x emissions;
- 0,85 kg CO_2 emissions.

Peak load reduction in the form of load shift on mines does *not* reduce the amount of electricity used over a certain period of time and therefore does not directly offer opportunities to improve the environmental impact. The environmental impact is directly related to the reduction in the amount of energy used (EE).

However if peak load reduction can prevent Eskom from building a new power station to supply in the national electricity profile it can have an enormous indirect impact on the environment. If this load shift is constant and sustainable it serves as "virtual power station" in Eskom's peak times. If the new procedure is implemented at its full potential in South Africa, it can be seen as a power station that supplies 225 MW electric power at the peak period of the day when Eskom needs it most. This "virtual power station" is the most environmental friendly power station ever to be built.

With the electricity cost savings through this new procedure, more money can be spent by the mine industry on research into more environmentally friendly energy sources. Therefore it remains advantageous for the mining industry, Eskom and the country to utilise the new procedure developed.

CHAPTER 7

CONCLUSION AND RECOMMENDATIONS

Through successful and innovative engineering research and development, a new approach was developed to enable the successful implementation of REMS on all the variations of clear water pumping systems in South African mines. Through specific case studies, the tool was modified to perfection. However, there still exists scope to extend it to other mine and industrial processes.

7.1 CONCLUSION

The primarily objective of this study was to develop a tool that could achieve maximum DSM (load shift) results in a reliable and sustainable manner in all deep, hard rock mines in South Africa. This objective has been met by demonstrating that REMS, (as developed over the duration of this study), was able to be implemented in all three types of mines. These are:

- Type 1: Mines with intricate pumping systems,
- Type 2: Pumping systems that include a 3CPFS,
- Type 3: Pumping systems with no control infrastructure and/or no 24-hour manned control room.

The following successful and innovative approaches have been developed and implemented over the course of this study. Together these approaches formed a new approach that ensured successful implementation and sustainable peak load reduction. This approach is now applicable to any clear water pumping system on a South African mine.

The first stage was to develop DSM technology with the ability to be implemented on-site. This had the advantage of real-time system data input. Therefore, real-time simulation and optimisation could be done, which resulted in an optimised control schedule relevant for that specific scenario on the mine.

The second stage was to empower the DSM technology with the ability to automatically control the mine pumping system at the optimum operating point. DSM performance was no longer dependant on the reliability of human operators. Humans were not necessary to verify whether the optimised schedule was realistic before they chose to implement it. Because the system received real-time data as inputs, the optimised schedule was realistic and because it had the ability of controlling the pumps, the realistic, optimised schedule could be implemented automatically.

The third stage was to develop a controller inside the DSM technology that had the ability to control any clear water pumping system in a South African mine. After initial studies it was established that mine pumping systems could be divided into any one of three different types. Through various sub-controllers the REMS controller was extended to handle all three types and therefore, any pumping system in South Africa.

The fourth stage was to give the DSM technology "stand alone" functionality. There are mines with no control rooms or no operators responsible for the pumping systems. Therefore, new and additional systems had to be put into place within REMS before it could take over the responsibility associated with the clear water pump process. It was important for the DSM technology to signal any violations of user constraints to mine personnel on site, as well as to the off site control room.

In this project, this approach was implemented for the first time on all three types of mines in South Africa. It was evident that the DSM results were consistently above expectation. This study has therefore conclusively demonstrated that REMS can be successfully implemented on the clear water pumping system of any South African mine.

Through a comprehensive study of the possible gold mines where the new approach could be implemented, an informed estimate of the national impact could be made. It was seen that the new approach has the potential to reduce Eskom's peak by 225 MW. This results in an almost 10% reduction of the 2 300 MW electricity consumed, by pumping systems in the mine industry, during Eskom's peak times.

This peak load reduction will have an electricity cost saving effect of almost R 34 million on the mine industry as well as a significant indirect effect on the environment.

7.2 CONTRIBUTIONS OF THIS STUDY

Operational contributions

It was shown in Chapter 2, that if maximum DSM results were to be realised the DSM technology would have to be independent of human operators. The only way to make an optimised control system of the pumps independent of human operators was to change the operation to an on-site system to gather real-time pumping system data and perform the simulation and optimisation processes in real-time, as the dynamic mine system changes.

The other operational contribution made, was to empower the control system with reliable automatic control access of the pumping system. The Optimised Schedule was then calculated at a central point on surface by the control system, sent through the communication network of the mine

to the various pumping stations on the levels below surface and was then executed through PLCs and electrical switchgear.

With these two new contributions, REMS was able to automatically control the pumping system at the optimum operational point, for a specific mine situation and within system constraints. Control room operators on the mine were no longer necessary to execute the optimised control schedule, or to make sure the Optimised Schedule would fit into the constraints of the mine situation for that specific scenario. Although they were still necessary, they were not part of the hourly, daily working operation of the optimised control system and therefore DSM performance results were not dependant on their performance any more.

When calculating the optimised pump schedule, the simulation and optimisation processes did not have to make assumptions of the conditions of the pumping system. With the enhancement of implementing REMS on-site, it had the advantage of automatically gathering real-time system information of the conditions, availability and statuses of the pumping system components. Therefore, the Optimised Schedule could be automatically executed, without a control room operator verifying the realism of it. Because of the real-time information input, the optimised schedule was also relevant for the specific mine scenario and would still realise the maximum possible DSM results available.

These two contributions were implemented at the four mines as discussed in this thesis. The results were above expectations. At Tshepong mine, REMS has been running for 12 months in auto control mode, achieving 103% of the predicted peak load reduction. At Bambanani mine, REMS has been controlling the clear water pumps for the last 9 months. After the first three months of growing pains, the system was in auto control mode for 86% of the time, achieving 106% of the expected peak load reduction. At Masimong 4 and Harmony 3 shafts, REMS has been auto controlling the pumps for the last 4 and 3 months and has also achieved higher than expected results.

It can therefore be concluded that these two operational contributions have made a huge difference to the whole DSM programme in that the full DSM potential of a system can now be achieved on a sustainable basis.

Technical contributions

Several technical contributions have been made to REMS that enabled the successful implementation of DSM initiatives on any type of clear water pumping system on deep level mine. It is important that the DSM technology should be generic and powerful in order to have the ability to be implemented on any mine pumping system. It was demonstrated in this thesis that the REMS controller now had the ability to successfully control a mine under any of the three possible types of situations. Hence it will be able to handle any clear water pumping system on any South African mine.

For this purpose the REMS controller was extended by various types of additional controllers. These were necessary to handle the three different setups of clear water pumping systems. Firstly, some of these are simple, and consist of only two pump stations with storage dams. Others, however, are more complex and intricate, consisting of at least four pump stations, including underground refrigeration plants as well as dumping valves from various levels. Thirdly, there are pumping systems that included 3CPFS, which required a special controller.

Apart from the main REMS controller, the following additional controllers were included into REMS to empower it with the ability to be implemented on all three types of mines:

Valve Controllers were necessary on mines where dumping valves existed between two levels with storage dams. In the case of Bambanani mine, the storage dam on the lower level supplied water to an underground refrigeration plant. The dumping valve was used in those cases when pumps could not supply enough water to the very important refrigeration dam. The dumping valve would then be opened to gravity feed the refrigeration dam with water from the upper dam.

To enable REMS to control the complete clear water pumping system correctly, these dumping valves had to be included into the controller and this required an additional valve controller.

"Minimum / Maximum Pump" Controllers were added to REMS to be able to handle dams with unusual maximum and minimum level constraints. In such cases the dam constraints were very close to each other, for example the lowest level of the dam at 80% and the highest level 100%. Without the min/max pump controller, REMS would start and stop the pumps to and from that dam very frequently, resulting in pump cycling.

The min/max pump controller enabled the person implementing REMS to mathematically calculate the optimum amount of pumps over the longest period of time, and still comply with the dam level constraints. Various real-time data from the pumping system can be used as inputs to the calculation where the output is the minimum and maximum number of pumps to run. This way of controlling the specific pumps reduces cycling.

"Total amount of water" Controllers were added to REMS to control the amount of water in the clear water pumping system. This was necessary at mines where ground water seepage increased the water in the system and a certain amount had to be pumped out to surface dams on an irregular basis. It is impossible for a human operator to determine the total amount of water in a complex mine system.

Because the water balance is very important for good DSM results, it was decided to add a controller to REMS to correctly determine the total amount of water in the hot and cold water system. When it is found that too much water is in the system, all the pumps have to react and pump the water to the correct levels. The additional controller then automatically gets rid of the surplus water at the most convenient time.

"3CPFS" Controllers had to be added to REMS to accommodate those types of mines that included a 3CPFS in the clear water pumping system. It was seen that there are not many mines that fall into this category and it was thought that it will not be possible to control the complete pumping system. But after an investigation it was seen that there are similarities between the control philosophy of a normal pump station and a pump station which included a 3CPFS.

A mathematical simulation model was developed for the 3CPFS which could be added to the other simulation models to form an integrated dynamic simulation model of the whole clear water pumping system. This was then optimised and included to the REMS controller to realise the minimum electricity costs of the whole pumping system. This resulted in maximum peak load reduction on the electrical pumps

User functionality contributions

Operational changes also had to be made to achieve the maximum peak load reduction on a sustainable basis. The DSM technology had the technical ability to successfully handle any clear water pumping system. However, to ensure long lasting results, user functionality contributions had to be added to make the technology attractive to the operators on the mine to use.

Improvements to REMS functionality as a result of user suggestions:

- User security settings: this gave certain users specific control privileges and other users could only operate, but not adjust, the system.
- Pump sets with own start / stop and other constraints. This was used where certain pumps in the total pumping system formed part of a set, e.g. pumps pumping into different columns, or pumps connected to certain electrical panels.
- REMS control configuration settings display on the viewer panel to enable control room operators to see at what dam levels pumps will be stopped or started by REMS.
- Indication of total running hours of the pumps to provide pump foremen with maintenance information.
- The ability to lock out pumps when maintenance was being done. This enabled control room operators to still keep REMS in auto control mode while certain pumps are locked out of the system for maintenance reasons
- A REMS historic action list; to see when a pump was stopped or started by REMS or manually.
- An alarm system with SMS functionality; to report any violation of a user constraint to mine personnel on site, as well as off site.

7.3 FINAL GENERIC REMS IMPLEMENTATION PROCEDURE

Subsequent to the completion of all the Case Studies, a generic implementation procedure has been developed for REMS DSM projects, that will cater for all the different types of mines and projects. This is shown in Table 9.

The man-days shown in Table 9 give average values; these will vary according to the type of project that is being encountered. In Appendix C this table is expanded into more detail.

NO.	MAIN STEPS OF REMS IMPLEMENTATION PROCEDURE	MAN DAYS
1	**DEVELOP BASELINE** Before the load shift feasibility study can be done the baseline of the mine equipment must be determined. It is necessary to obtain the baseline before the optimised mine profile is generated by the Potential Analyser. This is done because the baseline is compared with the optimised profile to calculate the load shift potential. In order to obtain the correct baseline the electrical trends must be verified with flow rates and temperature readings.	28
2	**DSM FEASIBILITY STUDY** To determine the DSM feasibility study information on the following must be gathered: How the system works, where DSM potential exists, how much DSM potential exists and how new control can be implemented. This information must now be gathered and verified to ensure production, safety, health and maintenance standards when applying DSM on the mine. This must be perfect in order to gain the confidence of the client.	38
3	**INFRASTRUCTURE INVESTIGATION** After the DSM potential is determined, it must be investigated how new control can be implemented to the mine equipment. REMS is dependant on remote control from one central point on the mine. An investigation study is necessary to determine the infrastructure that is to be added to the existing mine infrastructure.	31
4	**COMPONENT SPECIFIC SIMULATION MODEL** Mathematical models for each component at the mine will be investigated and configured. These models will be used in a proprietary integrated simulation model to simulate the mine.	74
5	**DEVELOP INTEGRATED SIMULATION MODEL** Integrate the models in step 4 with the new interface, adapt existing and develop new components needed for this simulation. Preliminary research has been done, but needs to be checked and updated with this specific DSM project in mind. This ensures the confidence of the client which is needed to allow us to do DSM on the mine.	56
6	**VERIFY INTEGRATED SIMULATION MODEL** The simulation model obtained in step 5 must be verified to ensure that accurate results of the mine are generated. Preliminary research information can now be extended to detailed verification to prove the process to the client.	56
7	**DSM OPTIMISER** With the results obtained from the simulation and verification processes, the integrated simulation model will now be optimised to find the lowest operating electricity cost point. To ensure safety of production for the client the experience gained in the preliminary research will now be extended to the satisfaction of the client. We must prove to the client that the optimised schedules will not affect any production, safety, health and maintenance standards.	46
8	**IMPLEMENT AND CONTROL INFRASTRUCTURE MODEL** REMS must communicate with the client's SCADA system. The sustainability of this DSM action is dependant on perfect integration of REMS and SCADA. The current SCADA system on the mine will be investigated to determine whether it complies with the required standards of REMS.	40
9	**DEVELOP COMMUNICATION PROTOCOL BETWEEN MINE SCADA SYSTEM AND REMS** A TCP/IP supportive interfaces needs to be developed to enable communication between REMS and SCADA. To ensure sustainability it must be ensured that all interfaces are generic. This is an important software task.	33
10	**CONFIGURE REMS** The completed REMS model must be configured to integrate with the current processes of the mine. Current operational procedures can not be changed. In this step this issue will be addressed by modifications to the existing REMS to adapt to the strategies used on the mine.	70
11	**DEVELOP AND CONFIGURE REMS SUPPORT AND MONITOR SYSTEM** The support and monitoring system will assist in the gathering, storing, analysing and distribution of important system data. It also gives feedback of the REMS working operation, which can be used when alterations must be made. This support and monitor system will be implemented at the remote site where the monitor room is situated. The support and monitoring of REMS ensures sustainability of the DSM actions.	45
12	**COMMISSION REMS** Finally REMS will be commissioned to do automatic real-time energy management on the mine.	50

Table 9: Main steps of REMS implementation procedure.

7.4 RECOMMENDATION FOR FURTHER RESEARCH

Throughout this thesis, it was established that REMS can be successfully implemented on any type of clear water pumping system in a South African mine. Through the implementation of the system on various mines, it was improved and adapted to perfection. Therefore, not much can be done to further improve the system.

However, one thing that can be improved on REMS is the fact that not all of the predicted cost savings were achieved at some of the case study mines. The cost savings directly relates to the morning and evening load shift results. Due to the fact that more attention was given to achieve evening load shift results, the morning peak load shift achieved was not 100% and resulted in lower actual cost savings achieved.

In future REMS can also be extended to other processes. The clear water pumping system is only one electricity intensive process on a mine. There are many other industrial and mining processes where load shift could be successfully implemented. The primary requirement for such processes must be sufficient surge capacities so that equipment can be switched off during peak times.

Such situations are found in other industrial and mining processes, such as:

1. Mine refrigeration plants
2. Mine ventilation fans
3. Mine vertical rock winders
4. Mine as well as industrial compressed air machines
5. Cement plants

In future REMS can be extended to also simulate, optimise and automatically control these processes on mines and industrial sites in South Africa.

REFERENCES

[1] Doering, Don S., et al: *"Tomorrow's Markets Global Trends and their Implications for Business"*, World Resources Institute, April 2002, pp. 10, 12.

[2] Energy Information Administration (EIA), *"The International Energy Outlook 2005 (IEO2005)"*, Office of Integrated Analysis and Forecasting, U.S. Department of Energy, Washington, DC 20585, July 2005, p. 1.

[3] Cambridge Energy Research Associates, CERA, http://www.cera.com.

[4] *"China ends 'bicycle kingdom' as embracing cars"*, China Daily News, http://www.chinadaily.com.cn/english/doc/2004-11/11/content_390685.htm, November 2004.

[5] Pimentel, D., et al: *"Will limits of the earth's resources control human numbers?"*, College of Agriculture and Life Sciences, Cornell University, Ithaca, NY 14853-0901, February 1999.

[6] Doering, Don S., et al: *"Tomorrow's Markets Global Trends and their Implications for Business"*, World Resources Institute, April 2002, p. 24.

[7] Cambridge Energy Research Associates and US Census Bureau.

[8] Automotive Aftermarket Suppliers Association, http://aftermarketsuppliers.org/articledetail.php?articleId=696.

[9] World Energy Outlook, *"IEA Director Releases Latest World Energy Outlook, Says Current Energy Trends Call for Urgent and Decisive Policy Responses"*, International Energy Agency (IEA), http://www.iea.org/Textbase/press/pressdetail.asp?PRESS_REL_ID=137, October 2004.

[10] Lovins, Amory B., *"Winning the Oil End Game Innovation for Profits, Jobs and Security"*, Rocky Mountain Institute, http://www.oilendgame.com/pdfs/WtOEg_ExecSummary.pdf, 2004.

[11] DME, *"Integrated energy plan for the Republic of South Africa."*, Department of Minerals and Energy, Pretoria, p. 9, March 2003.

[12] NER, *"Electricity Supply Statistics for South Africa 2003"*, National Electricity Regulator, PO Box 40343, Arcadia, 0007, Republic of South Africa, Tel: +27 12 401 4600, www.ner.org.za, 2003, p. 7.

[13] Eskom, *"Integrated Electricity Plan 5"*, IEP5, Eskom, Sandton, May 1996.

[14] Africa, A., *"Short to medium term demand side strategy"*, Eskom DSM, National Energy Efficiency Conference, VW Marketing Conference Centre, Midrand, South Africa, http://www.dme.gov.za/, 17 July 2001.

[15] Eskom, *"Eskom Holdings Annual Report 2005"*, Eskom, www.eskom.co.za/annreport05, 2005, pp. 53 -54.

