1. INTRODUCTION, BACKGROUND AND PROBLEM IDENTIFICATION

1.1 INTRODUCTION

The Oxford English Dictionary [1, pp. 281 & 529] has the following definitions:

Energy: "Ability of matter to do work" and "Fuel or other sources allowing work to be done"

Manage: "Handle, wield, control and regulate"

According to these definitions, energy management can essentially be seen as the controlling and regulating of sources allowing work to be done. This broad observation does however not make provision for an important element in the reasonably new energy management concept. What is important now, is the minimisation of the cost associated with this ability to do the work. Within this context, we are particularly concerned with the cost minimisation of electrical energy.

Calmeyer [2, p. 1] mentions that energy management should not merely be seen as having the purpose of minimising energy consumption and demand, but that the ultimate objective is cost optimisation. He continues that this does not necessarily involve the reduction of total electrical costs, but the reduction of cost per product. So if reducing electricity costs can increase productivity, total profit will increase. In essence, electrical energy costs can be reduced by using energy more efficiently and / or by the correct selection of time-differentiated tariffs.

According to Roos [3, p. 97], the end users of electrical energy want to amongst others:

- Reduce their costs
- Conserve energy
- Maintain profitability

He continues that by understanding customer acceptance criteria, one can persuade them to actively participate in a load management program. What should be realised is that customers, do not necessarily need to be external parties to an organisation, but may in fact be internal parties that need to increase energy efficiency.

Thumann and Mehta [4, pp. 377 – 389] regard energy management as "the judicious and effective use of energy to maximise profits (minimise costs) and to enhance competitive position". They also importantly focus on the fact that successful energy management does not only revolve around the conservation of energy but the comprehensive organisation of all matters which influence or may be influenced by energy usage within an energy-using establishment. A comprehensive energy management program is certainly not purely technical. It must be a total program that involves all areas of business and needs to concentrate on planning, communication and marketing. Often simply making people aware of energy wastage produces large savings. Thumann and Mehta go on to describe that energy management in large organisations needs to be very visible and a focal point of much of the general management. Energy management teams and program members also need to interact with almost all divisions of an organisation.

Turner [5, pp. 3 – 5] confirms the importance of organisational management involvement in energy management by stressing that good energy management represents a real chance for creative management to reduce a component of product cost that has become a considerable factor of late. In the past organisations that have taken advantage of energy management drives have done so because of the obvious involvement, motivation and commitment from the top executive. Once this commitment has been understood, managers at all levels of the organisation can and do respond seriously to the opportunities of large savings. Tissink [6, pp. 10.2 – 10.3] also mentions that in order to minimise electrical energy costs, specifically in the mining environment, it is essential that line management is directly responsible for the energy consumed within its own area of responsibility.

It thus becomes clear that good energy management is a careful combination of management involvement and skills and technical methods and methodologies for actually implementing the changes which management have shown support for. The next very important component of effective energy management is quantifying what is being dealt with. Lord Kelvin said a century ago: "When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely in your thoughts advanced to the stage of science." [7]. The importance of representing energy consumption numerically allows one to be able to mathematically analyse and manage consuming devices far more effectively.

Jacobsen [8, pp. 43 – 47] stresses the importance of technology in the process of energy management. He states that innovation of new technologies and improvements of existing technologies will be the dominant factor for survival in a future where proper energy usage and management will be of cardinal importance. The technological advances of specific interest are advanced methods of energy consumption modelling.

The study contained in this dissertation is intended to facilitate deep-level gold mining operations which do not have readily available power consumption data of their water reticulation systems. This is to be done by providing a method of determining the power consumption of various water reticulation system configurations. It will also be useful for the analysis of different prospective installations.

1.1.1 Overall Picture

In order to provide a clear picture of what is being addressed by this study, the following figure has been included at this point.

