DEMAND SIDE MANAGEMENT INTERVENTION ON A LARGE SCALE CANAL PUMPING SCHEME

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Abstract

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South Africa is the thirtieth driest country in the world and is classified as a semi-arid area. The annual rainfall differs from less than 200 mm at the west coast to more than 1000 mm on the east coast. The primary use of fresh water is for agricultural purposes.

It is necessary for large scale canal pumping schemes that enable the transfer of water over vast distances. Canal pumping schemes are energy intensive systems. It is therefore necessary to operate these schemes efficiently. From the investigation of DSM interventions on other similar systems in the industry, it has been identified that it is possible to implement a load shift intervention.

To ensure that a canal pumping scheme operates efficiently and cost effectively, the chosen Demand Side Management (DSM) intervention is optimised and implemented on such a site. An investigation was conducted to determine the possibility of an evening peak load shift project. A proposed integrated strategy was simulated and an optimised approach was developed. It was found plausible to implement a load shift intervention on the proposed site.

The proposed load shift intervention was implemented on a large scale canal pumping scheme in South Africa. An average evening peak period load shift impact of 4.67 MW was achieved over a three month period, despite the seasonal effect during the implementation. Load shift initiatives also realise the cost savings due to the pricing structure during peak periods and off peak periods. The intervention resulted in an annual cost savings of R3.2-million.

It is concluded that the implementation of the control philosophy developed was successful. Recommendations are made regarding the baseline as well as opportunities for further research.

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I apologise if the necessary recognition was not given. If anyone is of the opinion that I did not acknowledge their input, please contact me to make the necessary corrections.

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Nomenclature

c/kWh	cent per kilowatt hour	(c/kWh)
g	gravity constant	(m/s^2)
h	hydraulic rate	(m)
ha	hectare	(ha)
I	supply current	(A)
kg/m^3	kilogram per cubic meter	(kg/m^3)
km	kilometer	(km)
kVA	kilovolt-ampere	(kVA)
kW	kilowatt	(kW)
l/s	liter per second	(l/s)
m^3/s	cubic meter per second	(m^3/s)
mm	millimeter	(mm)
MVA	megavolt-ampere	(MVA)
MW	megawatt	(MW)
η	efficiency	(%)
P	density of liquid	(kg/m^3)
P_{elec}	electric power	(Watt)
P	power	(W)
Pf	power factor	(-)

P_h	hydraulic power	(Watt)
T	torque	(Nm)
ω	angular velocity	(rad/s)
Q	flow rate	(m^3/s)
R	rand	®
R/kVA	rand per kilovolt ampere	(R/kVA)
R/kW	rand per kilowatt	(R/kW)
V	supply voltage	(V)

Abbreviations

CT	current transformer
DSM	Demand Side Management
DWA	department of water affairs
EE	Energy Efficiency
EnMS	energy management system
ESCo	energy services company
GSM	global system for mobile
HMI	Human Machine Interface
IDM	Industrial Demand Management
MPC	model predictive control
M&V	measurement and verification
NMD	notified maximum demand
OLE	Object Linking & Embedding
OPC	OLE for Process Control
PLC	Programmable Logic Controller
SCADA	supervisory control and data acquisition
TDS	total dissolved solids
TOU	time of use
VCB	vacuum circuit breaker

VSD	Variable Speed Drive
VT	voltage transformer
WFD	water flow demand

CHAPTER 1 - INTRODUCTION

Chapter 1 provides a brief description of the electricity situation in South Africa and the need for DSM interventions. Canal schemes in South Africa are also discussed briefly.

1.1 Background

Irrigation canal pumping schemes supply water to remote tillage land that has little to no water access. Land is made available to produce food and thus ensures national food security in South Africa.

Water is an essential resource to the economy and its people. Water needs to be pumped over vast distances for different applications such as public water supply, industry and agriculture.

Water distribution schemes are very energy intensive systems. By regulating the usage of electricity for this industry, large savings can be obtained. Eskom's Demand-Side Management (DSM) initiatives encourage very large electricity users to reduce peak demand.

1.2 Electricity situation in South Africa

South Africa's primary electricity provider, Eskom, supplies approximately 45% of Africa's electricity as well as 95% of South Africa's electricity [1]. Eskom generates and distributes electricity to more than 5 million households and industries [2]. It is important for Eskom to ensure that sufficient supply of electricity is available to meet the demand of the consumers.

The problem that Eskom experiences is to ensure sufficient demand to the consumer at all times. It is difficult to ensure consistent supply due to:

- the continuous growth of consumers requiring the electricity services; and
- the peak periods when the demand is at a maximum.

When Eskom cannot provide the required demand for electricity, load shedding or load reduction is implemented. This means that a certain amount of electricity is taken out of the entire electricity grid to stabilise the system. This is implemented countrywide as a controlled option to protect the total electricity power grid from a total blackout [2].

A total blackout means that the power system will trip, taking the entire power grid offline. Load shedding is implemented to temporarily lower the demand for electricity.

South Africa started experiencing load shedding in the year 2007. Since then Eskom implemented measures to ensure maintenance of their power plants, increasing coal supply and improving plant performance. These measures led to the suspension of load shedding in May 2008 and onwards [3].

Coal is the world's most used primary fuel, accounting 36% of total fuel consumption internationally [4]. South Africa contains the world's ninth-largest amount of recoverable coal reserves and 95% of Africa's coal reserves [5].

The installed capacity of Eskom's electricity generation is a total of 44 084 MW, from which 37 745 MW is coal fired [1]. The remaining 6 339 MW is generated through nuclear stations, hydro stations, gas fired stations and pumped storage schemes. Figure 1 below illustrates the generation capacity of Eskom.

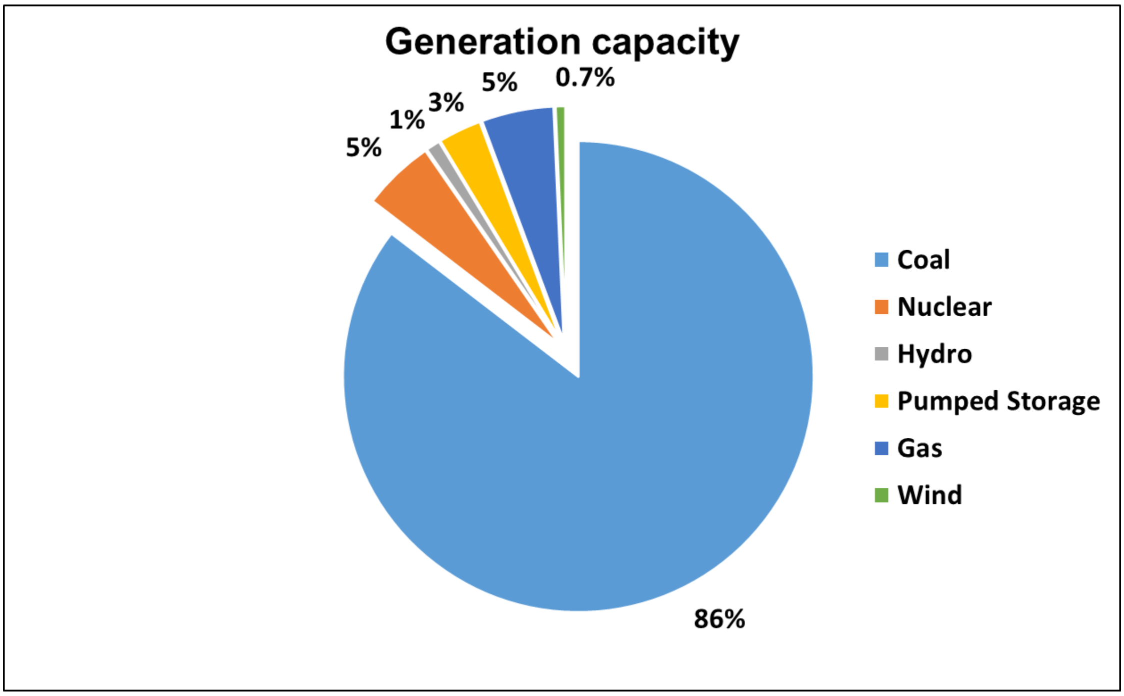

Figure 1: Breakdown of generating capacity of Eskom (adapted from [1])

In 2014, load shedding was reintroduced. Several electricity generation plants were forced to shut down due to the maintenance backlog. Poor management implicated a generation capacity short come [6].

The first big six-unit coal-fired stations were built in the 1970's with an expected life of 40 years [7]. The average age of all Eskom's power stations are approximately 30 years.

1.2.1 Time of Use (TOU)

Large scale irrigation canal pumping schemes can be classified as an industrial electricity user. In Figure 2 below the sectorial electricity usage is shown for South Africa against the United Kingdom. The industry in South Africa consumes much more electricity in proportion to the United Kingdom, although the United Kingdom has a larger population than South Africa [8].

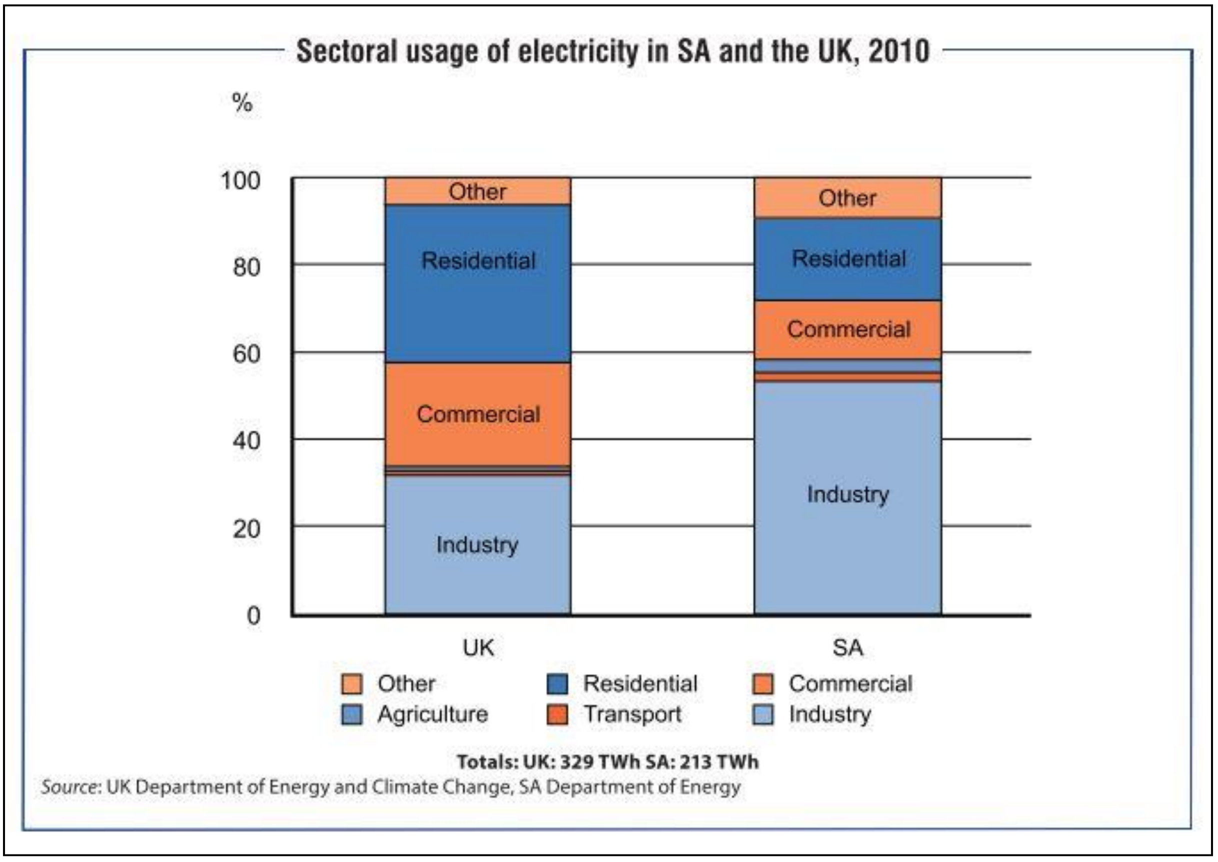

Figure 2: SA vs UK sectorial electricity usage [7]

The industry sector in South Africa is the most energy intensive system. This creates an opportunity to implement DSM interventions on the different systems present in the industry segment.

Due to the fact that different segments of South Africa uses different amounts of electricity, Eskom decided to use different tariff structures. This ensures that each sector is billed accordingly, therefore Eskom introduced the Time of Use (TOU) tariff structure [9].

TOU tariffs are a mechanism utilised by utilities to influence behavioural change in terms of electricity use, in this case the morning and evening peak periods of the low and high demand seasons.

The TOU tariff structure bills each consumer according to the electricity used at different times of a 24-hour profile day. Every electricity consumer has a different load profile. Figure 3 illustrates a typical residential load profile.

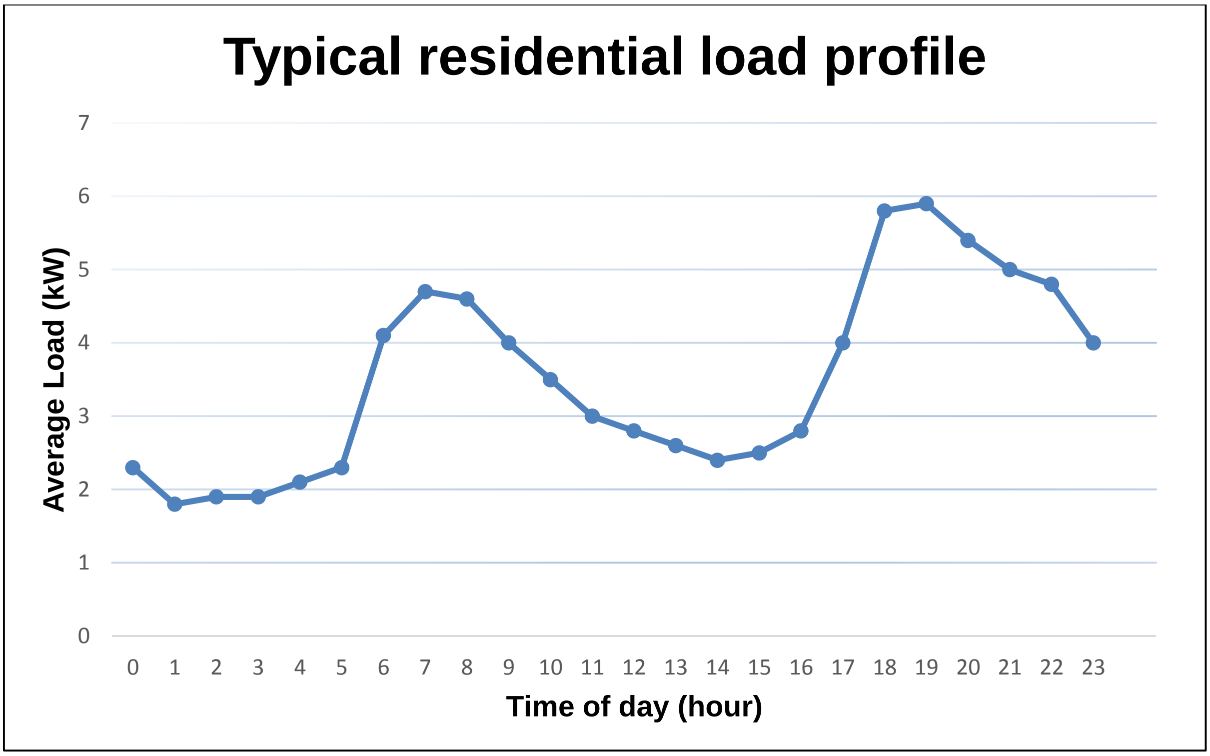

Figure 3: Illustration of a typical residential load profile (adapted from [10])

It can be seen in Figure 3 that there are two peak periods. One in the morning and another in the afternoon. There are also two different demand seasons during a year. The charges during each season and time period differ as well.

These charges differ between the high demand winter schedule (June to August) and low-demand summer schedule (September to May) as well as the different peak, off-peak and standard peak rates during a day. Eskom uses different TOU tariffs in line with developed countries worldwide, namely, Miniflex (>25 kVA and <5 MVA), Ruraflex (>25 kVA) and Megaflex (>1 MVA) [11].

Only the Megaflex TOU tariff structure is applicable to this dissertation and will be discussed briefly. The Megaflex TOU tariff is relevant to customers with a notified maximum demand

(NMD) greater than 1 MVA that are able to save electricity through different electricity saving interventions such as load shifting.

Figure 4 shows the Megaflex TOU periods as stipulated by Eskom. The following charges are applicable according to Eskom [12]:

- seasonally and time-of-use differentiated c/kWh active energy charges including losses, based on the supply voltage as well as the transmission zone;
- the three time-of-use periods namely peak, off-peak and standard;
- an ancillary service charge (c/kWh) based on supply voltage during all time periods;
- demand charge (R/kVA or R/kW) differentiated seasonally;
- percentage surcharge for transmission or discount for high voltage; and
- basic charge per month (R).

In Figure 4 below, the TOU periods, namely peak, standard and off-peak periods are shown. Each of these mentioned periods has its own tariff structure. Thus electricity costs are not the same in the different time periods of a 24-hour daily profile.

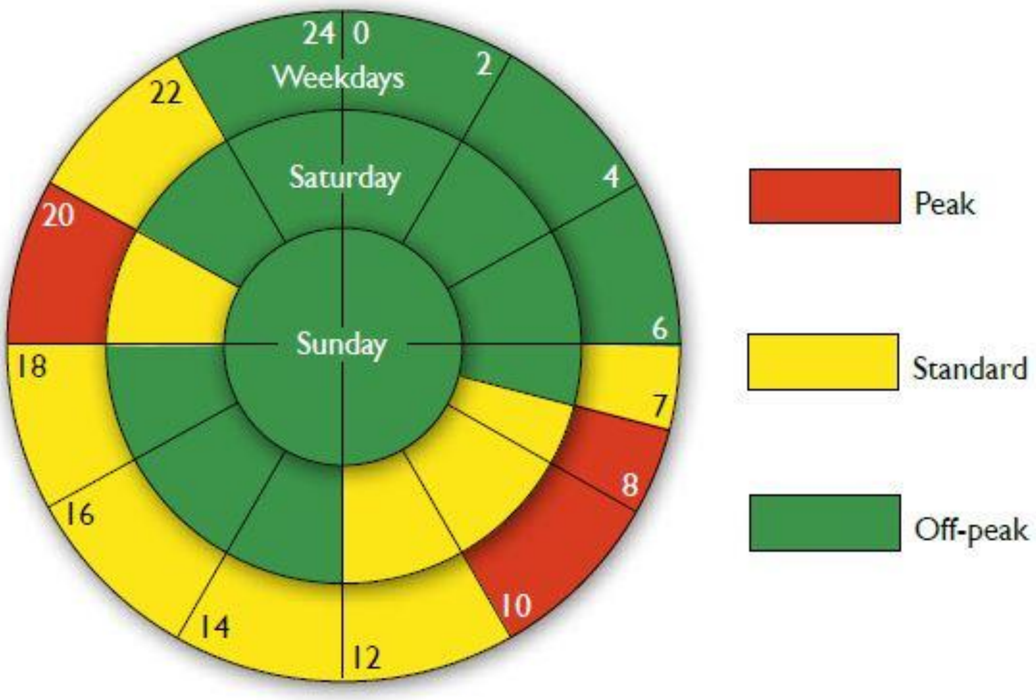

Figure 4: Eskom Megaflex TOU periods [13]

Indicated in Table 1 below is the tariff structure for the Megaflex TOU periods 2014/2015. It can be noted that the energy charge for the peak period during the high demand season is more than three times than the standard energy charge. Large cost savings can be obtained by implementing electricity saving interventions.

Table 1: Megaflex tariff structure 2014/2015 (adapted from [12])

Megaflex		Active energy charge [c/kWh]					
Transmission zone	Supply voltage	High demand season [Jun - Aug]			Low demand season [Sept - May]		
		Peak	Standard	Off-peak	Peak	Standard	Off-peak
≤ 300km	≥ 500V & < 66kV	222.73	67.48	36.64	72.66	50.01	31.73

The electricity situation in South Africa was discussed. It is clear that Eskom lacks on the supply side of their electricity network. Eskom introduced TOU tariff structures to bill each client according to their electricity usage. The TOU tariff structure most applicable to this dissertation has also been discussed.

In order to minimise the demand for electricity during the peak periods, Eskom introduced the DSM programme. This will be discussed in section 1.3.

1.3 Need for DSM interventions

From Section 1.2 it is known that there is an electricity supply problem in South Africa. In this section the need for DSM interventions will be looked at.

DSM was initially set in place to reduce the peak electricity demand in order for utilities to delay the building of further generation capacity. DSM reduces the overall electricity load of a power grid network. Implementing DSM also benefits the user with cost savings [14]. In order to implement DSM interventions on certain sectors, an Energy Services company (ESCo) is necessary.

ESCos play a significant role in the successful implementation of DSM projects. ESCos act as project managers to manage a specific project. Typically, ESCos will offer the following services [15]:

- feasibility studies;
- design, develop and arrange financing for energy efficiency projects;
- install and maintain the energy-efficient equipment relevant to application;
- monitor, measure and verify the energy savings achieved; and

- take on all or part of the risk of savings that each project will achieve during implementation.

When Eskom announces funding availability for DSM initiatives, ESCos submit tenders for possible electricity savings projects. Thus ESCos must ensure savings through successful implementation and monitoring of a specific project. An example of the project steps required to implement such a project can be seen in Figure 5 below [16]:

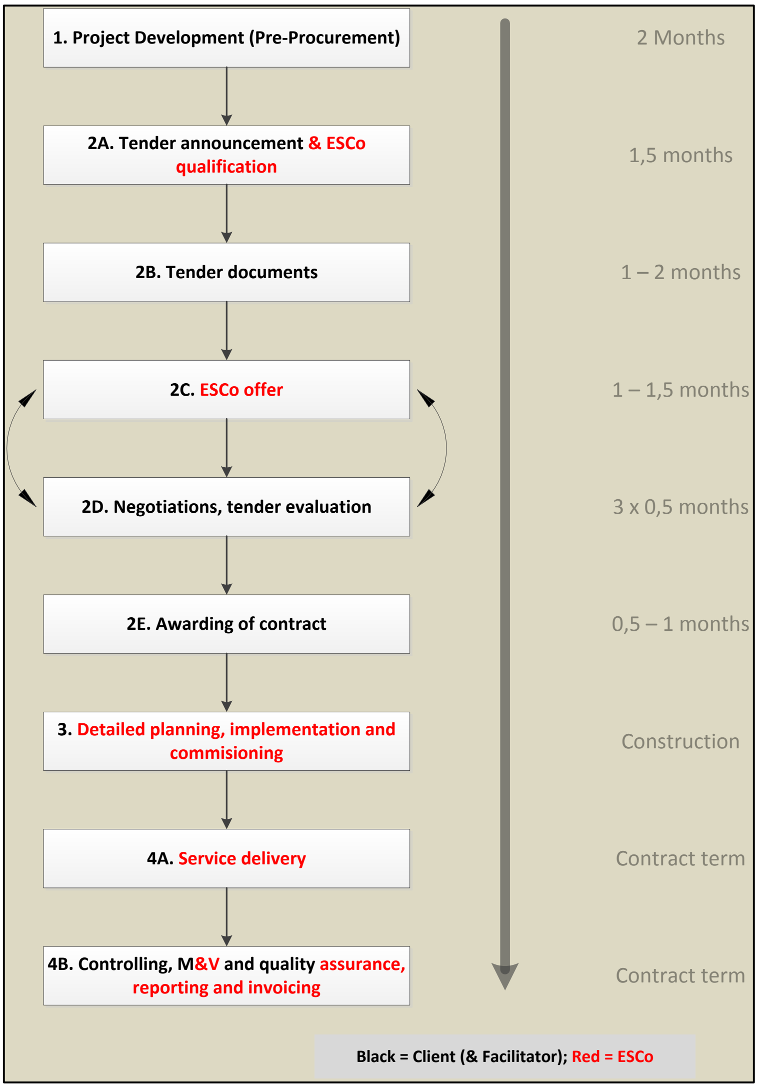

Figure 5: Overview of workflow between the client and ESCo

This process ensures the validity of the project implemented. The documentation, therefore, supplies Eskom with substantial proof that the ESCo implemented the project with the savings indicated. Due to the large electricity consumption of the water distribution utilities, there are significant opportunities to implement DSM projects.

As the demand for electricity increases annually, different Industrial Demand Management (IDM) initiatives were launched such as energy efficiency (EE) initiatives as well as DSM. The need for EE/DSM led to the formulation of specific policies and regulations as stipulated in the Regulatory Policy on Energy Efficiency and Demand Side Management [17]. Among the outcomes to be achieved through the EE/DSM policy are [18]:

- quick power system relief;
- relative cost effectiveness;
- quick deployment of interventions across residential, commercial and industrial sectors as well as quality employment;
- mitigation of greenhouse gas emissions and the resulting climate change impacts; and
- participants will realise relief from their electricity bills.

There are three different electricity saving initiatives set in place, namely energy efficiency, load shifting and peak clipping. The peak periods as stipulated in Megaflex tariffs, are highlighted below in Figure 6, Figure 7 and Figure 8. Each of the three initiatives will be discussed briefly.

Energy efficiency is the application of reducing energy usage to result in the same amount of work previously done. This can be achieved by replacing equipment with more efficient equipment, resulting in less electricity consumed to perform the same work output. In Figure 6, a typical profile of energy efficiency is shown.

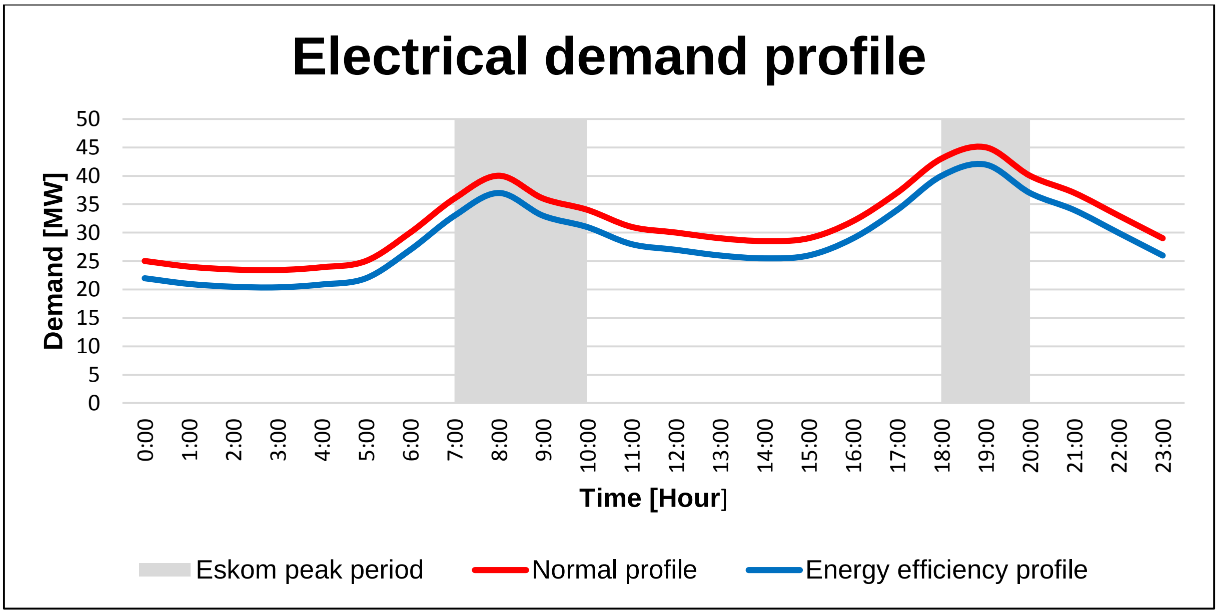

Figure 6: Typical energy-efficiency profile (adapted from [19])

Load shifting takes place when electricity usage is shifted from the peak periods to non-peak periods to result in a better load distribution for Eskom, as well as better pricing for the consumer. It is important to note that this does not result in electricity savings and only cost savings. In Figure 7 a typical load shift profile is shown.

