

Integration of DSM interventions into bulk water supply strategies

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ABSTRACT

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Supplying water to communities, industries and agricultural developments within South Africa is a cardinal task undertaken by the Department of Water Affairs (DWA). South Africa is a water-scarce country with an uneven fresh groundwater distribution. This makes the continued supply of potable water an arduous and essential task. Water schemes are spread widely across the country, utilising large dams and pump stations to supply water where needed. These pump stations are energy intensive.

The national peak demand for electrical energy has reached Eskom's total generation capacity. Different ways of reducing this demand are being investigated and executed, until the generation capacity can be increased. Eskom has introduced a time-of-use (TOU) costing method for large energy users. This makes it possible to shift load from national peak times to less expensive ones. To enable load shifting at pump stations within water transfer schemes (WTS), certain factors need to be investigated.

The DWA conducts an annual operating analysis (AOA) for its water schemes according to the appropriate catchment area. These AOAs are referred to as the "May-one" rules, as they are released by every first of May. They consist of various forecasted water supply scenarios. These are based on annual rainfall, catchment runoffs, user demands and other variables. A 1000 scenarios are generated stochastically, and then evaluated by genetic algorithms (GA). This determines which scenario best suites the supply and demand of water for a specific water scheme. From the results of the AOA, a set of water supply strategies (WSS) are generated.

How these WSS could impact DSM interventions and their savings, and how DSM could impact the execution of these WSS are the subject of this study. Their mutual interactions will be simulated and then verified based on the results from a case study. The case study this dissertation will focus on is referred to as Government Water Scheme-A (GWS-A) in Mpumalanga, South Africa. Load shift projects were implemented by HVACI on multiple stations within this scheme.

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NOMENCLATURE

Symbol	Unit	Description
C_v	-	Valve flow coefficient
E	J or kWh	Energy (1 kWh = 3600 J)
g	m/s ²	Gravitational constant
H	m	Head
K_v	-	Valve flow factor
P	kW	Power
Q	m ³ /s	Volume flow
t	hours	Time in hours
η	-	Efficiency
ρ	kg/m ³	Density