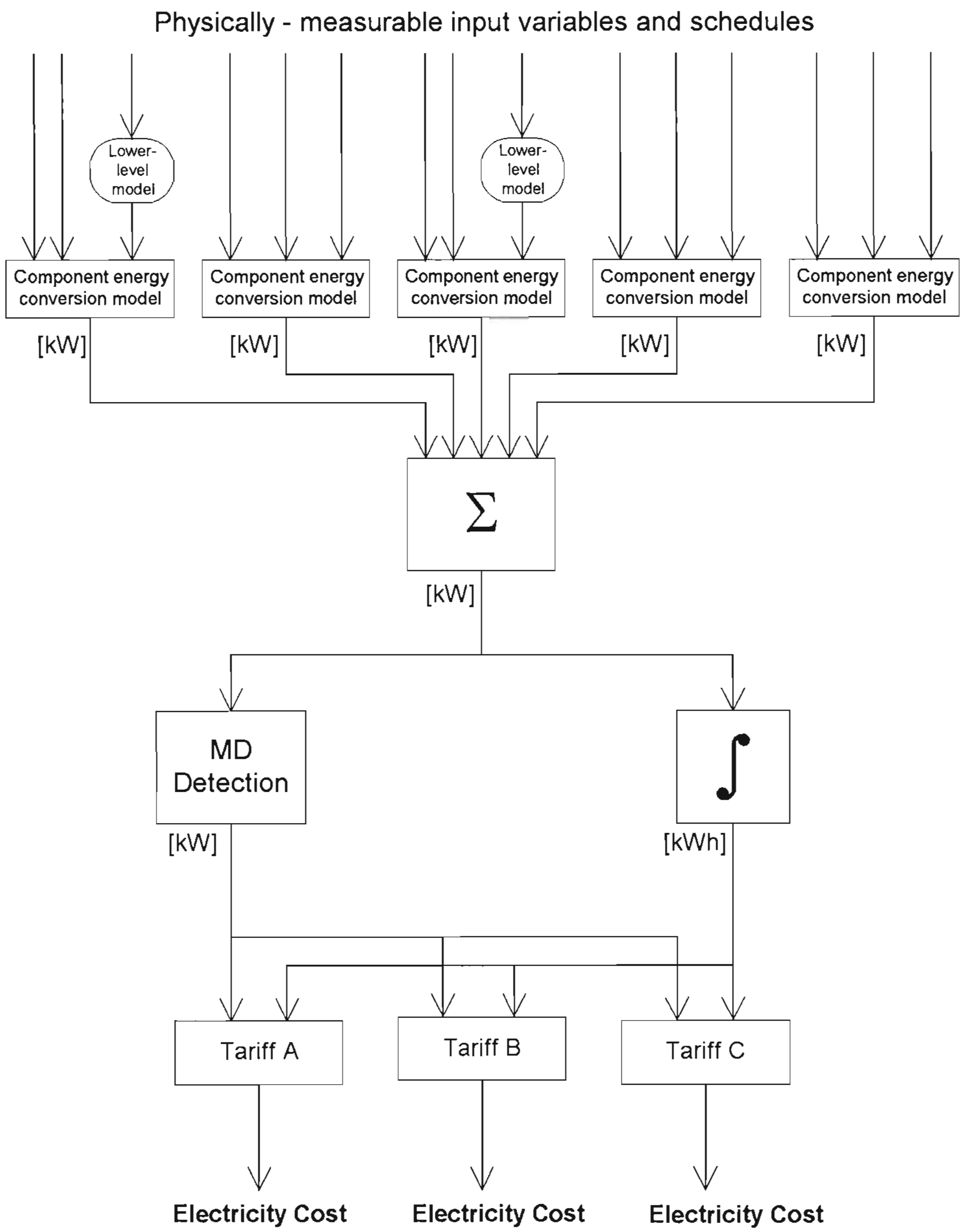

Figure 1.1: Path between physical variables and electricity cost

Figure 1.1 represents what is really being aimed at by this study. What broadly needs to be achieved is the development of a means of relating all input variables of the water reticulation system to respective electricity costs.