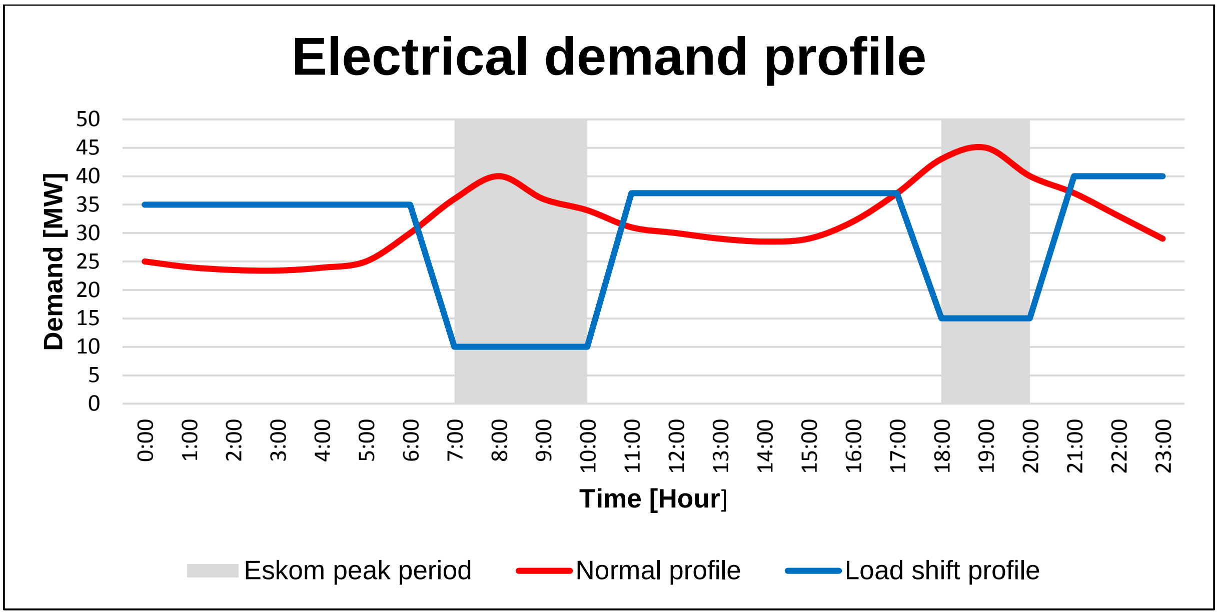

Figure 7: Typical load shifting profile (adapted from [19])

With peak clipping, electricity consumption is reduced during the peak periods. This consumption is not recovered in the off-peak periods. Figure 8 below indicates a typical peak clipping profile. Electricity savings as well as cost savings are realised with this intervention.

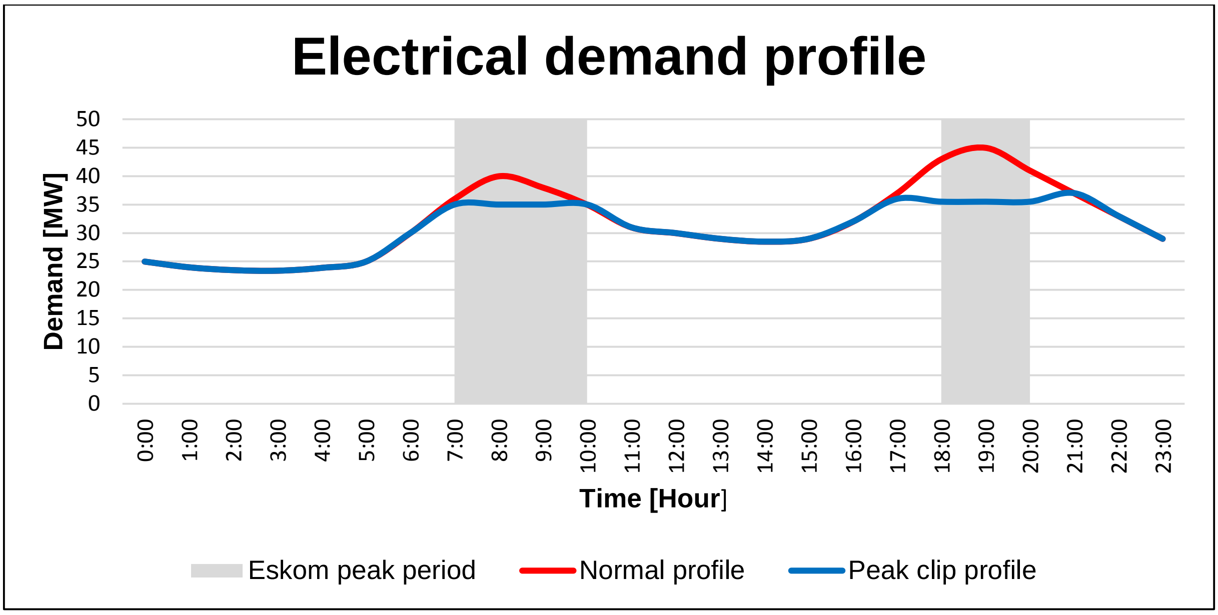

Figure 8: Typical peak clipping profile (adapted from [19])

1.4 Canal schemes in South Africa

South Africa is the 30th driest country in the world [20], making it a semi-arid area. From these available water resources, approximately 60% of the available water is used for agricultural irrigation purposes. Figure 9 below illustrates the water usage per sector.

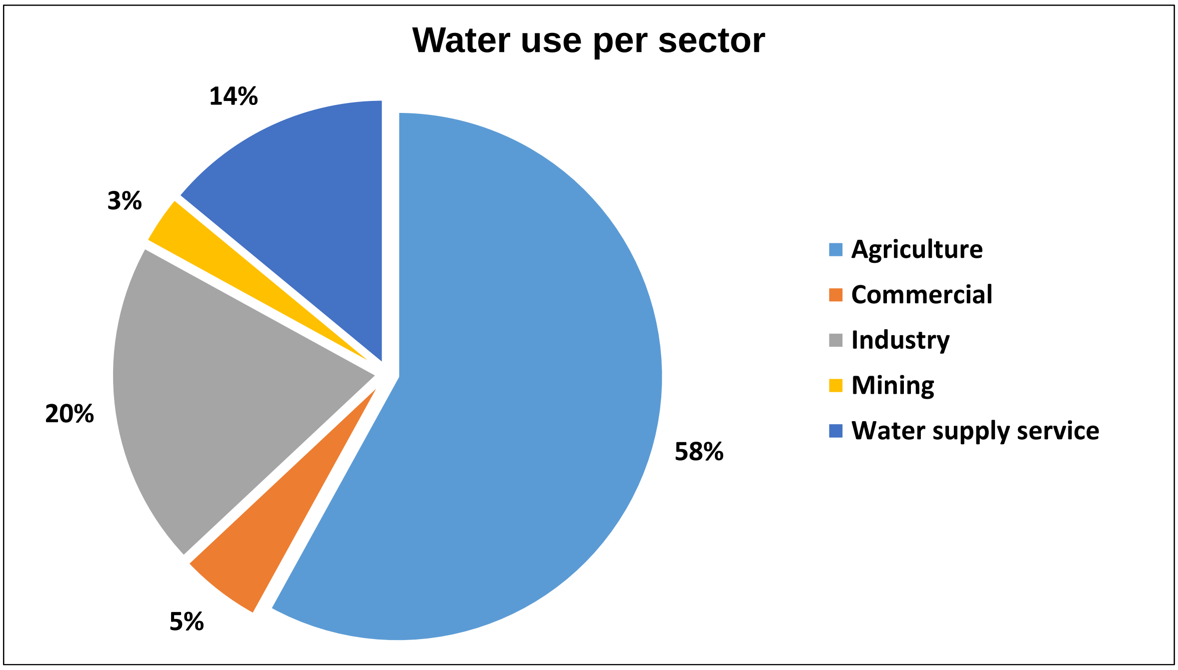

Figure 9: South Africa water use percentage per sector [21]

South Africa has rich amounts of fertile soil, which is underutilised due to the lack of water access. Certain parts of South Africa utilise canal schemes to solve this problem. A canal system will typically be built from one water source (dam, river or lake) over a vast dry or water scarce area and then ending in another water source. There are various water irrigation schemes located in the semi-arid areas of South Africa.

South Africa is classified as a semi-arid area. The total amount of land in South Africa is approximately 102 million ha. South Africa receives an annual average rainfall of 501 mm [22].

In Figure 10 it is illustrated that less than 200 mm rainfall is experienced along the arid west coast. In the east coast side of South Africa, as much as 1 000 mm and more is experienced annually. The problem with this type of climate is that the more fertile ground for crops is located to the west side of South Africa, where less rainfall is experienced.

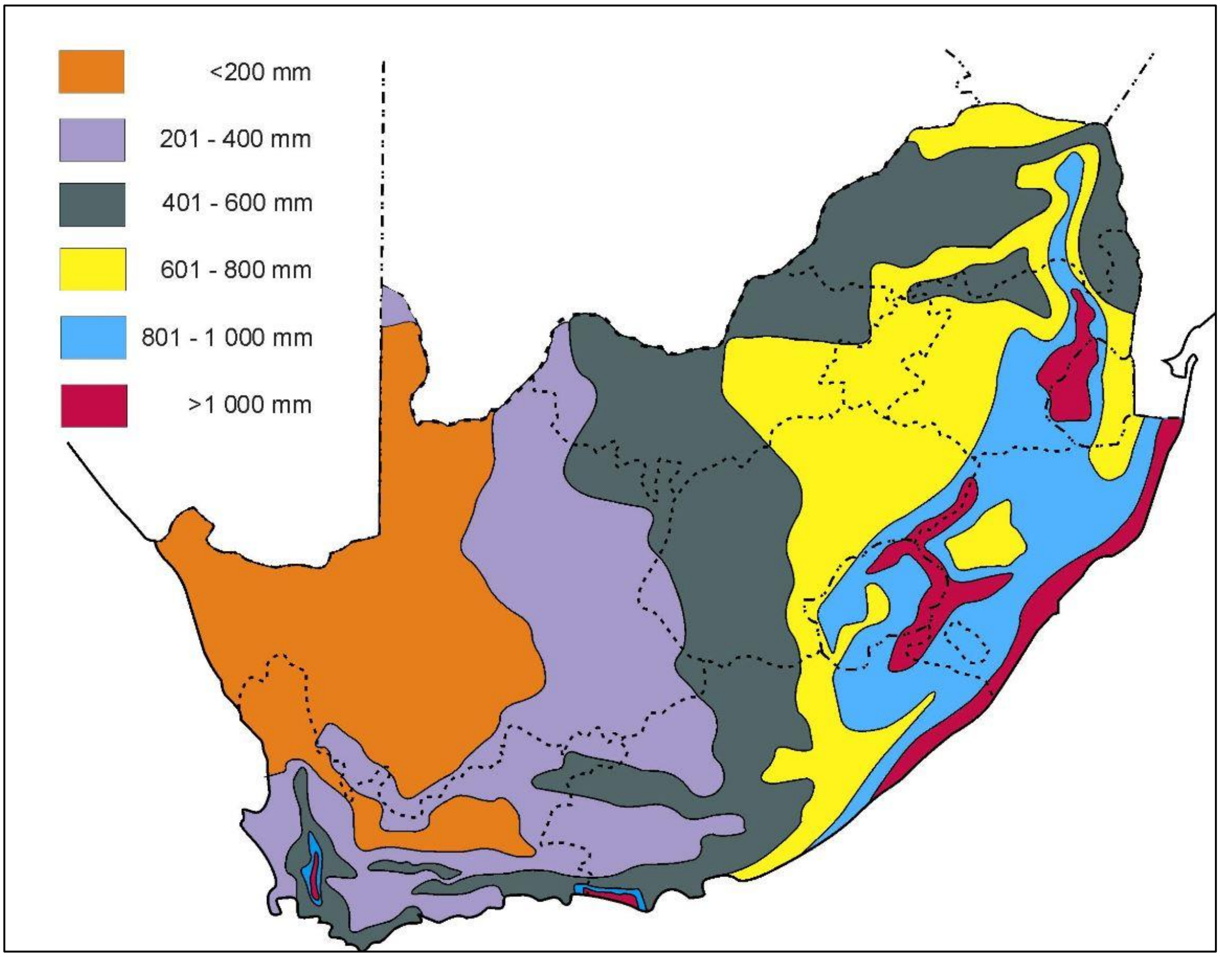

Figure 10: Annual precipitation in South Africa [23]

The area in South Africa where the largest fresh water system is located, has an annual rainfall of 600mm [23]. In Figure 11 the Orange River basin is shown, which stretches throughout South Africa and in parts of Namibia and Botswana. This basin is one of the largest river basins south of the Zambezi and has a catchment area of about 0.9 million km^2 [22].

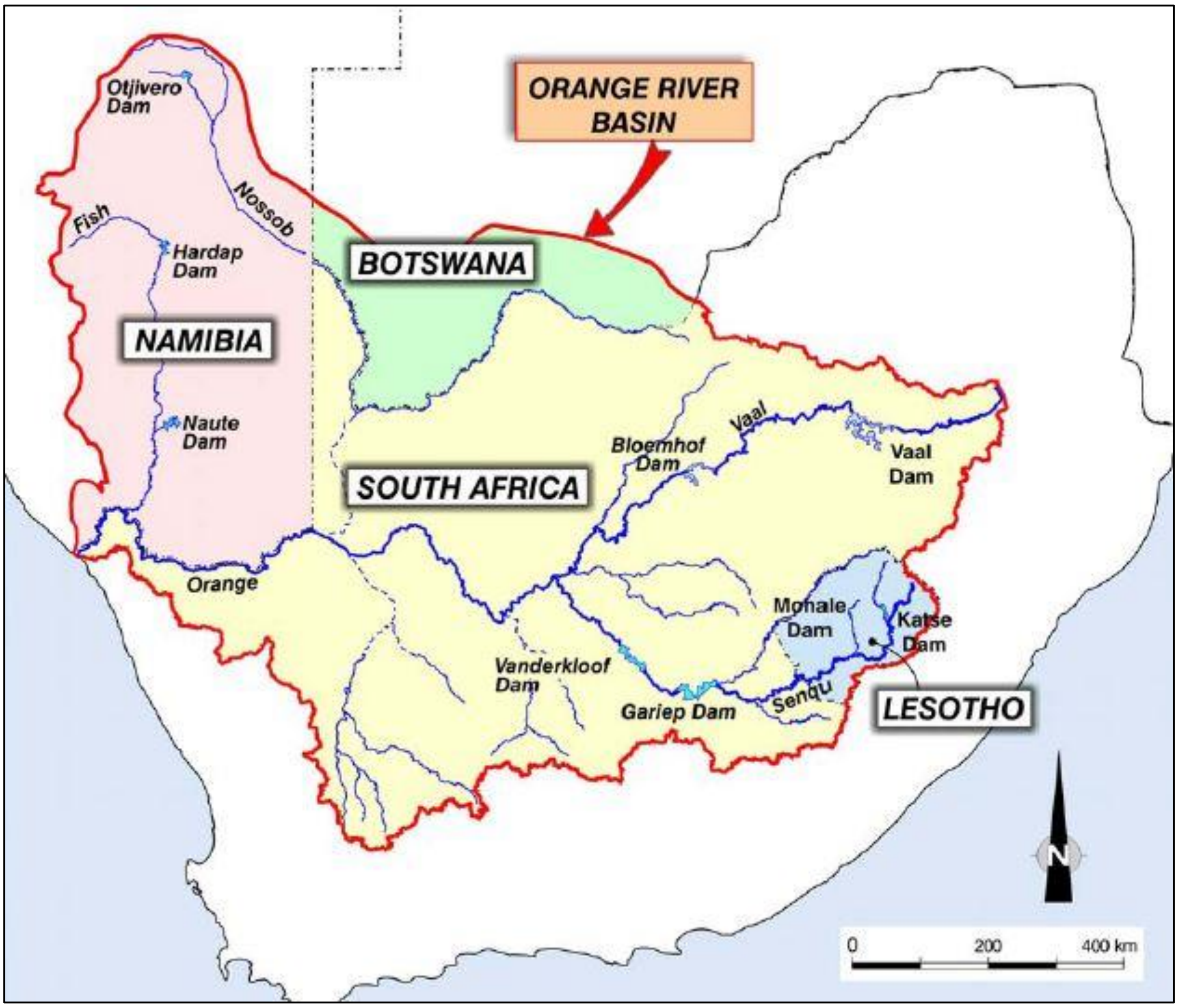

Figure 11: Orange River Basin layout [22]

Most of the irrigation schemes are sourced out of this river basin. This includes very large areas of the Northern and Western Cape as well as the Free State province. Due to the topography of most irrigation schemes, water needs to be pumped to a higher point of elevation to ensure sufficient water flow. These pump stations usually require large pumps to ensure a sufficient head. These pump stations are energy intensive and therefore this creates viable opportunities for ESCos to implement DSM initiatives.

In 2010, there was a recorded total of 302 small scale irrigation canals in South Africa. These irrigation canal schemes had a command area with a total of 47 667 ha. The primary water source for these small scale irrigation canal schemes is 96.7 % from rivers [24].

1.5 Objectives of this study

The objectives of this study are summarised below:

- investigate and understand different DSM interventions on pumping systems and the effect on a typical canal scheme;
- develop a DSM intervention strategy and the control system for implementation;
- simulate the control system and verify the results with a drop test;
- optimise the control system for a specific case study;
- implement the control system on specific case study;
- validate the results obtained from the implemented control system;
- discuss the results obtained; and
- make recommendations for further optimisation as well as further research.

1.6 Dissertation overview

In Chapter 1 the energy generation and electricity demand of South Africa was discussed. It is also identified that South Africa has an uneven water distribution. It was concluded that canal pumping schemes are necessary for water distribution. Canal schemes in South Africa are also discussed in Chapter 1.

In Chapter 2, typical large scale canal pumping schemes will be discussed. It will be followed with the investigation of DSM strategies implemented on large scale pumping systems. From the literature survey implications and risks of these DSM strategies implemented will be discussed.

Chapter 3 will focus on the development and implementation of the proposed control philosophy specific to the case study chosen for this dissertation. A simulation will be developed for the control philosophy. The reader will also be introduced to the case study plant and its unique challenges.

Chapter 4 focuses on the implementation and verification of the proposed control philosophy on the case study. The results obtained will be discussed in comparison with the results of the simulation for this case study. From here the impact of the study as well as the unique challenges faced during the implementation of this study will be discussed. The potential for further optimisation will be discussed.

Chapter 5 will conclude the study as well as recommend further research on this topic.

CHAPTER 2 - Overview of DSM interventions and canal schemes

Chapter 2 focuses on large scale irrigation canal schemes worldwide. Existing DSM strategies implemented on similar systems are also discussed as well as the implications and risks thereof.

2.1 Introduction

In Chapter 1, the electricity situation in South Africa was discussed, and it was concluded that there is an electricity shortage. The importance of DSM initiatives was discussed. It was determined in Chapter 1 that South Africa is a semi-arid area. Water needs to be distributed over vast distances. Canal schemes in South Africa were subsequently discussed.

In Chapter 2 the entire working of canal pumping schemes will be discussed. Information is provided regarding studies done on similar systems. The existing DSM strategies on pumping systems in the industry are discussed to provide a solid background. The implications and risks of DSM initiatives are also discussed.

2.2 Large scale irrigation canal pumping schemes

2.2.1 Canals

Irrigation uses a total of 70% of the freshwater available in the world, resulting in the largest user of freshwater. These irrigation practices produce up to 40% of the world's food crops on only 17% of all arable land available [25].

With the ever growing demand for food and increasingly scarce water supply, it is very important to manage water resources sustainably. Large scale irrigation canal pumping schemes, therefore, need to be designed, built and managed efficiently. Minimum loss of water throughout the transfer and management thereof is crucial.

Irrigation schemes are divided into two categories namely large– and medium irrigation schemes. A large irrigation scheme can be defined as a scheme that has a culturable command area of more than 10 000 ha, whereas a medium irrigation scheme is defined as a scheme that has a culturable command area of between 1 000 and 2 000 ha [26]. For the purposes of this dissertation, the focus is on large scale irrigation schemes.

Each canal scheme has its own design specifications according to the water demand. Thus the water flow and supply capacity needs to meet the demand. The increasing water demand is also taken into consideration.

The starting point of an irrigation canal pumping scheme is a water source such as a river, dam, lake, storage basin, mountain flow, etc. [27]. From there, the water is transferred by means of a canal. Water can either be gravity fed to a certain point of elevation from where the water is pumped; or pumped directly out of the water source. From the pump station, water is then pumped to a higher geographical area from where it is then gravity fed over vast distances.

Alongside the flow of the canal, water is then extracted for agricultural use or it is pumped into a balancing dam/reservoir from where water is extracted. The remainder of the water which is not extracted, is usually transferred to another water source such as a river. The canal system will always end up flowing into another water source. In Figure 12, a basic layout of a typical canal pumping scheme is shown. The black arrows indicate the direction of flow of the fresh water.

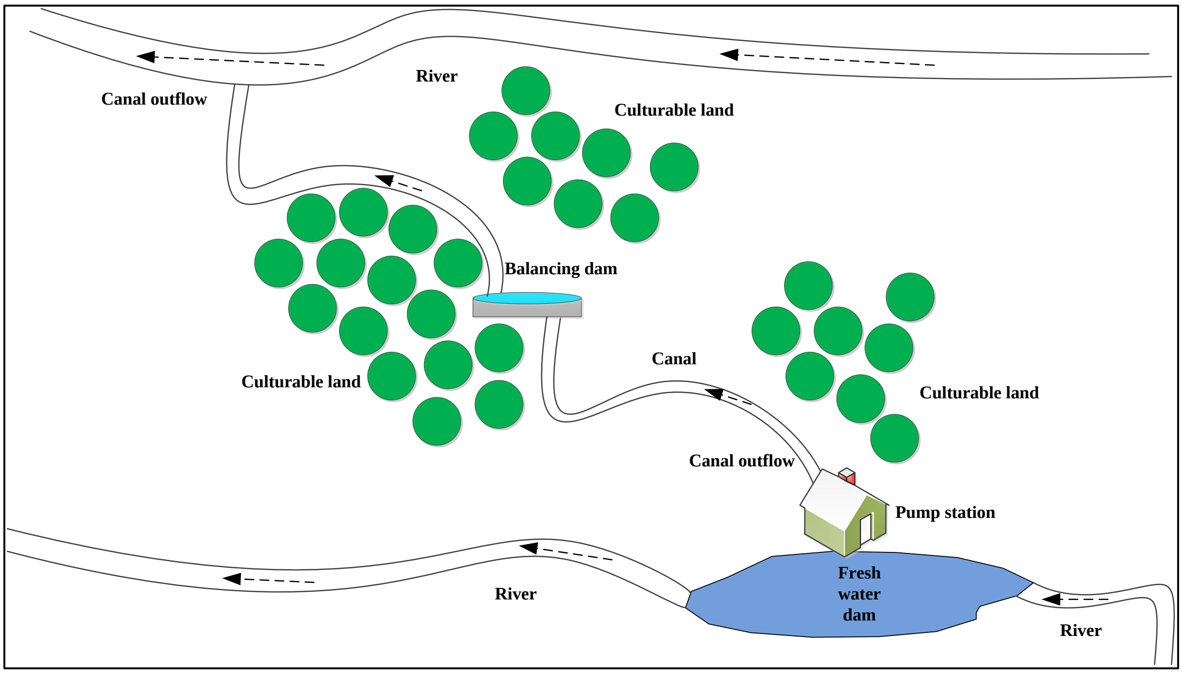

Figure 12: Basic layout of a typical canal pumping scheme

Canal designs can vary based on the shape of its cross-section. These shapes are numbered and shown in Figure 13, below. The forms include:

- square (A);
- triangular (B);
- trapezoidal (C);
- circular (D);
- parabolic (E); and

- irregular (F).

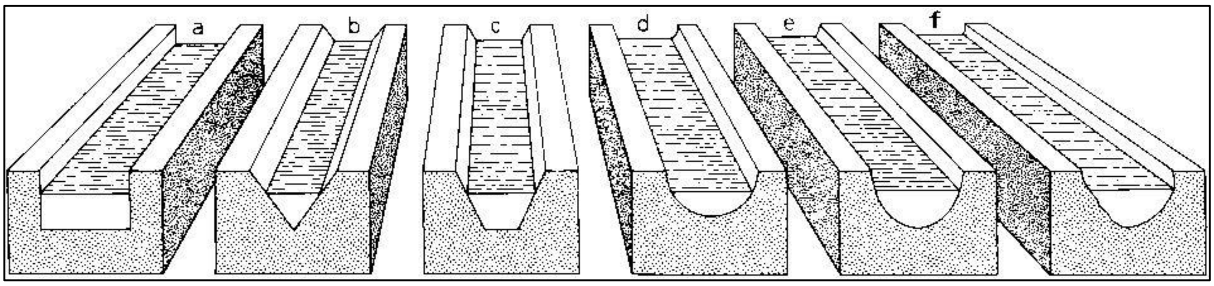

Figure 13: Cross-section of variant canal shapes [28]

The most common shape used is the trapezoidal cross-section (C). Trapezoidal cross-section canals can again be divided into a symmetrical and non-symmetrical shape. For the purposes of this dissertation, only trapezoidal symmetrical cross-section canals will be discussed. A typical trapezoidal canal is shown below in Figure 14.