[16] NER, *"Electricity Supply Statistics for South Africa 2003"*, National Electricity Regulator, PO Box 40343, Arcadia, 0007, Republic of South Africa, Tel: +27 12 401 4600, www.ner.org.za, 2003, p. 8.

[17] Nortje, T., *"South Africa's DSM Programme: A savings opportunity"*, Eskom DSM, International Pump User Conference, Johannesburg, June 2005.

[18] Eskom, *"Eskom Holdings Annual Report 2005"*, Eskom, www.eskom.co.za/annreport05, p. 106.

[19] NER, *"Electricity Supply Statistics for South Africa"*, National Electricity Regulator, Sandton.

[20] Du Plessis, J., *"Lighting Up South Africa 1996"*, National Electricity Regulator, Progress Report, Johannesburg, 1997.

[21] Spalding-Fecher R., Praetorius B., *"Residential Demand Side Management and climate change mitigation"*, Domestic Use of Electrical Energy Conference, 1999.

[22] Cowart, R., *"Efficient Reliability: The Critical Role of Demand-Side Resources in Power Systems and Markets"*, Prepared for the National Association of Regulatory Utility Commissioners, June 2001.

[23] Finamore, B., et al: *"Demand-Side Management in China, Benefits, Barriers, and Policy Recommendations"*, Natural Resources Defence Council, October 2003.

[24] Nadel, S., Geller, H., *"Smart Energy Policies: Saving Money and Reducing Pollutant Emissions through Greater Energy Efficiency"*, Report No. E012, September 2001.

[25] Lovins, Amory B., Lovins, L. Hunter, *"Mobilising Energy Solutions"*, The American Prospect, Vol. 13 No. 2, January, 2002.

[26] Prindle, W., *"Testimony on Energy Efficiency and Demand Response Policies with Regard to H.R. 3406"*, Alliance to Save Energy, December 2001.

[27] Nadel, S., *"Utility Energy Efficiency Programmes: A Brief Synopsis of Past and Present Efforts"*, American Council for an Energy-Efficient Economy, Washington, D.C., August 2000.

[28] Wuppertal Institute 2002, *"Completing the Market for Least-Cost Energy Services"*, Wuppertal Institute for Climate, Environment and Energy, http://www.wupperinst.org/energy-efficiency/dsm.html, 2002.

[29] EREC, *"Renewable Energy Policy Review United Kingdom"*, European Renewable Energy Council, 26 rue du Trone, B-1000, Brussels, May 2004.

[30] Eskom, *"Eskom News"*, Eskom, Sandton, March 2005, pp. 16 – 17.

[31] Eskom, *"Eskom Supports Energy Efficiency with DSM Programme, Importance of Energy Efficiency in Industrial and Commercial Sectors"*, ICUE Conference V&A Waterfront Cape Town, paper available at http://www.eskomdsm.co.za/news8.php, May 2005.

[32] DME, *"Capacity Building in Energy Efficiency and Renewable Energy"*, Report No. 2.3.4 – 31, Department of Minerals and Energy, Pretoria, September 2005.

[33] Rodrigues, M., *"Electrification - R500m for smart electricity use programme"*, Engineering News, 14 February 2003.

[34] Nadel, S., Yang Z., and Shi Y., *"Integrated Resource Planning and Demand-Side Management Manual for China and Other Developing Countries"*, American Council for an Energy-Efficient Economy, Washington, D.C., 1995.

[35] Goldstein, D., and Geller, H., *"Equipment Efficiency Standards: Mitigating Global Climate Change at a Profit"*, Physics and Society, Vol. 28, No. 2, April 1999.

[36] Clark, A., *"Economic analysis of Eskom's energy-efficient lighting programme for low income households"*, Energy and Development Research Centre, University of Cape Town, 1997.

[37] DEAT, *"South Africa Country Report"*, Department of Environmental Affairs and Tourism, Fourteenth Session of the United Nations Commission on Sustainable Development, September 2005.

[38] Eskom, *"Eskom's Retail Tariffs Restructuring Plan: 2005"*, Eskom, PO Box 1091, Johannesburg, 2000, South Africa, www.eskom.co.za/tariffs/trp2005/Pricing/20Plan/202005.doc, 2005

[39] Holt, E., *"Energy Efficiency in a Restructured UK Electric Industry"*, Regulatory Assistance Project (RAP), August 1995.

[40] NAESCO, *"What is an ESCO?"*, National Association of Energy Service Companies, 1615 M Street, NW, Suite 800, Washington DC, 20036, USA, www.naESCo.org, 2005.

[41] NAESCO Press Release, *"New Report Documents $2 Billion Annual Investment in Energy Efficiency by ESCos"*, National Association of Energy Service Companies, 1615 M Street, NW, Suite 800, Washington DC, 20036, USA, www.naESCo.org/industry/press020530.htm, 30 May 2002.

[42] Kushler, M., and Witte, P., *"Can We Rely on the Market to Provide Energy Efficiency? An Examination of the Role of Private Market Actors in an Era of Electric Utility Restructuring"*, Report No. U011, American Council for an Energy-Efficient Economy, September 2001.

[43] Gcabashe, T., *"Eskom Chief Executive Calls on all South Africans to use Electricity Efficiently"*, Opening Speech at Energy Efficiency Month in South Africa, available at: www.enerficiency.org.za/htm/quotes/eskom_ceo.htm, 4 May 2005.

[44] Demand Side Management Technology Review Workshop, *"Building Side Electric Power Technologies"*, Columbia Sustainable Development Initiative (SDI), February 2000.

[45] NUS Consulting Group, International Electricity Survey and Cost Comparison, April 2004.

[46] Measurement and Verification, Quarterly Report, August 2005.

[47] *"Preliminary Energy Outlook for South Africa"*, Energy Research Institute, Department of Mechanical Engineering, University of Cape Town, Private Bag, Rondebosch 7701, October 2001, p. 4.

[48] Delport G. J., Lane I. E., *"Electricity cost management in mining"*, Power Engineering Journal, Vol. 10, No. 4, pp. 169-175, 1996.

[49] Chamber of Mines, *"Mining Industry Fact Sheet 2002"*, The Economics Advisory Unit of the Chamber of Mines, www.bullion.org.za, October 2003.

[50] *"Preliminary Energy Outlook for South Africa"*, Energy Research Institute, Department of Mechanical Engineering, University of Cape Town, Private Bag, Rondebosch 7701, October 2001, p 10, Figure 7.

[51] Schuettler, D., *"South Africa's Deepmine plans digging deeper for gold elusive frontier"*, Indian Express Newspapers (Bombay) Ltd., 27 May 1998.

[52] Lane, I. E., *"Load audits and simulation to develop DSM potential in the mining sector"*, Report for Department of Mineral and Energy Affairs, Report no. ED9206, August 1996, pp. 16 – 17.

[53] Marais, A., *"Braamhoek design contract awarded"*, Engineering News, 6 August 2004.

[54] IST Group (Pty) Ltd, P O Box 95355, Waterkloof, 0145, South Africa, www.ist.co.za, 2005.

[55] ESI Africa, *"World Class Projects among 2004 Eta winners"*, ESI Africa, Issue 4/2004, http://www.esi-africa.com/archives.php, December 2004.

[56] Midvaal Water Company, PO Box 31, Stilfontein, 2550, South Africa , www.midvaal.org.za, 2005.

[57] National Power Contractors cc, 179 Eland Road, Randvaal, Gauteng, South Africa, www.natpower.co.za, 2005.

[58] H20NET Scheduler, MWH Soft Inc., 370 Interlocken Boulevard, Suite 300, Broomfield, CO 80021 USA, www.mwhsoft.com, 2005.

[59] MISER Pump scheduling, Tynemarch Systems Engineering Ltd, Crossways House, 54-60 South Street, Dorking, Surrey, RH4 2HQ, United Kingdom, www.tynemarch.co.uk, 2005.

[60] DERCETOE, Beca Applied Technologies Ltd, PO Box 6345 Auckland, New Zealand, www.derceto.com, 2005.

[61] Multitrode Pump View, Multitrode Pty Ltd, Brisbane Technology Park, 18 Brandl Street, Eight Miles Plain QLD 4113, Australia, www.multitrode.com, 2005.

[62] Mathews, E. H., den Boef, M., *"Implementation of DSM strategies at Kopanang mine"*, Centre of Research and Commercialisation, University of Potchefstroom, 2004.

[63] Borland home page, Corporate Headquarters 100 Enterprise Way Scotts Valley, CA 95066-3249, USA, http://www.borland.com, 2003.

[64] Regional and Operational Information, *"Anglo Gold Ashanti Country Report 2004"*, Anglo Gold Ashanti (Pty) Ltd, December 2004.

[65] Frontline Systems Inc, P.O. Box 4288, Incline Village, NV 89450, USA, www.solver.com, 2005.

[66] Mathews, E. H., Director, TEMM International, Personal Communication, Tel.: (012) 991 5568, February 2004.

[67] Rautenbach, W., Krueger, D.L.W., *"Reducing the electricity cost of a Three-Pipe Water Pumping System – a Case Study using software"*, Journal of Energy in South Africa, Vol. 16, No. 5, November 2005.

[68] Butterworth M, Environmental engineering, MiningTek, CSIR, Meiring Naude Road, Brummeria, Pretoria, South Africa, 2001.

[69] Hazen-Williams head loss equations, LMNO Engineering, Research, and Software, Ltd. 7860 Angel Ridge Rd. Athens, Ohio USA, 2000.

[70] Mathews, E. H., Van Heerden, E., Arndt, D.C., *"A Tool for Integrated HVAC, Building, Energy and Control Analysis, Part 2: Control Simulations with QUICKcontrol"*, Building and Environment, Vol. 34, No. 5, pp. 451-467, 1999.

[71] Nortjé, T., Manager, Industrial Projects, Eskom DSM, Personal Communication, Mobile: +27(0)82 331 3789, 24 November 2005.

[72] Eskom DSM, *"The 12 Commandments for ESCos"*, Eskom, PO Box 1091, Johannesburg, 2000, South Africa, www.eskomdsm.co.za/news22.php, 2005.

[73] Le Roux, H., *"Giant ramping up to 1 300 kg/m"*, Engineering News, 20 May 2005.

[74] Else R., *"Energy Evaluations and load shift feasibility in South African mines"*, Thesis submitted in fulfilment of the requirements for the degree philosophiae doctor, Department of Mechanical Engineering, Potchefstroomse Universiteit vir Christelike Hoër Onderwys, 2003.

[75] Eskom, *"Eskom Environmental data: Statistic, Acronyms"*, Eskom, P O Box 1091 Johannesburg, www.eskom.co.za/enviroreport01/stats.htm/using20one/20kilowatt-hour, 2000.

APPENDIX A

BASELINE CALCULATIONS

Before a DSM project can commence the historic trend of electricity consumption for the specific process must be determined. This is done by calculating an average daily profile from various months. Preferably summer months and winter months as the electricity consumption on mine processes can vary according to seasons. The daily average trend is called the baseline and is compared with the achieved results as the load management performance and cost savings are calculated. Graphs of the baselines for the different pump stations are shown in Appendix A. They are combined to form the baseline of the complete clear water pumping system.

BAMBANANI BASELINE CALCULATIONS

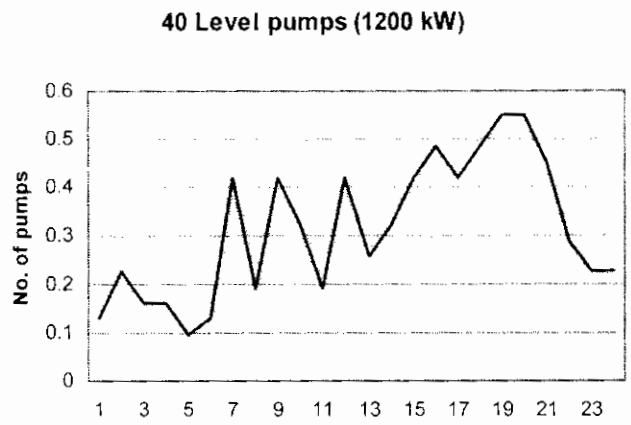


Figure A1: Daily average number of pumps on 40 Level pump station.

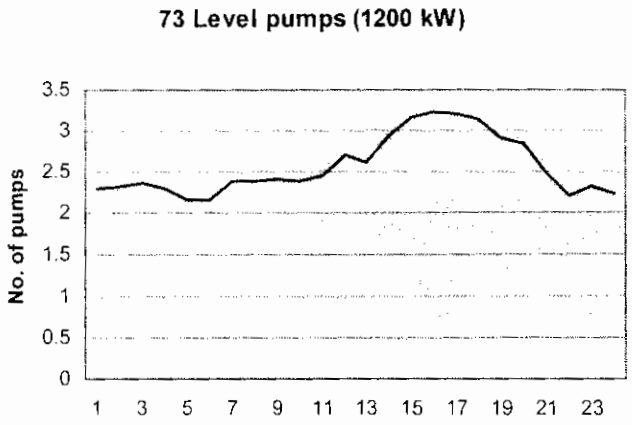


Figure A2: Daily average number of pumps on 43 Level pump station.

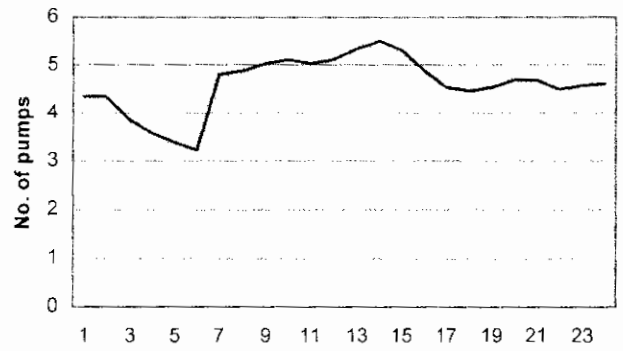


Figure A3: Daily average number of pumps on 91 Level pump station.

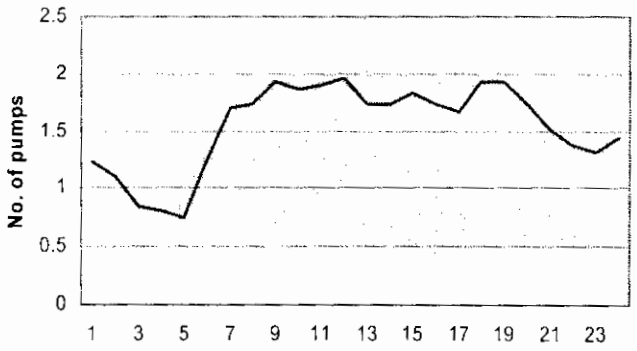


Figure A4: Daily average number of pumps on 105 B Level pump station.

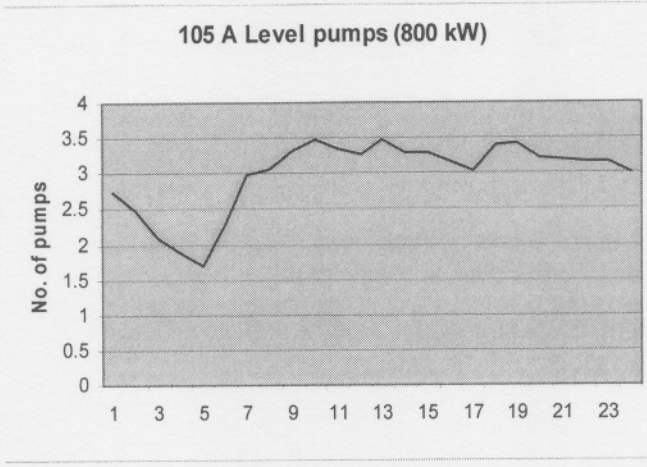


Figure A5: Daily average number of pumps on 105 A Level pump station.

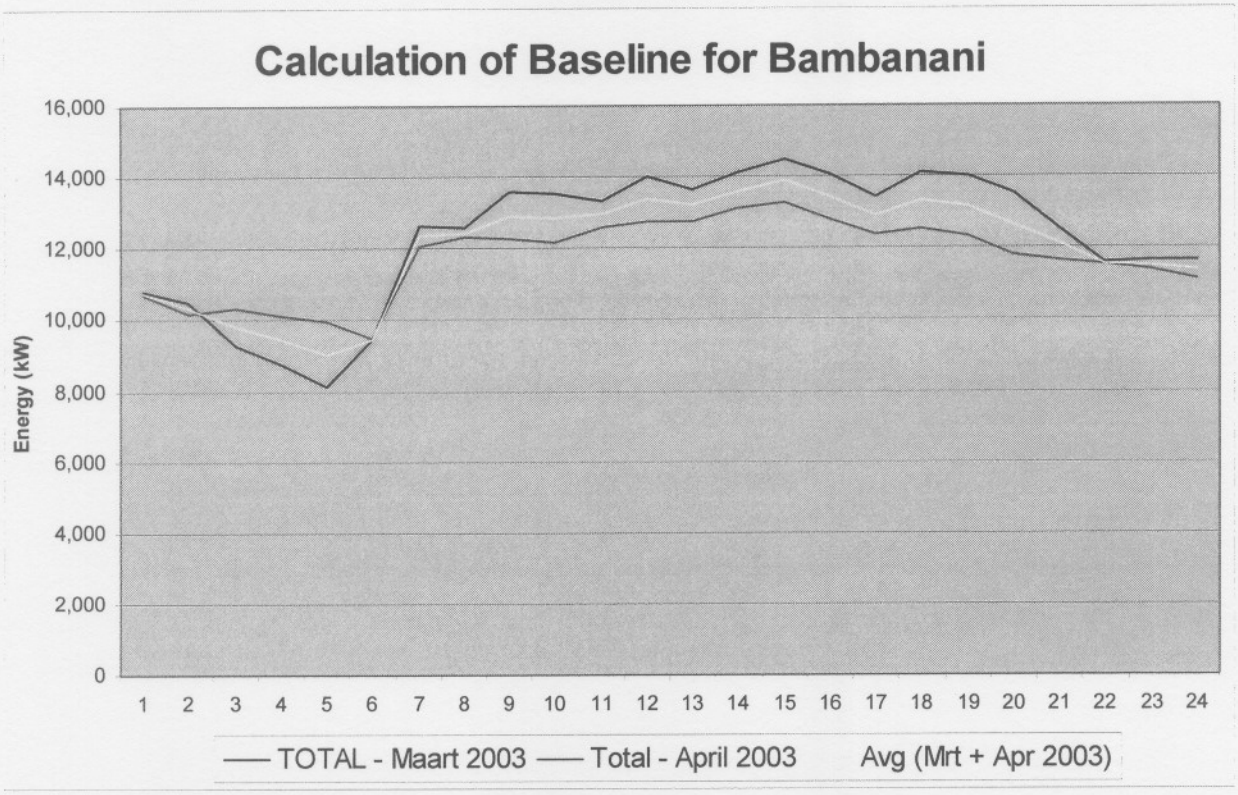


Figure A6: Combined baseline for complete clear water pumping system.