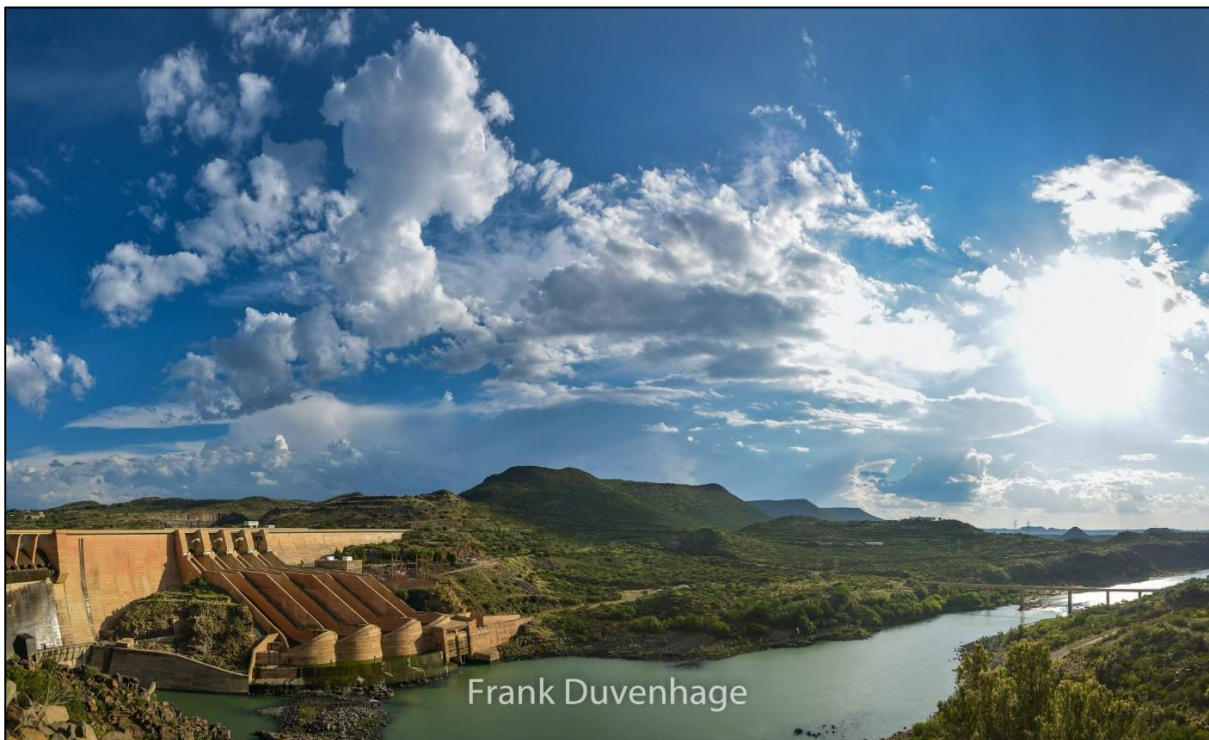
ABBREVIATIONS

AOA	Annual operating analysis
BPS	Booster pump station
CL	Comeback load
CT	Comeback time
DE	Drive end
DOE	Department of Energy
DSL	Dead storage level
DSM	Demand Side Management
ECS	Electricity Cost Savings
EMS	Energy management system
EPP	Evening peak period
ESCo	Energy Services Company
FSC	Full Scale Capacity
FSL	Full storage level
Hrs	Hours
HSCCP	Horizontal split case centrifugal pumps
IBT	Interbasin Transfer Schemes
kPa	Kilopascal
KPI	Key performance indicators
kWh	Kilowatt-Hour
m	Metre
LHWP	Lesotho Highlands Water Project
MAR	Mean annual runoff
MI	Mega litre
MCC	Motor control centre
MPS	Main pump stations
MVA	Megavolt ampere
MW	Megawatt
MWh	Megawatt-hour
NDE	Non-drive end
NERSA	National Energy Regulator of South Africa
NL	Normal load
OCGT	Open cycle gas turbine

OPEC	Oil producing and exporting countries
PA	Performance assessment
PID	Proportional integral derivative
PL	Preparation load
PLR	Peak Load Reduction
PLC	Programmable logic controller
PRV	Pressure-reducing valve
REMS-P	Real-time Energy Management System for Pumping
REMS-WSO	Real-time Energy Management System for Water Supply Optimisation
SCADA	Supervisory control and data acquisition
SEC	Specific energy consumption
SA	South Africa
TOU	Time-of-use
VRESAP	Vaal River Eastern Sub-system Augmentation Project
VSCCP	Vertical split case centrifugal pumps
WC/WDM	Water Conservation and Water Demand Management Strategy
WMA	Water management areas
WSS	Water supply strategies
WTS	Water transfer schemes
WTP	Water treatment plant
ZAR	South African Rand

1. INTRODUCTION

A dam wall in the Orange River, Northern Cape¹



(Supplementary figures or information with no academic contribution to this dissertation will be referenced as footnotes and not in the bibliography)

¹ D.F. Duvenhage, photo taken at Van der Kloof Dam, depicting the dam wall and outlet.

1.1 Overview

This chapter aims to provide the reader with a comprehensive understanding of the background leading to the inception of this study.

1.2 The power supply situation in South Africa

This sub-chapter provides a summary of the past and present conditions of the national power supply network in SA. It will address the following points:

- Past and present supply capacity (installed, peak and available) and demand
- The national energy crisis and the factors leading thereto
- Long-term solutions and their pros and cons (supply-side).

1.3 Solutions to the power supply shortage

This sub-chapter offers a summary of the issues surrounding solutions to the national energy shortage. It will address the following points:

- Short-term solutions and their pros and cons (demand side)
- Major energy users across SA, according to market sector
- The details and aims of Demand Side Management and Energy Efficiency.

1.4 Water schemes in South Africa

This sub-chapter provides a description of the various water schemes (WS) in SA and how applicable DSM projects are. The following points will be addressed:

- A short history of WS in SA and where their need originated from
- A summary of the different WS and their purposes, capacities, power-demands and consumer bases
- A comprehensive description of the applicability of DSM projects on WS.

1.6 Introduction Conclusion

This sub-chapter provides a short summary of the Chapter 1 and a final conclusion thereof, leading the reader to the next chapter and its subject matter. It also gives the final and holistic problem statement; describing the origin and goals of this study and its content.

1.2 The power supply situation in South Africa

South Africa (SA) is a resource-rich country situated on an equally resource-rich continent. Not only does SA possess a multitude of minerals and expanses of fertile land; it also has of the highest grades of coal in vast deposits. SA produces the fifth largest amount of coal in the world, and the reserves equal more than a third of all in the Southern Hemisphere [1]. The large deposits of coal provide for about 77% of South Africa's total (thermal and electrical) energy needs [2] [3].