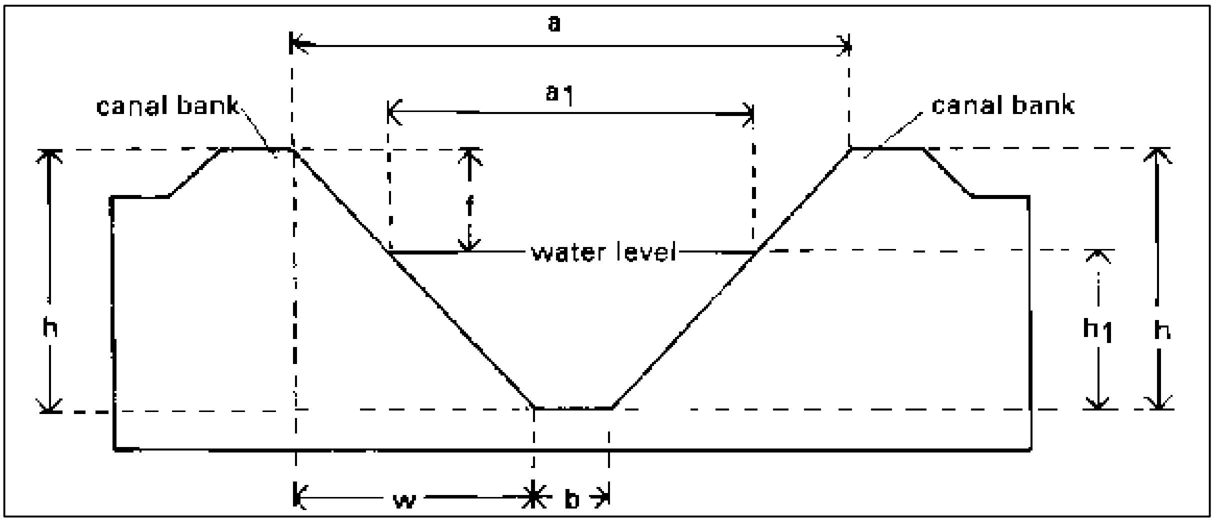

Figure 14: Trapezoidal canal measurements [28]

From Figure 14 above:

a = top width of the canal

a_1 = top width of water level

h = height of the canal

h_1 = height or depth of the water in the canal

b = bottom width of the canal

h;w = side slope of the canal

f = free board (h - h_1)

Free board refers to the extra depth of a canal section which is above the water surface. A free board will ensure a 100% flow rate capacity in a canal. To allow for certain conditions, a free board value is required to be added extra for the maximum expected depth. The conditions include [29]:

- difference or deviations between design and construction;
- operational flexibility (as well as operator mistakes);
- hydraulic jumps;
- uneven land settlement after construction due to earth composition;
- accommodation of transient flow conditions;
- increasing hydraulic roughness due to lining deterioration, weed growth; and
- wind loading.

An example of a free board is shown in Figure 15. It can be observed that the design of this specific canal was done sufficiently.

Figure 15: Example of a free board [29]

It is therefore important to keep the free board height in consideration during the design phases of a canal. In Figure 16, the relation of the free board height and the flow rate of water is shown. It can be seen that the higher the flow rate of a canal, the higher the bank height or free board needs to be.

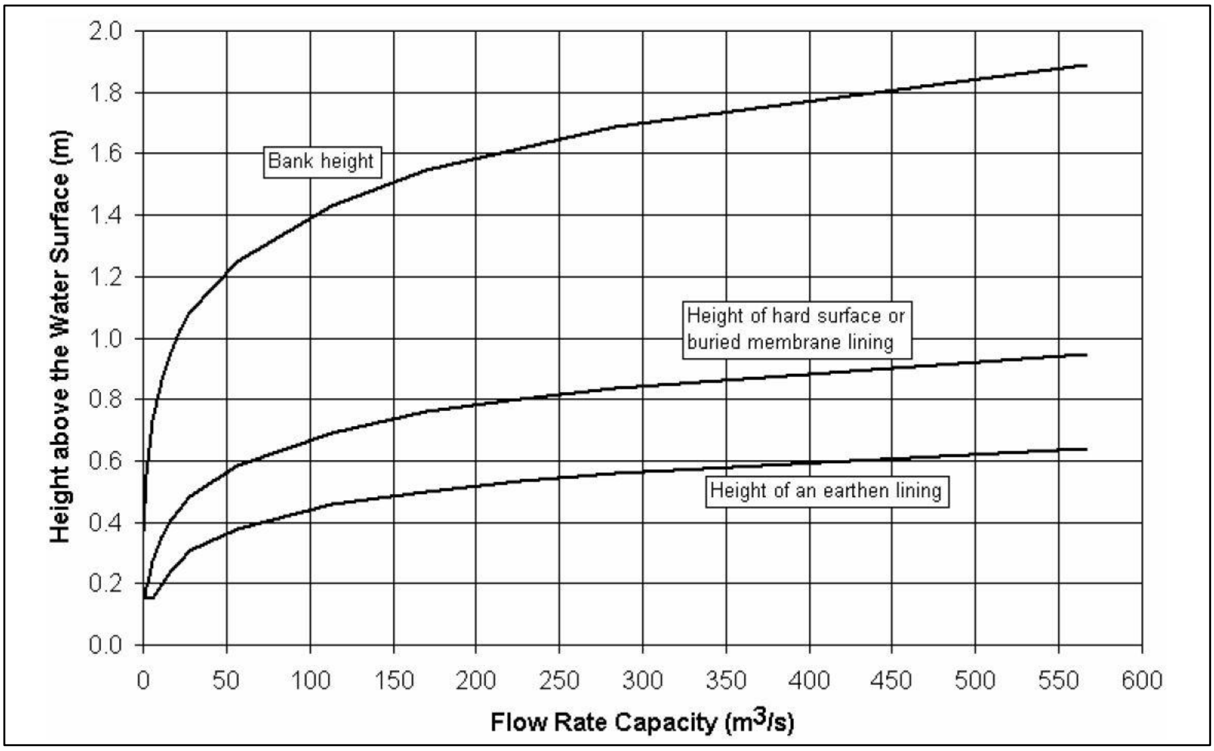

Figure 16: Free board height in relation to the flow rate [29]

Upon choosing the correct free board height, it needs to be operated within its design parameters. When a canal is flooded, damage can be caused. An overflowing canal, shown below in Figure 17 can have various negative effects. Firstly the precious water resource is being wasted. Enormous erosive damage is also caused alongside the canal walls. This damage can lead to significant amounts of financial expenditure.

Figure 17: Overflowing canal [29]

The side slope of the canal which, is not illustrated in Figure 14, is calculated in ratio. There are different ratios applicable to the type of material used for the lining of the canal. In Table 2 below the ratio of the acceptable slope is shown in relation to the material choice [30].

Table 2: Side slope ratio [30]

Material	Side slope (Ratio)
Rock	Nearly vertical
Muck and peat soils	¼:1
Stiff clay or earth with concrete lining	½:1 to 1:1
Earth with stone lining or each for large channels	1:1
Firm clay or earth for small ditches	1 ½:1
Loose, sandy earth	2:1
Sandy loam or porous clay	3:1

The side slope's ratio is compared to the vertical height of the canal. An example of a loose, sandy earth slope (2:1) can be observed below in Figure 18. The ratio 2:1 means that the length of the slope is two times the distance of the vertical height (w:h = 2:1)

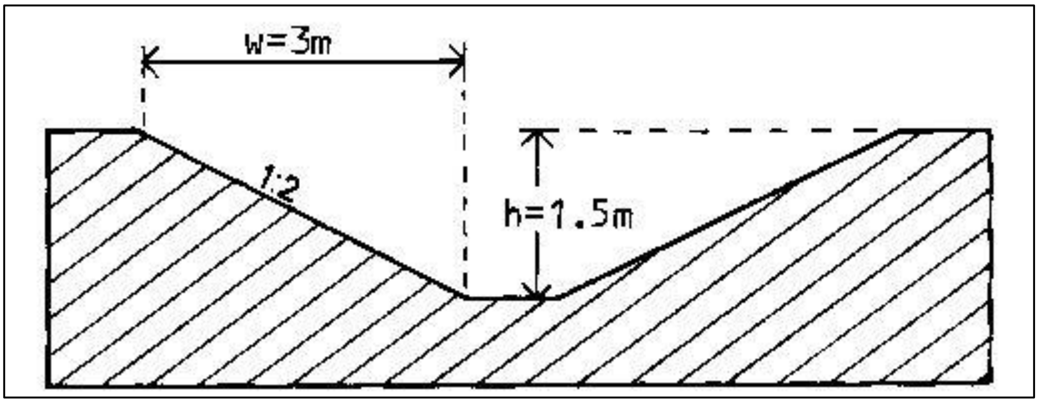

Figure 18: Side slope [28]

Two types of canals are used to transfer water, namely earthen canals and lined canals. Earthen canals are basically dug in the ground and the bank of the canal is made up of the removed earth. These type of canals require high maintenance and has high water loss due to seepage. Earthen canals are not an effective solution for long distance water transfers and is not considered for large scale canal pumping schemes.

As seen in Table 2, there are many different types of lined canals. Lined canals are built for five primary reasons namely:

- transmission of water at high velocities through areas of difficult excavation in a cost effective fashion;
- transmission of water at high velocities at a reduced construction cost;
- to decrease canal seepage, which conserves water;
- to reduce annual operation and maintenance costs; and
- to ensure stability of the canal section.

In South Africa, canals are maintained, kept operational and as efficient as possible. Canal inspections are done annually, which is referred to as the “dry week”. During this period no water is transferred and inspection is done on the lining of the canal. Any cracks formed are fixed accordingly and weed growth in the canal is removed.

2.2.2 Pumps

Pump stations used in the canal schemes are operated to deliver constant flow rates. Typical pumps and the electric motors will be discussed. As well as typical problems encountered with such systems.

For applications such as water distribution, centrifugal pumps are the most widely used [31]. The different types of centrifugal pumps will be discussed.

The principle of the centrifugal pump is to increase the pressure from the pump inlet to the outlet. This is done by transferring mechanical energy from the motor to the fluid by means of the rotating impeller [32].

The operation of the centrifugal pump starts with the rotation of the impeller. As the impeller rotates, liquid starts to move, guided by the shape of the inlet vanes. These vanes force the liquid through the impeller vanes to the outlet of the pump. This flow causes a partial vacuum at the inlet and atmospheric pressure causes the system to rotate continuously. As the liquid exits the vanes of the pump, the desired velocity is reached.[33]

As a result of this operation, pressurized fluid exits the pump discharge at a certain delivery pressure [34]. In Figure 19 the principle of a centrifugal pump is shown.

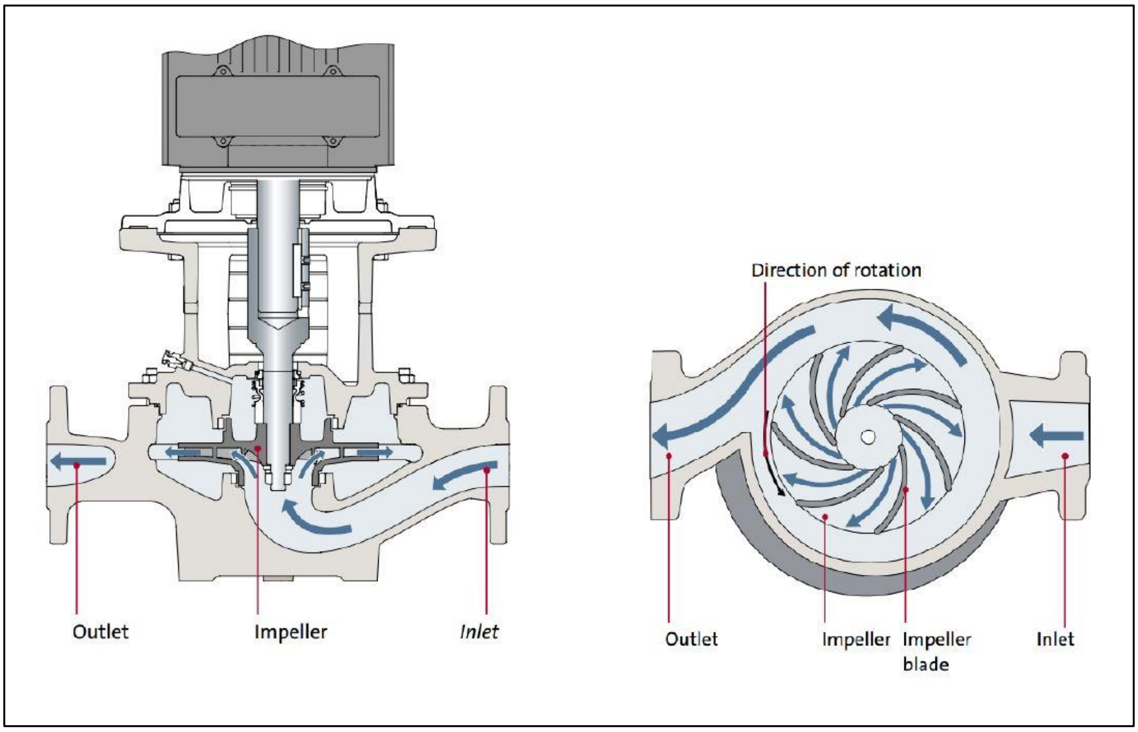

Figure 19: Principle of a centrifugal pump [32]

If the delivery pressure required is more than the efficient design of a single stage centrifugal pump, multiple stages are added. This is known as a multistage centrifugal pump. A multistage centrifugal pump has more than one impeller on a single shaft. The impellers are consequently arranged in series. The discharge of one impeller is the suction for the next impeller, meaning the water is pumped from one impeller to the next. This provides a much larger pump head [35]. The multistage centrifugal pump is presented in Figure 20.

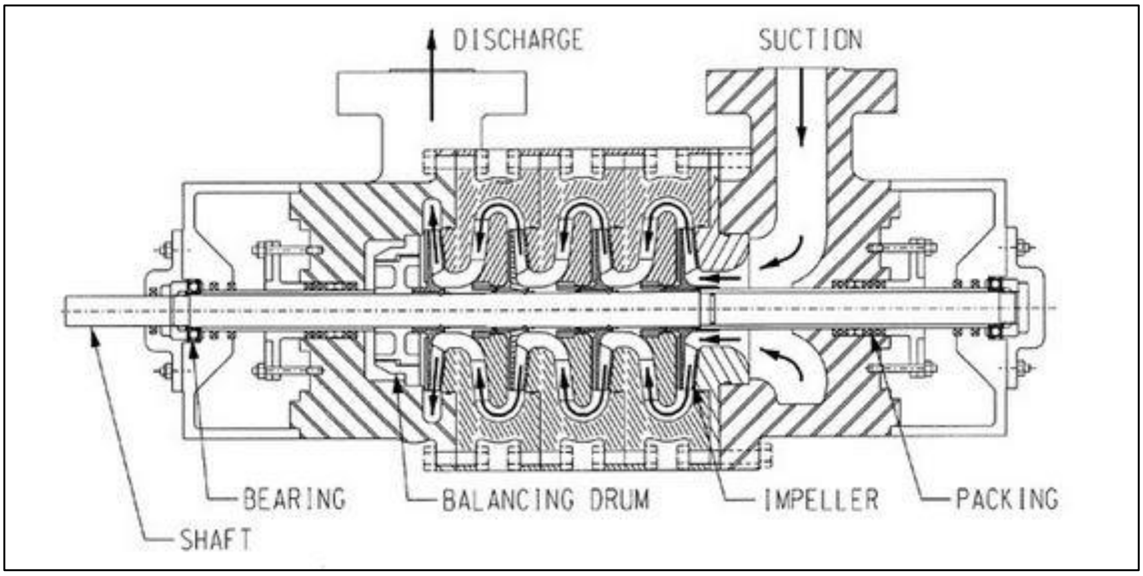

Figure 20: Multistage centrifugal pump [36]

Another widely used type of centrifugal pump, is the double-suction single stage pump. It consists of two general single stage centrifugal pumps mounted back-to-back, each with its own impeller. An example is shown in Figure 21, where the two impellers are driven by the same shaft. Two types, namely vertical and horizontal split case pumps are available. They differ from each other in respect of the manner in which their volute casings open. These casings are also referred to as a split casing centrifugal pump [37].

Figure 21 indicates a horizontal split case centrifugal pump. This pump has a better head delivery and is more efficient in transferring large amounts of water. Centrifugal pumps are also available with submerging capabilities. These submersible centrifugal pumps are not commonly used in large scale canal scheme applications.

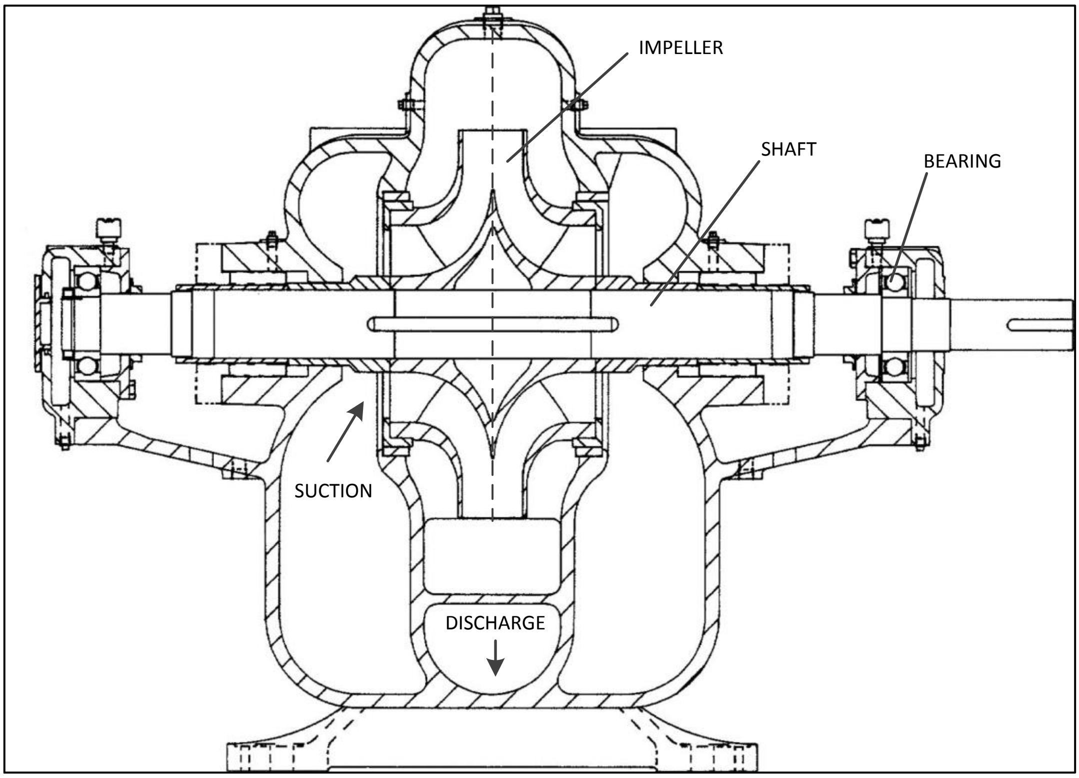

Figure 21: Split case centrifugal pump [36]

Transferring water through a canal scheme usually requires the capability to overcome high static pressure heads. A high flow rate is also required to meet the demand for water for all the irrigated crops. Proportionally high power is also required. This can be determined by using the hydraulic power equation (1).

$$P_h = \frac{\rho * g * Q * h}{\eta} \quad (1)$$

Where:

P_h = Hydraulic power (Watt)

ρ = Density of liquid (kg/m^3)

g = Gravity constant (m/s^2)

Q = Flow rate (m^3/s)

h = Hydraulic rate (m)

η = *Efficiency (dimensionless)*

The configuration of centrifugal pump sets can differ from site to site. It can either be set up in series, parallel or a combination of series and parallel. Pumps set up in series deliver a better pressure head.

Each pump handles the same flow rate, but the total head produced is an additive of the pumps used [38]. This is often done to ensure a better inlet pressure for the secondary pump when pump set configurations are set up. In Figure 22, the difference between a single and double series pump configuration is shown.

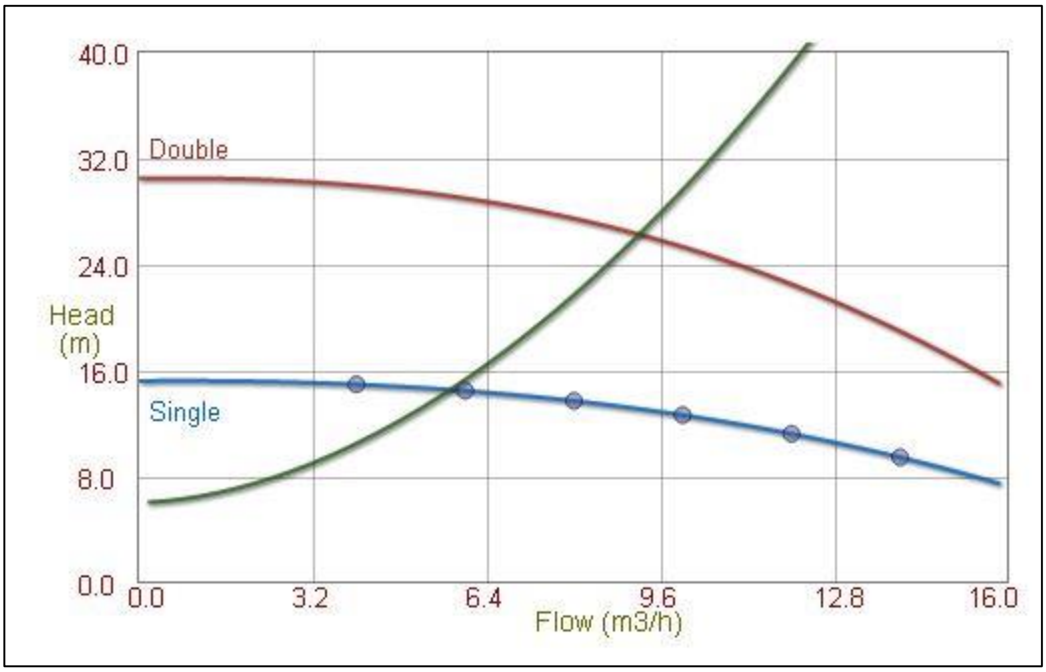

Figure 22: Series pump configuration of flow vs head [39]

A configuration of parallel pumps increases the flow rate. This means that the flow rates are additive with a common head [38]. This configuration is the most often used in the water pumping industry. In Figure 23, the difference between a single and double parallel pump configuration is shown.

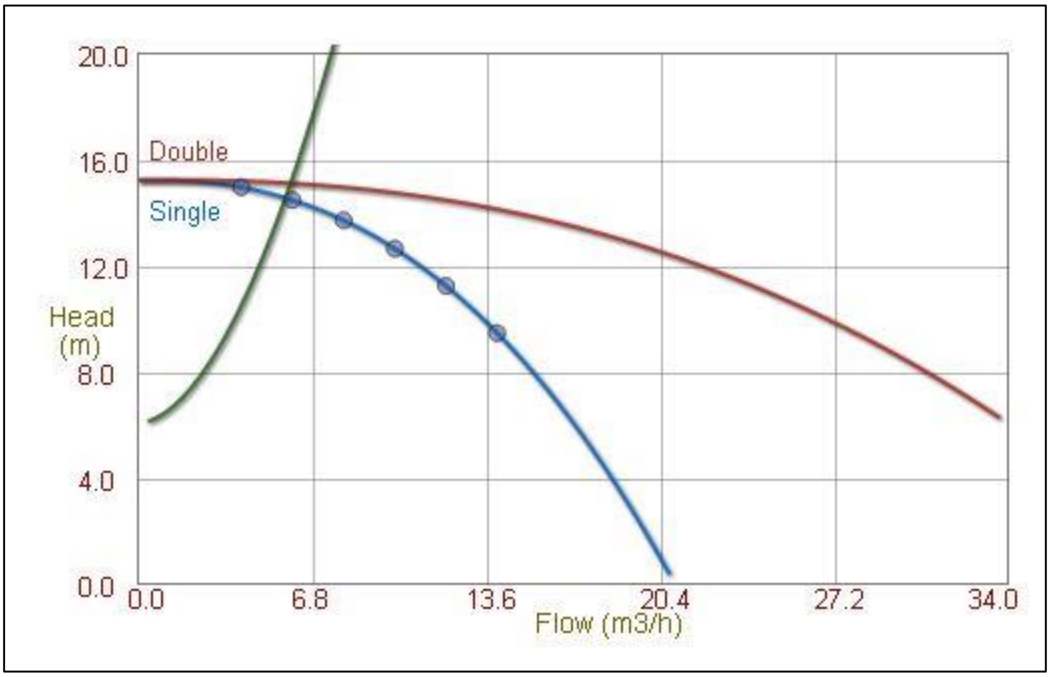

Figure 23: Parallel pump configuration of flow vs head [39]

It is thus important to choose the most applicable pump for the specific application. It is also important to select the correct configuration upon the choice of head or flow. Following on the choice of a pump, it is also necessary to use the correct motor to power the pump. This will be discussed in the following section.

2.2.3 Motors

In order to supply the necessary electrical energy to these pumps, the correct electric motor is required. The most commonly used electric motor is the squirrel-cage induction motor. Electrical energy is converted into mechanical energy from the magnetic flux through the magnetic circuits. The circuit is formed by the stator and rotor [40].

In order for torque to be created on the motor shaft, a moment of force is created by the magnetic flux linkage between the stator and rotor. The power output is defined by the speed of rotation on the shaft given in (2) [41]. This power drives the shaft and transfers energy to the pump.

$$P = T * \omega \quad (2)$$

Where:

P = Power

T = Torque

ω = Angular velocity

Squirrel-cage induction motors are popular in industry applications due to its reputable reliability, easy maintenance and high availability. Electronic speed control is also available for these motors. The use of Variable Speed Drives (VSD) is also possible for these motors. The stator of this electric motor consists of a conventional wound stator that has a specified amount of poles and phases. The rotor has casted or braded bars imbedded on it [41]. The squirrel-cage induction motor is presented in Figure 24.