HARMONY 3 SHAFT BASELINE CALCULATIONS

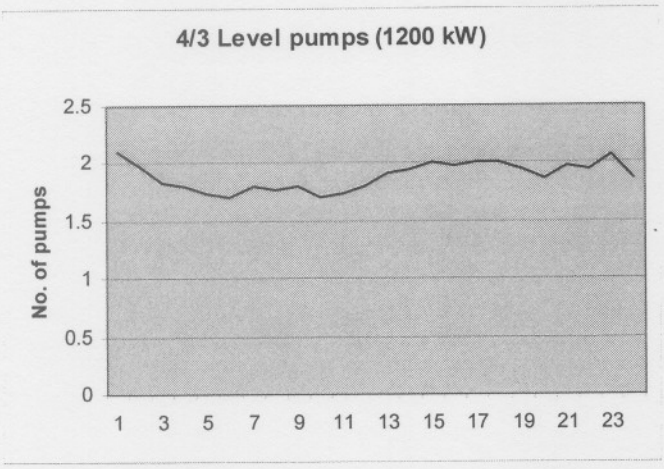


Figure A7: Daily average number of pumps on 4/3 Level pump station.

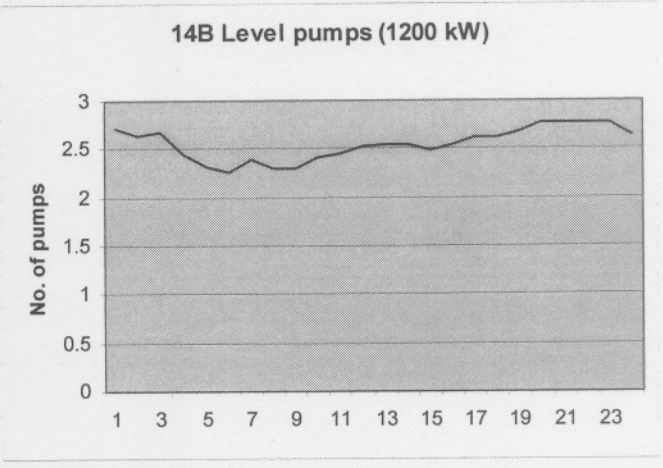


Figure A8: Daily average number of pumps on 14B Level pump station.

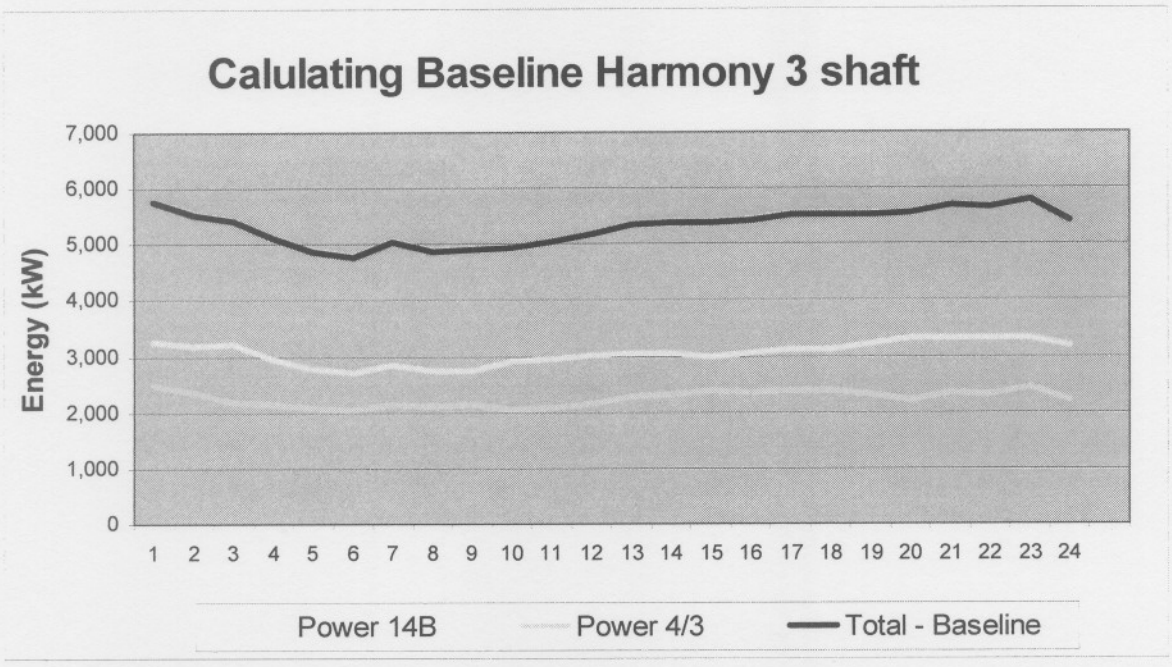


Figure A9: Combined baseline for complete clear water pumping system.

MASIMONG 4 SHAFT BASELINE CALCULATIONS

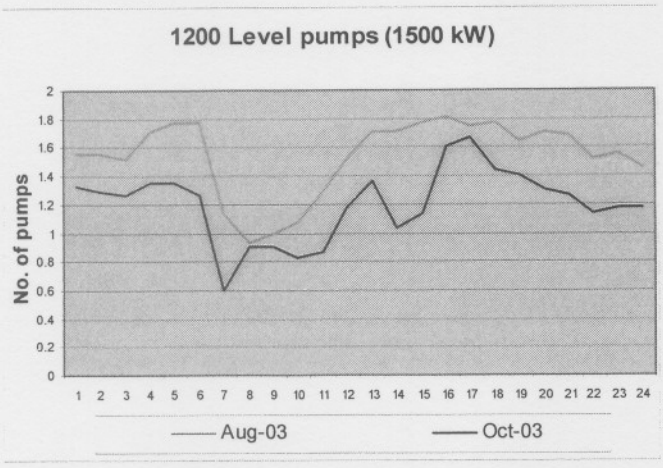


Figure A10: Daily average number of pumps on 1200 Level pump station.

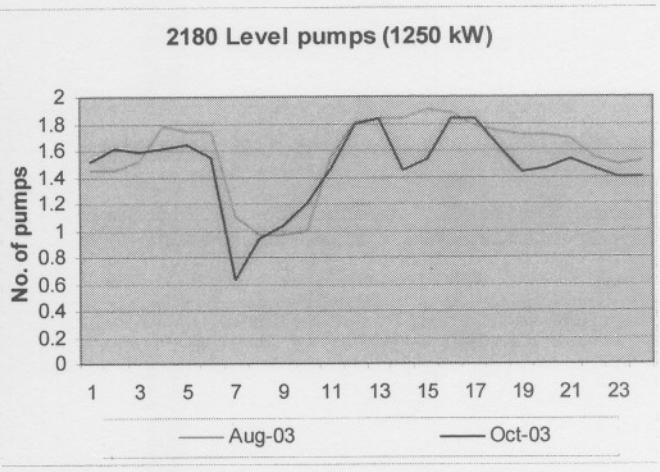


Figure A11: Daily average number of pumps on 2180 Level pump station.

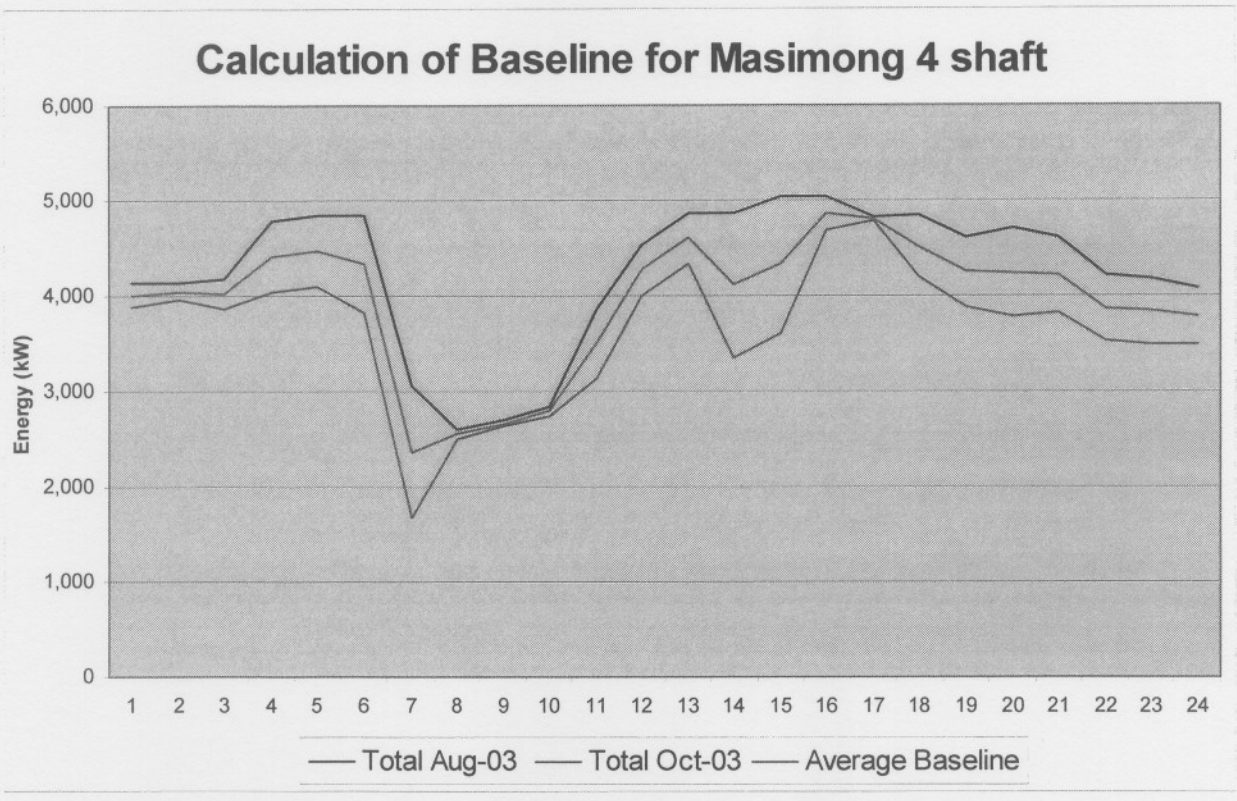


Figure A12: Combined baseline for complete clear water pumping system.

APPENDIX B

SCOPE OF WORK FOR REMS IMPLEMENTATION

Before a REMS can be implemented on a mine approval must be obtained from mine management. To obtain this, the complete Scope of Work of the project is documented and presented to the mine. In this Appendix a combined Scope of Work for Bambanani, Masimong 4 shaft and Harmony 3 shaft is demonstrated.

LOAD SHIFT THROUGH IMPLEMENTATION OF A REAL TIME ENERGY MANAGEMENT SYSTEM (REMS) ON THE CLEAR WATER PUMP SYSTEMS AT THE HARMONY FREE STATE OPERATIONS

HVAC INTERNATIONAL (PTY) LTD

AND

HARMONY GOLD

JANUARY 2004

OPTIMISATION OF THE CLEAR WATER SYSTEM AT THE HARMONY FREE STATE OPERATIONS TO ACHIEVE MAXIMUM LOAD SHIFT AT MINIMUM ELECTRICITY COST

BAMBANANI MINE OPTIMISATION OF THE CLEAR WATER PUMP SYSTEM

SYSTEM LAYOUT

At Bambanani water is used to cool the underground mining conditions and operations. This water is cooled via two underground fridge plants. From the fridge plants the water flows to the mining operations and then back to the settlers. From the settlers the water is pumped via the clear water pump system and again back to the two fridge plants. The water completes this cycle continually throughout the day. A minimum amount of water is pumped to the surface.

At present Bambanani mine pumps from 105 level an average of 650 l/s clear water throughout the day. The water from 105 level is pumped to 92 level and 73 level hot water dams. 91 level and 73 level hot water dams feed 75 level dam that supplies 75 level fridge plant with sufficient water. From the 73 level dam water is pumped via the 73 level pump station to 40 level hot water dam. 40 level hot water dam feeds 58 level dam to supply 58 level fridge plant with sufficient water. From 40 level hot water dam water is also pumped to the surface via 40 level pump station. The current total installed capacity to pump this water is
28 MW. This can be seen in *Figure 47*

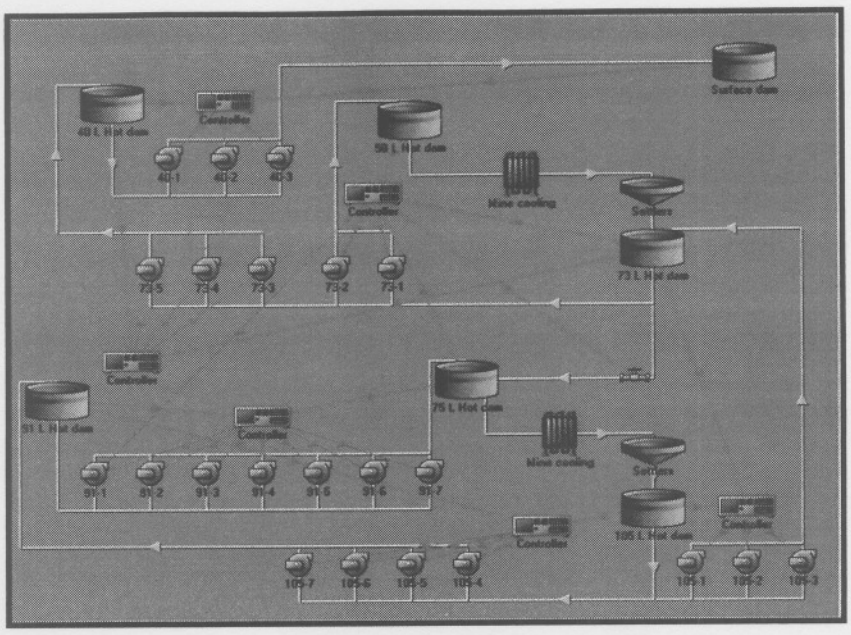


Figure 47: Simulation model of the pumping and cooling processes at Bambanani gold mine.

PRICING STRUCTURE

Eskom provides alternative pricing structures for large consumers of electricity. The six main tariffs available to them are NightSave, MegaFlex, MiniFlex, RuraFlex, Real-time Pricing (RTP) and Wholesale Electricity Pricing (WEP). RTP and WEP are still in the testing phase with various pilot sites being used. Many mines are not fully aware of these alternatives and the possible benefits to them with regard to DSM opportunities. The more advanced tariffs are advantageous for industries that are capable of shifting load for a certain period of time

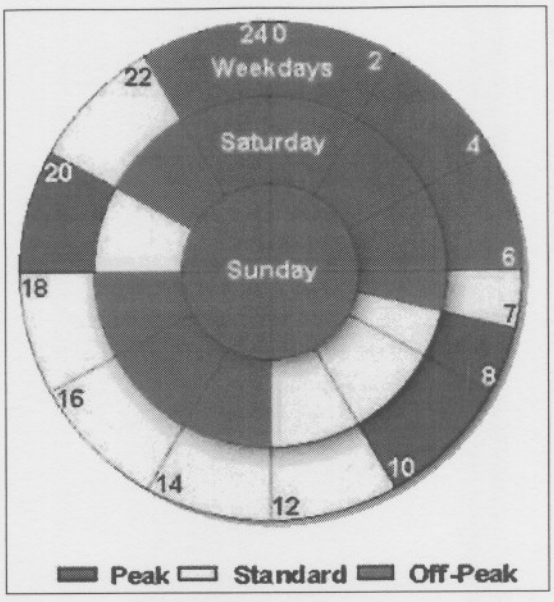


***Figure 48**: Time-of-use for MegaFlex*

Bambanani mine is currently on the MegaFlex tariff. MegaFlex is more suitable for large consumers that need a supply of 1 MVA and above. The TOU period can be seen in *Figure 48*. This is ideal for large consumers capable of shifting load for long periods (4 to 5 hours per day). The only negative is that this tariff is very rigid with little room for innovative scheduling. Optimisation will be used to find the optimum operating schedule of the underground pumping system.

DATA AVAILABILITY

Bambanani mine has a comprehensive Supervisory Control and Data Acquisition (SCADA) system. All underground dam levels and the operation of pumps are logged.

CONCLUSION

The management is keen on any savings and open to suggestions. The infrastructure is in place to easily automate the systems under investigation. As a result of the SCADA system being in place most of the operational condition data are easily available. The pumping system has large dams that can be used for storage. This is a pre-requisite for load shifting.