The heart of the study the development and verification of the component energy conversion models as shown in the figure. Once these have been satisfactorily developed, it will then be a reasonably simple task summing their consumption, integrating and detecting the maximum demand to apply the energy usage to a number of different tariffs to find the most cost-effective.

The general aim of this study is thus to develop energy conversion models that will allow the user to experiment by changing inputs to the model such as physical parameters and schedules and observe the effect of the changes on electricity cost using different available tariffs and so find the most cost effective.

1.2 PRACTICAL ENVIRONMENT

1.2.1 Anglogold Introduction

The study was done with the support of Anglogold, which has a number of gold producing shafts in South Africa, many of which have sophisticated data capturing systems. Shafts which have full Supervisory Control And Data Acquision (SCADA) database systems are able to monitor much of the energy flow through the mine. Shafts without such systems are the intended true beneficiaries of this study.

Anglogold is a newly formed company which has taken over ownership and control of the Anglo American Gold Mines. The company is responsible for 3 main regions of Gold Mines in South Africa. These mines are situated in the Witwatersrand Basin, the largest gold mining region in the world with known and estimated reserves of 643 million ounces. All are deep-level operations, mining at an average depth of 2 100 metres below surface (6 900 feet) and in the West Wits region as deep as 3 777 metres (12 400 feet). In addition to the above, there is Ergo, a metallurgical operation using unique technology to extract gold from low-grade waste dumps.

The actual mines are as follows:

- Vaal River: Great Noligwa, Kopanang, Tau Lekoa and Moab Khotsong mines
- West Wits: Western Deep Levels and Elandsrand mines
- Free State: Joel, Bambanani, Tshepong and Matjhabeng
- Ergo: a metallurgical operation using unique technology to extract gold from low-grade mine waste dumps
- Driefontein: a prospective joint venture with Gold Fields Limited in which AngloGold is aiming to increase its level of ownership from 21,5% to 40%

The South African mining industry is one of the main electricity consuming sectors of the country. In the past, it has represented up to 27% in 1985 [9, p. 1] and 18.2% in 1999 [10, p. 96] of the country's energy consumption. Of this about 17,6 % of the energy and maximum demand usage is from the underground water pumping systems [9, p. 5].

1.2.2 Energy Policy

Anglogold, being one of the main electricity consumers of the country, have realised the importance of effective energy management as one of their main cost saving initiatives. An energy policy was developed in 1998 by Arnold [11], Anglogold's energy engineer. Any energy management changes or investigations, which are undertaken, must be done under any particular constraints stipulated in the company's official energy policy.

The Anglogold policy has two important subsections, namely economic considerations and environmental considerations. In keeping with international trends and possible legislation, it is very important for any industrial operation to pay careful attention to environmental impact from any of their activities. Anglogold has thus included environmental considerations in its energy policy, with particular interest in primary fuel availability.

The policy also clearly defines the organisational structure with reference to the line of responsibility of the energy manager. This emphasises the organisational involvement and awareness as mentioned earlier. It is very important in the whole energy management scenario of any organisation, to ensure that accountable parties are clearly identified. The Anglogold policy makes provision for various levels of this responsibility.

To standardise all measurements of various energy sources and consumers so that benchmarking can be done, the policy covers standard units, conversion and efficiency metrics. It then continues to define the system, format, and frequency that is to be used when measuring, recording and reporting energy use.

The final part of the policy defines the method the company will use for budgeting and billing the users of the various energy types.

1.2.3 Present data and tools available

A number of the Anglogold shafts such as Tshepong near Odendaalsrus in the Freestate have sophisticated SCADA systems. Others do not have any such data gathering systems and rely on rated specifications of system components and rudimentary mechanical measuring devices.

Tools which are used at present for energy management include load shedding, load shifting, historically-based load forecasting, power factor correction, cogeneration, alternative energy source usage, energy storage and tariff selection.

As can be seen from the list above, simulation and load forecasting based on system configurations are not readily available. This study provides a method for forecasting and simulating energy consumption for the water reticulation systems of deep-level mines, allowing different configurations, tariffs and schedules to be simulated whether the shaft has sophisticated data capturing systems available or not.