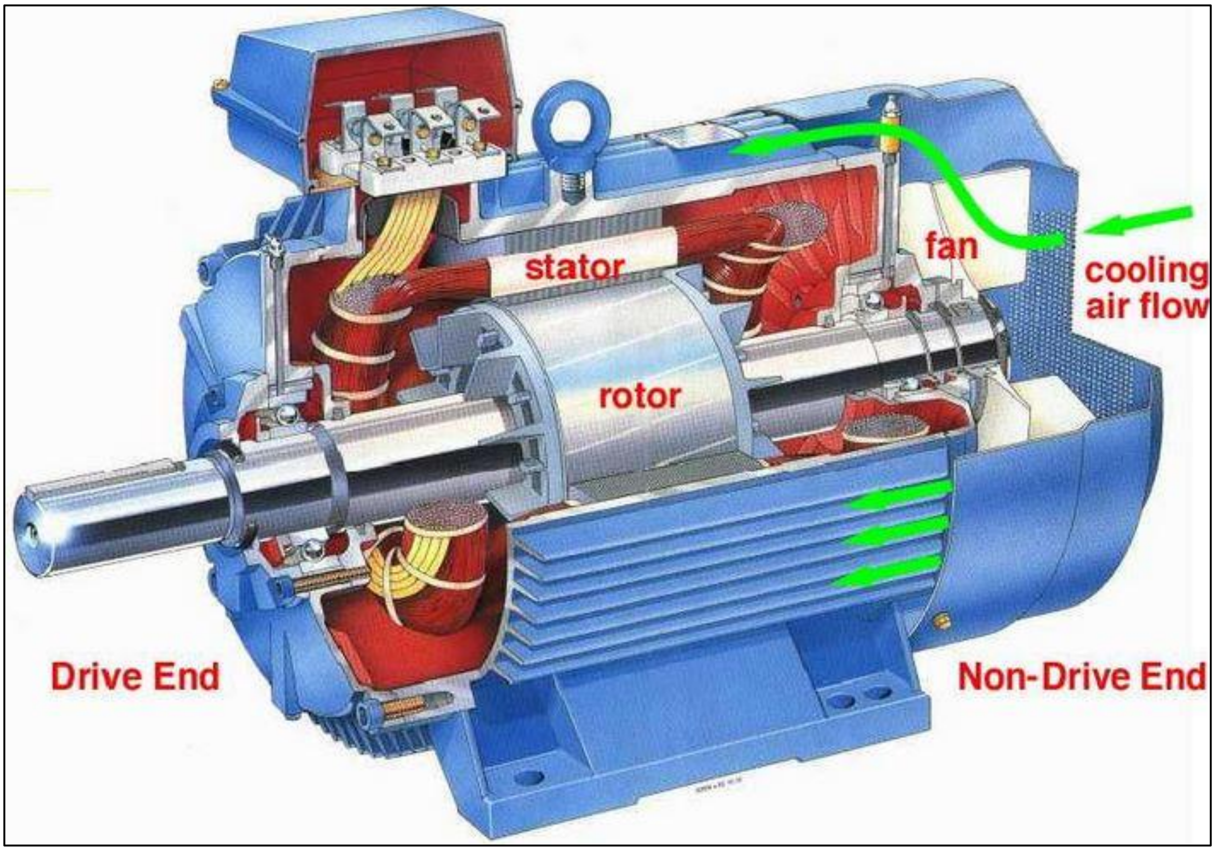

Figure 24: Squirrel-cage induction motor [42]

Most induction motors used in the industry have a 3-phase power supply. The electrical power used can thus be calculated by using equation (3)

$$P_{elec} = \sqrt{3} * \mathrm{V} * \mathrm{I} * \mathrm{pf} \tag{3}$$

Where:

P_{elec} = Electric power (Watt)

V = Supply voltage (V)

I = Supply current (A)

pf = Power factor (dimensionless)

In order to determine the efficiency, the pump and motor need to be taken into consideration. Therefore a combination of equations (1) and (3) can be used. The efficiency of the pump and motor can be defined in equation (4).

$$\eta = \frac{P_h}{P_{elec}} \qquad (4)$$

Using the mentioned equations namely (1), (3) and (4), the most applicable motor can be chosen for the pump. If the selections are made to be sufficient, the entire system will be more efficient and there will be less unnecessary maintenance.

2.2.4 Problems encountered

Various problems have been encountered on the water transfer systems in canal schemes. The problems include cavitation, choked flow and water hammering.

Cavitation is a phenomenon that is encountered when the suction pressure drops below the vapor pressure of the liquid. This causes vapor bubbles to form in the liquid. These bubbles are formed at the inlet of the impeller when the pressure drops as the velocity increases. The liquid stage of the fluid changes to the gas stage. The bubbles formed at the inlet of the impeller then move to a higher pressure range alongside the impeller vanes. There they collapse and a large force is exerted on the impeller. This results in pitting on the impeller vanes [43].

The impeller can be damaged to such an extent that the pump’s efficiency decreases dramatically [43]. Presented in Figure 25, the effect of cavitation on an impeller of a centrifugal pump can be observed.

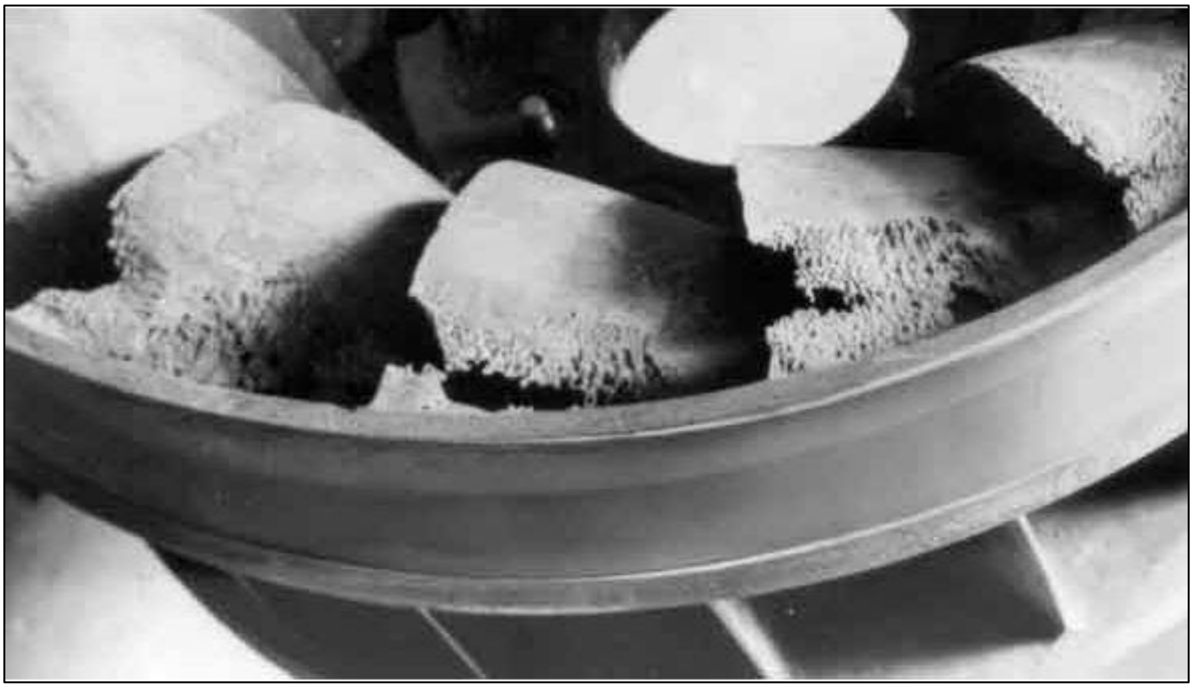

Figure 25: Effect of cavitation on a centrifugal impeller [44]

Two problems are usually encountered in the pipe systems at the outlet of pump systems. The first problem usually encountered is choked flow. This is due to the Venturi effect. The Venturi effect is caused when a fluid flows through a constricted section in a pipeline. At that point, the cross sectional area decreases causing an increase of velocity in the fluid and a decrease in pressure [45].

Keeping the Venturi effect in mind, choked flow occurs when the pressure drop across the pipe section is increased. The flow then reaches its maximum flow rate capacity. When this occurs, there will be no additional flow in the pipeline. The pumps, therefore, provide more flow than what the pipeline was initially designed for [46].

The second problem encountered in water systems, is called water hammering. Water hammering occurs when a sudden drop in the flow of fluid is experienced. This causes a pressure wave to be transmitted alongside the pipe section damaging the equipment. An example causing water hammering can be by rapidly closing a water valve [47]. Large scale canal pumping schemes use open canals mainly in the transfer of water where this does not occur; however, water hammering can be experienced in the short pipelines in and out of the pump stations.

All of the above mentioned problems need to be taken into consideration when attempting to perform safe load management on a canal pumping scheme.

2.2.5 Typical large scale irrigation canals

Typical large scale irrigation canal pumping schemes can vary extensively in length, size and capacity. In South Africa, the largest canal scheme has a network of 1 176 km long canals. These canals irrigate 29 181 ha [48].

The Narmada main canal in India is the largest lined irrigation canal in the world. The main canal has a total length of 458 km and a normal flow rate of 32 m^3/s. However, the canal has a design capacity flow rate of 1 132 m^3/s which irrigates an area of approximately 1.8 million ha [49]. The canal network has 2 500 km of branch canals and an additional 5 500 km of smaller distributaries and other associated canals [50].

The largest irrigation canal in the southern hemisphere is located in Australia namely the Mulwala canal. It extracts water from Lake Muwala and distributes water in a 2 880 km long canal network. The main canal has a flow rate of up to 115 m^3/s. The Mulwala canal irrigates an area of about 700 000 ha [51].

2.2.6 Water management on irrigation pumping canal schemes

A study has been done on the control of the water level in large scale irrigation canal schemes by R.R. Negenborn, P.J. van Overloop, T. Keviczky and B. De Schutter [52]. A case study was chosen from where their model predictive control (MPC) was implemented on; this case study had 7 different canal systems within the large scale canal scheme.

This was also done by a control program in order to control the inflow and outflow parameters in order to maintain the desired water level in a large scale canal [52]. The proposed MPC was compared to a centralized control system. Thus the MPC system can control multiple water systems in a large area whereas the centralized control system is only able to control a single water system [52].

Another study has been done by D. Dolezilek and A. Kalra [53] to automate canal schemes for management of the water as well as the power. The conventional flow monitoring and control system used for open canals in India was discussed as well as the requirements for the automation of a canal scheme system. The proposed result for total automation of such a system is presented in Figure 26.

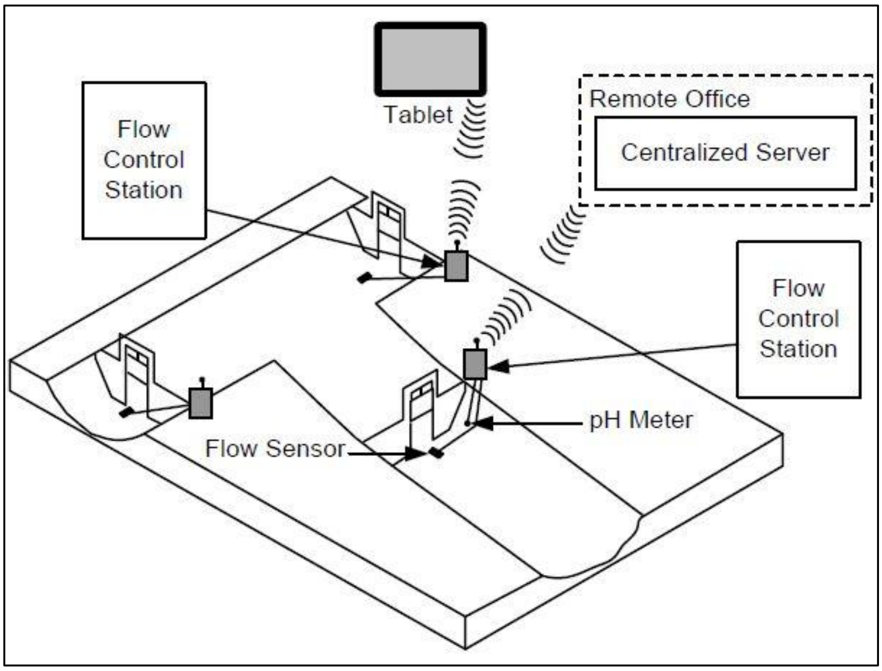

Figure 26: Complete system overview of case study control [53]

By implementing the automation on the water and power management of a canal scheme system, several benefits can be realised over conventional systems which include [53]:

- improved safety;
- reliability;
- effectiveness; and
- controllability.

The performance of a canal scheme can be improved if the irrigation boards of each district understand the future challenges of the increasing water demand and scarcity of the resource [53].

2.3 Existing DSM strategies on large pumping systems

In Section 1.3, the different DSM interventions were discussed namely energy efficiency, peak clipping and load shifting.

Due to the fact that the primary goal of canal systems is to move a specified amount of water on a daily basis, load shifting will be the best DSM intervention to implement. The principle of load shifting is to move the electricity load out of peak periods into off-peak periods. By doing this, the amount of water moved over a 24-hour period should still be the same.

Energy efficiency interventions on pumping systems will not be that sufficient. This is due to the fact that energy efficiency lowers the energy usage over a 24-hour profile. Thus less water will be pumped over a 24-hour profile resulting in an insufficient amount of water transferred for the day. This causes that the energy saved will be needed to use to deliver the water needed thus concluding in little to no energy saved. Installing new, more efficient pumps as part of an energy efficiency intervention will also not be a solution. This is due to the high input cost which will not rectify the savings achieved from the implementation thereof.

The implementation of a peak clipping will also not be that effective. Load clipping will only reduce the electricity usage during the peak periods, but no comeback load will be provided throughout the off-peak periods. Thus less water will also be pumped over a 24-hour profile.

In order to maintain the same amount of water to be moved over a 24-hour profile, as well as achieving cost savings, load shifting will be the most applicable intervention to use.

The advantage of using a load shift intervention is that it does not require costly equipment to be installed in order to achieve significant electricity savings. Changing the operation schedule is a very effective way to realise load shifting savings. Load shifting projects previously done on similar systems will be reviewed and discussed. These similar systems include water pumping systems, mining water reticulation systems and inter basin transfer schemes.

2.3.1 Water pumping systems

Water pumping systems supply potable water from treatment plants. A supervisory control and data acquisition (SCADA) system is installed on most of these pump stations. These water pumping systems are dependent on systems such as SCADAs for control purposes. These systems read and log valuable historic information for parameters such as flow, pressure and reservoir levels. This information is useful to support performance improvements of these processes [54].

A study has been done by M.P. Slade [55] on the cost optimisation of surface potable water pump system. A load shift project was implemented on a potable water pumping system in the Northern Cape, South Africa [55].

M.P. Slade identified the relation of mine pumping systems and water distribution systems. These systems all work on the same principle, namely extracting water from a source, ensuring a sustainable high flow rate at a high pressure head which requires large reservoir storage capacities as well as large installed capacity of pumps. The pumps are used to transfer water to higher elevation points over a certain distance [55].

The study by M.P. Slade was done on a water pumping system that extracts water from a fresh water river, purifying the water for human consumption and pumps the water over vast distances with the help of booster pumps and holding reservoirs. The systems contain three high lift pump sets, and each motor with an installed capacity of 780 kW and a flow rate of 270 l/s [55].

Apart from only investigating the electricity usage, other factors also need to be investigated to ensure a better understanding and to ensure efficient operation of the system [56]. This includes:

- all the installed capacities of pumps;
- reservoir capacities;
- available flow rates of pumps;
- available flow rates of the connecting pipelines;
- control levels of reservoirs;
- control levels of intake river; and
- amount of pumps simultaneously operational.

All these factors were considered during the simulation to ensure that a load shift saving is possible. Part of such a water distributing system is that a certain amount of water needs to be transferred on a daily basis. Targets are set out to ensure that these amounts of water are moved within a 24-hour profile. This ensures that the projected demand is met [55].

During the implementation of such a project, the client usually wants the system automated. The automation of such a system ensures that the agreed savings target is met. Another benefit of automation is that the human factor is taken out of the equation. By doing this, more sustained savings will be possible if the operator is taken out of the decision making process of switching a pump on or off [55].

The Energy Management System (EnMS) receives data through a common network from the SCADA. The SCADA is a system operating with coded signals over communication channels to provide control to remote equipment such as pumps. The SCADA system can indicate all the important information such as flow rate, pump statuses and important reservoir levels [55].

If there is a SCADA system online, all the information is available for an EnMS. An EnMS can be programmed to take all the control parameters into account and follows a specified control philosophy. The control philosophy is developed in relation to the specific needs and requirements of a site or system. For instance, a load shift intervention can be programmed into the EnMS. If all the control parameters are within the desired range before the peak period, the EnMS will automatically control the pumps [55].

The EnMS is then capable of gathering all the information from the SCADA, analyse the data through mathematical models and then schedule the time and use of the pumps. This scheduling can be used in real-time to effectively monitor the system. The EnMS sends the information to the SCADA which then relays it to the PLCs and finally to the relevant equipment [55].

The EnMS system was implemented on the water pumping system. Through the scheduling which was done, savings of 3.6 MW during the morning peak as well as 3 MW during the evening peak were realised. This in return resulted in an annual cost saving of R 825 000 in the year 2007 [55].

It was also noted by M.P. Slade that the load shifting initiative was achieved mostly every weekday. This is due to the fact that the pumping system usually operates 24-hours per day as well as the extra pumps available, therefore more water was pumped during the off-peak periods to meet the daily quota [55].

A load shift study was done by A. Nortjé [57] on a water transfer scheme in Mpumalanga, South Africa. This scheme provides water to Eskom power stations as well as Sasol technologies. Large amounts of water are required for the supply to the end user as well as to other users along the pipeline [57].

During the implementation phase of the study done by Nortjé, various infrastructure upgrades were completed. This included the replacement of relay logic controls with PLC's, Human Machine Interface (HMI) as well as a SCADA system [57].

All of this was done through the ESCo and the financial support of a typical DSM project by Eskom. This ensured a much more efficient and effective way of the pump control on these various sites. In addition to these infrastructure upgrades, an EnMS was also installed on the various sites [57].

This implicated that schedules were able to be generated through all the available information. The schedule generated by the EnMS ensured that the minimum amount of pumps were operated during the peak periods resulting in a good load shift opportunity [57].

An annual cost saving of R 4.765 million was achieved through the implementation of this DSM intervention. The cost savings were due to a successful load shift initiative with a total of 12.6 MW. In Table 3 below the load shift achieved on the different pump stations is presented. Note that a combined saving was achieved at pump station 1 and 2, because they operate in collaboration with each other.

Table 3: Load Shift savings achieved by A. Nortjé (adapted from [57])

Pump Station (PS)	Number of Pumps	Installed Capacity [kW]	Load shift Achieved
1	4	1 650	3.7 (Combined)
2	4	1 725	
3	5	2 150	3.1
4	4	3 050	5.9

Similarly the EnMS was implemented on six pumping schemes in South Africa in a study done by Prof M. Kleingeld, Dr G. Bolt and C. Scheepers [58]. Part of the pumping schemes was a 40 km canal. During the implementation of the study new infrastructure was installed to enable pump control through the EnMS. A new control philosophy was also developed and implemented for efficient operation. The target of 10.15 MW was comfortably achieved by using the new control philosophy [58].

The implementation of load shifting interventions on water pumping systems is very successful, as can be noted from several case studies. The system which was implemented on water pumping systems was optimised from mining water reticulation systems. Mining water reticulation systems will subsequently be discussed.

2.3.2 Mining water reticulation systems

Pumping systems in the gold mining industry in South Africa consume approximately 35% of the total electricity consumed, making it one of the mine's largest electricity expenditures [59]. Mine pumping systems reticulate clear water for cooling the working conditions underground as well as a couple of other applications. When the scheduling of this important system does not affect the production of a mine, a load shift intervention can be implemented to achieve savings.

In order to achieve a load shift on a mining water reticulation system, the schedule will need to be adapted efficiently. This can be done by implementing the EnMS that has been specifically developed for such systems. The EnMS has been thoroughly tested by simulating the conditions of such a system and comparing it to real-time data. It has been concluded that it is a very efficient system and several projects that have been implemented, yielded successful results.

A Study has been done by R.P. Richter [60] comparing the effect of manual and automated DSM pumping projects. The study done by R.P. Richter was implemented on several gold mines in South Africa.

There is an extensive difference between implementing a DSM project using manual pump control and automatic pump control. Manual pump control has been used since deep shaft mining commenced. This was due to the lack of technology which is used today, such as PLCs and network opted control [60].

Certain mines still prefer manual operation of their pumping systems due to [60]:

- human control during operations enhancing the physical supervision on pumps; and
- lower input infrastructure cost.

Although manual operation has advantages, there are typical problems that can occur such as [60]:

- damaging pumps to due delayed opening of discharge valves;
- high maintenance due to pump cycling;
- inadequate bearing temperature as well as vibration monitoring; and
- incorrect data logged for the use of maintenance on pumps.

Using an automated system would require more infrastructure. As previously mentioned, additional infrastructure such as a SCADA system, fibre optic cables for communication and an EnMS system will be required. Using an automated system to control the pumping reticulation system will have several benefits such as [60]:

- very accurate and reliable data at pre-set time intervals;
- pump control can be achieved by predefined schedules;
- longer pump cycle life due to precise control; and
- continuous monitoring which can respond with immediate feedback ensuring preventive damage.

There are certain disadvantages as well when using automated control, which includes [60]:

- additional maintenance on the control systems mentioned;
- costly infrastructure; and
- inadequacy of automated system under emergency conditions.

Keeping the above mentioned into consideration, R.P. Richter concluded the study on various deep level mines. It was found that automated projects performed consistently better than manually operated projects. An increase in the load shift performance of 38% was recorded when manual operation of these pumping systems was upgraded to automated systems [60].

The data obtained from the various implemented projects between manual and automated systems were compared based on [60]:

- engineering economic methods;
- consistency thereof; and
- cost savings including maintenance and labour costs.

It was found that automated systems delivered accurately predictable results that were more consistently recorded. Additional cost savings that vary between 36% and 45% can be expected with the automation of a system [60].

N.C.J.M de Kock [61] conducted a study of the load shift impact on six mines. The substantial benefits realised on case studies conducted on the mines were highlighted. When taking all of the results obtained from N.C.J.M de Kock's study into consideration, they account for approximately 85% of additional benefits in electricity cost savings from the DSM pumping projects implemented [62].

A combined evening load shift of 33.8 MW was realised on average during the DSM intervention. Which resulted in an annual cost saving of R 4.32-million in the year 2006. The savings are due to the effective implementation of an EnMS specifically designed for water pumping systems. The results of the study are shown in Table 4 below [61].

Table 4: Load shift achieved by N.J.C.M de Kock (adapted from [61])

Mine	Installed Capacity [MW]	Load shift Achieved [MW]
1	26.0	4.5
2	27.0	3.5
3	23.8	7.0
4	18.8	4.0
5	11.0	3.8
6	47.2	11.0

A. Prinsloo [63] conducted a study to optimise a complex mining reticulation system for the realising of electricity cost savings. The study was conducted on a gold mine in South Africa. The implementation of an EnMS on this complex water reticulation system yielded an average saving of 3.66 MW. The EnMS had the capability to be programmed to control almost any type of system regardless of the complexity. An annual cost saving of R300 000 was achieved for the year 2003/2004 [63].

After considering the results of the different case studies discussed, the implementation of DSM interventions on mining water reticulation is very successful. Mining water reticulation systems are basically very similar to canal schemes in the sense that the primary purposes, namely water transfer for a specific application are achieved.

2.4 Implications and risks associated with DSM interventions

2.4.1 Infrastructure

DSM interventions implemented on a specific site usually require infrastructure upgrades. These infrastructure upgrades are paid by Eskom. Eskom awards a project to a certain ESCo on a tender basis. The funds for the implementation of the project is provided by Eskom.

These funds are used to upgrade or repair the infrastructure on site to realise savings. Relevant to this study, only load shifting will be discussed. The aim of the infrastructure is to realise sustainable load shift savings.

After the implementation has been completed as well as the performance assessment period is finalised, the client takes ownership of the infrastructure. An independent entity called the Measurement and Verification (M&V) team verifies the impact of the implementation done by the ESCo.

The client is then responsible for the maintenance of the infrastructure as well as for showing the impact of the implementation for a certain period set by Eskom. This in return helps Eskom to reduce the load during peak times, especially when the power network is under pressure.

The type of infrastructure needed varies from each site due to the difference in layout as well as the condition the existing infrastructure is in. When the implementation of a DSM initiative commences, the automation of such a system is very important. Automation of such a system can improve savings and the operation to a point of sustainability. The automation of a system depends on different aspects of each independent system. Automating the system thus varies with each project implemented.

Additional to the infrastructure installed, an EnMS is also funded by Eskom. The EnMS has the capability to log important condition monitoring data, which can be viewed by operators as well as logged for maintenance purposes. The main aim of the EnMS is to schedule the operation of energy users such as pumps out of peak periods. The scheduling is also done as safely and efficiently as possible.

2.4.2 Maintenance

The EnMS that is installed on site also requires a backbone to work from. This includes the communications network including PLC's, optic fibre and a SCADA system. The mentioned infrastructure needs to be in a working condition if it is already installed. It is therefore necessary to ensure that it is operational.

With the help of this system, it is possible to do condition monitoring on the energy intensive equipment used. It is then possible to provide a sustainable method to prevent any unnecessary maintenance on complete failure of the equipment used.

The EnMS aids in this regard where real-time information can be observed by the operators which includes important information such as bearing temperatures, flow rate, efficiency of equipment, etc.

The EnMS can be programmed to issue an alarm if the equipment falls short of pre-set operating parameters. This will minimise maintenance as well as improve the efficiency of the energy intensive equipment. This will return better plant availability as well as improved savings of the DSM initiative.

2.4.3 Effect of stopping/starting

When a load shift project is implemented on a specific operation system, the equipment is stopped and started more frequently. For instance the motors of pumps at a pumping station which are stopped and started more often can be damaged over the long term. Overloading of the motor, starter and contactor are experienced.

As a motor is started, the current experienced during the starting period can reach up to 7 times the operating current of the motor. The machine loads experienced before start-up are due to the locked rotor torque that needs to be overcome. In Figure 27 below the difference between the start-up current and normal operating current of a typical motor is shown [64].

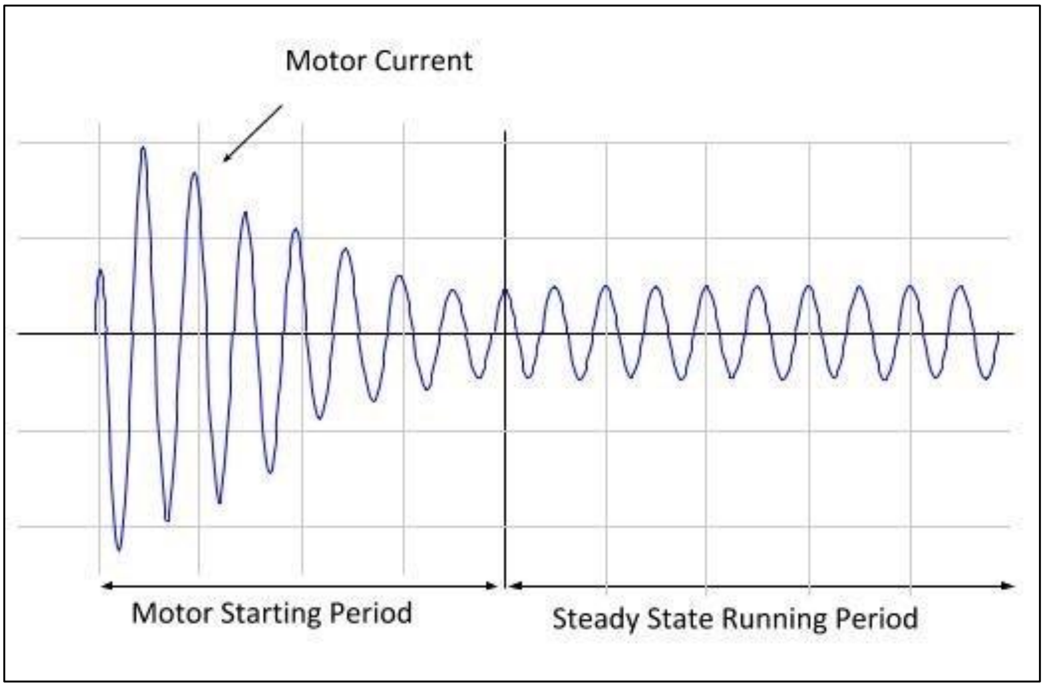

Figure 27: Motor current at start-up [64]

There are different methods and techniques to counter the effect of high current at motor start-up. Each has its own advantages and limitations. The more commonly used methods of motor starting are:

- electronic soft start;
- rotor resistance;
- primary resistance;
- auto-transformer;
- Star Delta;
- direct online.

From these different methods, electronic soft starters are the most widely used in pumping applications. Electronic soft starters control the start-up of the motor by controlling starting current, acceleration time and the overload current. The electronic soft starter reduces stress on the mechanical systems as well as limiting the current during the starting process [65].