OPTIMISATION OF THE UNDERGROUND CLEAR WATER PUMPING SYSTEM

There are two types of constraints applicable on this system. These are the available number of pumps and minimum and maximum dam levels. On level 105 there are 10 electrical pumps. On level 91 there are 9 electrical pumps. There are 7 electrical pumps on level 73 and on level 40 there are another three electrical pumps installed.

The clear water dam levels and other warm water dam levels must be kept between 40% and 90% at all times as per client constraints. To keep the water balance intact the clear water pump system must supply the dams that feed the fridge plants with sufficient water.

OPTIMISATION PROCEDURE

The calculated load shift is based on the following profiles for the year 2003.

- Settler flow
- Daily amount of water pumped
- Equipment constraints
- Underground dam capacities

The 5.8 MW load shift profile is obtained by pumping the same amount of water, as was previously done, but shifting pumping load from the evening peak.

Production and operating constraints that were taken into account are the following:

- Maximum number of pumps active daily
- Minimum and maximum dam levels and dam capacities
- Underground water usage
- Safety constraints
- Maintenance constraints
- Allowable on/off switch periods for all elements

RESULTS

Table 10 gives the results that were obtained from the optimisation model. The hourly amount of electricity used on the pumping system is given. *Table 10* also supplies the average measured electricity consumed by the pumping system for 2003. By comparing the figures of the measured electricity used with the simulated electricity used during the second peak period (between 18:00 and 20:00), the load shift potential can be determined. This is illustrated in *Table 10.*

Hour of day	Measured electricity consumption on pumps (MW)	Simulated electricity consumption on pumps (MW)
01:00	10,693	13,100
02:00	10,173	13,100
03:00	10,347	13,100
04:00	10,107	13,100
05:00	9,947	13,100
06:00	9,507	13,100
07:00	12,053	13,100
08:00	12,333	13,100
09:00	12,280	3,756
10:00	12,160	7,913
11:00	12,573	13,100
12:00	12,733	13,100
13:00	12,773	13,100
14:00	13,093	13,100
15:00	13,267	13,100
16:00	12,787	13,100
17:00	12,400	13,100
18:00	12,547	13,100
19:00	**12,347**	**5,600**
20:00	**11,787**	**5,600**
21:00	11,640	13,100
22:00	11,520	13,100
23:00	11,360	13,100
00:00	11,147	13,100

Table 10: Average hourly electricity used on the clear water pumping system.

The average daily pump load profile, before the REMS intervention and our recommended optimised profile are shown in *Table 10.* Note that it was previously not possible for this very energy conscious mine to react to on the high price signal.

It is impossible, to stay within constraints, e.g. dam levels, amount of pumps available, etc. if a full optimisation of the complete system is not done as we suggested with REMS. The result is a missed load shift opportunities especially during the evening peak.

The full potential of the new on-site REMS technology can be realised when the current profile is compared to the recommended optimised profile. By comparing the current load profile with our recommended optimised profile it can be seen that there exist more than 5.8 MW load shift potential between 18:00 and 20:00.

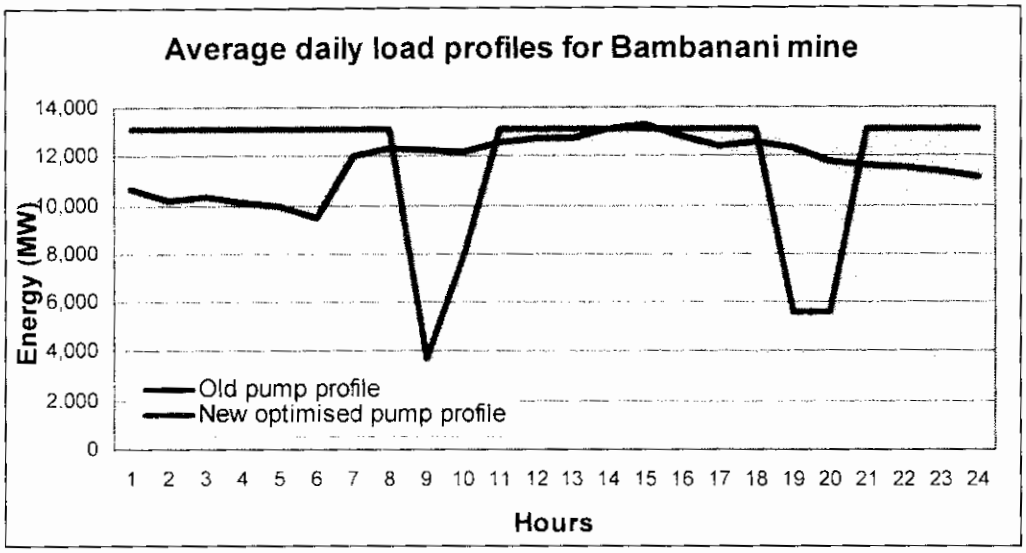


Figure 49: Average daily load profile for Bambanani clear water pumps.

The area under each load profile represents the average daily energy use on the pumps. The amount of energy used for each profile is the same. As the peak time energy is more expensive, a load shift results in an energy cost saving.

As a result of the 5.8 MW load shift, a ballpark figure for the energy cost savings is R100 000/MW/year. This means that REMS will lead to an extra cost saving of R 580 000 per year for Bambanani mine.

MASIMONG4 GOLD MINE OPTIMISATION OF THE CLEAR WATER PUMP SYSTEM

SYSTEM LAYOUT

At Masimong 4 water is used to cool the underground mining conditions and operations. This water is cooled via a surface fridge plant. From the fridge plant the water flows to the mining operations and then back to the settlers. From the settlers the water is pumped via the clear water pump system back to the surface to be cooled again. This water cycle continues throughout the day.

At present Masimong 4 mine pumps from 2180 level an average of 162 l/s water throughout the day. From level 2180 water is pumped to the hot water dam on level 1200. This water is then pumped via the 1200 level pump station to the surface dam. The current installed capacity to pump this water is 11 MW. This can be seen in *Figure 50*.

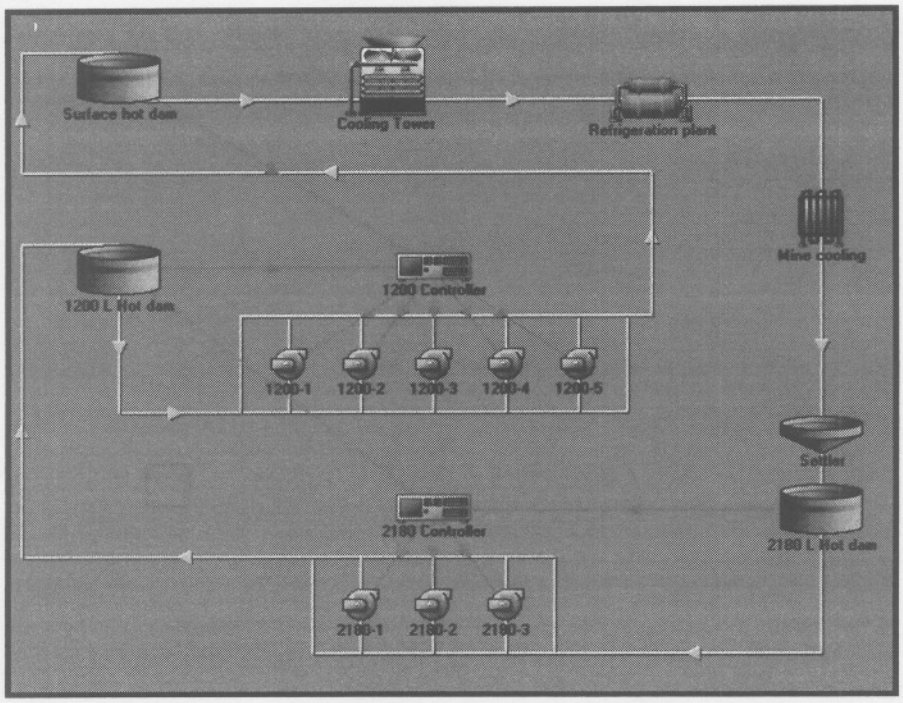


Figure 50: Simulation model of the pumping and cooling processes at Masimong4 gold mine.

OPTIMISATION OF THE UNDERGROUND CLEAR WATER PUMPING SYSTEM

There are two types of constraints applicable on this system. These are the available number of pumps and minimum and maximum dam levels on each level. On level 2180 there are 4 electrical pumps. The level 2180 hot water dam must be kept between [illegible] client constraints.

On level 1200 there are also 4 electrical pumps. The hot water dam level on level 1200 must be kept between 30% and 100% as per client constraints. To keep the water balance intact the clear water pump system must supply the surface hot dam with sufficient water.

RESULTS

Table 11 gives the results that were obtained from the optimisation model. The hourly amount of electricity used on the pumping system is given. Table 11 also supplies the average measured electricity consumed by the pumping system for 2003. By comparing the figures of the measured electricity used with the simulated electricity used during the second peak period (between 18:00 and 20:00), the load shift potential can be determined. This is illustrated in Table 11.

Hour of day	Measured electricity consumption on pumps (MW)	Simulated electricity consumption on pumps (MW)
01:00	4,137	5,000
02:00	4,137	5,000
03:00	4,169	5,000
04:00	4,782	5,000
05:00	4,839	5,000
06:00	4,839	5,000
07:00	3,065	5,000
08:00	2,613	2,600
09:00	2,710	2,600
10:00	2,847	2,600
11:00	3,871	5,000
12:00	4,532	5,000
13:00	4,863	5,000
14:00	4,863	5,000
15:00	5,040	5,000
16:00	5,048	5,000
17:00	4,831	5,000
18:00	4,839	5,000
19:00	4,605	0,250
20:00	4,702	0,250
21:00	4,613	5,000
22:00	4,210	5,000
23:00	4,177	5,000
00:00	4,073	5,000

Table 11: Average hourly electricity used on the clear water pumping system.

The average daily pump load profile, before the REMS intervention and our recommended optimised profile are shown in *Table 11*. Note that it was previously only possible for this very energy conscious mine to react partly on the high price signal.

It is impossible, to stay within constraints, e.g. dam levels, amount of pumps available, etc. if a full optimisation of the complete system is not done as we suggested with REMS. The result is a missed load shift opportunities especially during the evening peak.

The full potential of the new on-site REMS technology can be realised when the current profile is compared to the recommended optimised profile. By comparing the current load profile with our recommended optimised profile it can be seen that there exist more than 3.9 MW load shift potential between 18:00 and 20:00.

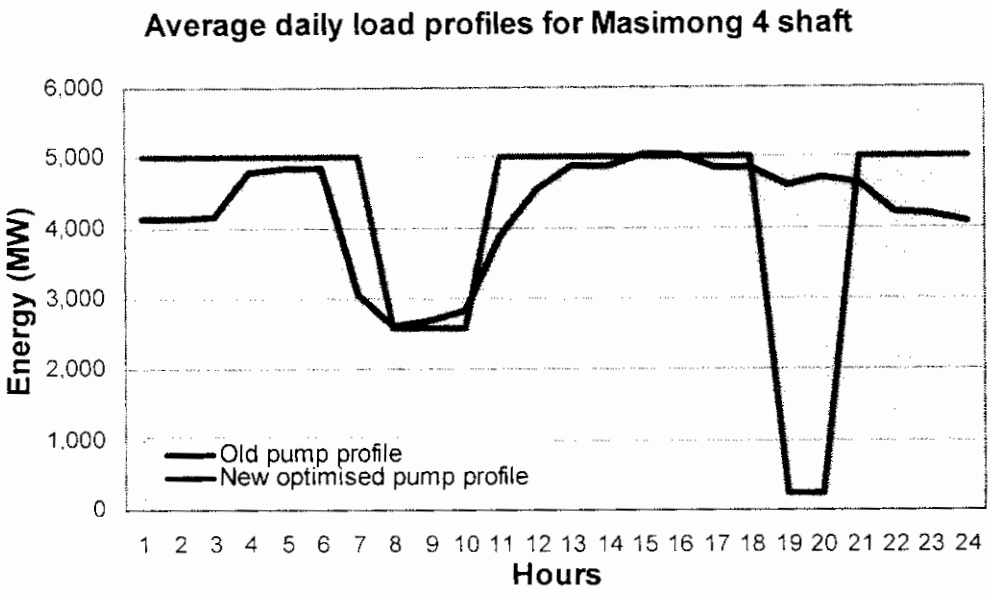


Figure 51: Average daily load profile for Masimong 4 clear water pumps.

The area under each load profile represents the average daily energy use on the pumps. The amount of energy used for each profile is the same. As the peak time energy is more expensive, a load shift results in an energy cost savings.

As a result of the 3.9 MW load shift, a ballpark figure for the energy cost savings is R 100 000/MW/year. This means that REMS will lead to an extra cost saving of R 390 000 for Masimong 4 mine.

HARMONY3 GOLD MINE OPTIMISATION OF THE CLEAR WATER PUMP SYSTEM

SYSTEM LAYOUT

At Harmony3 water is used to cool the underground mining conditions and operations of various neighbour mines. The mine is currently used as a pumping station. It pumps the water from Merriespruit 1 and Merriespruit 3 to the surface. The Masimong 4 and 5 operations are dependant on the pumping operations of Harmony3 since the underground water table between these mine is connected. When Harmony3 stops pumping, Masimong4, Masimong5, Merriespruit1 and Merriespruit3 will flood. This mine pumps a daily average of 19 Ml water.

At present Harmony3 mine pumps from 14B level an average of 162 l/s water throughout the day. From level 14B water is pumped to the hot water dam on level 4/3. This water is then pumped via the 4/3 level pump station to the surface dam. The current installed capacity to pump this water is 11 MW. This can be seen in *Figure 52*

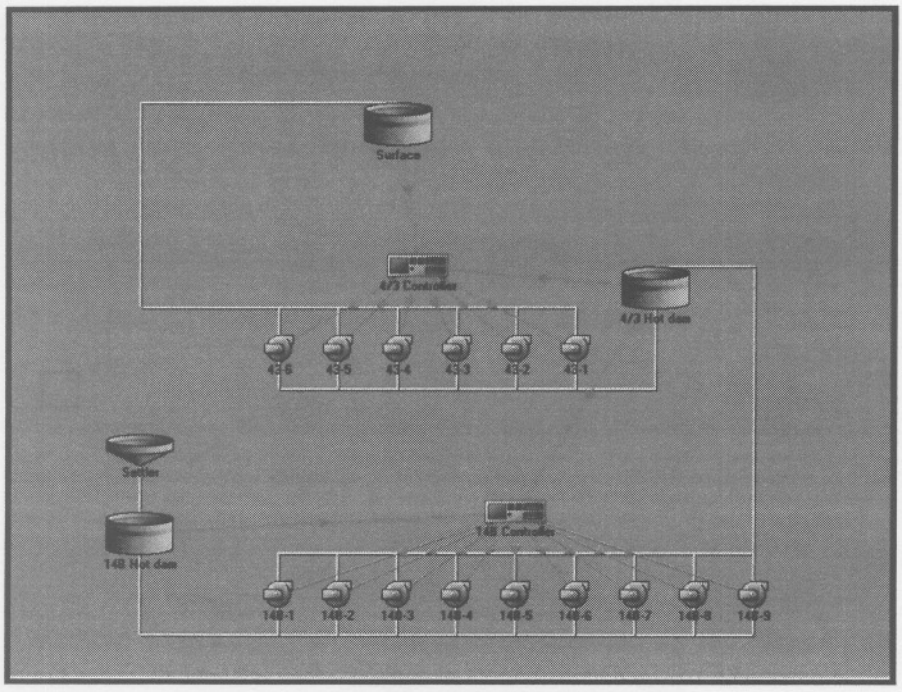


Figure 52: Simulation model of the pumping and cooling processes at Harmony3 gold mine.

OPTIMISATION OF THE UNDERGROUND CLEAR WATER PUMPING SYSTEM

There are two types of constraints applicable on this system. These are the available number of pumps and minimum and maximum dam levels on each level. On level 14B there are 9 electrical pumps. The level 14B hot water dam must be kept between 30% and 100% at all times as per client constraints.

On level 4/3 there are also 6 electrical pumps. The hot water dam level on level 4/3 must be kept between 30% and 100% as per client constraints. To keep the water balance intact the clear water pump system must supply the surface hot dam with sufficient water.

RESULTS

Table 12 gives the results that were obtained from the optimisation model. The hourly amount of electricity used on the pumping system is given. Table 12 also supplies the average measured electricity consumed by the pumping system for 2003. By comparing the figures of the measured electricity used with the simulated electricity used during the second peak period (between 18:00 and 20:00), the load shift potential can be determined. This is illustrated in Table 12.

Hour of day	Measured electricity consumption on pumps (MW)	Simulated electricity consumption on pumps (MW)
01:00	5,191	5,977
02:00	4,982	6,600
03:00	4,877	5,968
04:00	4,599	4,602
05:00	4,390	4,400
06:00	4,285	4,400
07:00	4,529	4,400
08:00	4,390	110
09:00	4,425	257
10:00	4,459	2,933
11:00	4,529	6,288
12:00	4,668	6,600
13:00	4,808	6,600
14:00	4,843	6,600
15:00	4,843	6,536
16:00	4,877	5,839
17:00	4,982	5,060
18:00	4,982	4,473
19:00	**4,982**	**0,750**
20:00	**5,017**	**0,750**
21:00	5,121	3,328
22:00	5,086	6,600
23:00	5,226	6,600
00:00	4,877	6,600

Table 12: Average hourly electricity used on the clear water pumping system.

The average daily pump load profile, before the REMS intervention and our recommended optimised profile are shown in *Table 12*. Note that it was previously only possible for this very energy conscious mine to react partly on the high price signal.

It is impossible, to stay within constraints, e.g. dam levels, amount of pumps available, etc. if a full optimisation of the complete system is not done as we suggested with REMS. The result is a missed load shift opportunities especially during the evening peak.