1.3 LITERATURE STUDY

1.3.1 Total Plant Study

Delport's Ph.D. [9, pp. i – ii, 1 – 5 & 38 – 40], entitled "Integrated electricity end-use planning in deep level mines" provides a comprehensive identification of major energy consuming sections of deep-level gold mines. The study suggests methodologies and strategies for mine-wide integration of energy management procedures. In order to do this all major energy consuming systems within the deep-level mining environment had to be identified and modelled to a certain degree, one of which is the water pumping system. Delport suggests mathematical models for pumps, friction losses and efficiency in the system, but does not provide for any other components, which may be found and thus does not refer to a water reticulation system as in this study. This study thus builds on Delport's models by verifying and refining what has been done and developing models for system components which have not been modelled such as turbines and Three Chamber Pipe Feeder systems. This study will also present models for multiple components and methodologies for integration of the different models. Delport provides for system delays and storage devices [9, pp. 69 – 71] qualitatively, but these components still need to be incorporated into the entire water reticulation system mathematically.

1.3.2 Component Study

A need exists to provide the deep-level gold mines of South Africa with a means of determining their energy usage for pumping under different operating conditions and configurations. Much literature exists relating the power usage of common water reticulation system components such as pumps, turbines and losses to other variables such as flow rate. This study will build on this knowledge and continue to include specific devices such as three chamber pipe feeder systems and integrating the different components in different configurations as one would find in the deep-level mining environment. With modern mathematical methods and technology having progressed as far as they have, an entire system can be treated as a whole once analysis of individual components have been analysed and integrated [12, pp. 1 – 2] Literature used for mathematical analysis of the common components include:

- Mechanical Technology [13]
- Pump Handbook [14]
- Introduction to Fluid Mechanics, 2nd Edition [15]
- Pump Application Desk Book [16]
- Solutions of Problems in Fluid Mechanics Part 1 [17]

This list of literature provides a reasonable overview of the mathematical derivations and laws governing fluid flow relevant to most of the components of interest. They do however not present methods of integrating the mathematics of different components to be able to analyse a complete system. They also only present basic fundamental facts, which will need to be used to generate models of system components that are not common.

1.3.3 Inputs, Outputs and System Variables

In order to model different water reticulation system components all inputs, outputs and different variables involved need to be identified and related to possible inputs and outputs of individual system building blocks [9, pp. 46 – 51]. The methodologies developed in this regard as discussed in full detail in the next chapter.

The literature mentioned in the previous section, provide clear guidelines for all influences that may exist on the devices for which models need to be generated. Usually the output of the models and of systems of models needs to be energy values. Other variables, which typically need to be taken into account, are flow rates, gravity, liquid density, device efficiency, pipe diameter, fluid velocity and other factors associated with device energy losses.

For all components it must be remembered that they form part of and are in fact fluid-dynamic systems themselves. This means that in order to relate energy to the flow of liquids one needs to use a principle like Bernoulli's theorem [18, pp. 410 – 423], which will be dealt with in more detail in Chapter 3.

1.3.4 Overview of mine water reticulation system

Water, which is chilled on surface and passed down a mineshaft, has a number of uses. Chilling the water is mainly to control the ambient temperature within the mine, from bulk air cooling devices that form part of the air ventilation system [19, p. 11.3]. The water is also amongst others used to drive hydraulic rock drills and in some cases for water jet cleaning during the cleaning shift after blasting. Drinking water is a completely different system and so does not have any influence on the main reticulation system.

In order to ensure that there is enough water at all times mines generally have two sets of storage dams. One set on surface and one set approximately midway down the shaft, which is usually above most of the active mining levels. Each set consists of a hot water dam for water that has been used and a chilled water dam for water that is still to be sent to the workplace. All cooling is generally done on surface, by passing the hot water through evaporator towers for pre-cooling and then through a fridge plant to chill to obtain the desired temperature.