The lifetime of the equipment used can be dramatically increased by utilising the starting systems mentioned. Although it is only for the short period during the start-up, huge costs of maintenance on the motors and pumps are reduced. When the operators control the pumps, they must be wary not to switch pumps on or off unnecessarily. The EnMS can aid with the scheduling of pumps so that they are switched on and off as efficiently as possible.

2.5 Conclusion

In Chapter 2 the various systems of a typical large scale irrigation pumping scheme were discussed, including the equipment and the possible results of insufficient management thereof. DSM initiatives implemented on similar systems, such as water pumping systems for potable and clear water purposes, as well as mine reticulation systems, were discussed. It was clear that large energy savings as well as substantial cost savings were achieved annually.

From studies mentioned in Chapter 2, it can be concluded that load shifting initiatives on a large scale canal pumping scheme can be viable. The EnMS implemented on the various sites can be easily adopted to function on a canal pumping scheme. Certain alterations will be required to be effective on the chosen case study.

By effectively shifting the load from the peak period to the off peak period, substantial energy savings, as well as cost savings, will be possible. The implications and risks of implementing a load shift on the equipment were also discussed briefly.

CHAPTER 3 - DSM methodology on large canal pumping schemes

Chapter 3 provides information regarding the investigation methodology, the simulation thereof as well as the verification process. The verification and the calculation of the baseline are also discussed.

3.1 Introduction

After briefly discussing the background in Chapter 1, Chapter 2 consisted of an extensive discussion on different DSM interventions as well as canal pumping schemes. The focus in Chapter 3 is about the development of an implementation methodology for a DSM intervention on a large scale canal pumping scheme.

The DSM intervention chosen for the specific application is a load shift during the evening peak period of Eskom. To implement such an intervention, a simulation needs to be compiled to investigate the feasibility thereof. After the simulation has been completed, it will be practically implemented on the pumping station to validate the simulation. A test will be done over a seven day period to test the system for a full operational cycle.

During this period, data will be obtained to verify the simulation. The proposed control strategy will be discussed as well as the implementation thereof.

3.2 Investigation methodology

The investigation was done on a case study in the form of a canal pumping scheme situated in the upper Orange catchment scheme as defined by the Department of Water Affairs. The investigation of this plant is required to confirm all the relevant data as well as to identify possible constraints and variables. The findings will be discussed below in the following sections.

3.2.1 Site description and layout

The purpose of obtaining a site description and layout is to get a better understanding of how the site operates. It is also necessary to obtain any site specific challenges in terms of operation or maintenance.

The main purpose of this canal pumping scheme is to provide water for irrigation applications. The water is drawn from a fresh water dam where an annual quota of 250 million cubic meter is set out by the Department of Water Affairs. In Figure 28 below, the basic layout of canal scheme S is presented. Due to client confidentiality the case study will be referred to as canal scheme S.

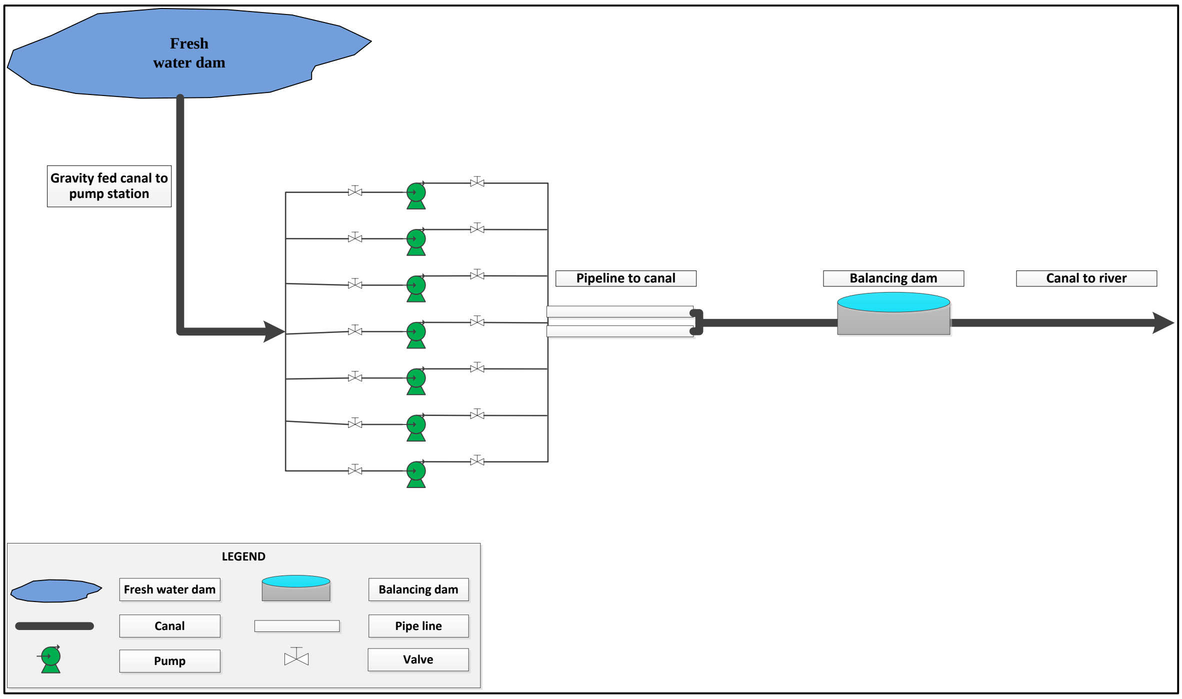

Figure 28: Basic site layout

Water is drawn through a 13.6 km, 18 m wide gravity fed canal line with a capacity of 54 m^3/s from the fresh water dam to the pumping station. There is no capacitance before the pump station. Water is pumped directly out of the canal into the pump station.

The pumps feed water into two 900 m long, 1.8 m diameter pipelines with a total head of 47 m. From there on the water is gravity fed down a canal for 112 km which includes two balancing dams until it flows into a river. This river eventually flows back into the Vaal River again. This stretch of canal has capacities of 15.2 m^3/s (before the balancing dam) and 13.2 m^3/s (after the balancing dam) respectively.

In Figure 29 a satellite view of the pump station is presented. This only presents the pump station, inlet and outlet canals to and from the pump station.

Figure 29: Satellite view of canal scheme S

Water is pumped from the pump station to a high geographical area from where the water is gravity fed to the balancing dam referred to as BDS2. This balancing dam has a depth of 3.75 m and a volume of 1.5 million cubic meter. Balancing dam BDS2 has a storage capacity of one day (24-hours) if no water is pumped into the canal.

Another balancing dam referred to as BDS1, has been built between BDS2 and the pump station with a capacity of 750 000 m^3. The construction of BDS1 was completed after the implementation of this case study had been implemented. It will therefore not be considered in the simulation model.

Water is split into numerous smaller canal branches after BDS2, but will not be taken into consideration in the simulation. The focus will only be from the pump station to balancing dam BDS2. This is due to the fact that the flow requirements of the pump station are only taken into account to the point of BDS2. Balancing dam BDS2 level is monitored and can be seen as the end point of water in the simulation.

The goal of balancing dam BDS1 was to ensure a larger buffer capacity of water if no water can be pumped due to unforeseen circumstances. This enables the pumping scheme to provide water at a constant rate to the client. The constraint that arises when no water is pumped, is the time it takes for the water to reach the balancing dams due to the length of the canal.

A basic layout of canal scheme S is presented in Figure 30. In the figure BDS1 is also indicated. Figure 30 does not represent the true distances between the pump station and the two balancing dams. This is due to the extensive length of the canal. Each balancing dam can communicate with the pump station as well as each canal section. The telecommunications system installed, ensures sufficient information to control the pump station.

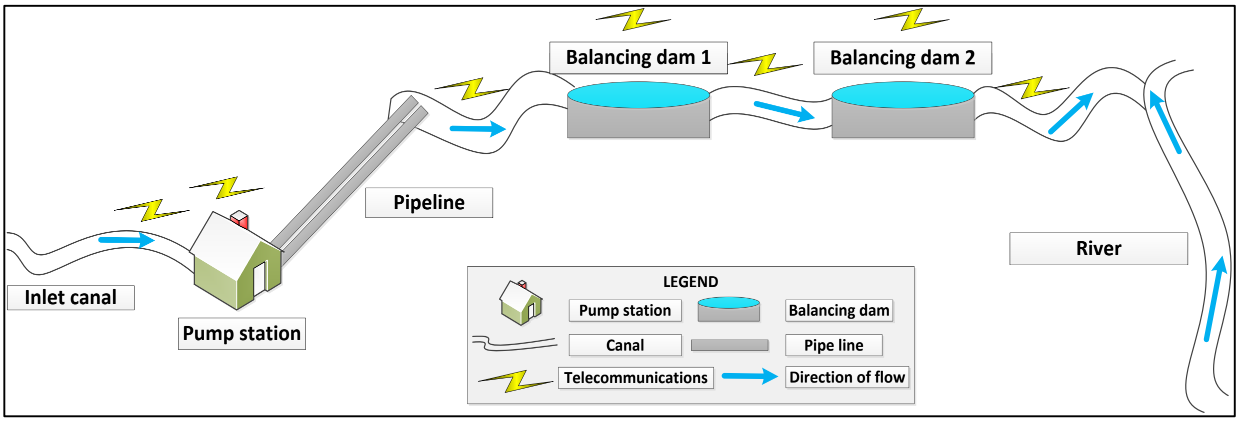

Figure 30: Canal scheme S layout

3.2.2 Pump station

The pump station consists of seven pumps (Sulzer and Mather & Plat) with electrically actuated intake and outlet valves. The water is pumped from the inlet canal through a split case centrifugal pump into a common manifold. The water is then pumped from the common manifold through two pipelines up to a higher geographical area from where the water is gravity fed to the balancing dams.

A power factor is maintained at 0.92 and the pump station makes use of a capacitor bank. The intervals for switching pumps on and off take an estimated time of 10 minutes. This is due to precaution checks taken by the personnel. These precautions include:

- avoid water hammering in the pipelines;
- protection of the transformer;
- preserving lifetime of the switch gear due to mechanical degradation.

The pump specifications are summarised below in Table 5.

Table 5: Pump specifications

Pump No.	Installed motor capacity [kW]	Pump capacity [l/s]	Manufacturer
1	655	1 000	Mather & Plat
2	1 296	2 000	Mather & Plat
3	1 854	3 000	Mather & Plat
4	1 957	3 000	Sulzer
5	1 957	3 000	Sulzer
6	1 957	3 000	Sulzer
7	1 957	3 000	Sulzer
Total	11 633	18 000	-

The discussed pump station cannot run more than six pumps at once, due to the maximum flow capacity in the canal of 15.2 m^3/s. If more pumps are operated simultaneously it will cause the canal to overflow. A maximum power delivery of 10 MW through the sub-station is possible. It will also not be possible to operate a combination of pumps which has a capacity larger than 10 MW.

After the preliminary investigation was done on site, the average power usage needed to be investigated. The site does not have a SCADA system that can log data such as power usage or water flows. All data logging done by the pump station is in logbooks.

To determine the feasibility of a load shift project, the pumps' running hours that were written in the logbooks were used to calculate initial baselines. The data was used to determine what the weekdays', Saturdays' and Sundays' usage of the pump station was, measured hourly for a 24-hour profile.

Presented in Figure 31 below, is the power usage of the pump station. As it can be seen, the power usage during weekdays is well below the maximum capacity of 10 MW. Thus it will be possible for the comeback load to be achieved during the off-peak periods.

This creates a potential to do a load shift during the peak demand hours of 18:00 to 20:00. This profile is only an indication for a possible load shift project. In order to gather the acceptable power usage data, portable loggers were installed on the main incomers of the pump station.

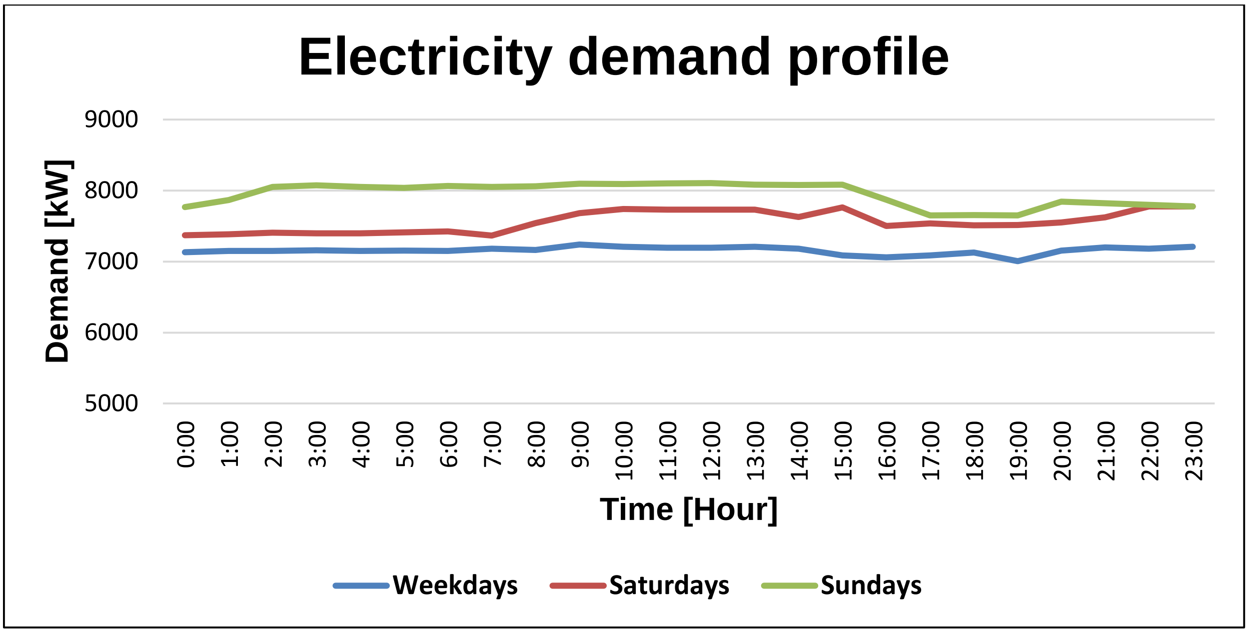

Figure 31: Electricity demand profile for the pump station

In Figure 31 the average weekdays', Saturdays' and Sundays' profiles are shown. These profiles represents the power usage during a day. The data represented in Figure 31 was taken out of the logbooks for a period of three months. From the data, it is evident that the weekend power demand was higher than the weekday demand. This can be due to the demand for power for the specific season or the type of crop which needs a constant high amount of water.

3.3 Baseline verification and calculation

In order to verify the results and savings of the implementation of such a project, a baseline needs to be calculated. The baseline data is then compared to the data during the testing phase after the implementation. This testing phase is called performance assessment.

In order to compile a baseline, the normal power usage of a typical month is required. The site on which the case study is implemented does not have a SCADA system that can log data, such as power usage and water flow. In order to accurately measure the power usage of the pumps, portable loggers needed to be installed. The data collected will then be summarised in a profile over a 24-hour period.

The portable Dent logger, as shown in Figure 32 below, is used to log the power usage. Loggers are then connected with clamps called current transformers (CTs) and voltage transformers (VTs). These clamps are presented in Figure 33.

Figure 32: Portable logger

Figure 33: Voltage transformers (left) and current transformers (right)

Using these portable loggers is easy and safe when working with high voltage stations. A dent logger derives the data from the voltage and current inputs close to a dedicated circuit disconnect breaker [66].

The portable Dent logger is calibrated to ensure that the correct data is recorded. A calibration certificate is required to provide sufficient proof of verification. All of the portable loggers used to log data are certified with a calibration certificate.

The baseline developed in this dissertation is verified by an independent group known as the M&V team. The calibration certificates of the loggers used are documented as proof of the verification process.

The M&V team ensures that the equipment used to calculate the baseline is also used during the assessment period of the project performance. The performance assessment period mentioned is a three month period in which the performance of the implemented project is measured. This period is also verified by the M&V team.

When a baseline is calculated, it must adhere to certain regulations [67]:

- the data obtained needs to be summarised in 30 minute intervals and compiled in a 24-hour daily profile;
- the data used must consist of a complete cycle of operations, usually identified as at least three consecutive months; and
- the baseline must include all the equipment affected by the load shift procedure.

The baselines calculated from the recorded data are shown in Figure 34. These baselines represent an average weekday's, Saturday's and Sunday's profile.

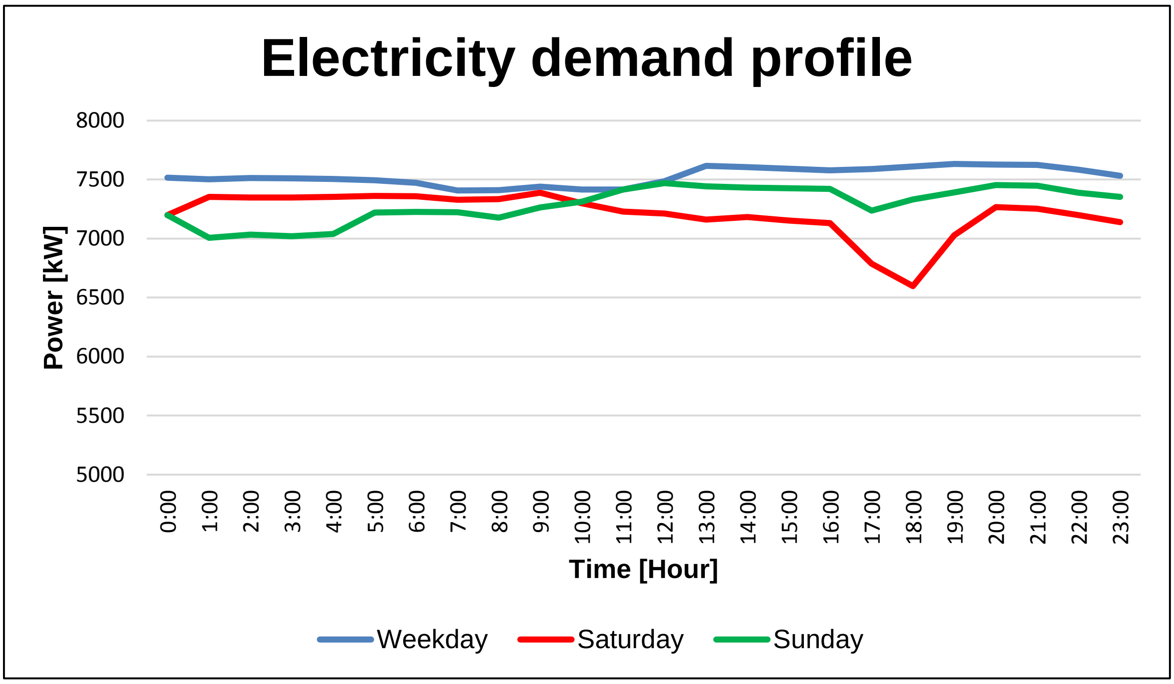

Figure 34: Weekday, Saturday and Sunday baselines

These baselines are scaled *energy neutral* in relation to actual values for a specific day or period. Now that the baselines are identified, the next step is to calculate the potential load shift impact on the power profile. The impact is defined by the average weekday profile minus the actual power usage during the peak period. The load is then shifted from the peak period to the off-peak period. Important to note is that the comeback load does not exceed the installed capacity of the pump station or the designed flow capacity of the canal.

The period referred to as the comeback load is the off-peak period where the load from the peak period is shifted to. The total load during 18:00 to 20:00 will be divided into an eight hour interval after the peak period. When the proposed profile is scaled, it is important to scale it *energy neutral* to the average weekday profile. This means that the same amount of energy is used in the proposed profile as in the baseline profile. Another popular scaling method, is scaling according to the required volume of water to be pumped per day. As mentioned, this case study's baseline will be scaled *energy neutral*.

To scale the data used *energy neutral*, the following equation is used:

$$Daily\ Scaling\ Factor = \frac{\sum average\ weekday\ half\ hour\ data}{\sum load\ shift\ average\ weekday\ half\ hour\ data} \qquad (1)$$

Each half hourly data point of the actual data used is then multiplied by the factor calculated in (1). Thus this ensures that the total actual data is the same as the total scaled load shift data making the two sets of data *energy neutral*.

In order to investigate the effect of a load shift on the pumping station, a proposed profile needs to be created. The proposed profile consists of two consecutive weeks (7 day profiles) of data. Firstly, a typical week of operation is logged through the portable loggers. Then, during the following week, the load shift intervention is implemented and the data is logged on the portable loggers.

To perform a load shift, the operating pumps are shifted from the evening peak period (18:00 to 20:00) to the off-peak period (00:00 to 06:00). This means pumps are switched off during the peak period and switched on during the off-peak periods. Thus the work done by the pumps is still the same in a 24-hour day, it is just shifted to another time.

The amount of electricity not used during the two hour peak period is divided into the six hour period evenly to perform the comeback load.

The proposed profile with a total potential impact of 5 MW is shown in Figure 35. This proposed profile indicates that a minimum of one pump can be operated during the peak period of 18:00 to 20:00, which was specified by the client to protect the pipeline as well as the canal. A larger load shift saving is possible due to the variant of pump sizes.

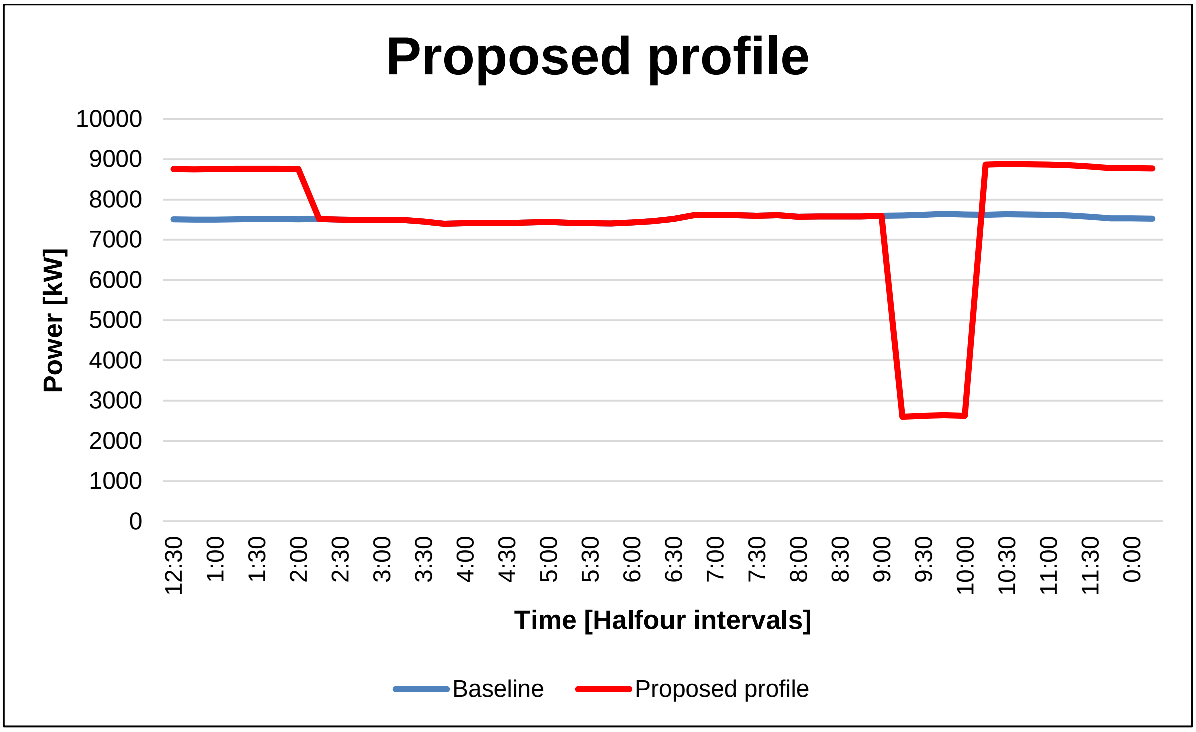

Figure 35: Proposed load shifting profile

The daily demand differs continuously, implicating that it is important to shift load as much as possible. Depending on the water demand, not every day will reflect such a load shift as observed in the proposed profile. During the weekend periods, there is no restriction on the amount of water being pumped, because the cost of electricity is at a flat rate during weekends.

Unforeseen circumstances can relate to the high demand for water where no pumps can be switched off, or a very low demand where only one or two pumps are running. Therefore it is important to achieve a sustainable average impact.

3.4 Simulation of control philosophy

3.4.1 Control strategy design

In order to design a control strategy, the following factors need to be taken into account:

- minimum and maximum operation of pumps;
- flow rates of the pumps;
- installed capacities of the pumps;
- inlet and outlet capacities of the canal;
- minimum and maximum operation levels of the inlet canal;
- minimum and maximum operation levels of balancing dam BDS2.

The following constraints listed in Table 6 were specified by the client. This will be used as the control levels in the simulation. If the water reaches a point higher than the maximum control level, each of the dams / reservoirs mentioned will overflow. If the water goes below the minimum control level, different effects will occur.

The fresh water dam will not have sufficient pressure to provide water to the inlet canal. The balancing dam and the canal will not provide sufficient flow to the system as well as not enough water will be available for the extraction methods, resulting in small pumps sucking in air. The inlet canal will cause choked flow in the pipeline causing cavitation in the pumps. It is therefore very important to simulate, and thus control, these levels correctly.

Table 6: Dam/reservoir control levels

Dam / Reservoir	**Maximum control level**	**Minimum control level**
Fresh water dam	100%	43%
Balancing dam BDS2	100%	30%
Canal	100%	30%
Inlet canal	95%	83%

The simulation that will be done, will not take the fresh water dam's control levels into account due to the size of the fresh water dam. The dam has a capacity of 3 187.56 million cubic meters. As mentioned, an annual quota of 250 million cubic meters is set out by the department of water affairs (DWA) for the canal scheme to be withdrawn. This withdrawal amounts to 12% of water.

The dam's water level has kept a level of 85% and more for the last three years [68]. This can be ascribed to the good rain the area experienced during the last couple of years. The pump station pumps directly out of the inlet canal that is gravity fed from the fresh water dam. For simulation purposes, a reservoir will be simulated as the inlet parameter of the pump station.

Indicated in Figure 36 below is a picture of the inlet canal which transfers water directly into the pumping station. Presented in Figure 37 is an illustration of where the reservoir is used for the simulation purposes. It will have the same effect as the inlet canal, due to the fact the both are controlled by a minimum and maximum set point.