The full potential of the new on-site REMS technology can be realised when the current profile is compared to the recommended optimised profile. By comparing the current load profile with our recommended optimised profile it can be seen that there exist more than 3.8 MW load shift potential between 18:00 and 20:00.

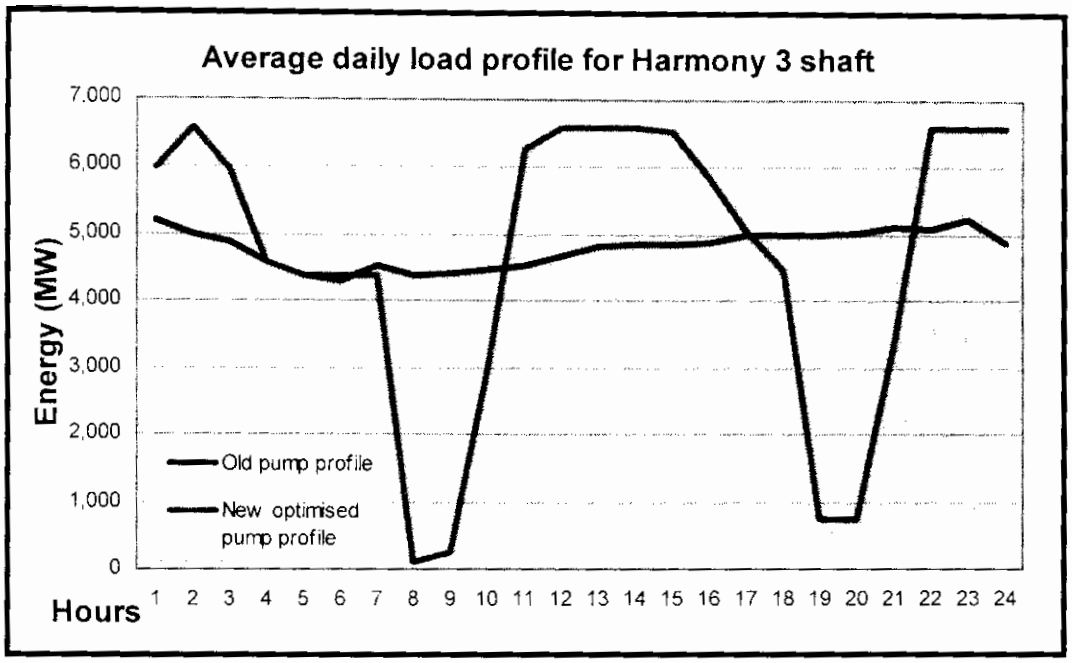


Figure 53: Average daily load profile for Harmony3 clear water pumps.

The area under each load profile represents the average daily energy use on the pumps. The amount of energy used for each profile is the same. As the peak time energy is more expensive, a load shift results in an energy cost savings.

As a result of the 3.8 MW load shift, a ballpark figure for the energy cost savings is R 100 000/MW/year. This means that REMS will lead to an extra cost saving of R 380 000 for Harmony3 mine.

APPENDIX C

DETAILED IMPLEMENTATION PROCEDURE OF REMS

After REMS was implemented on the various types of clear water pumping systems, a generic implementation procedure has been developed for REMS DSM projects, that will cater for all the different types of mines and projects. The detailed, generic implementation procedure together with man-days is shown this Appendix. The man-days are average values and will vary according to the type of project that is being encountered.

DETAILED IMPLEMENTATION PROCEDURE OF REMS

NO.	STEPS AND DESCRIPTION	MAN DAYS
1	**DEVELOP BASELINE** Before the load shift feasibility study can be done the baseline of the mine equipment must be determined. It is necessary to obtain the baseline before the optimised mine profile is generated by the Potential Analyser. This is done because the baseline is compared with the optimised profile to calculate the load shift potential. In order to obtain the correct baseline the electrical trends must be verified with flow rates and temperature readings.	**28**
1.1	Identify data required that is not available on the mine. *To apply DSM to the mine certain data from the mine processes may be needed that is not currently being measured. These shortcomings must be identified in this step.*	3
1.2	Identify the appropriate measuring equipment to measure data required from 1.1. *To measure the data required in step 1.1, new measuring equipment is needed at certain stages in the mine processes. The measuring equipment must be identified.*	3
1.3	Install measuring equipment. *The new measuring equipment is now installed at the various stages in the mine processes.*	4
1.4	Electrical trends. *Collect the electrical trends for the mine for the past 3 months (12 months if available). Gather all this information to form an archive of the electricity usage of the mine. This data will later be used to compare with the optimised profile to determine the DSM potential.*	4
1.5	Collect calibration data. *Calibration data for the baseline such as equipment efficiencies in the mine must be gathered. All these must be used to ensure that the baseline is correct calibrated.*	4
1.6	Collect verification data. *The verification data for the baseline such as flow rates and temperatures of all the different processes in the mine must be gathered. This information will also be used when a mathematical simulation model is designed, representing the mine.*	4
1.7	Verify baseline. *Verify the baseline with the data collected in 1.7 and 1.8 to ensure the correct baseline. If there are any differentiations the process must be repeated or it must be discussed with mine personnel.*	4
1.8	Meet with managers of mine to discuss the baseline. *The findings of the baseline must be discussed with the mine mangers. Make sure they are satisfied that the current situation on the mine is reflected in the baseline. This is a very important step because the baseline will be used in the load shift and cost savings calculations for the duration of the project. If there are any differences concerning baseline the necessary steps must be repeated.*	2
2	**DSM FEASIBILITY STUDY** To determine the DSM feasibility study information on the following must be gathered: How the system works, where DSM potential exists, how much DSM potential exists and how new control can be implemented. This information must now be gathered and verified to ensure production, safety, health and maintenance standards when applying DSM on the mine. This must be perfect in order to gain the confidence of the client.	**38**
2.1	System layout. *The system layout of the whole mine should be obtained. This step is very important to get an over-all idea of the strategies used in the mine and must be arranged with the mine managers. This means that the complete process must be fully understood.*	6
2.2	Collect design data and control strategies *Design data for the mine and control strategies for the different control processes must be collected to ensure that an authentic simulation model can be designed. This is a laborious task.*	4
2.3	Configure REMS Potential Analyser. *After the system layout is obtained and the design data and control strategies are gathered the REMS Potential Analyser can be configured according to the specific mine. It is important to build the Analyser correct to represent the specific mine.*	10
2.4	Obtain a preliminary optimised profile. *Once the Analyser is built a preliminary optimised profile according to load shift is obtained. Because it goes through several interactions until correct it must be repeated several times. This optimised profile will be compared to the baseline to determine the DSM potential.*	2
2.5	Compare optimised profile with baseline. *To determine the DSM potential the previous behaviour (baseline) of the mine must be compared with the optimised profile generated by the Analyser. The difference of the two is the load shift potential that exists.*	8

2.6	Complete load shift feasibility study report. *All the DSM potential findings are documented in a Scope of Work.*	4
2.7	Discuss load shift feasibility report with mine managers. *The Scope of Work for the mine from 2.6 must now be discussed with the mine managers. The document states the DSM potential that exists and how it will be realised with the REMS technology.*	2
2.8	Get permission from mine managers to continue with DSM project. *The mine managers must agree on the findings in the Scope of Work and must give permission for the DSM project to continue. The different section managers of the mine must be informed on the findings of the DSM feasibility study and must be informed that the project is progressing. This is necessary to get co-operation from them in later stages.*	2
3	**INFRASTRUCTURE INVESTIGATION** After the DSM potential is determined, it must be investigated how new control can be implemented to the mine equipment. REMS is dependant on remote control from one central point on the mine. An investigation study is necessary to determine the infrastructure that is to be added to the existing mine infrastructure.	**31**
3.1	Discuss REMS control philosophy with mine personnel. *Meet with specific personnel responsible for instrumentation projects. Discuss with them the control philosophy and interaction of REMS with the various mine equipment.*	3
3.2	Identify additional infrastructure. *It is necessary to identify the additional infrastructure that is needed for REMS to control the mine equipment from one central point. Normally this will include a SCADA system, programmable logic controllers (plc's), a communication network and transducers.*	8
3.3	Discuss implementation of additional infrastructure with mine managers. *List and document the additional infrastructure necessary. Discuss the implementation procedure of it with mine managers.*	2
3.4	Develop infrastructure implementation model. *Together with the mine personnel, develop an infrastructure implementation model. Supply the model with different implementation phases and start / end dates. Also determine the responsibilities that technical mine personnel must supply with each implementation phase.*	6
3.5	Quotations from subcontractors. *Get quotations from different subcontractors to supply and commission the additional infrastructure. Usually the mine has got preferred subcontractors.*	10
3.6	Compare and choose a subcontractor. *Together with the mine managers compare the different quotation and choose subcontractors to supply and commission the additional infrastructure.*	2
4	**COMPONENT SPECIFIC SIMULATION MODEL** Mathematical models for each component at the mine will be investigated and configured. These models will be used in a proprietary integrated simulation model to simulate the mine.	**74**
4.1	Identify mine components with the most DSM potential to be modelled and simulated.	10
4.2	Identify simulation components which need to be adapted according to the existing models. *Examples of typical components that may need to be adapted are motors, pumps, chillers and cooling towers.*	8
4.3	Use information from manufacturer's catalogues to adapt mathematical models where needed.	8
4.4	Transform the adapted mathematical models into components that comply to the requirements of the existing simulation software *The existing software for integrated simulation is component based. The mathematical models must therefore be transformed to comply with the same requirements (i.e. types of input and output) of other existing components.*	10
4.5	Program the adapted simulation components to incorporate the mine components.	8
4.6	Identify new simulation components not yet developed.	5
4.7	Use information from manufacturer's catalogues to develop the new mathematical models.	5
4.8	Transform the new mathematical models into components that comply to the requirements of the existing simulation software.	8
4.9	Program the new simulation components to incorporate the mine components.	8
4.10	Develop new user interface to include Eskom tariffs and DSM actions for al components (i.e. existing, adapted and new).	4
5	**DEVELOP INTEGRATED SIMULATION MODEL** Integrate the models in step 4 with the new interface, adapt existing and develop new components needed for this simulation. Preliminary research has been done, but needs to be checked and updated with this specific DSM project in mind. This ensures the confidence of the client which is needed to allow us to do DSM on the mine.	**56**

5.1	Obtain layout of system to be simulated. *Study the layout of the system obtained in 2.1. This system layout must be studied with the DSM potential in mind for the mine. Each component and the whole mine must be studied with this in mind.*	8
5.2	Apply boundary data for the mathematical models *For each component of which a mathematical model is build, the boundary values must be obtained from the system layout. These values must be built into the mathematical models to ensure the completeness of the models.*	6
5.3	Integrate all the mathematical models into one simulation model *After the boundary data is build into the mathematical models all the models must be taken and put into one simulation model. This model represents the whole mine and is used to simulations on.*	10
5.4	Prepare verification data for simulation	4
5.5	Obtain the relevant information for each measured component on the mine *Information to be obtained is: performance parameters, scheduling and control strategies.*	4
5.6	Enter input data into software simulation *After all the relevant information is gathered from the mine, these values must be entered into the simulation model obtained in step 3.3.*	8
5.7	Conduct simulations for each adapted or new simulation component	10
5.8	Enter simulated data into data structure *The results obtained from the simulation model are entered into a database and will be used to compare with. This step is important because the correctness of the results, and input values can be verified.*	6
6	**VERIFY INTEGRATED SIMULATION MODEL** The simulation model obtained in step 5 must be verified to ensure that accurate results of the mine are generated. Preliminary research information can now be extended to detailed verification to prove the process to the client.	**56**
6.1	Plan measurements to be taken for verification of integrated simulation model. *The measuring points and position of the data loggers must firstly be decided upon. Measurements typically taken include water flow rates, temperatures and electricity consumption of DSM potential components at the identified points.*	8
6.2	Obtain mine data to verify simulation model.	6
6.3	Prepare this data for verification purposes	6
6.4	Conduct real-time comparison of measured and simulated data. *To compare the data, the average, as well as maximum difference between the real-time simulated and measured values is firstly calculated. The percentage that the simulation values are within a certain accuracy limit, is then also determined.*	20
6.5	Verify new integrated simulation model.	8
6.6	Implement corrections and revise models where required. *This can be an iterative process. Where the component models are insufficiently accurate, measurements will again be conducted and compared to the simulated results of the updated models.*	8
7	**DSM OPTIMISER** With the results obtained from the simulation and verification processes, the integrated simulation model will now be optimised to find the lowest operating electricity cost point. This is the final step concerning the mathematical simulation model. During the preliminary research a rough and first optimised simulation model for the specific mine was obtained. To ensure safety of production for the client the experience gained in the preliminary research will now be extended to the satisfaction of the client. We must prove to the client that the optimised schedules will not affect any production, safety, health and maintenance standards.	**46**
7.1	Specify mine operational constraints. *After the mathematical simulation model is verified to be the same as the real mine process, the mine constraints needs to be specified. Constrains can be the levels of dams at certain periods, availability of pumps and the daily maintenance issues.*	10
7.2	Apply mine operational constraints to the optimised simulation model. *The constraints specified in 7.1 must be applied to the simulation model. This application is very important to ensure the authenticity of the model.*	10
7.3	Specify variables for the model. *The variables where most DSM potential exists needs to be specified.*	6
7.4	State the objective function for the optimisation model. *After the variables are specified the objective function can be stated. The objective function is the function where the cost is minimised and the electricity load shifted out of Eskom's peak times is maximised.*	6

7.5	Obtain the optimised model. *From the objective function stated in 7.4 the optimised model can be obtained. Finally an optimised model can be compiled that will use electricity tariffs to minimise the cost and maximise the load shift of the mine.*	8
7.6	Create the optimised operating schedule from the output of the optimisation model.	6
8	**IMPLEMENT AND CONTROL INFRASTRUCTURE MODEL** Our REMS must communicate with the client's SCADA system. The sustainability of this DSM action is dependant on perfect integration of REMS and SCADA. The current SCADA system on the mine will be investigated to determine whether it complies with the required standards of REMS.	**40**
8.1	Discuss implementation of REMS with personnel on mine. *Determine which SCADA system is in place at the mine and how REMS can be integrated with current system.*	6
8.2	Investigate current SCADA system. *Investigate what measurements are logged on the SCADA system and how this system is used to control the equipment at the mine.*	4
8.3	State shortcomings in SCADA system where modification is required.	4
8.4	Discuss the shortcomings with technician in charge of SCADA system.	6
8.5	Modify current system to adapt to new procedures.	8
8.6	Investigate current hardware. *Investigate current installed infrastructure (communication lines, pc's, etc.) between SCADA and equipment to be controlled.*	4
8.7	Modify current hardware system to enable communication. *Implement hardware to enable communication between equipment to be controlled and the SCADA system.*	8
9	**DEVELOP COMMUNICATION PROTOCOL BETWEEN MINE SCADA SYSTEM AND REMS** A TCP/IP supportive interfaces needs to be developed to enable communication between REMS and SCADA. To ensure sustainability it must be ensured that all interfaces are generic. This is an important software task.	**33**
9.1	Determine the best communication method. *This step is important and must be thoroughly conducted before making any changes to the SCADA system. The communication between all the different processes and the control of it must be determined here.*	15
9.2	Program SCADA interface in REMS. *After determining the best communication method, a REMS interface must be programmed to collect and send data from and to the SCADA system.*	10
9.3	Test new SCADA and REMS interface. *This and the previous step is import to ensure good two way communication between REMS and the SCADA system. Because REMS is controlled from a remote system on site, communication between REMS and SCADA must work 100%.*	8
10	**CONFIGURE REMS** The completed REMS model must be configured to integrate with the current processes of the mine. We can not change current operational procedures. In this step this issue will be addressed by modifications to the existing REMS to adapt to the strategies used on the mine.	**70**
10.1	Configure REMS according to current operating strategies. *REMS must be configured to integrate with the current operating strategies on the mine. The information gathered of the system layout and the mine processes will be used here.*	10
10.2	Simulate response of equipment *Simulate with a software simulation program how the new controlled equipment will react when controlled by REMS algorithms.*	10
10.3	Verify the simulation process and modify if necessary. *The simulation of the response of the equipment must be verified to compare with the mine equipment.*	12
10.4	Modify the REMS configuration according to results from 10.2 and 10.3. *Make the necessary adjustments to REMS according to the results obtained from the previous two steps.*	16
10.5	Finalise REMS configuration.	10
10.6	Obtain current operating strategies and equipment constraints.	12
11	**DEVELOP AND CONFIGURE REMS SUPPORT AND MONITOR SYSTEM** The support and monitoring system will assist in the gathering, storing, analysing and distribution of important system data. It also gives feedback of the REMS working operation, which can be used when alterations must be made. This support and monitor system will be implemented at the remote site where the monitor room is situated. The support and monitoring of REMS ensures sustainability of the DSM actions.	**45**

11.1	Develop system to transfer daily operating data of REMS. *The operating data needs to be sent daily to the remote monitoring room. This will be send via modem from the mine.*	14
11.2	Develop database structure for important operating data. *A structure at the remote site were all the important operating data will be stored must be developed. Typical operating data that will be stored is real-time operating schedules, availability of mine equipment and feedback reporting of control room operators on the mine.*	8
11.3	Develop structure to analyse data from 11.1. *After the daily operating data is collected at the remote monitoring room it must be analysed. This information will later be used in weekly and monthly reports about the performance of REMS.*	8
11.4	Develop structure to generate required reports *Reports consisting of i.a. the cost savings and load shift should be distributed weekly and monthly to the mine. Daily reports consisting of percentage auto / manual control, equipment availability, R/c saving and MW load shift is also send to the mine when the project is in the beginning phase. A structure to generate the required reports should be implemented.*	15
12	**COMMISSION REMS** Finally REMS will be commissioned to do automatic real-time energy management on the mine.	**50**
12.1	Discuss commission strategy with mine management. *Before the commissioning process starts the strategy must first be discussed with the mine management.*	8
12.2	Implement REMS interface. *The interface that was developed in 7.2 to ensure two way communication between REMS and the SCADA system can now be implemented on the mine.*	10
12.3	Test REMS interface. *After the implementation of the interface between REMS and the SCADA system on the mine, the interface must be tested. This test must be performed to make sure there is clear communication between the mine's SCADA system and REMS.*	6
12.4	Commission REMS. *After the communication interface exists, the REMS configuration can be installed and commissioned.*	12
12.5	Test newly implemented system. *After commissioning REMS on the mine the system must be tested. These tests can continue to exist for the duration of the project to ensure maximum cost savings.*	10
12.6	Update REMS at planned intervals *Regularly update and calibrate optimisation model to adapt to changing mine conditions. This step will continue at regular intervals for the duration of REMS on the mine.*	4

Table C1: Detailed, generic implementation procedure of REMS.