It therefore comes as no surprise that 86% of SA's electricity is generated by coal-fired power stations [4] [5], as seen in Figure 1.

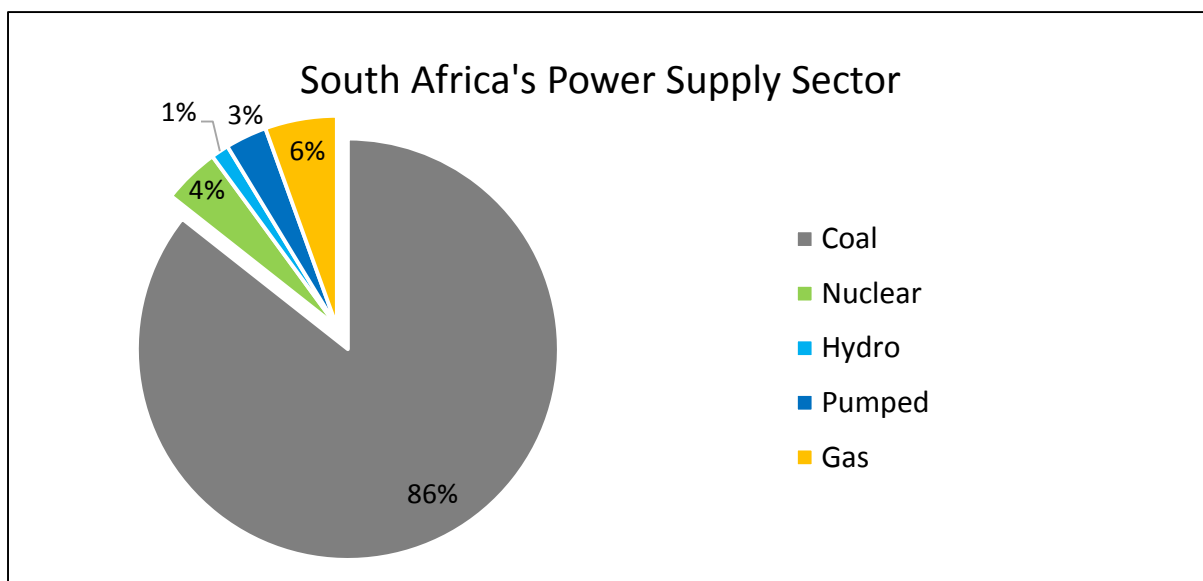


Figure 1: South Africa's Power Supply Sector

Eskom runs and maintains 22 power stations², of which 13 are coal-fired [5]. The average age of this generating fleet is 30 years [5], with the coal-fired stations at an average age of 33 years, as seen in Figure 2 on the next page. The majority of this generation fleet was built during the previous government's ruling, with plans to export electricity to the rest of Africa [6].

These plans meant that SA had a total installed capacity of 38 000 MW by 1994. With the addition of new plants (post 1994) such as Majuba, Ankerlig and other smaller ones operated by the distribution division³, this increased to the 44 145 MW it is today [4].

² This excludes small units such as Colley Wobbles, First Falls, Ncora, Second Falls and Klipheuwel Windfarm.

³ This includes the units mentioned in footnote 2, above.

All this led to SA having an overcapacity in its energy sector [6]. With the commencement of the new government, the customer base of Eskom grew drastically [6]. Providing electricity to the masses was, therefore, viewed as the ideal way to encourage trust, especially since SA had a surplus in electricity generation. With this being the focus of Eskom and the new government, expanding the generation capacity became a low-ranked priority [7].