Figure 36: Inlet canal to pump station

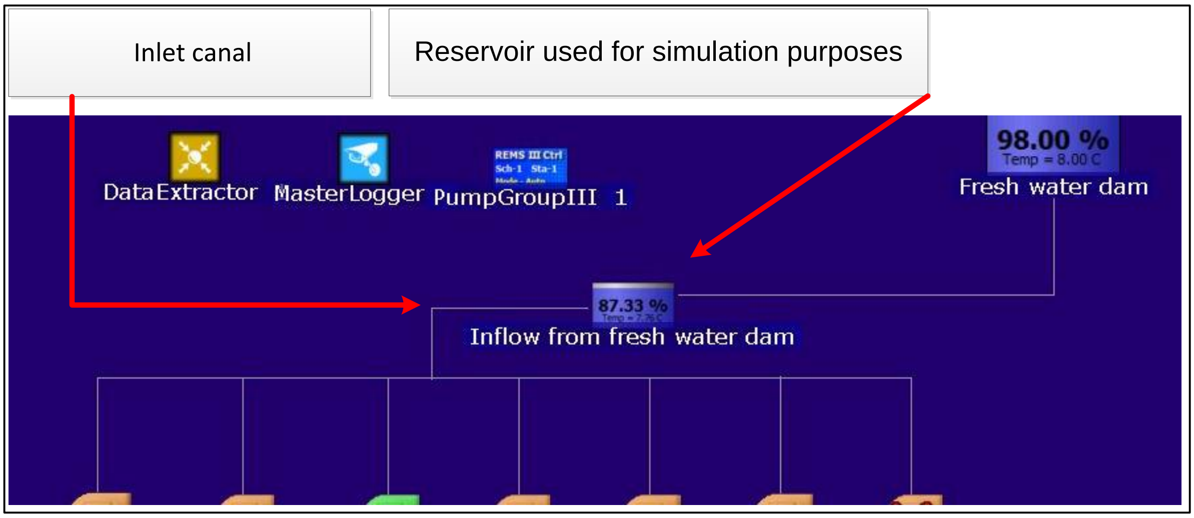

Figure 37: Screenshot of reservoir in simulation

Water pumped from the inlet canal is kept between depth levels of 2.5m and 3m. It is also converted to percentage in Table 6 above. If the level of the canal drops below 2.5m it will cause low suction on the pumps, causing pumps to trip. If the level rises above 3.2m, the canal will flood and a large quantity of water will be wasted.

Canal scheme S has several constraints that need to be considered in the simulation process. Thus the information provided can now be taken into consideration with the development and testing of the simulation model.

3.4.2 External considering factors

Other factors can also influence the result of a project other than the control set points of the canal scheme. These factors include the type of crop planted, the rainfall for this area as well as the water demand throughout the year.

In the area where canal scheme S is located, the two most common types of crops planted are wheat and maize. Other types of crops are also planted, but wheat and maize are the preferred crop planted by the farmers in this area. Each type of crop uses different amounts of water to grow up to the optimum size.

In Table 7 below the water usage efficiencies are shown for a couple of crop types. Maize and wheat have the highest water use on an area of kilogram per cubic meter. The temperatures during the summer season in this area can reach maximums of up to 40°C. Thus the evaporation rate is at its maximum resulting in a high demand for water.

Table 7: Typical water use efficiencies of several crops in South Africa (adapted from [69])

Crop	Water use Efficiency (kg/m^3)
Maize	0.8 – 1.6
Wheat	0.8 – 1.4
Seed cotton	0.4 – 0.6
Sugarcane	0.6 – 1.0

Maize and wheat require a sufficient amount of water to reach their optimum stage from where they can be harvested [70]. It is therefore necessary to ensure that sufficient water is provided to the crops during the growing period. It will not always be possible to switch off pumps and perform a load shift when the demand for water is very high.

The rainfall in this area can also have an effect on the load shift performance at canal scheme S. On average the most rain is experienced during the months of December to March. The most rain is experienced during the summer periods. In Figure 38 below, the average rainfall in the case study area is shown from 2008 to 2013.

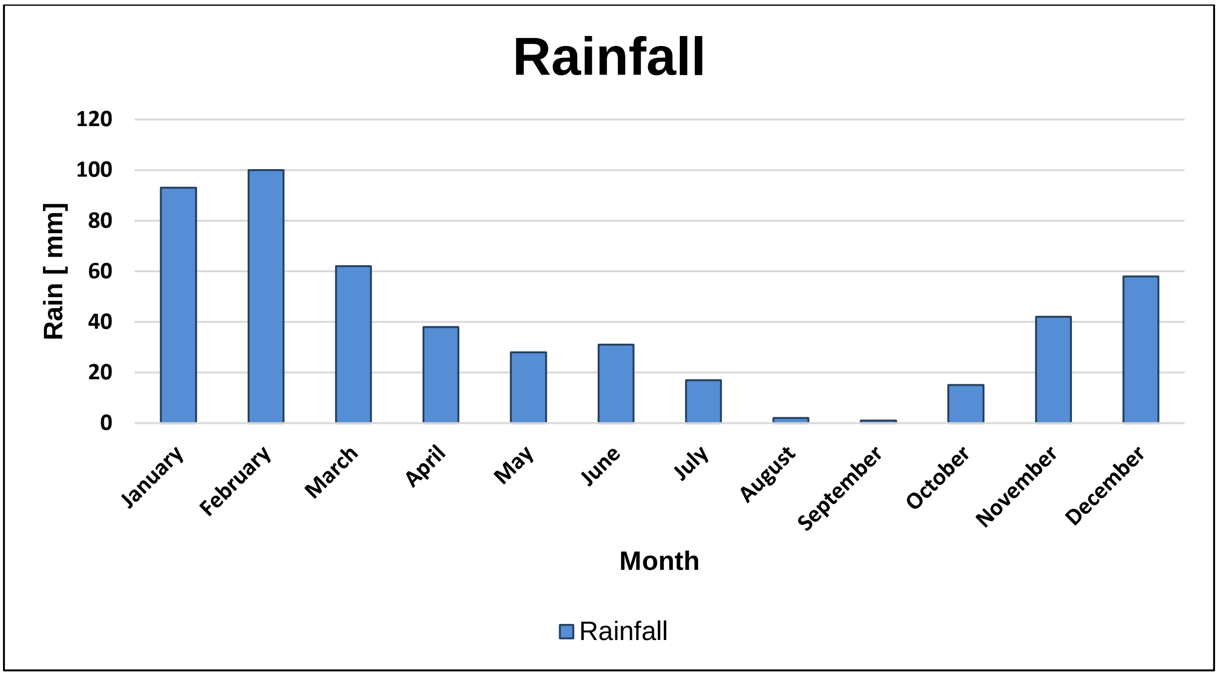

Figure 38: Average monthly rainfall data 2008 – 2013

Rainfall on such an irrigation system has a vast effect. A high demand for water is needed for the crops, but with this amount of rain experienced, the crops do not need irrigation water from the canal scheme for a certain period. This period is dependent of the evaporation rate. In return, this creates a very low demand for water for the canal scheme. The pump station is then not required to use a large amount of pumps. The power profile is so low that very little to no savings can be achieved.

Presented in Figure 39 is the rainfall data for the year 2014. The amount of rainfall measured in mm is plotted against the average rain for each month of the year. The rainfall observed can relate to the previous rain of each month in Figure 38, except for the month of November. An abnormal high amount of rain was experienced during November 2014.

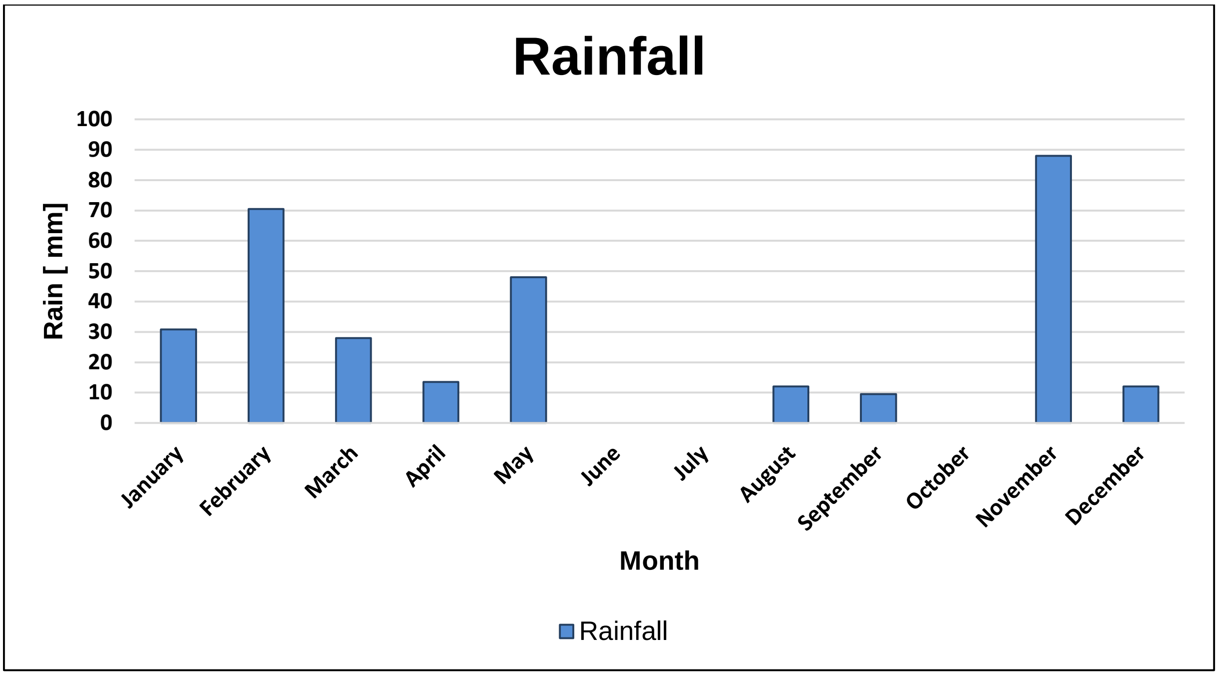

Figure 39: Average monthly rainfall data 2014

The area in which the case study is located, is a water scarce area. In the year of implementation the total annual rainfall was 312 mm. This again indicates the importance of water provision through this canal pumping scheme for the crops.

Another factor to keep in mind when constructing a simulation model, is the annual water flow demand (WFD). The WFD differs each month. In Figure 40 the annual WFD is indicated for canal scheme S. The WFD is plotted on each month of the year on the x-axis against the required water flow measured in m^3/s on the y-axis.

It can be clearly observed that the WFD is very low during the winter season and increases dramatically during the summer season. The fluctuation in the water flow directly influences the power usage of the pump station at canal scheme S. If the WFD is low, fewer pumps will be required to operate and vice versa.

The demand for water that fluctuates throughout the year as illustrated in Figure 40, is due to different reasons. The annual rainfall has an effect because the amount of rain experienced is a substantial amount in a certain time such as a day, week or month. This dramatically changes the WFD to the consumer. Another factor is the type of crop planted in a specific season of the year. Each crop requires a certain amount of water for optimal growth as discussed. The season the crop grows in also has its own temperature variations that directly affects the evaporation rate of the water.

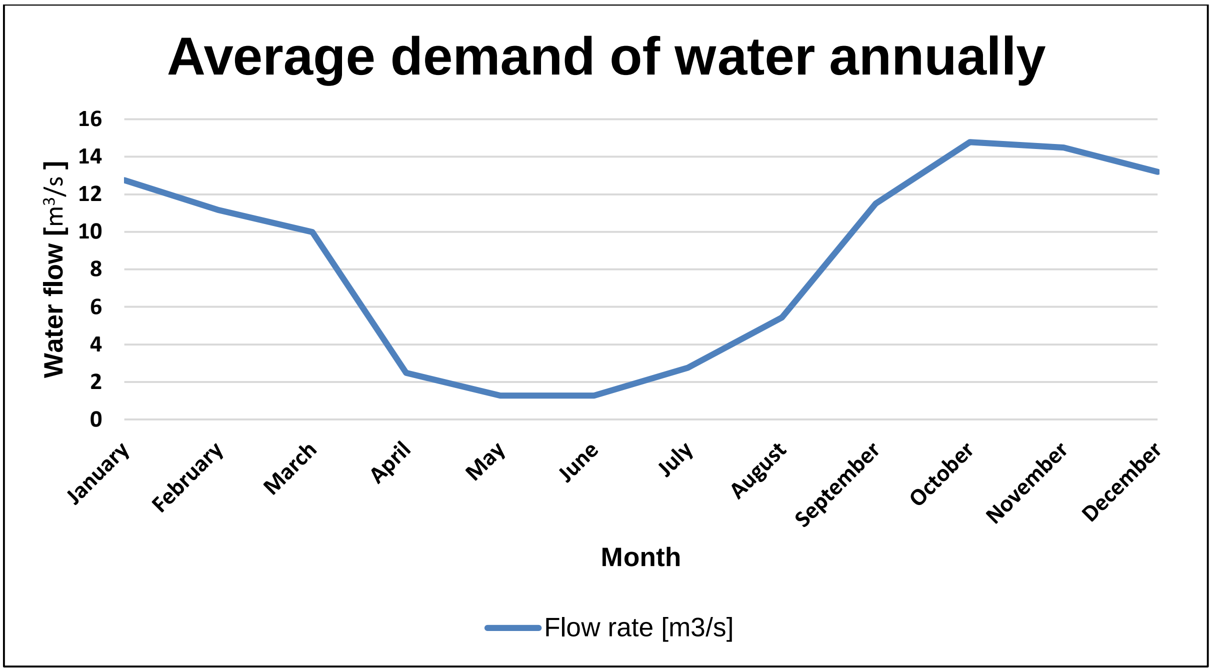

Figure 40: Annual water demand on canal scheme S

The amount of savings achieved each month will fluctuate as well. It is therefore necessary to take the effect of the WFD into consideration when selecting a target load shift saving for canal scheme S. The seasonal rainfall effect and crop type planted also need to be taken into account in the selection of the target.

3.4.3 Simulation

Taking all the factors and constraints of canal scheme S into consideration, firstly a period in the seasonal WFD must be chosen to be simulated. If the focus is only on a certain part of the season where the WFD is within a specified range calculated from historic data, a more accurate simulation can be done. The period chosen is in the last trimester of the year, namely September to December. During this time, the WFD increases, moderate rain is experienced and new crops are planted which initiate the increase in the WFD.

An EnMS will be used for simulation purposes. The EnMS package used for simulation purposes, has been used in previous studies and proved to be a viable system to use [57]. The system is able to simulate in real-time. This function is also accommodated with a second per interval control, enabling the option of simulating actual conditions of week to week scenarios. The layout in Figure 41 will be used to simulate the pump station.

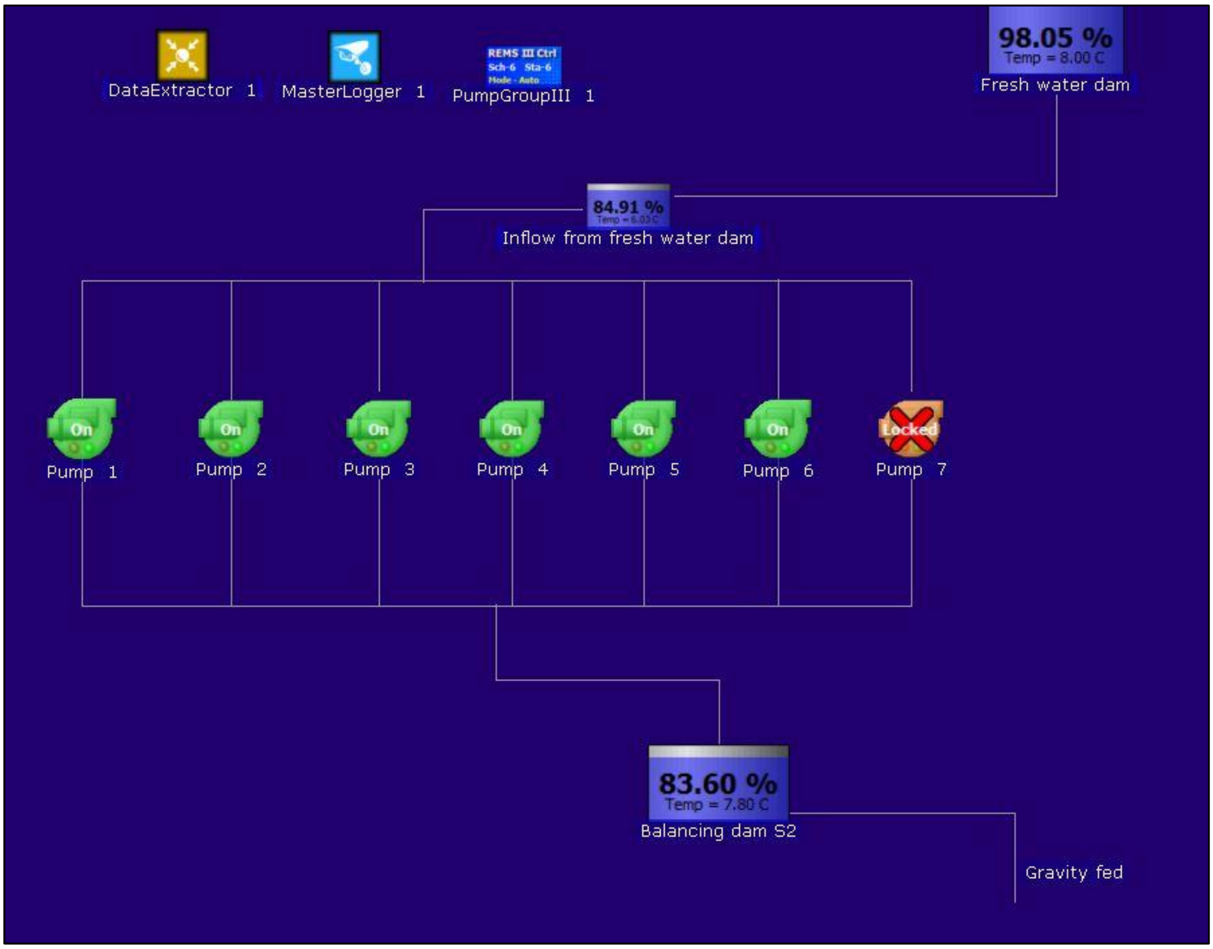

Figure 41: EnMS layout

As illustrated in Figure 41, Pump 7 is locked and will not be used in the simulation. This is due to the fact that it acts as a backup pump. The length of the canal, which stretches from the outlet at the pump station to BDS2, causes water to take approximately 24-hours to reach BDS2. The capacity of BDS2, when converted to time, relates to approximately 24-hours. The time that it takes to reach the BDS2, and the capacity converted to time, are roughly the same and an assumption is made that these two aspects cancel each other out. Therefore, these times will not be taken into consideration in the simulation.

After the simulation in the EnMS was allowed to operate for a certain time to result in real-time data for a four month period, the power usage data was analysed to construct a proposed profile. The power usage from the peak demand period to the off-peak demand period was analysed in the simulation.

During this simulation period, it was found that it is possible to do a load shift with the constraints given. The average weekday power usage profile for four months is plotted against the baseline profile which was scaled *energy neutral* in relation to the power usage profile. The power usage profile is plotted in red and the scaled baseline in blue.

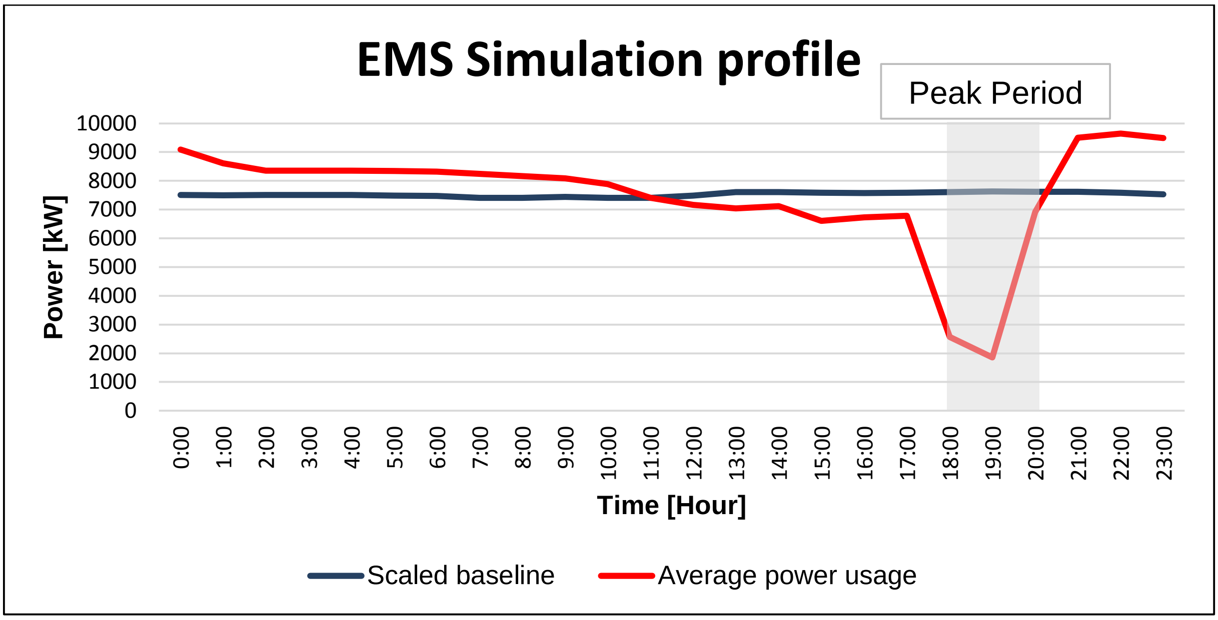

Figure 42: EnMS Simulation profile

Presented in Figure 42, it is possible to achieve the comeback load needed to ensure enough water is pumped during the off-peak period. The power usage is below the maximum capacity of 10 MW.

A saving of 5.4 MW is achievable from the simulation done. Note that this saving is possible for the period in the last third of the year. The upstream dam levels were also simulated to ensure that they stay in the control levels set out in this dissertation.

Figure 43 indicates the upstream level as well as the maximum and minimum control levels. The upstream dam level is plotted in blue, the maximum control level in red and the minimum control level in black. It is observed that the level during the simulation was well within the parameters.

This ensures that load shift will not have a negative effect on the operating level of the inlet canal. The five days as illustrated in Figure 43, are the weekday averages of the 3 month simulation period.

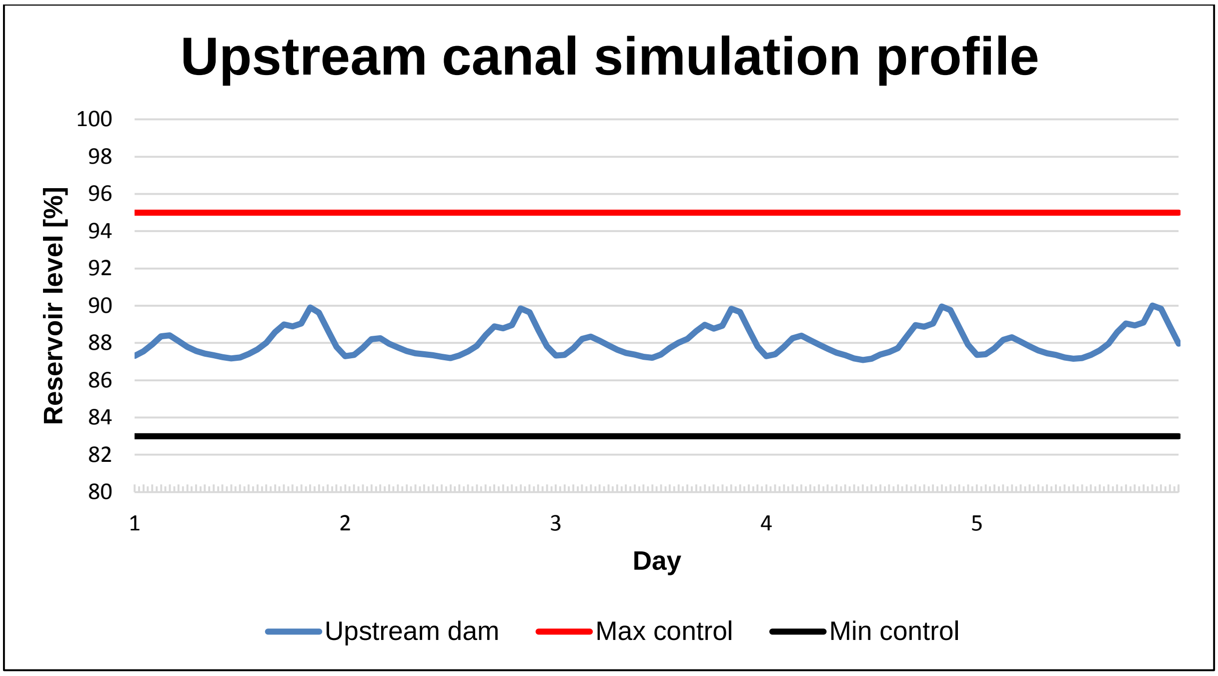

Figure 43: Upstream reservoir level simulation result

The results discussed indicated that it was all within the constraints selected for the simulation model. In order to verify if the simulation model was done successfully and within the parameters, a drop test is required.

3.5 Control philosophy verification

The next step is to verify if the simulation model is viable. A basic drop test was done to verify the simulation model. A drop test is where data is logged for a normal operation week where simulation DSM methodology is implemented on site to verify the results found in the simulation. Any unforeseen technical issues that were not included in the simulation model, should arise in the drop test.

In order to initiate the test, the personnel at the pump station need to be notified in advance. They must ensure that the canal and reservoir levels are in the required control parameters. The drop test was done in a typical week of operation during the summer season.

Presented in Figure 44 below are the results obtained from the drop test. Every weekday is plotted in Figure 44 on a 24-hour profile against the power measured in kW used. It was possible to do a load shift every day of the five weekday period.

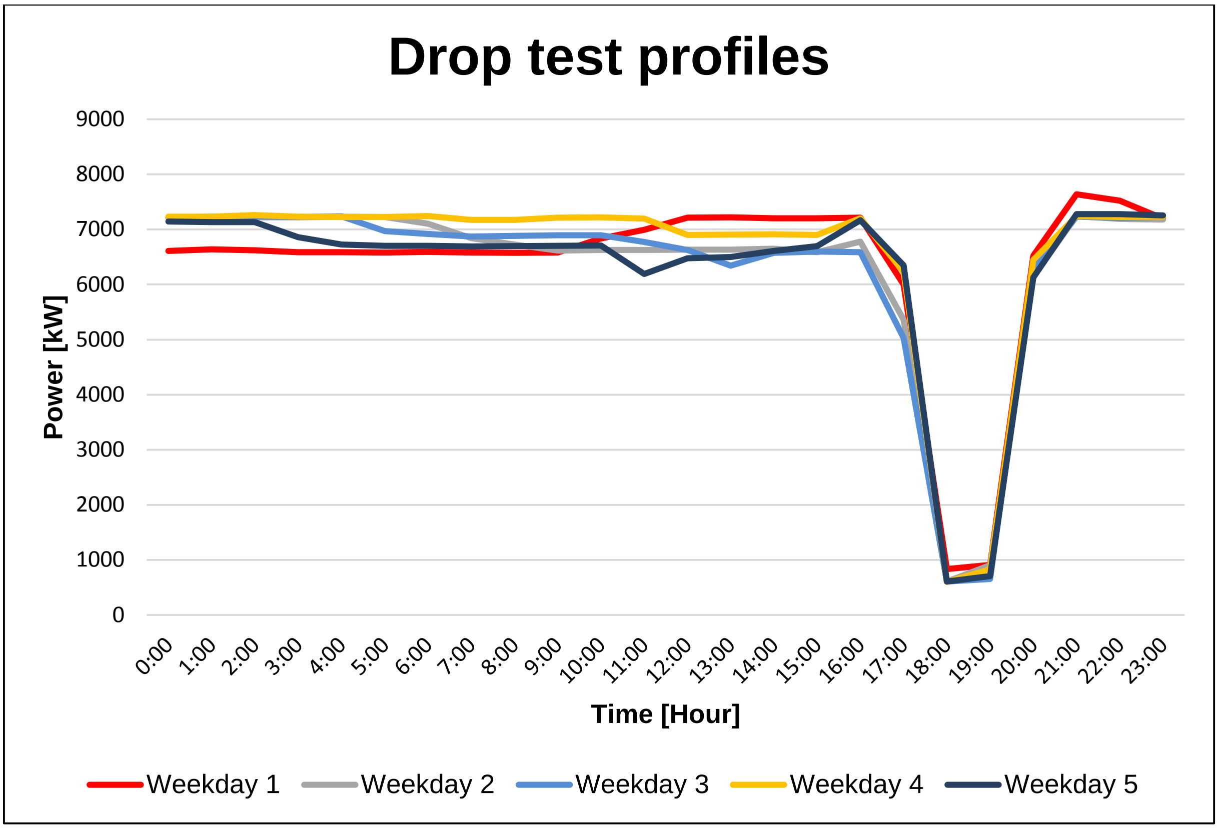

Figure 44: Weekday drop test results

Due to the variations of pump sizes at the pump station, the profiles for each weekday differ from one another. The power usage profile of each weekday also differs from another weekday because of the different water demands set out for each day. Overall, good load shifting was achieved every day of the week during this drop test period.