APPENDIX D

USER ACCEPTABILITY QUESTIONNAIRE

User acceptability is one of the most important issues when sustainable results must be achieved. In order to test the user acceptability of the REMS product, two types of questionnaires were given to the mine after implementation was completed. Management level and operational level questionnaires were given to the specific persons and presented valuable feedback that was used to improve the process. The two types of questionnaire can be seen in this Appendix.

MANAGEMENT LEVEL:

REMS AFTER IMPLEMENTATION QUESTIONNAIRE FOR TSHEPONG MINE

CONTACT DETAIL

Name: _____

Position at mine: _____

Office Tel. no.: _____

Email address: _____

PRE-IMPLEMENTATION

1. Was the process of gathering mine system data time consuming for you or your personnel?

Yes	☐
No	☐
Do not know	☐

Comment: _____

_____

2. Were you presented with clear preliminary results about the proposed project?

Yes	☐
No	☐
Do not know	☐

Comment: _____

_____

3. Did you think at that stage that the DSM results promised were possible to realise on your mine?

Yes	☐
No	☐
Do not know	☐

Comment: _____

_____

4. Was it possible to realise the results on your own?

Yes	☐
No	☐
Do not know	☐

Comment: _____

_____

IMPLEMENTATION PROCEDURE

5. How did you experience the implementation procedure?

Good	☐
Not good	☐
Do not know	☐

Comment: _____

_____

6. Were you satisfied with the technology implemented on your clear water pump system?

Yes	☐
No	☐
Do not know	☐

Comment: _____

_____

7. Were you confident that no mine constraints would be violated in order to realise DSM results?

Yes	☐
No	☐
Do not know	☐

Comment: _____

_____

8. Do you think REMS controls the pumps in a smarter way than your control room operators / pump attendants?

Yes	☐
No	☐
Do not know	☐

Comment: _____

_____

SUSTAINABILITY OF DSM RESULTS

9. Are you satisfied with the DSM results?

Yes	☐
No	☐
Do not know	☐

Comment: _____

_____

10. Do you think the results are sustainable?

Yes	☐
No	☐
Do not know	☐

Comment: _____

_____

11. Are you satisfied with the after-implementation REMS support?

Yes	☐
No	☐
Do not know	☐

Comment: _____

_____

ANY OTHER COMMENT:

_____

_____

_____

_____

_____

_____

OPERATOR LEVEL:

AFTER IMPLEMENTATION QUESTIONNAIRE FOR TSHEPONG MINE

CONTACT DETAIL

Name: _____

Position at mine: _____

Office Tel. no.: _____

Email address: _____

INCLUSION OF OPERATOR LEVEL USERS

12. Was the purpose of the new technology explained to you before the project started?

Yes	☐
No	☐
Do not know	☐

Comment: _____

_____

13. Did you think it was possible to automatically control the pump system?

Yes	☐
No	☐
Do not know	☐

Comment: _____

_____

14. Do you think the new technology (REMS) is necessary to control the pumps to realise DSM results?

Yes	☐
No	☐
Do not know	☐

Comment: _____

_____

IMPLEMENTATION PROCEDURE

15. How did you experience the implementation process?

- Good ☐
- Not good ☐
- Do not know ☐

Comment: _____

_____

16. Was your knowledge about the pump system used when the REMS controllers were configured?

- Yes ☐
- No ☐
- Do not know ☐

Comment: _____

_____

OPERATOR LEVEL USER BENEFITS

17. Do you think the pump system is controlled in a smart way?

- Yes ☐
- No ☐
- Do not know ☐

Comment: _____

_____

18. Does REMS help you in your daily tasks?

- Yes ☐
- No ☐
- Do not know ☐

Comment: _____

_____

19. Do you feel the REMS project is a team effort between the mine and REMS engineers?

Yes	☐
No	☐
Do not know	☐

Comment: _____

_____

20. Are you satisfied with the after implementation support?

Yes	☐
No	☐
Do not know	☐

Comment: _____

_____

ANY OTHER COMMENT:

_____

_____

_____

_____

_____

_____

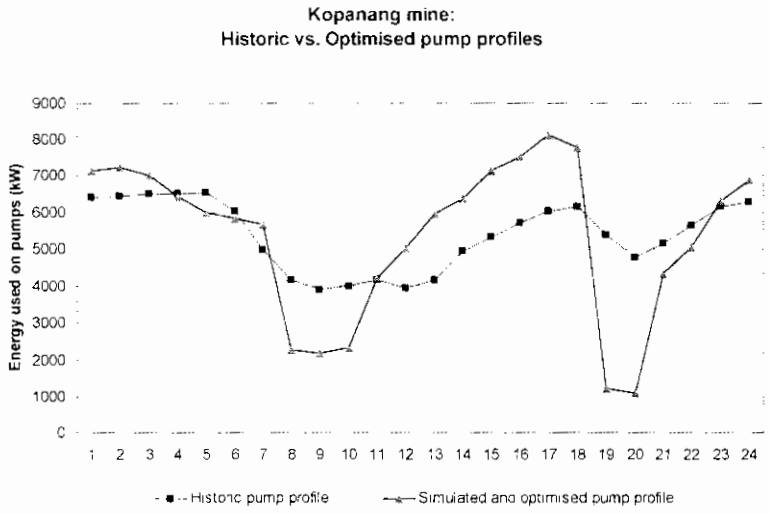
APPENDIX E

SIMULATION AND OPTIMISATION RESULTS OF POTENTIAL GOLD MINES WHERE THE NEW PROCEDURE CAN BE APPLIED

A comprehensive study has been done about possible gold mines where the new approach described in this thesis could be implemented. Preliminary simulation and optimisation models of the pumping systems were built to determine the load shift potential. The information was used to determine the national impact of the new approach. For every mine a daily profile with the baseline and optimised profile is shown, together with the load shift and cost savings potential, as can be achieved with the REMS technology.

ANGLO GOLD MINES

KOPANANG

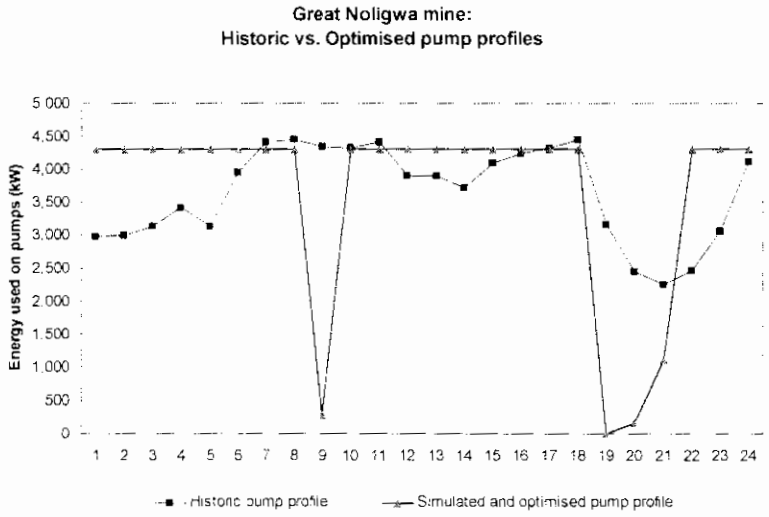


Potential morning peak reduction: 1.8 MW

Potential evening peak reduction: 3.9 MW

Potential annual electricity cost savings: R 480k

GREAT NOLIGWA

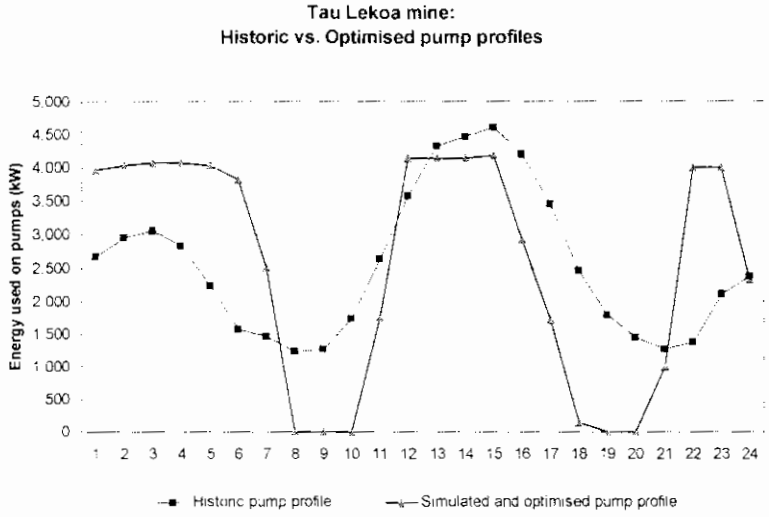


Potential morning peak reduction: 1.4 MW

Potential evening peak reduction: 2.7 MW

Potential annual electricity cost savings: R 407k

TAU LEKOA

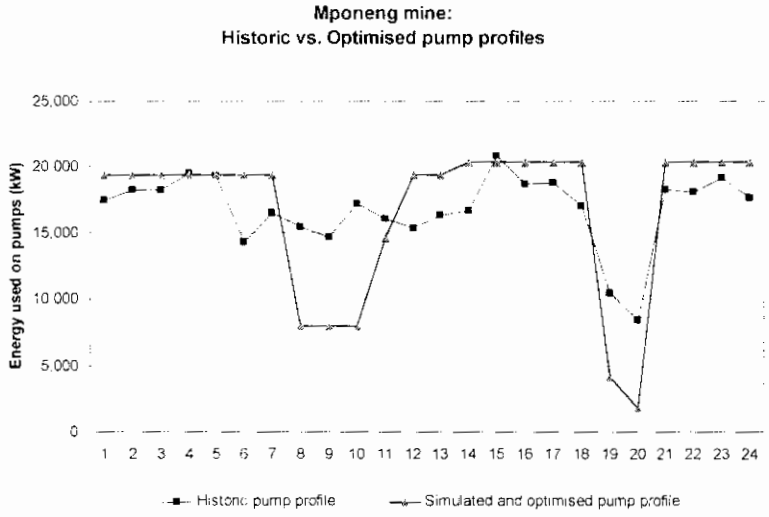


Potential morning peak reduction: 1.4 MW

Potential evening peak reduction: 1.6 MW

Potential annual electricity cost savings: R 355k

MPONENG

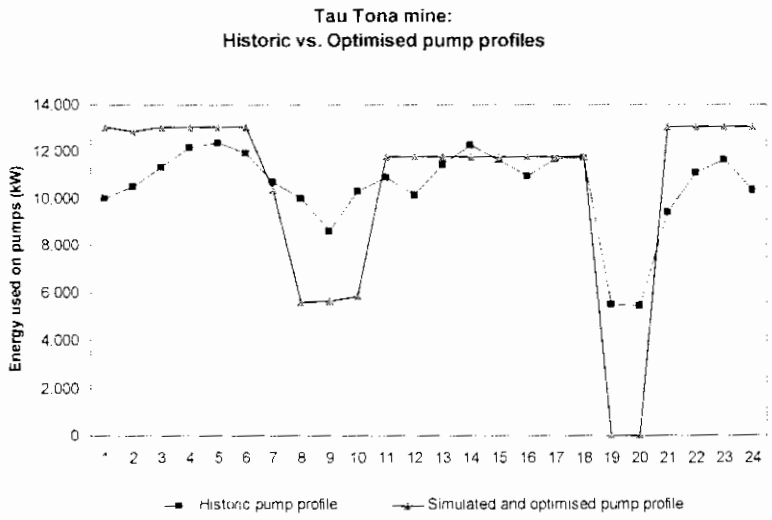


Potential morning peak reduction: 7.5 MW

Potential evening peak reduction: 6.5 MW

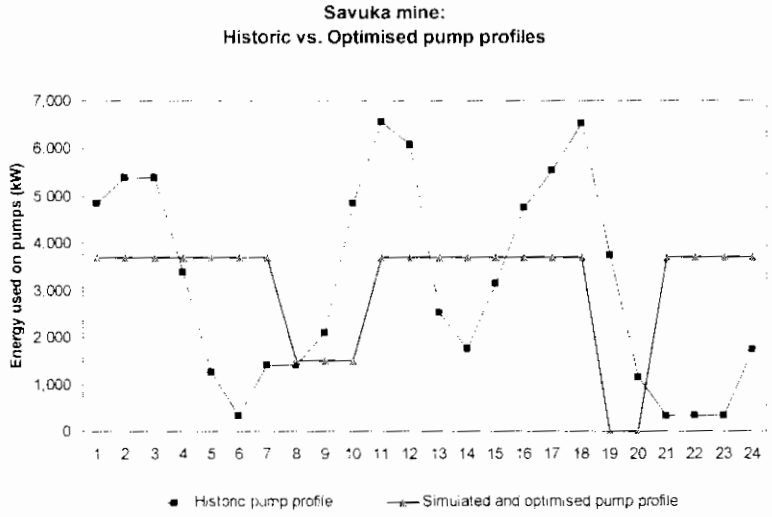
Potential annual electricity cost savings: R 1,389k

TAU TONA



Potential morning peak reduction:	3.9 MW
Potential evening peak reduction:	5.4 MW
Potential annual electricity cost savings:	R 921k

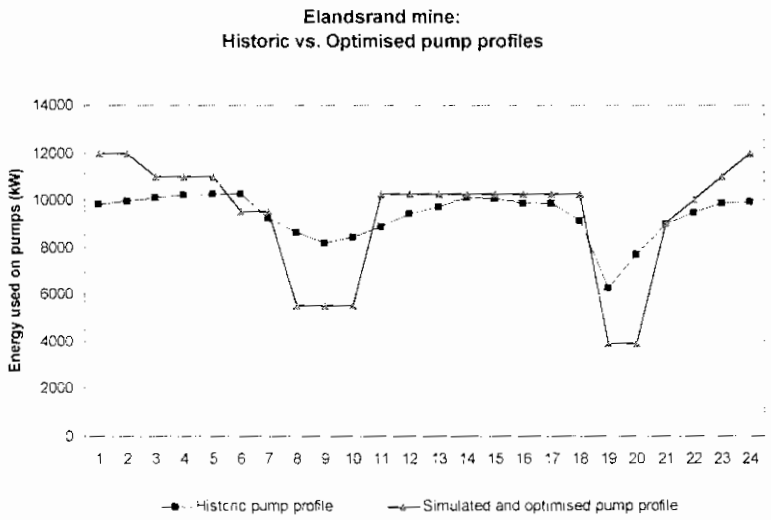
SAVUKA



Potential morning peak reduction:	1.3 MW
Potential evening peak reduction:	2.4 MW
Potential annual electricity cost savings:	R 380k