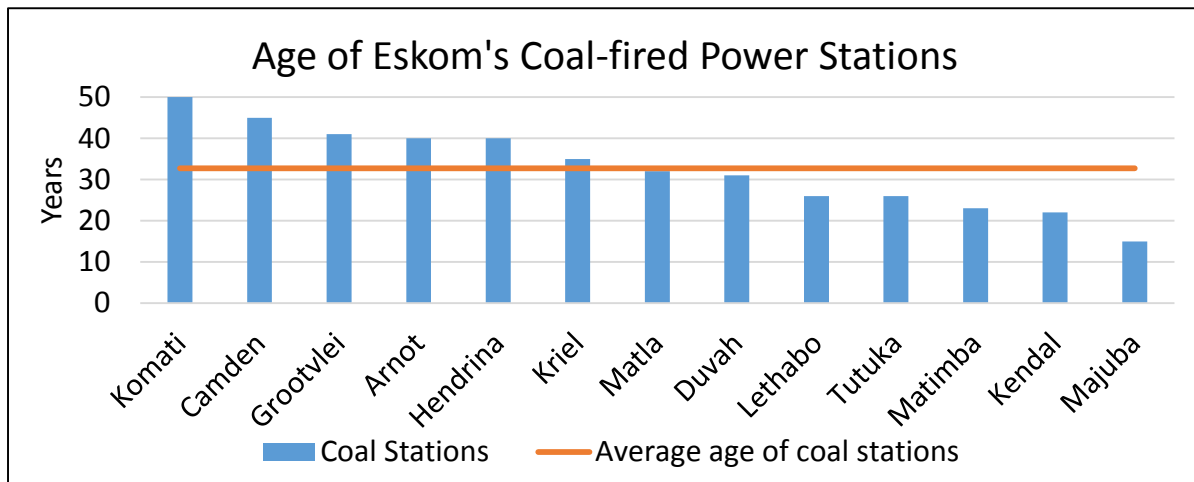


Figure 2: Age of Eskom's Coal Power Stations

With the great increase in the number of customers, the demand slowly started nearing Eskom's maximum supply capacity. As stated in the White Paper on the Energy Policy of the Republic of South Africa in 1998, SA was due to exceed its generation capacity by 2007 [8] [9]. Instead of Eskom further investing significantly in its generation capacity, the government opted to promote private sector involvement [6].

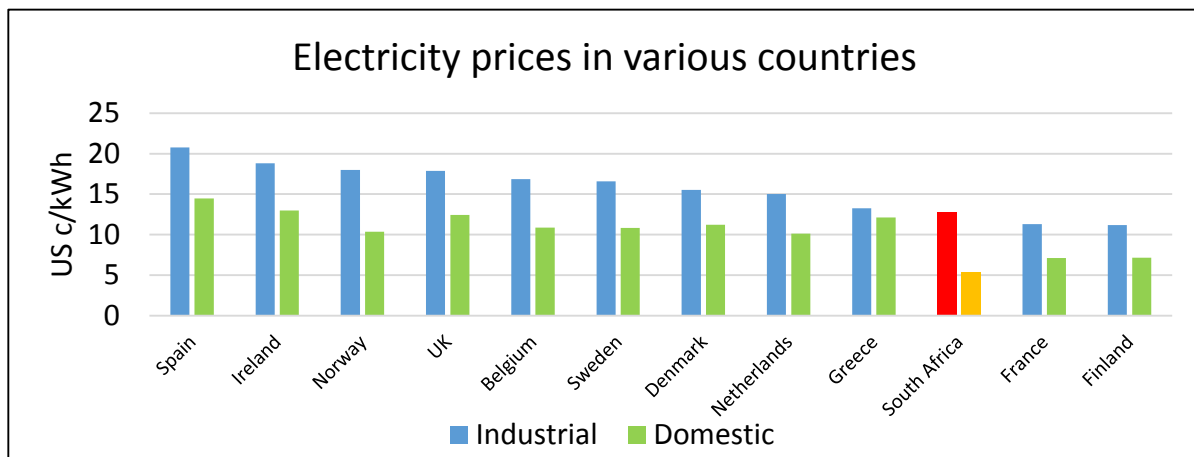


Figure 3: Electricity prices in various countries

Foreign private investors were, however, deterred from this by very low, government-controlled, electricity prices [6] [7]. South Africa's electricity prices were in fact among the lowest in the world, as can be seen in Figure 3.

By 2004, government realised that the overcapacity brought forward by the previous regime was rapidly depleting [6]. Because of the lower than expected private sector involvement, there

existed a shortage of funds available for expanding this generation capacity [7]. As a result of this funding shortage, drastic price increases were necessary. These increases aimed to remunerate financing to be able to cope with the increase in demand [7]. These increases are evident in Figure 4 [10], after the energy crisis in 2008.