In Figure 45 below a saving of 5.6 MW was achieved. It is 4% higher than the 5.4 MW estimated by the simulation model. The difference in results is due to the variation in pump sizes as well as the demand flow for the two different periods. During the drop test period, another combination of pumps was used, different to those of the simulation model. The demand water flow differs as well.

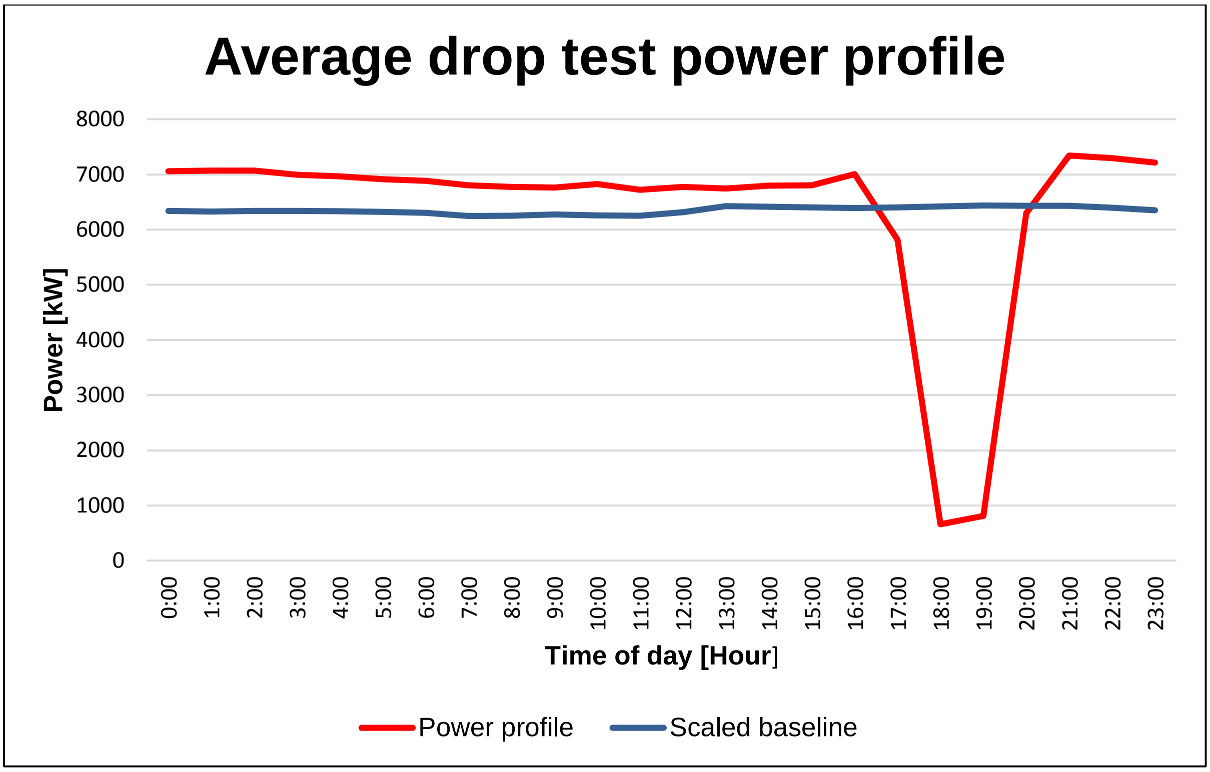

Figure 45: Average drop test power profile result

During the drop test, the inlet canal level was monitored. Telemetry is installed at the inlet of the pump station to monitor the level. The upstream canal drop test profile is shown in Figure 46 below. It can be observed that the level stays within the control parameters. After the load shift is done, more water needs to be pumped to ensure enough flow for the comeback load.

The inlet canal level does not exceed the parameters set, although it takes a couple of hours for the water to reach the pump station down the 13.6 km canal. The variation in the days is due to different water quantities needed by the end users. The inlet level is plotted in the blue colour over a five day weekday period. The maximum control level is plotted in red and the minimum control level in black.

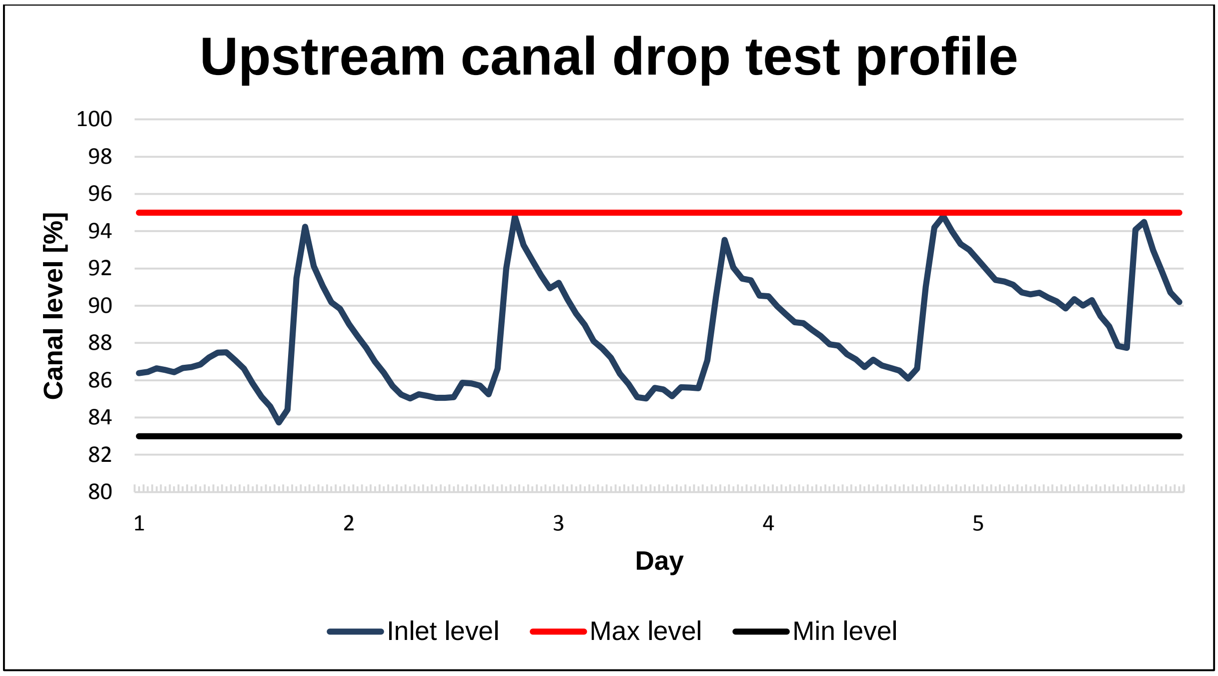

Figure 46: Inlet canal drop test result

From the drop test done, it is possible to do a successful load shift with the simulation model at hand. The upstream canal fluctuates just within the parameters and the comeback load is below the pump station's maximum capacity.

Results from the simulation and verification of the simulation indicate that it was successful. If the simulation is applied to the other periods of the year, the effect will be the same, but the load shift saving results will differ.

If the simulation results are extrapolated to the WFD profile, which is based on historic data, a trend can be realised. This trend can then be used as a baseline from where results can be obtained. By using this method, a more realistic target can be set to achieve in the performance assessment period and thereafter on canal scheme S.

Presented in Figure 47 is the average achievable peak period power reduction in relation to the demand for water flow required. The profile plotted is the water flow on the x-axis measured in m^3/s against the savings on the y-axis measured in MW. The savings increase in relation to the increase of the demand, but only to a certain point. From there on the savings decrease dramatically. This is due to the high demand for water that results in no pumps being able to be switched off. Water is needed urgently and cannot be delayed.

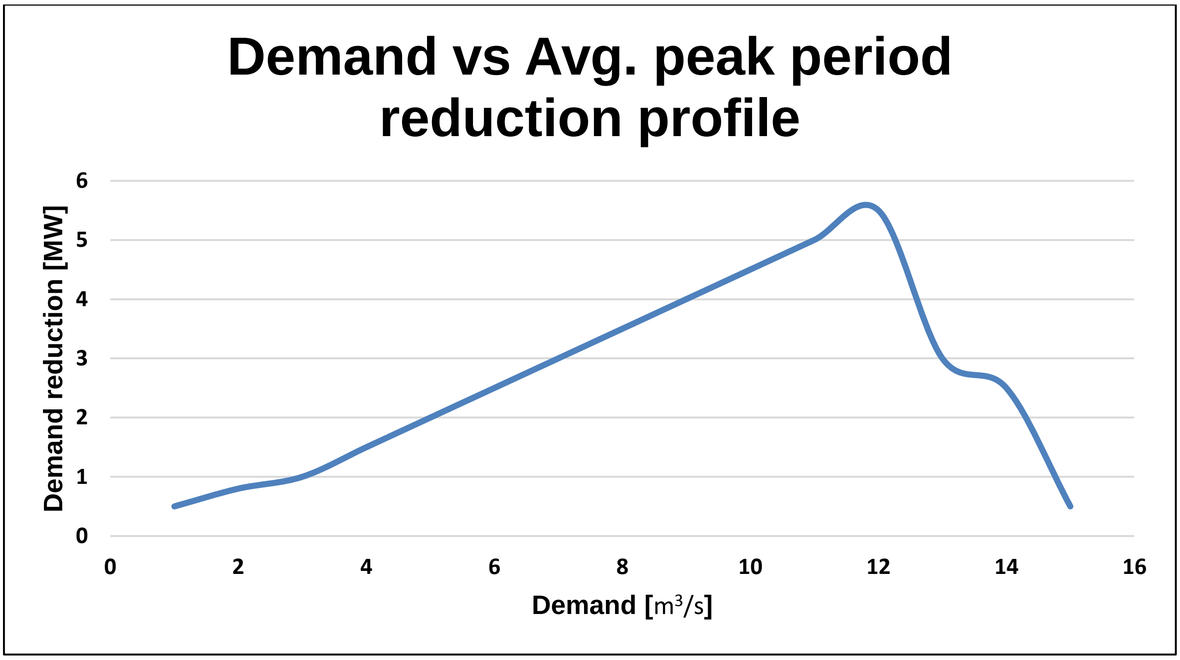

Figure 47: Saving results according to the water flow

Now that the average peak period power reduction is defined over the demand for water, it can be quantified in relation to Figure 40. Illustrated in Figure 48, is the quantified results of the simulation profile. The blue line indicates the peak period reduction saving calculated in MW over each month of a year. It can be noted that the peak period reduction varies with the WFD. The red line indicates the average profile that can be achieved for the year.

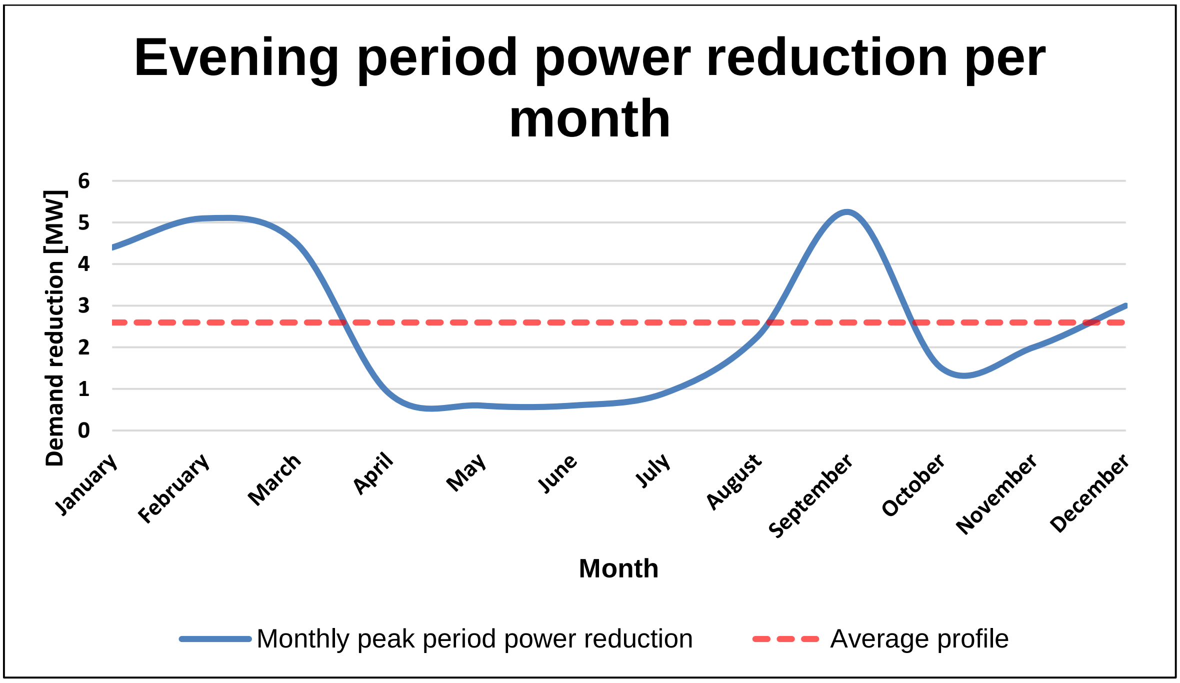

Figure 48: Evening period power reduction possible per month

Taking the findings into consideration, an average evening peak reduction of 2.6 MW is set to be achieved at canal scheme S. The target is calculated using the annual saving possible and taking the average thereof. Thus the target is able to be achieved throughout the year.

From the results shown, it is thus possible to apply the simulation to any season or period of a year. This indicates that it is viable to apply the load shift intervention on canal scheme S.

3.6 Conclusion

In Chapter 3 the investigation of the chosen case study was discussed in more detail. The constraints and operations of the canal pumping scheme were identified and discussed. Portable loggers were installed to identify a baseline. The development of a DSM methodology on a large scale canal pumping scheme was developed.

External factors which can influence the outcome of the simulation were also discussed. It was taken into consideration and a simulation was done on a specified period in the year.

The simulation conducted resulted in a demand reduction of 5.4 MW. The drop test average profile of the five weekdays showed a demand reduction of 5.6 MW and a definite validation of the simulation model. During this test period, the comeback load was below the indicated maximum capacity and the inlet canal level was kept between the defined operation parameters.

A target of 3 MW is set to be achieved in the performance assessment period of canal scheme S. The target is lower than the simulation results, which reflects an average annual load shift intervention saving.

The control philosophy reflects a load shift during the evening peak period including all the constraints provided. The control philosophy proved to be viable on canal scheme S.

CHAPTER 4 - Results

Chapter 4 discusses the implementation of the control philosophy on canal scheme S. The performance assessment period, impact of the study as well as the potential for further optimisation are also discussed.

4.1 Introduction

After the DSM methodology was developed, tested and simulated in Chapter 3, it is implemented in Chapter 4. The results of this implementation are also discussed which is known as the performance assessment period.

The Measurement and Verification teams' roles are briefly discussed. The impact of implementing this strategy on the chosen case study is discussed. Realising what the most effective scaling method is, better and more savings are possible.

4.2 Implementation

After a successful simulation and verification of the DSM methodology, it is now possible to be implemented on the canal scheme S. The load shift will be done with the implementation of the control philosophy on the canal pumping scheme via the EnMS.

4.2.1 Pump station

The EnMS can stop and start pumps. The pumps in operation will not be stopped and started by the EnMS. This will be done manually by the operators due to the complexity of the system, although the EnMS will only recommend the stopping and starting of pumps.

The main priority for load shifting is to shift the load from the peak period (18:00 to 20:00) to the off-peak period (22:00 to 05:00). If it is not possible to put the load back in the system during the off-peak period, it may be done during the standard tariff period.

Pumps 1 to 6 are used to pump, where Pump 7 acts as a backup pump. All the pumps need a 10 minute interval between each other when switched on or off. The EnMS calculates the time intervals that the pumps need to be switched off, in order that only one pump is operating from 18:00 to 20:00.

It is not possible to stop and start the pumps from the SCADA system. This needs to be done at the Human Machine Interface (HMI) located close to the pumps. This ensures that the operators check the conditions of each pump before starting it. This creates a safe environment through visually observing that no one is near the pumps. It also enhances the pump's operation life through ensuring the oil levels are correct, valves are in the correct positions, etc.

4.2.2 EnMS system

The EnMS calculates how much time is needed before 18:00 and starts recommending to switch off the pumps. Due to the complexity of the pumping system, the EnMS will not be doing automated control. Rather, an operating schedule will be recommended to the operators who will switch the pumps on and off from the HMI control. During the implementation of the control philosophy, the philosophy was updated according to any problems encountered. This ensured the most effective implementation of the control philosophy.

The EnMS is the chosen control system to be used. The EnMS communicates with the SCADA system through an Object Linking & Embedding (OLE) for Process Control (OPC). This enables the capability of the EnMS to operate the pumps automatically. As previously mentioned, the EnMS will only recommend the most efficient control to the operators. The EnMS is also capable of displaying alarms to assist the operators in effective control of the pumps. Another function of the EMS is to log the operation data.

A simplified layout of the canal pumping scheme used for the EnMS is shown in Figure 49. The EnMS has a pump controller function, enabling it to program according to the specified DSM methodology with all the constraints. It is also possible to program the EnMS to recommend the most efficient pump to use during load shifting. Note that again this will only be a recommendation and not be specifically used due to the change of the water flow required.

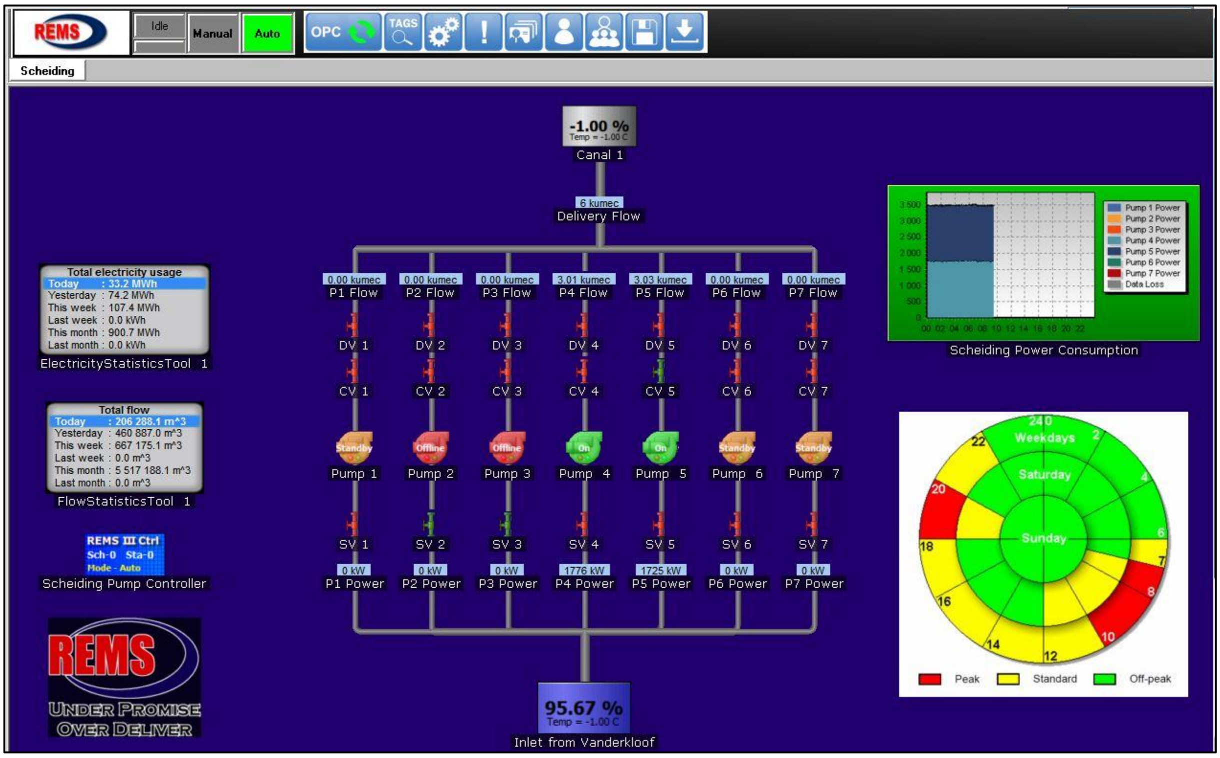

Figure 49: EnMS layout used at canal scheme S

The EnMS has different advantages if used to automatically control the pump operations:

- selecting the most efficient pumps to operate;
- more sustainable load shift profiles due to no human interference;
- better and more efficient starting and stopping of desired pumps;
- safer and more sustainable pump operation.

The EnMS can also cause disadvantages such as:

- when incorrect lockout of pumps are done and maintenance is under way, it could start a pump causing serious damage;
- operators need training in new system;
- if a network failure occurs the EnMS will not be able to control the pumps;
- different complex algorithms need to be programmed to provide total automatic control and alarm the operators when a system is malfunctioning or close to an operating parameter.

The EnMS provides a big advantage to the canal pumping scheme in terms of better control and easier observation in terms of reporting to the plant managers. The EnMS also acts as a logging system to ensure feasible data for further research and better control.

The EnMS has a password protected option to secure the programming and keeping it out of reach of unwanted authorisation. A lockout procedure is defined to ensure that it is done correctly. If done incorrectly or if the procedure is incomplete, it can have serious repercussions for both man and machine.

4.2.3 Implementation delays

During the installation period, a problem was detected with the flow meters. It was determined that the specific flow meter used for such an irrigation canal pumping scheme was not sufficient.

There are large variety of flow monitor technologies available on the market. The most common used flow meter for such an application is an ultrasonic flow meter presented in Figure 50. These flow meters are accurate and reliable.

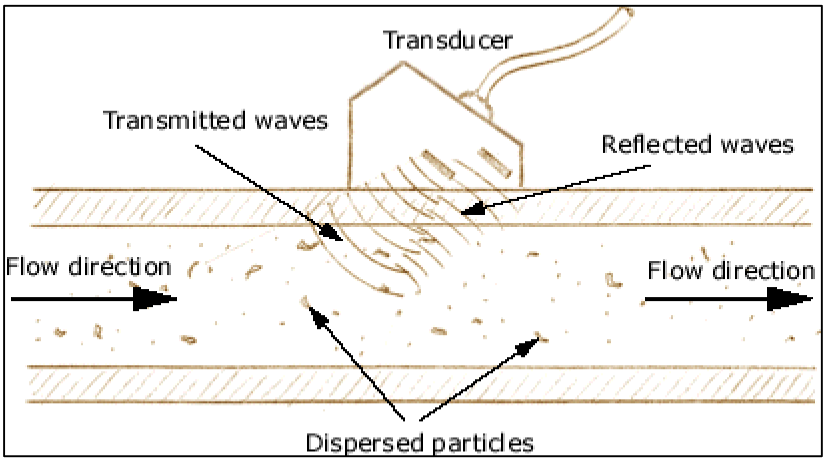

Figure 50: Ultrasonic flow meter

In Figure 50 an example is shown of how an ultrasonic flow meter works. It transmits a wave that then reflects from a solid particle in the water back to the flow meter. Thus the signal distorts in the direction of flow, the amount of distortion is then converted into flowrate. With such a flow meter it is possible to determine the cubic flow per meter going through a pipe. These particles in the water are known as the total dissolved solids (TDS) in water.

The problem encountered with the flow sensors was that it did not show any flow when it was tested. This was due to the fact that the water did not have enough TDS per cubic meter to distort the wave transmitted, meaning that the water was too clean to measure. The application of this water is only used for irrigation purposes. The water does not need to go through a water treatment for human consumption at this stage of water distribution.

Thus the assumption was made that the water will have enough TDS per cubic meter, and the appropriate flow meters were then chosen upon the TDS range of a water sample taken to ensure correct operation.

During the completion of installations and moving to the implementation phase, the power factor correction switchgear failed. More specifically a vacuum circuit breaker (VCB) failed. This happened due to aging infrastructure. The damaged equipment was then replaced, delaying the implementation phase once again.

4.3 Performance assessment

As part of the total bill of quantities of infrastructure installed, monitoring equipment forms part of it. This offers the capability to log important data such as the power usage, etc. All the relevant data is then sent from the EnMS via GSM networks to a local database. Data is sent daily after midnight ensuring a full 24-hour cycle of data for each day.

This data is then automatically processed through pre-set algorithms to generate a daily report with all the relevant data such as the power consumption. The daily report can be customised as needed. The report is then sent to all relevant personnel on a daily basis. An example of the power consumption graph included in the daily report, is presented in Figure 51 below.

The baseline, optimised baseline, as well as the actual profile for the specified period are plotted on the graph. It is plotted over a 24-hour daily profile against the power used which is measured in kW.