HARMONY GOLD MINES

ELANDSRAND

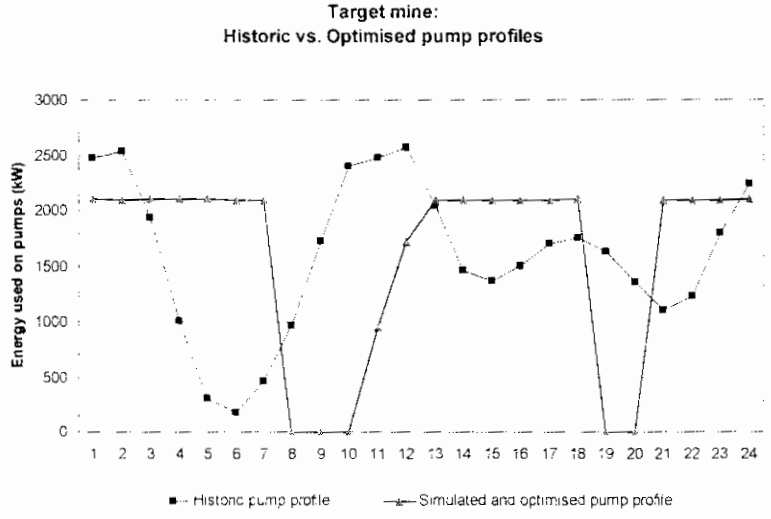


Potential morning peak reduction: 2.9 MW

Potential evening peak reduction: 3.0 MW

Potential annual electricity cost savings: R 600k

TARGET

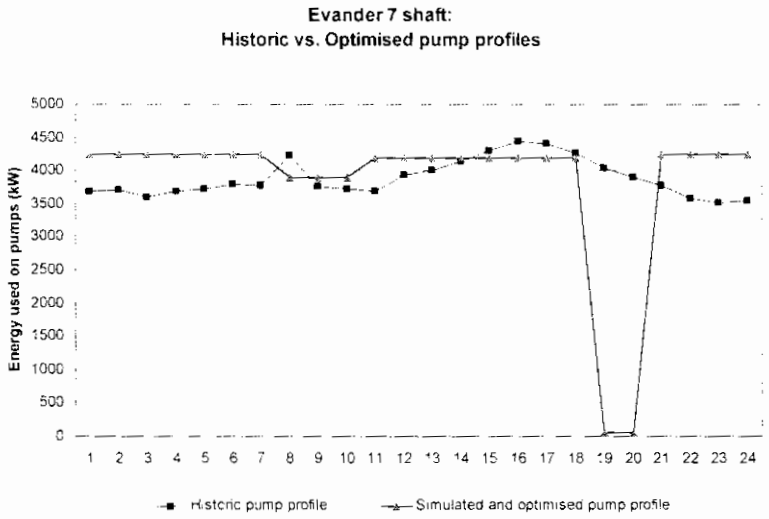


Potential morning peak reduction: 1.7 MW

Potential evening peak reduction: 1.5 MW

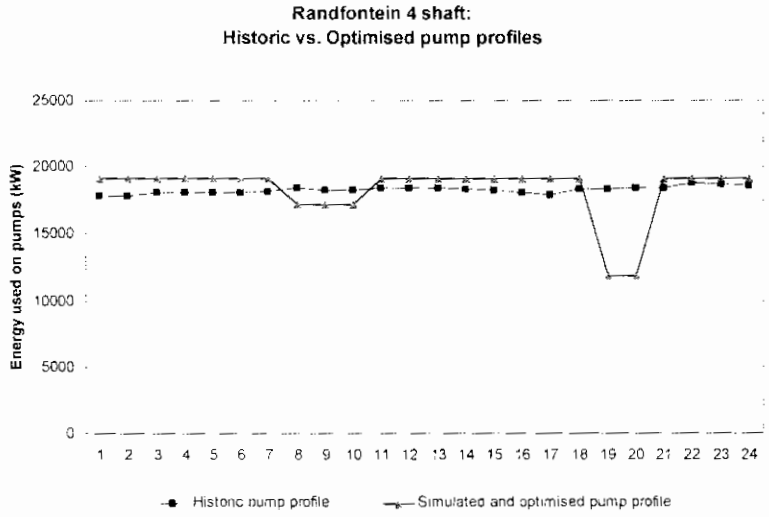
Potential annual electricity cost savings: R 324k

EVANDER 7 SHAFT



Potential morning peak reduction:	0.0 MW
Potential evening peak reduction:	3.9 MW
Potential annual electricity cost savings:	R 346k

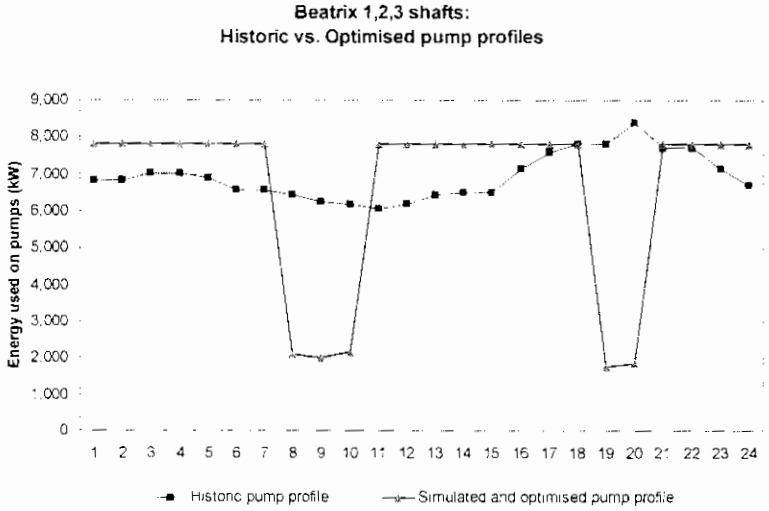
RANDFONTEIN 4 SHAFT



Potential morning peak reduction:	1.1 MW
Potential evening peak reduction:	6.5 MW
Potential annual electricity cost savings:	R 644k

GOLD FIELDS MINES

BEATRIX 1,2,3 SHAFTS

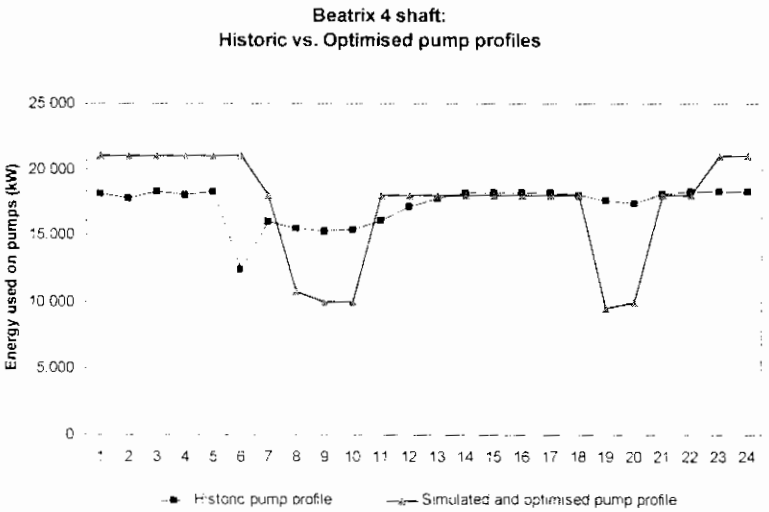


Potential morning peak reduction: 4.2 MW

Potential evening peak reduction: 6.3 MW

Potential annual electricity cost savings: R 1,184k

BEATRIX 4 SHAFT

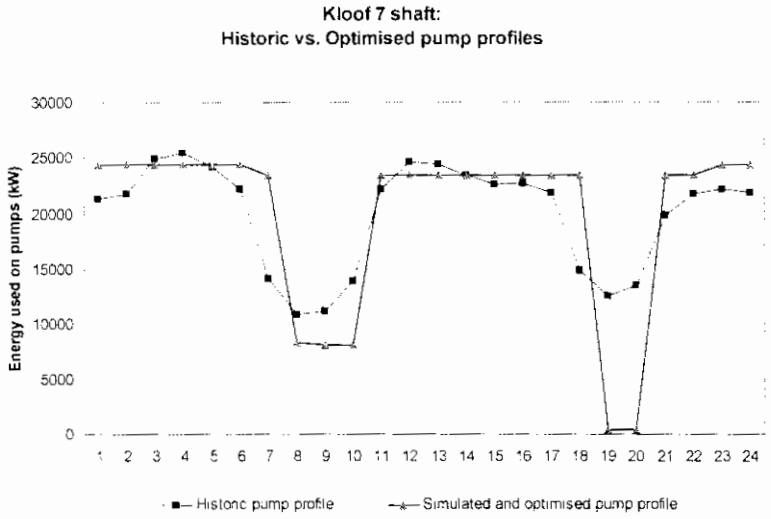


Potential morning peak reduction: 5.0 MW

Potential evening peak reduction: 5.1 MW

Potential annual electricity cost savings: R 1,283k

KLOOF 7 SHAFT



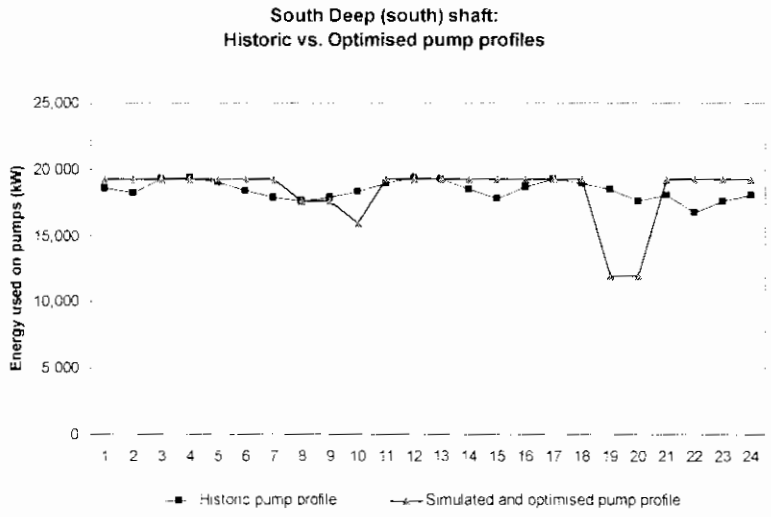
Potential morning peak reduction: 3.8 MW

Potential evening peak reduction: 12.6 MW

Potential annual electricity cost savings: R 1,392k

PLACER DOMES MINES

SOUTH DEEP (SOUTH SHAFT)



Potential morning peak reduction: 0.9 MW

Potential evening peak reduction: 6.1 MW

Potential annual electricity cost savings: R 578k

APPENDIX F

CONTROL AND INSTRUMENTATION EQUIPMENT REQUIRED AT MASIMONG 4 AND HARMONY 3 SHAFTS

Previously, type 3 mines, which did not consist of adequate control and instrumentation equipment, had never been considered for DSM projects, since automated load shift required an intensive investment in capital infrastructure. REMS was adapted to control the pumping system with the minimum control infrastructure. This Appendix describes the additional control infrastructure that was implemented at Masimong 4 shaft and Harmony 3 shaft.

MASIMONG 4

Masimong currently has a surface control room, but no SCADA. A new SCADA will have to be supplied and installed.

This Adroit SCADA will be linked to the two pump stations on 1280 level and 2100 level via a new fibre optic network for communication. The network will comprise of an Ethernet switch in the surface control room mounted in a 19" rack cabinet and connected to the SCADA via Ethernet.

The fibre in the shaft will be connected on each level to a switch that in turn will be connected via Ethernet to a Quantum Schneider Ethernet module in each PLC rack. Each PLC rack will consist of a CPU, Ethernet module, analogue and digital input and output modules. A vibration transmitter, flow switch, pressure switch and electric actuator will be installed on each pump and connected to a junction box via single pair cables. The junction box will then be connected via a multicore cable to the PLC for interlock, trip and remote monitoring and controlling.

All LT and HT drives will be interfaced with the PLC to facilitate remote control and monitoring of the pumps from a surface control room. Each PLC will be mounted in an enclosure with a HMI installed in the panel door to facilitate local control and indication. The system will be commissioned and tested on a pump-by-pump basis to ensure minimum interruption of the day-to-day operation of the mine. All fibre optic cable will be spliced and tested prior to commencing with commissioning. All loop drawing for panels and junction boxes will be supplied. A breakdown of the main equipment items is given below:

	Main PLC 1280 level consisting of the following:
QTY	
1	140CPU11303 CPU 512K 1XMB+
1	140CPS11410 AC P/S 115/230V
1	140XBP01600 Backplane 16 slot
4	140DAI55300 AC input 4 x 8 Channel 115V ac
3	140DRA84000 Relay output 16 x 1 NO
3	140ACI040 Analogue input module 16 channel

1	140NOE77110 Ethernet module
1	XBTF024110 Magelis 10.4" colour operator interface panel
1	XBT – Z9710 cable
	Panel for PLC 1280 level:
1	Panel consisting of a PLC section 1800 (200) x 1200 x 300 and an electrical section 1800 (200) x 800 x 300 manufactured from 3CR12
1	Wiring of PLC and operator panel including terminals, wire, rail, trunking, wire numbers, 24V Black Max power supply etc
1	Wiring of electrical panel including 12 x 2.2 kW contactors, thermal overload, local stop start, push buttons etc
	Field Instrumentation 1280 level:
6	SOR 6NN – K45 – R1 – F1A pressure Switches
6	Mc Donnel & Miller Model F57 – 4LJ flow switches
6	Monitran vibration sensors Model: MTN1185 – CM8 – 20F Range: 0 – 20mm/sec
7	Polycarbonate junction boxes including terminals, trunking, wire numbers etc
1	Installation of field instrumentation underground, installing cable and termination, junction boxes Etc
1	Termination of electrical equipment
6	DN200 full bore ball valve, A105 carbon steel body, 304SS ball and stem, R-PTFE seta and seals c/w 3:1 ratio gearbox and 110Volt electric actuator ELD2500
	Main PLC 2100 level consisting of the following:
1	140CPU11303 CPU 512K 1XMB+
1	140CPS11410 AC P/S 115/230V
1	140XBP01600 Backplane 16 slot
4	140DAI55300 AC input 4 x 8 Channel 115V ac

3	140DRA84000 Relay output 16 x 1 NO
3	140ACI040 Analogue input module 16 channel
1	140NOE77110 Ethernet module
1	XBTF024110 Magelis 10.4" colour operator interface panel
1	XBT – Z9710 cable
	Panel for PLC on 2100 level:
1	Panel consisting of a PLC section 1800 (200) x 1200 x 300 and an electrical section 1800 (200) x 800 x 300 manufactured from 3CR12
1	Wiring of PLC and operator panel including terminals, wire, rail, trunking, wire numbers, 24V Black Max power supply etc
1	Wiring of electrical panel including 12 x 2.2 kW contactors, thermal overload, local stop start, push buttons etc
	Field Instrumentation 2100 level:
6	SOR 6NN – K45 – R1 – F1A pressure Switches
6	Mc Donnel & Miller Model F57 – 4LJ flow switches
6	Monitran vibration sensors Model: MTN1185 – CM8 – 20F Range: 0 – 20mm/sec
7	Polycarbonate junction boxes including terminals, trunking, wire numbers etc
1	Installation of field instrumentation underground, installing cable and termination, junction boxes Etc
1	Termination of electrical equipment
6	DN200 full bore ball valve, A105 carbon steel body, 304SS ball and stem, R-PTFE seta and seals c/w 3:1 ratio gearbox and 110Volt electric actuator ELD2500
	Network: Fibre optics

2500 m	12 Element 12 Fibre Mine Shaft cable
400m	4 Fibre 6 Element Heavy Duty Duct cable
1	Installation of fibre optic cable in haulage
1	RS2-4TX/1FX switch
3	RS2-3TX/2FX switch
4	FE-C107-ST Fibre to copper converters
3	3M Splice box
64	MM pigtails
64	ST midcouplers
64	Splice protectors
10	Grey glands
88	Fusion splices
1	Enclosure
23hrs	Labour
1	19" Rack wall mount c/w fan and filter
	Network: SCADA
2	Mecer PC with 17" monitor
1	Adroit 5.0 Standalone System – 5000 Scanned points not configured with all configuration tools and drivers
	Network: Software:
2	Development of HMI data panel
2	Development of PLC software
1	Development of SCADA software
1	Final test and commissioning
	General
1	Loop drawing, schematics etc
1000	Metres one pair 0.5mm², screened, dekabon orange instrumentation cable

1000	Metres two pair 0.5mm², screened, dekabon orange instrumentation cable
1000	Metres sixteen pair 0.5mm², screened, dekabon orange instrumentation cable
	Reactors
8	1500 kW 6600 Volt Reactor Starter complete with shorting contactors. Timers with taps at 60% 70% and 80% rated for 8 starts per hour for pump start
8	Design, manufacture and routine test
8	Delivery of Reactors to Harmony Free State Operations
8	Implementation of Reactors

HARMONY 3

Harmony 3 also does not have a SCADA system at present.

A newly developed Adroit SCADA system will have to be installed and linked to the two pump stations on 4/3 level and 14B level via a fibre optic network for communication. This network will comprise of an Ethernet switch in the surface control room mounted in a 19" rack cabinet and connected to the SCADA via Ethernet.

The fibre in the shaft will be connected on each level to a Switch. On 4/3 level the network will be expanded 1500m to the pump station. The switch will then be connected via Ethernet to a Quantum Schneider Ethernet module in each PLC rack. Each PLC rack will consist of a CPU. Ethernet module, analogue and digital input and output modules. A vibration transmitter, flow switch, pressure switch and electric actuator will be installed on each pump and connected to a junction box via single pair cables.

The junction box will then be connected via a multicore cable to the PLC for interlock, trip and remote monitoring and controlling. All LT and HT drives will be interfaced with the PLC to facilitate remote control and monitoring of the pumps from a surface control room. Each PLC will be mounted in an enclosure with a HMI installed in the panel door to facilitate local control and indication.