One main interest in the system from an energy point of view is the fact that the water which has been consumed in the workplace needs to be returned to surface by pumping. The other main interest is that the water, which is going to the workplace from the surface, gets there by flowing down the shaft and so obtaining kinetic energy. Considering that some gold mines in South Africa actively mine to a depth of 3700m, allows one to appreciate why as great a percentage of the mine-wide energy consumption is used for pumping, as well as how much energy is being wasted if the water going down the shaft is simply allowed to flow down.

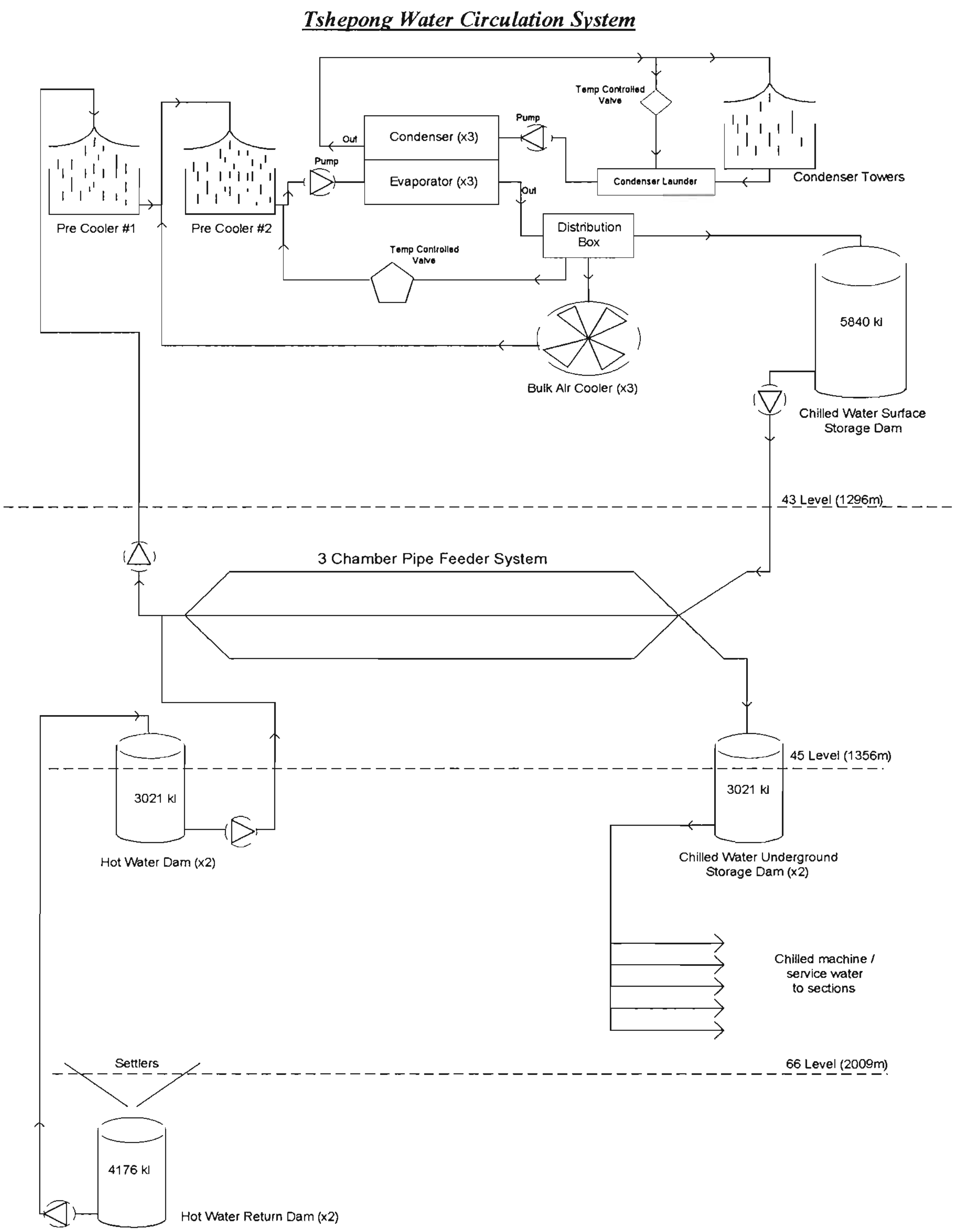

Figure 1.2: Typical Water Reticulation System

The layout shown in figure 1.2 is the basic layout of the water reticulation system of Tshepong mine in the Freestate. Tshepong mine was used to verify the models proposed in this study because of the advanced data capturing system installed there. There is also a three chamber pipe feeder system installed, which allows the verification of models for it. The three chamber pipe feeder system uses the head of cold water to balance the head of hot water that needs to be pumped to surface, thereby avoiding having to pump against the large head that normally exists.

Other factors that are important in the water reticulation system are the storage tank capacities and the delay for water to naturally flow from one point in the system to the next. It can for example not be assumed that the water, which has left the underground chilled water dam, is immediately available to be pumped.

1.4 PROBLEM IDENTIFICATION

1.4.1 Introduction

At this point it is clear that energy conversion models need to be developed to allow the user to be able to manage scheduling, configuration and tariff selection. This management will be done by allowing experimentation with different input conditions to a set of models. The questions now arise of who this user is? What exactly does experimenting with scheduling, configurations and tariffs mean? What needs to be modelled and how is everything going to be integrated?

The reason that it is beneficial to model the water reticulation system in particular is that it is one of the most flexible in terms of scheduling without negatively influencing production or worker comfort. The operators of the water reticulation system can adjust the timing of pumping and other related water flow controls within reasonably wide tolerances. The main concern is that there is sufficient water available for mining activities, along with a safety factor. The use of storage facilities are obviously one of the main reasons that this is possible.