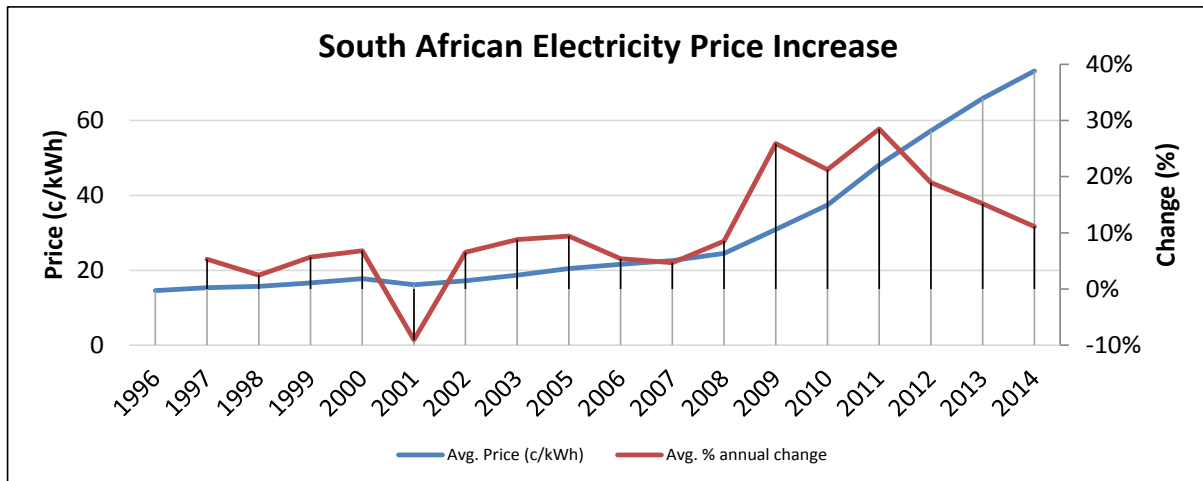


Figure 4: South African Electricity Prices

These drastic increases were twofold in purpose:

1. To discourage further excessive electricity consumption
2. To raise necessary funds to address the diminishing generation capacity.

The energy crisis of 2008 is evident in Figure 5, where it can be seen that the peak demand on Eskom's integrated grid came dangerously close to the net production capacity.

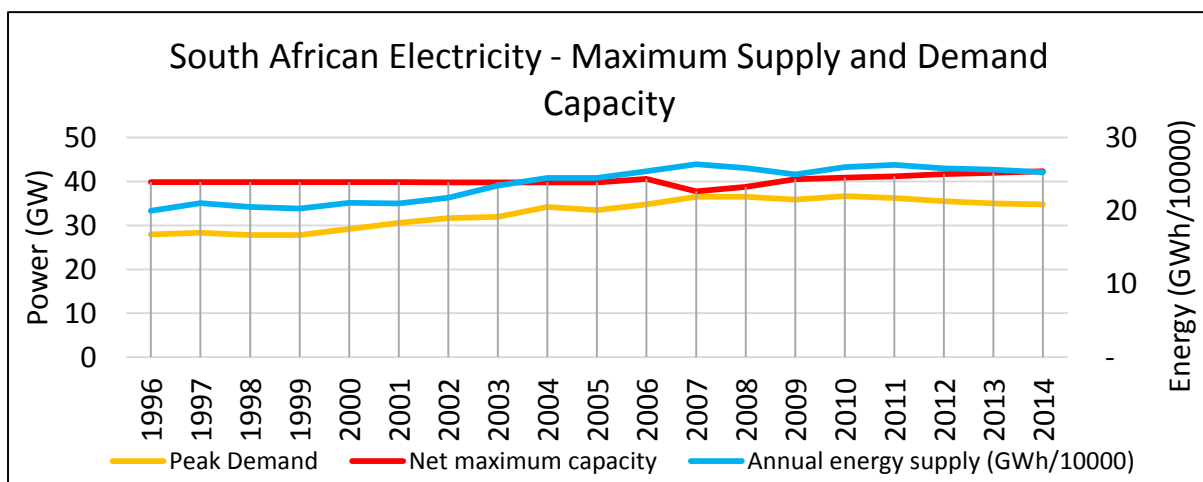


Figure 5: South African Electricity - Maximum Supply and Demand Capacity⁴

During both 2007 and 2008, the peak demand neared the net production capacity of Eskom, as anticipated in the White Paper in 1998 [8]. This led to great focus being placed on strategies

⁴ Multiple sources: NERSA Electricity supply statistics '96, '98, '00, '01, '02, '04, – '06 and System Adequacy Outlook Issue 6 and Eskom Integrated reports '03, '05, '07 – '14

to decrease the peak demand while Eskom implemented projects to increase its generating capacity.