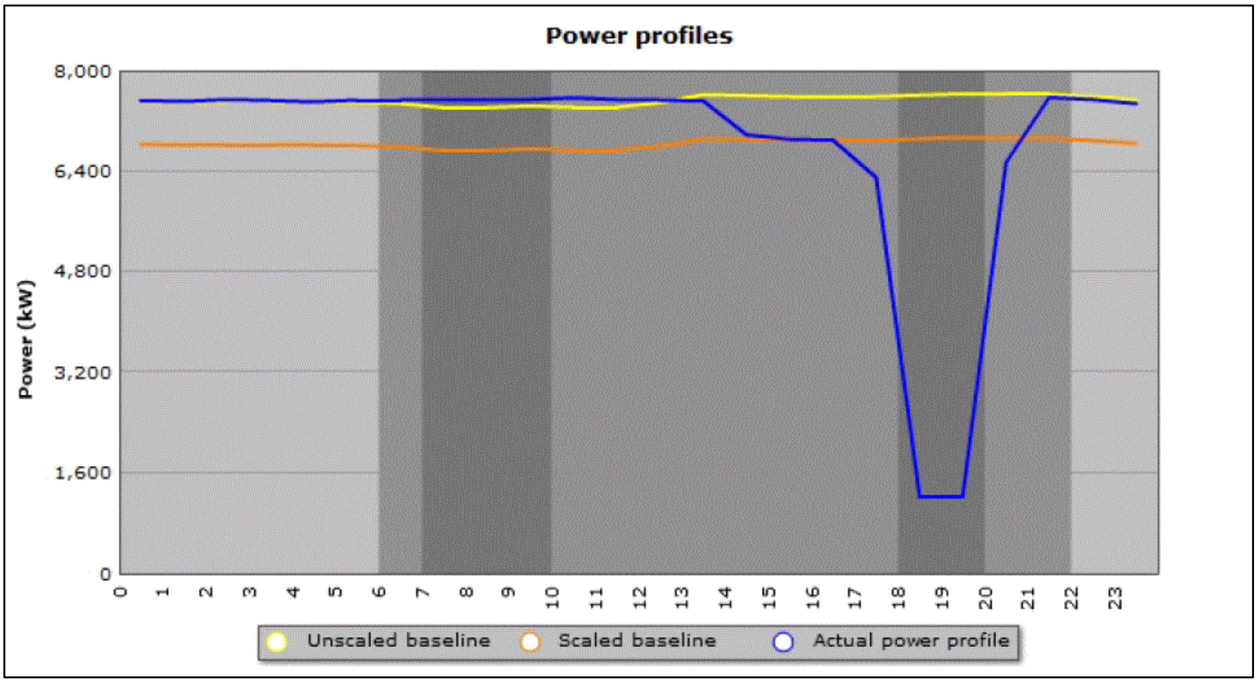

Figure 51: Daily power profile used in daily report

In order to ensure that data is logged at all times, other backup systems need to be in place if the monitoring system or the EnMS fails. Portable loggers such as those mentioned, are used for the baseline verification and calculation is used. Another solution is to use the log sheets kept at the pumping station itself. Both these methods will need to be imported manually into the algorithm programming to be analysed and reported.

After the implementation took place, as well as getting the monitoring system in place for daily feedback, the performance period was initiated. The performance assessment period is where an independent measurement and verification team evaluate the performance of the implementation done by the ESCo. This period usually consists of a 3 month performance assessment with an optional 4th month. The 4th month can be used if one of the 3 months is identified as a condonable month. A condonable month is identified by the M&V team if there are too many condonable days in that specified month [71].

A condonable day can be defined as a day where the savings or performance for that day cannot be taken into account for the performance period due to one of the following implications:

- communication failure;
- SCADA network failure;
- PLC failure;
- breakdowns;

- equipment maintenance;
- dry week;
- very high water demand.

The achieved savings for the performance assessment from September to November are summarised below in Table 8:

Table 8: Performance assessment savings

Month	Saving (MW)
September	5.20
October	5.47
November	3.34
Average	**4.67**

Excellent savings were achieved during the first two months of performance assessment, September and October. In the last month of performance assessment, November month resulted in lower savings.

This was due to the higher amount of rain experienced during this month which resulted in a lower water demand. On average, an impact of 4.67 MW was achieved during the performance assessment period as shown in Table 8.

The independent M&V team published the monthly performance assessment reports for the assessment period. In these reports all the results that were achieved are shown. These reports are certified and verified by the M&V team.

All relevant parties also sign the documents as proof of agreement on these published documents. The weekday performance assessment profiles of the respective months are shown in Figure 52, Figure 53 and Figure 54.

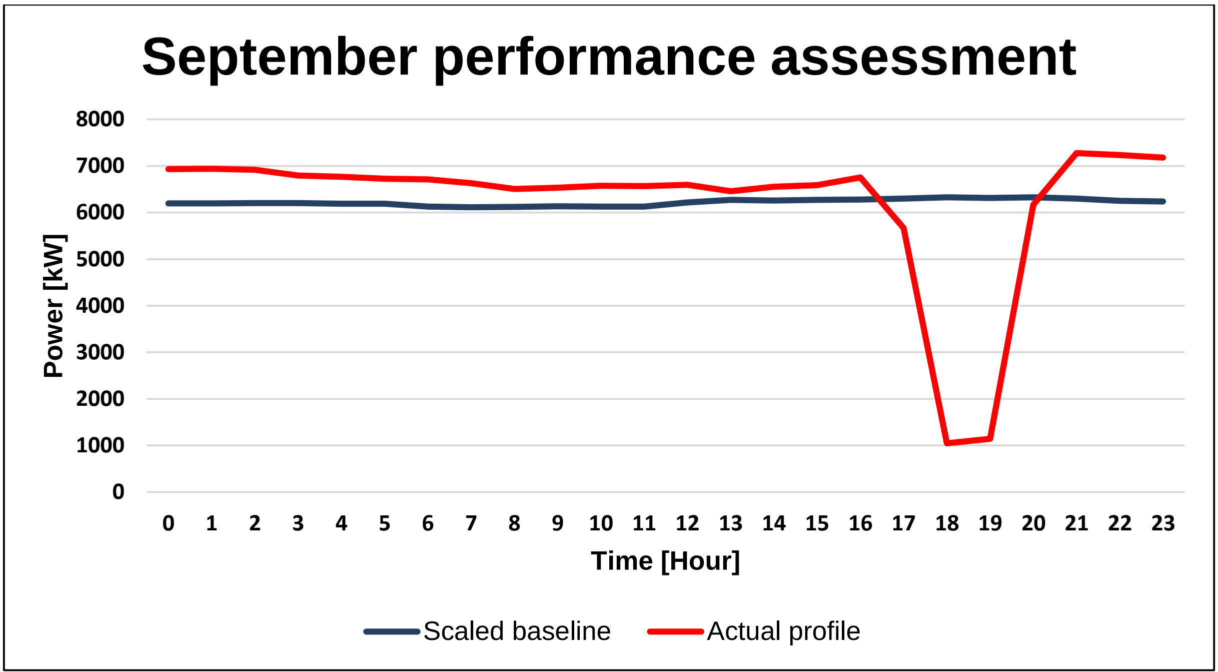

Figure 52: September performance assessment result

During the month of September, evening peak demand reduction of 5.2 MW were achieved. The red line indicates the actual profile achieved and it is plotted against the scaled baseline in blue. The savings achieved can be ascribed to a sufficient demand for water and good cooperation from the personnel of canal scheme S.

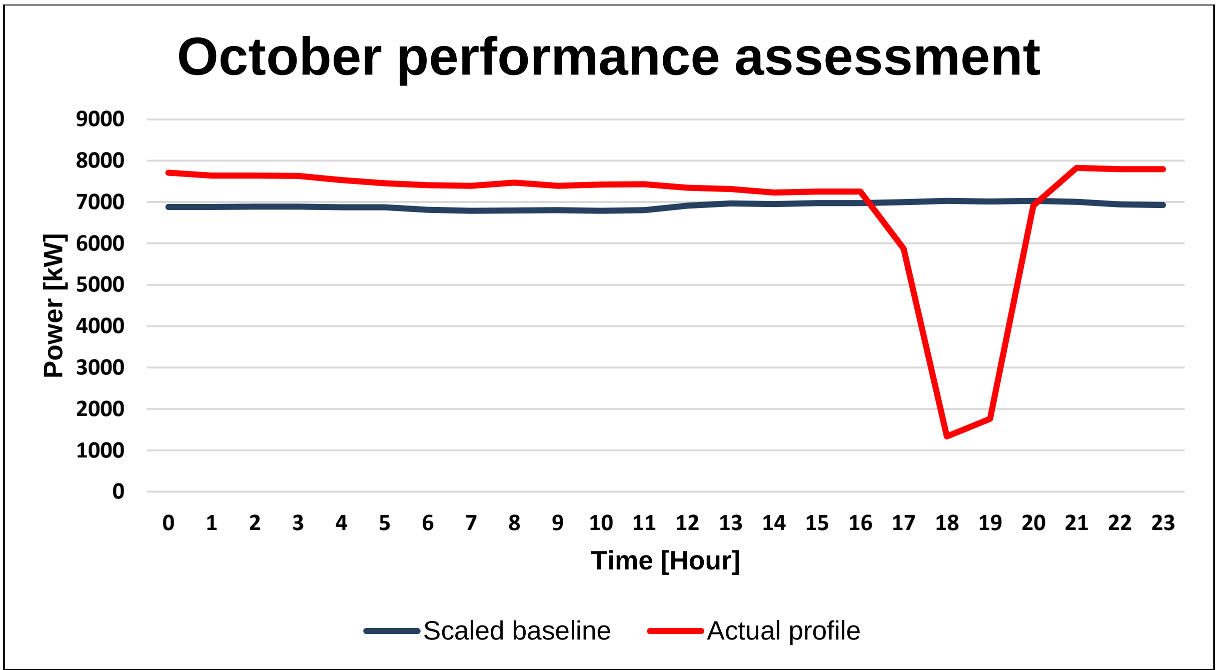

Figure 53: October performance assessment result

During the month of October, evening demand reduction of 5.47 MW were achieved. The red line indicates the actual profile achieved and it is plotted against the scaled baseline in blue. The evening peak demand reduction achieved can be ascribed to a sufficient demand for water and good cooperation from the personnel of canal scheme S.

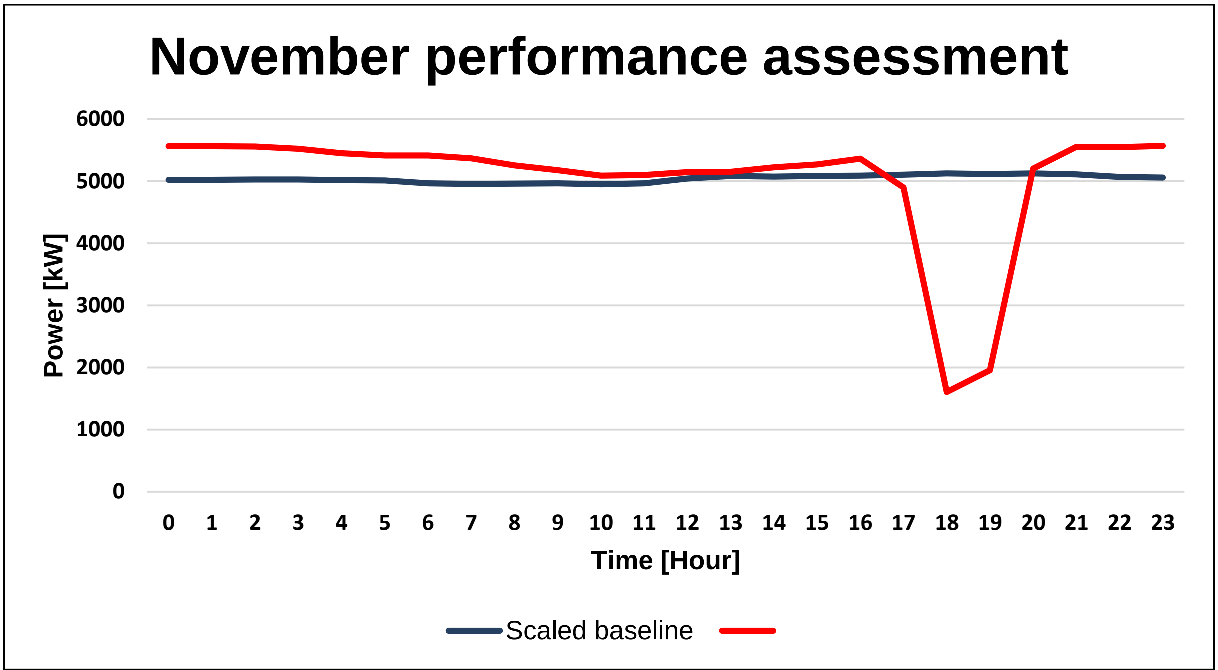

Figure 54: November performance assessment result

During the month of November, an evening demand reduction of 3.34 MW were achieved. The red line indicates the actual profile achieved and it is plotted against the scaled baseline in blue. Less, but still an acceptable amount of savings was achieved during the month of November. The drop in savings is due to the high amount of rain in the area, which can be observed in Figure 39.

Each actual power profile result from the three performance assessment periods is presented in Figure 55. The power usage for the last month is much lower in comparison to the other months. This can be ascribed to the amount of rain experienced during the month of November. This lowered the demand for water and resulted in fewer pumps being operated.

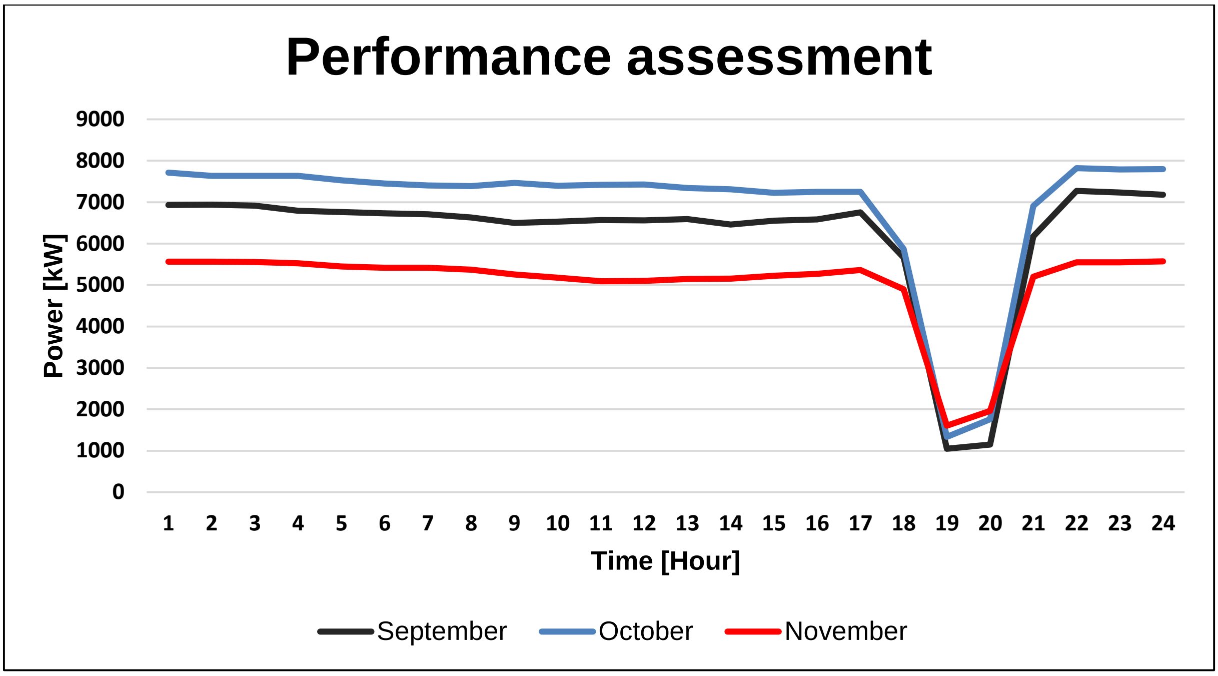

Figure 55: Performance assessment comparison

From Figure 55 it can be observed that a load shift was possible in every month of the performance assessment period. This was possible despite the fluctuation of the water demand each month. The personnel from canal scheme S followed the recommendations reported by the EnMS to achieve load shift profiles.

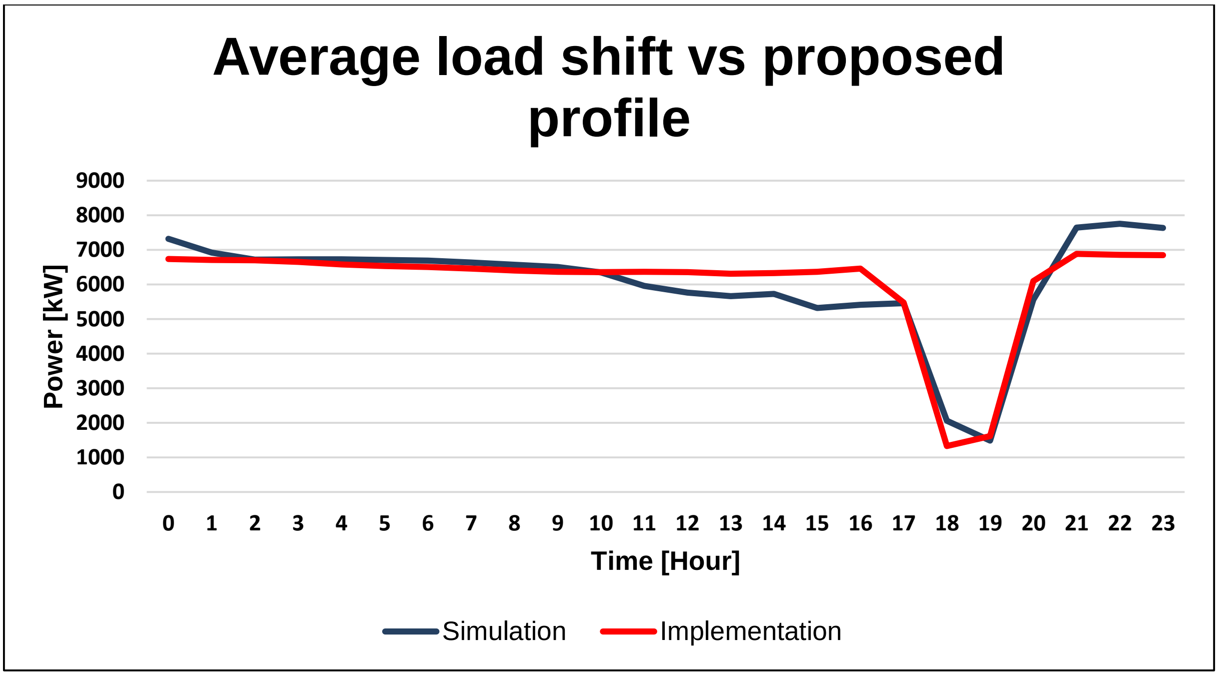

Figure 56: Average savings profile

The average performance assessment period profile for the combined three month period is plotted against the proposed profile in Figure 56. Both profiles were scaled *energy neutral* in relation to each other.

The actual profile's comeback load is distributed throughout the rest of the day and not just during the off peak period as in the proposed profile. The reason for that is due to the high demand for water. The balancing dam's level needs to be kept between the control levels and water is drawn from the balancing dam throughout the day to ensure optimal growth for the crops. An annual cost saving resulted in a total of R 3.2-million using 2014/2015 Eskom tariffs.

4.4 Impact of this study

From the results obtained in the performance assessment period, the implementation of the DSM methodology deemed to be successful.

Several benefits were observed during the implementation of the load shift initiative at the canal pumping scheme which included:

- improved infrastructure;
- improved maintenance;
- better personnel decision making;
- more effective pump station control;
- improved energy usage awareness;
- improved energy savings; and
- improved knowledge in terms of power consumption.

The external factors mentioned played a big role in the result of the performance achieved. These external factors include:

- water supply;
- water demand;
- seasonal rainfall;
- temperature and humidity; and
- sowing and harvesting of crops yearly timeline.

With the external factors kept in mind, the implementation of the DSM methodology resulted in an over achievement of 55% from the target set for canal scheme S.

The seasonal rainfall was experienced from November and onwards, which resulted in excellent load shift savings during the first two months of performance assessment. This was much higher than expected from the simulated results as well.

4.5 Potential for further optimisation

After completion of the implementation phase of this study, it was realised that further cost savings are possible. If the same strategy that was used during the evening period be implemented on the morning peak period, additional savings can be realised.

The only focus for this study was the load shift during the evening peak period. Eskom's generation capacity falls short during the evening peak due to the high demand for electricity. This is why the focus of the ESCo is to only reduce the evening load peak.

Due to the long delay of the water transferred, certain adjustments will be needed on the control philosophy used. The demand for water during the warmest time of day will also need to be taken into account. A proposed profile is shown below in Figure 57 to illustrate more savings achievable at canal scheme S.

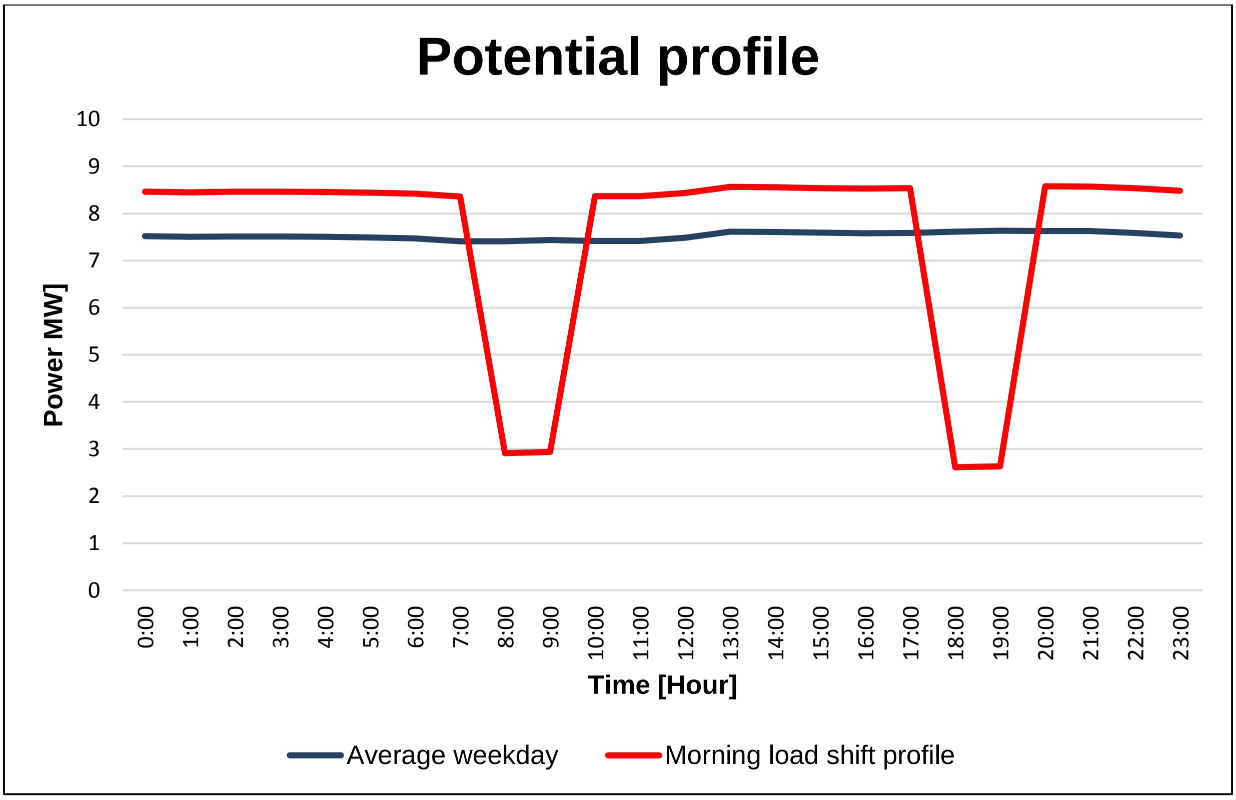

Figure 57: Potential profile

The morning load shift profile indicates an added morning peak reduction of 4.5 MW. This morning peak load reduction will not only benefit Eskom, but also the client. The total load reduction for the morning and evening peak periods will result in 9.5 MW of power savings. The comeback load is implemented throughout the day and not just in the off-peak period as in the case study implemented. The comeback load will be possible due to the fact that the total power usage will be below the 10 MW constraint.

4.6 Conclusion

In Chapter 4 the implementation of the load shift project was discussed. Time delays were also discussed in the chapter. During the performance assessment period savings of 4.67 MW were realised. This was 55% more than the 3 MW target which was set.

It was determined in the impact of the study done that it would be possible to achieve the target savings. The external factors which had the biggest impact on the outcome of the project were discussed and considered throughout the implementation of the study. Several other benefits were also realised in the impact of the study.

Even more savings are possible when further optimisation is done. An additional morning load reduction of 4.5 MW is possible when implementing a morning load reduction as well. During the implementation and conclusion of this project, delays were experienced and constraints were identified. Other hidden benefits were also discussed as well as further power savings for the canal pumping scheme.

CHAPTER 5 - Conclusion and recommendations

Chapter 5 concludes the study and recommendations for further study are discussed.

5.1 Conclusion

In this dissertation it has been determined that the demand for electricity is exceeding the generation capacity of Eskom. It is known that in South Africa the annual precipitation is very uneven. The distribution of water is therefore necessary for the economy of South Africa as well as food security.

Therefore, water needs to be pumped over vast distances to provide water in the needs for agricultural purposes. These water transfer schemes require high flow rates to function effectively. Parallel with these requirements, the equipment used is energy intensive.

DSM interventions, more specifically load shifting interventions, have already been implemented on various pumping systems and have proven to be highly effective. The implementation of load shifting interventions has long term financial implications as well as responsibilities for the client and Eskom. Therefore, it is important to ensure that load shifting results are kept sustainable throughout the lifetime of the DSM project.

It was found viable to implement a load shift intervention on a large scale canal pumping scheme. Shifting the load out of the evening peak period to the off peak period proved to result in sufficient evening load reduction without compromising the water supply target. The need for an EnMS was identified to recommend a schedule for pump control.

An in-depth investigation was conducted on canal scheme S to determine the operating parameters, system variables as well as constraints. The different elements which were important to consider were discussed. Portable loggers were installed to determine the basic electricity usage of the pumping station. After the calculations were completed, a weekday baseline for load shifting during the evening peak period of 3 MW was proposed.

A simulation model was built to determine the effect of a load shift on canal scheme S. It was determined that an evening load reduction of 5.4 MW was able to be achieved. The comeback load during the off-peak period was possible due to the comeback load being below the maximum capacity of 10 MW of the transformer. To verify the simulation model, a drop test was done over a typical operation week. It was determined that an average evening load reduction of 5.6 MW was possible during this week period.

The simulation which was done, was only for a certain period of the year. The simulation provided evidence that the DSM methodology was viable to be implemented. The results of the simulation model were extrapolated to forecast results for the rest of the year. An average target was calculated from the season evening load reduction in a year. This resulted in the target of 3 MW.

It was considered applying an automated system with the use of the EnMS, but due to the lack of infrastructure it was decided to rather implement manual control. The EnMS only provided a recommendation schedule to switch pumps off during the peak period.

During the performance assessment period of canal scheme S, the average evening load reduction for the three month performance assessment period was 4.67 MW. This resulted in 55% higher evening load reduction than the target of 3 MW.

Potential for further optimisation concluded that additional load reduction can be realised. This can be done by implementing a load shift intervention in the morning peak period as well.

The implementation of the DSM methodology which was developed, proved to be successful as predicted by the simulation model. An annual cost saving of R 3.2-million was realised.

5.2 Recommendations for further research

The control philosophy which was developed, based on the implementation of a DSM initiative, proved to be very successful. An evening peak load shift was achieved during this implementation which benefited not only Eskom, but the client as well.

It is, therefore, recommended that the strategies and control be implemented on other canal pumping schemes as well. Each scheme where it will be implemented on, will have its own constraints and limitations upon investigation. Effectively, the principle will remain the same and it would be possible to use the EnMS with great success.

It will be important to take the seasonal effect into consideration for each canal pumping scheme independently. Each canal scheme is located in an area that differs from the others. The location of a canal scheme influences the rainfall profile throughout the year, the type of crop planted as well as the WFD needed to ensure sufficient growth of a crop.

It is also recommended to investigate the effect of the seasonal changes on the canal scheme. This will provide better forecasting for the WFD as well as the type of crop to plant and which time in the season will be the most ideal. This will increase the effective use of water which is a very scarce and important resource.

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