1.4.2 End-user identification

Ultimately this study is of interest to the management of any mine, which is able to apply the models to their own environment. It has been done particularly with deep-level gold mines in mind. It is also of benefit to the management of prospective mines to decide on different configurations by testing to see which will be the most economically viable by comparing energy operating costs to initial installation costs.

Naturally other parties that this study is of interest to are parties responsible for costs savings, such as energy engineers if they exist in the particular mine or section engineers in charge of the water reticulation system.

1.4.3 The purpose of modelling

By generating energy conversion models for each component (device or integrated system of devices) in the water reticulation system of a mine, one is able to determine exactly how much power that component is using or delivering under different input conditions. Summing the power used by all the devices and integrating over the period that they are active for produces a value for the total energy consumed of the entire system [20, p.14]. Maximum demand and other dynamic values can then also be determined by integrating the power values over whatever integration period is of particular interest.

Once these models have been developed for general cases, they can be employed for systems where there is little knowledge of the usage of energy, by taking a few sample measurements to determine basic constant input conditions for the models such as flow rate. Employing the models over any scheduling and tariff conditions then follows this.

1.4.4 Future Systems

One of the main benefits as mentioned before is the fact that these models can be used to evaluate the energy consumption patterns of future installations. It may for example be of interest to a prospective mine to determine what kind of energy recovery system needs to be employed. Depending on individual circumstances installing a three chamber pipe feeder system may prove to be more economical than merely installing conventional turbines. It may also be necessary to decide between conventional mechanical turbine-pump drives and electrical turbines, which would allow the generated energy to be used by other users in the mine during Maximum Demand times.

Wagner and Oberholzer [21, pp. A78 – A80] confirm the importance of potential costs to mine managements when having to take capital expenditure decisions. Feasibility and cost studies are usually time consuming and costly. Modelling provides a very useful tool for examining prospective operating costs.