The system will be commissioned and tested on a pump-by-pump basis to ensure minimum interruption of the day-to-day operation of the mine. All fibre optic cable will be spliced and tested prior to commencing with commissioning. All loop drawing for panels and junction boxes will be supplied. Below is a detailed breakdown of the necessary equipment:

	Main PLC 4/3 level consisting of the following:
QTY	
1	140CPU11303 CPU 512K 1XMB+
1	140CPS11410 AC P/S 115/230V
1	140XBP01600 Backplane 16 slot
4	140DAI55300 AC input 4 x 8 Channel 115V ac
3	140DRA84000 Relay output 16 x 1 NO
3	140ACI040 Analogue input module 16 channel
1	140NOE77110 Ethernet module
1	XBTF024110 Magelis 10.4" colour operator interface panel
1	XBT – Z9710 cable
	Panel for PLC on 4/3 level:
1	Panel consisting of a PLC section 1800 (200) x 1200 x 300 and an electrical section 1800 (200) x 800 x 300 manufactured from 3CR12
1	Wiring of PLC and operator panel including terminals, wire, rail, trunking, wire numbers, 24V Black Max power supply etc
1	Wiring of electrical panel including 12 x 2.2 kW contactors, thermal overload, local stop start, push buttons etc
	Field Instrumentation on 4/3 level:
6	SOR 6NN – K45 – R1 – F1A pressure Switches
6	Mc Donnel & Miller Model F57 – 4LJ flow switches

6	Monitran vibration sensors Model: MTN1185 – CM8 – 20F Range: 0 – 20mm/sec
7	Polycarbonate junction boxes including terminals, trunking, wire numbers etc
1	Installation of field instrumentation underground, installing cable and termination, junction boxes Etc
1	Termination of electrical equipment
6	DN200 full bore ball valve, A105 carbon steel body, 304SS ball and stem, R-PTFE seta and seals c/w 3:1 ratio gearbox and 110Volt electric actuator ELD2500
	Main PLC 14B level consisting of the following:
1	140CPU11303 CPU 512K 1XMB+
2	140CPS11410 AC P/S 115/230V
2	140XBP01600 Backplane 16 slot
7	140DAI55300 AC input 4 x 8 Channel 115V ac
5	140DRA84000 Relay output 16 x 1 NO
5	140ACI040 Analogue input module 16 channel
1	140NOE77110 Ethernet module
2	140XBP01600 Backplane expander modules
1	140XCA71706 Backplane expander cable
1	XBTF024110 Magelis 10.4" colour operator interface panel
1	XBT – Z9710 cable
	Panel for PLC on 14B level:
1	Panel consisting of a PLC section 1800 (200) x 1200 x 300 and an electrical section 1800 (200) x 800 x 300 manufactured from 3CR12
1	Wiring of PLC and operator panel including terminals, wire, rail, trunking, wire numbers, 24V Black Max power supply etc

1	Wiring of electrical panel including 18 x 2.2 kW contactors, thermal overload, local stop start, push buttons etc
	Field Instrumentation on level 14B:
9	SOR 6NN – K45 – R1 – F1A pressure Switches
9	Mc Donnel & Miller Model F57 – 4LJ flow switches
9	Monitran vibration sensors Model: MTN1185 – CM8 – 20F Range: 0 – 20mm/sec
10	Polycarbonate junction boxes including terminals, trunking, wire numbers etc
1	Installation of field instrumentation underground, Installing cable and termination, junction boxes Etc
1	Termination of electrical equipment
9	DN200 full bore ball valve, A105 carbon steel body, 304SS ball and stem, R-PTFE seta and seals c/w 3:1 ratio gearbox and 110Volt electric actuator ELD2500
	Network: Fibre optics
2200m	12 Element 12 Fibre Mine Shaft cable
1500m	4 Fibre 6 Element Heavy Duty Duct cable
1	Installation of fibre optic cable in haulage
1	RS2-4TX/1FX switch
3	RS2-3TX/2FX switch
3	3M Splice box
64	MM pigtails
64	ST midcouplers
64	Splice protectors
10	Grey glands

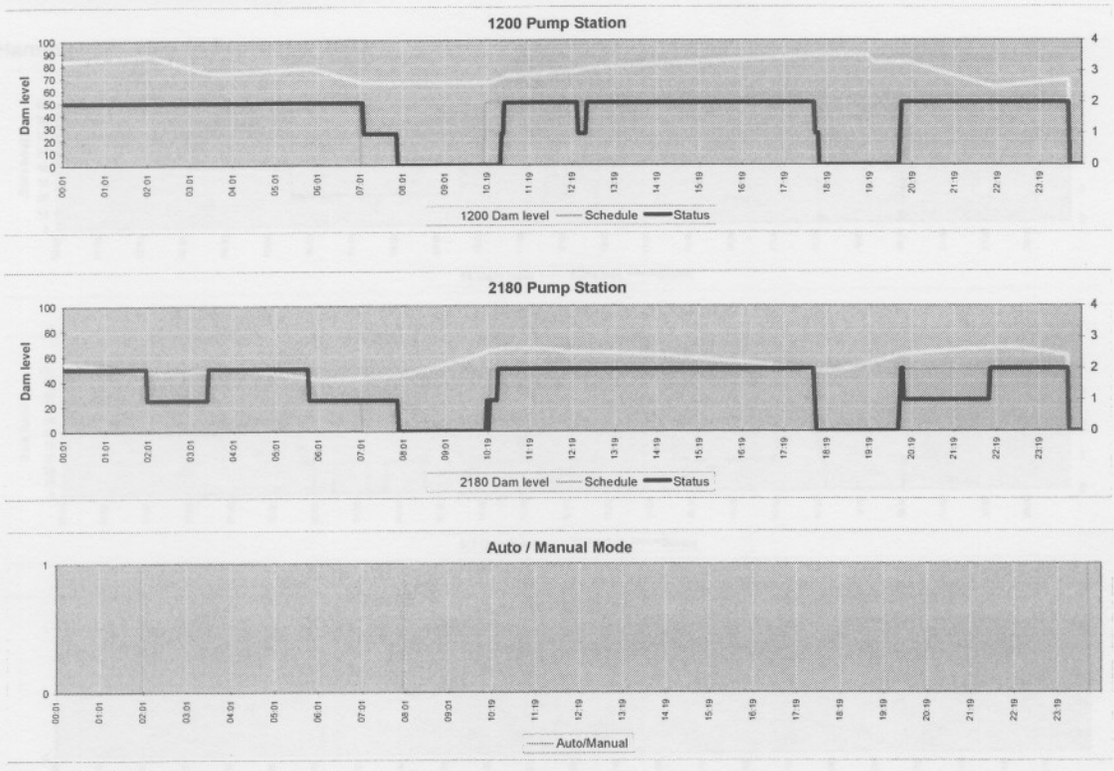
88	Fusion splices
1	Enclosure
23hrs	Labour
1	19" Rack wall mount c/w fan and filter
	Network: SCADA
2	Mecer PC with 17" monitor
1	Adroit 5.0 Standalone System – 5000 Scanned points not configured with all configuration tools and drivers
	Network: Software
2	Development of HMI data panel
2	Development of PLC software
1	Development of SCADA software
1	Final test and commissioning
	General
1	Loop drawing, schematics etc
1500	Metres one pair 0.5mm², screened, dekabon Orange instrumentation cable
1500	Metres two pair 0.5mm², screened, dekabon Orange instrumentation cable
1500	Metres sixteen pair 0.5mm², screened, dekabon Orange instrumentation cable

APPENDIX G

DAILY REPORTS

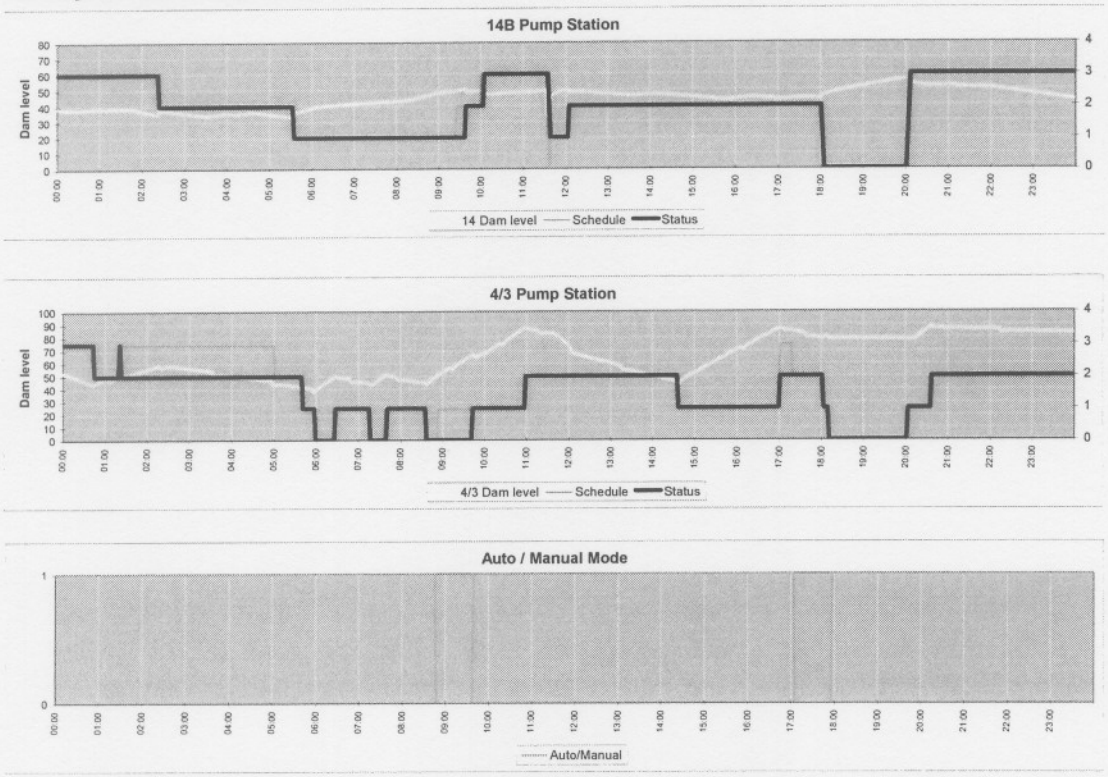
Daily reports are generated once a week to evaluate the operational performance of REMS as well as the control setup. On these daily reports the condition of the pumps can also be monitored. Useful information is send through to mine personnel responsible for the maintenance of the pumping system. In future the running hours of each pump can be included in these reports. Example daily reports for Masimong 4 shaft, Harmony 3 shaft and Tshepong mine can be seen in this Appendix.

Masimong 4# Wed 14 September 2005



Evening load shift:	4.67 MW
Electricity cost saving:	R 1017.10
Daily problems:	System in manual mode from 2:00 – 8:00 (am) due to maintenance.

Harmony 3# Wed 14 September 2005

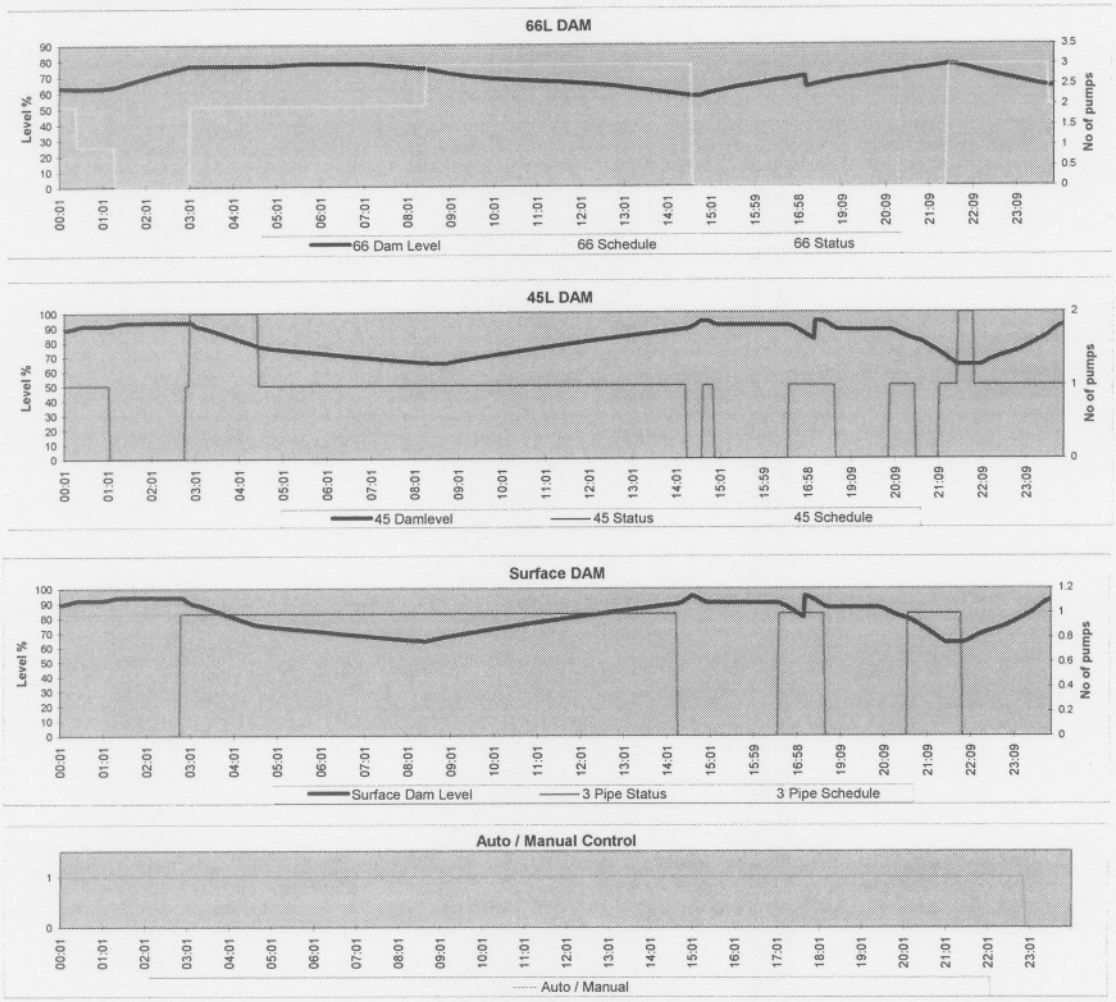


Evening load shift: 4.00 MW

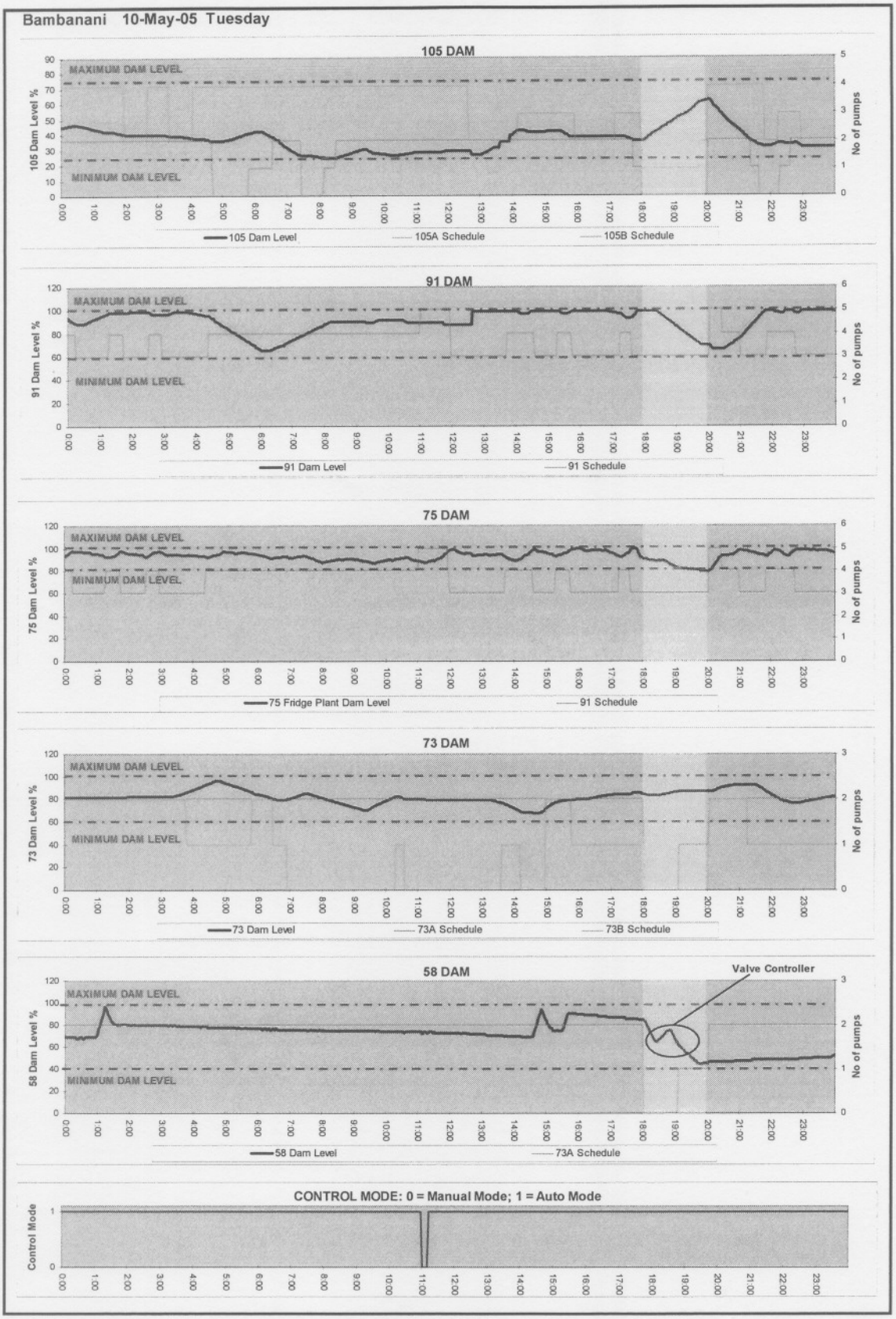
Electricity cost saving: R 998.31

Daily problems: System in manual mode from 8:50 – 9:40 (am) and 17:05 – 17:55 due to maintenance on 4/3 level pump station.

Tshepong 14-Sep-05 Wednesday



Evening load shift:	3.18 MW
Electricity cost saving:	R 450.19
Daily problems:	None


Bambanani 10-May-05 Tuesday
105 DAM
MAXIMUM DAM LEVEL
MINIMUM DAM LEVEL
105 Dam Level %
No of pumps
105 Dam Level
105A Schedule
105B Schedule
91 DAM
MAXIMUM DAM LEVEL
MINIMUM DAM LEVEL
91 Dam Level %
No of pumps
91 Dam Level
91 Schedule
75 DAM
MAXIMUM DAM LEVEL
MINIMUM DAM LEVEL
75 Dam Level %
No of pumps
75 Fridge Plant Dam Level
91 Schedule
73 DAM
MAXIMUM DAM LEVEL
MINIMUM DAM LEVEL
73 Dam Level %
No of pumps
73 Dam Level
73A Schedule
73B Schedule
58 DAM
Valve Controller
MAXIMUM DAM LEVEL
MINIMUM DAM LEVEL
58 Dam Level %
No of pumps
58 Dam Level
73A Schedule
CONTROL MODE: 0 = Manual Mode; 1 = Auto Mode
Control Mode