The lead time of projects involving new generation facilities, is in excess of seven years [6]. The average construction time for Eskom's coal fired power stations is nine years⁵. This meant that if construction started soon after the revelation brought forward in 1998, new stations could have been operational by 2008-2010. As construction on new stations (Medupi and Kusile) only started in 2007, the expected commissioning dates are around 2017-2018. The construction of these stations has also been interrupted by delays due to Labour disputes and funding difficulties [11].

It became evident that projects were required that could be implemented sooner, but still positively impact the electricity supply situation. Clearly, addressing the supply of electricity is the most obvious and long-term solution. This approach, regrettably, has the longest lead times before its effects will be seen. Alternatively, the current installed capacities could simply be maintained more effectively to insure the high operating capacities.

Other long-term solutions include peak-demand power generation units [12]. These include power stations such as the gas turbines and pumped storage hydro-electrical stations. The benefits of these solutions are that they can provide power to the national grid at intermittent intervals. This means that they can be started and stopped relatively quickly, in contrast to the large coal-fired stations.

Their major disadvantage is that their operating costs are high. In the case of gas turbines, expensive diesel is required in large volumes. The disadvantage, or rather restriction, of the pumped-storage schemes is that they require an abundance of water, and electricity, throughout the day [13].

The alternative solution is to address the demand for electricity. This would have a positive impact on the constrained situation, without putting any further stress on the national grid. These projects would primarily consist of projects that aim to reduce the overall peak demand. This approach ultimately led to the introduction of policies by the National Energy Regulator of South Africa (NERSA) that would speed up the process of implementation.

⁵ This was calculated based on available information from Eskom's website: <http://www.eskom.co.za/Whatweredoing/ElectricityGeneration/PowerStations/>

1.3 Solutions to the power supply shortage

To combat the imminent overloading of the electricity grid, it was decided that short-term solutions were needed. In 2004, the National Energy Regulator⁶ put into place the *Regulatory Policy on Energy Efficiency and Demand Side Management for the South African Electricity Industry*⁷ [14]. This Policy allowed for energy efficiency (EE) and demand side management (DSM) to become a license condition of all electricity suppliers in SA. The *2004 EE/DSM Policy* furthermore introduced the role of energy service companies (ESCOs) into the electricity sector[14].

An ESCo is considered any company that provides a service to clients by aiding them in saving energy. This is done by first evaluating the aforementioned client's current energy use and then developing a project scope to lower this energy use or -costs. Finally, the funding of the project will be acquired and then implemented.

ESCOs found their origin in the aftermath of the energy crisis in the US in the 1970s. The crisis was a result of the OPEC oil restriction and the Iranian revolution, which led to a rapid increase in oil prices. This increase made large industries aware of the need to use energy more efficiently, resulting in the emergence of ESCOs [14].

As part of the *2004 EE/DSM Policy*, an independent measurement and verification (M&V) body was introduced. This body is responsible for conducting all M&V functions, and is accountable to NERSA. Eskom is responsible for evaluating the proposed projects of ESCOs and ultimately for allocating funds accordingly. There are strict criteria for the allocation of funds to ESCOs, as set out by NERSA [14]. The flowchart in Figure 6 illustrates these relationships [15].

The major issues constraining SA's national power supply are the daily peak demands. These peak demands occur primarily in the mornings when the nation wakes up for the day, and in the evenings when they return back home from work [12]. These peaks are additional to the standard base-load, which results from continuous, daily consumption of electrical energy by industries and households alike. These peaks regularly come very close to the national peak supply capacity of Eskom, as explained in Chapter 1.2. It is this peak demand, which forms the basis of most EE/DSM projects in South Africa.