In prospective systems, one needs to evaluate the operating cost against the cost of installation by using accounting techniques such as the Internal Rate of Return (IRR), Minimum Attractive Rate of Return (MARR) and Net Present Value (NPV) of the initial investment [2, pp. 61 – 63]. The lifetime of the investment would generally be the expected gold-producing lifetime of the shaft. To this factors such as unexpected operation size reductions or expansions due to gold price fluctuations need to be kept in mind.

1.4.5 Scheduling and Tariffs

As mentioned a big advantage of modelling is to be able to experiment with different schedules and tariffs. Scheduling of the pumping functions in the water reticulation system can be rather flexible because of the storage facilities that mines have on surface and underground. Naturally the larger the storage capacity of the dams, the more flexible the schedules can become. In certain cases it may even be advantageous for the mine to investigate enlarging the size of the storage dams or at least ensuring that they are clean, depending on the influence that this proves to have from the models.

The underlying constraints that exist for scheduling are the water requirements for mining operations, storage capacities and volume of water that can be pumped at a specific instance.

Along with evaluating different schedules, the user needs to be able to evaluate the influence of the water reticulation system on the entire electricity account of the mine, using different tariffs. The mines which are customers of Eskom, South Africa's electricity producer, have the choice of a number of tariffs, which include Nightsave, Megaflex [22] and Real Time Pricing (RTP).

1.5 OBJECTIVES

1.5.1 Main Objective

A means of relating physical parameters and scheduling of water reticulation systems in deep-level gold mines to electricity costs needs to be developed. This means must include energy conversion modelling and must be of such a nature that similar systems, configurations and schedules can be simulated to produce electricity costs of a set of particular conditions using different available tariffs.

1.5.2 Specific Objectives

Specific objectives for the achievement of the main objective are as follows:

Extension of Delport's Models

Delport's work as mentioned in section 1.3.1 needs to be verified and extended, paying particular attention to the shortcomings and discontinuities of his model propositions.

Modelling Methodology

A modelling methodology needs to be generated and closely followed in order to develop models systematically and ensure that they remain completely compatible and within the systems context.

Separate Modelling

Accurate mathematical models of all general energy producing, energy consuming and energy recovery components of a deep-level gold mine need to be developed and verified. These include pumps, turbines, pipe and other losses and three chamber pipe feeder systems.

Model Integration

Generated models need to be able to be coupled together in any configuration that is to be simulated. They thus need to be completely compatible. Energy values obtained from the individual components need to be summed and integrated over a relevant time frame. The output of the system of models with physical and test inputs, needs to be an accurate value for the cost of running the water reticulation system for a specified length of time.

External Compatibility

All modelling which is done, must be configured in such a way that it can be generally used in any typical deep-level gold mining configuration. This means that inputs and outputs must conform to formats and standards that are typically used in such environments.

Experimentation

Modelling must be done in such a way that different schedules, configurations and tariffs can be experimented with. This does not necessarily mean that the models need to have tariffs as an input, but final outputs must be of such a nature that they can easily be used to calculate costs from standard tariffs. Schedules typically would govern the periods in which the models are run. Configurations data would need to form direct inputs to a model system.

Future Systems

Models which are able to simulate the power consumption of the water reticulation systems of existing mines, should also be able to simulate proposed systems, allowing informed cost decisions to be taken before a mine is developed as described in section 1.4.4.

1.6 STRUCTURE OF DISSERTATION

This dissertation has been constructed in the knowledge that all mines have individual water reticulation systems that do not necessarily conform to any specific standards. The theory and practical examples presented within this dissertation are of a general nature and might require slight adjustments for systems that have specific individual components or operating conditions.

Chapter 2 addresses the methodology used to generate the energy conversion models. It elaborates in the types of models, criteria, approach, models contexts and constraints. In general, it defines how the bridge between the real and mathematical world will be crossed.

Chapter 3 deals with the actual mathematical development of models. This includes mathematical tools used to generate the models as well as the presentation of final models.

Chapter 4 focuses on the verification of models that have been developed by using data obtained from actual case studies.

Chapter 5 demonstrates how the developed models can used to examine and subsequently reduce electricity costs of pumping water around a deep-level gold mine.