⁶ The previously known National Energy Regulator (NER) is now known as NERSA

⁷ Hereafter referred to as the *2004 EE/DSM Policy*

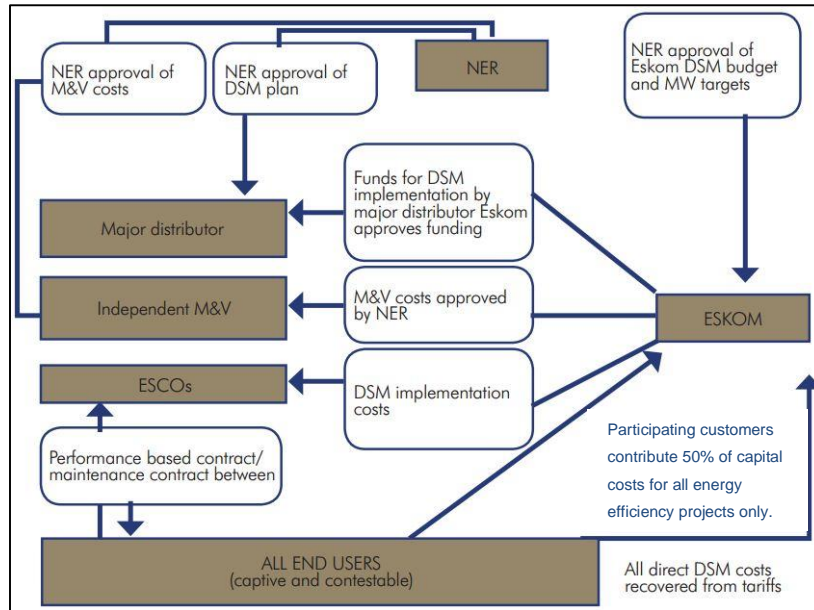


Figure 6: DSM management programme

A summary of the interactions between an ESCo and Eskom, for the procurement of a DSM/EE project, is given in Figure 7 (adapted from[14]).

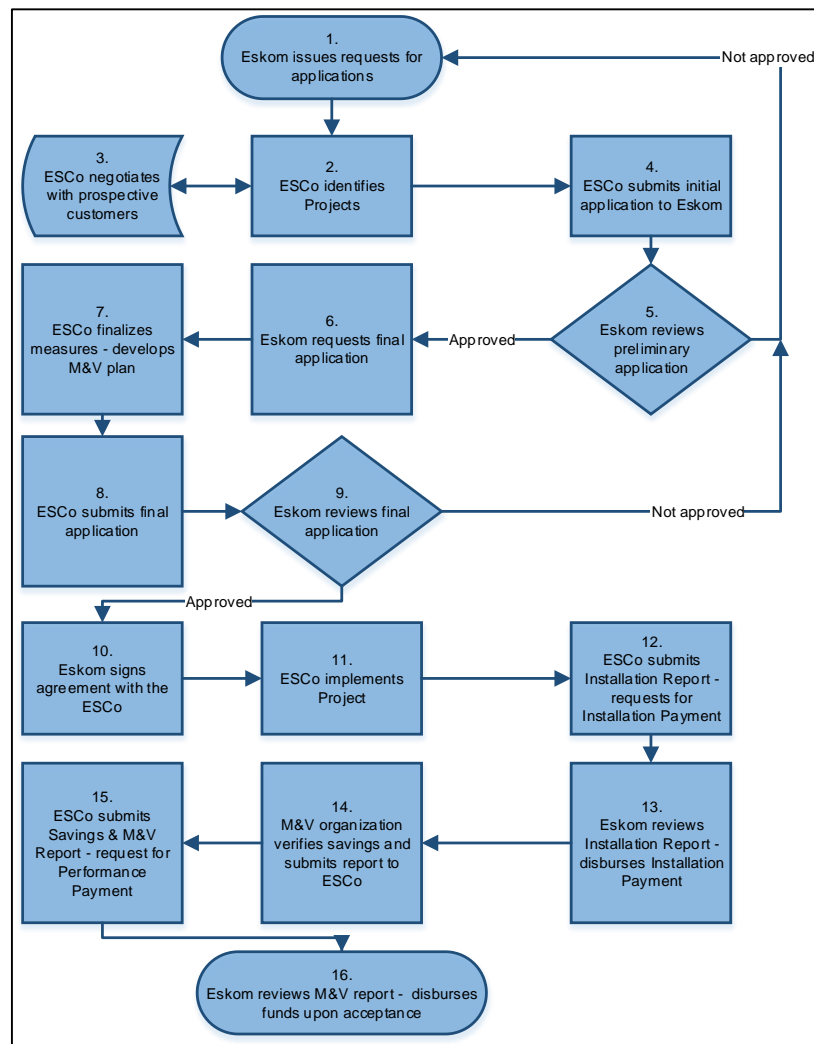


Figure 7: DSM/EE Project phases

An example of the daily national load profile can be seen in Figure 8, where it becomes clear that the peaks result in a sudden increase in demand on the grid [16].

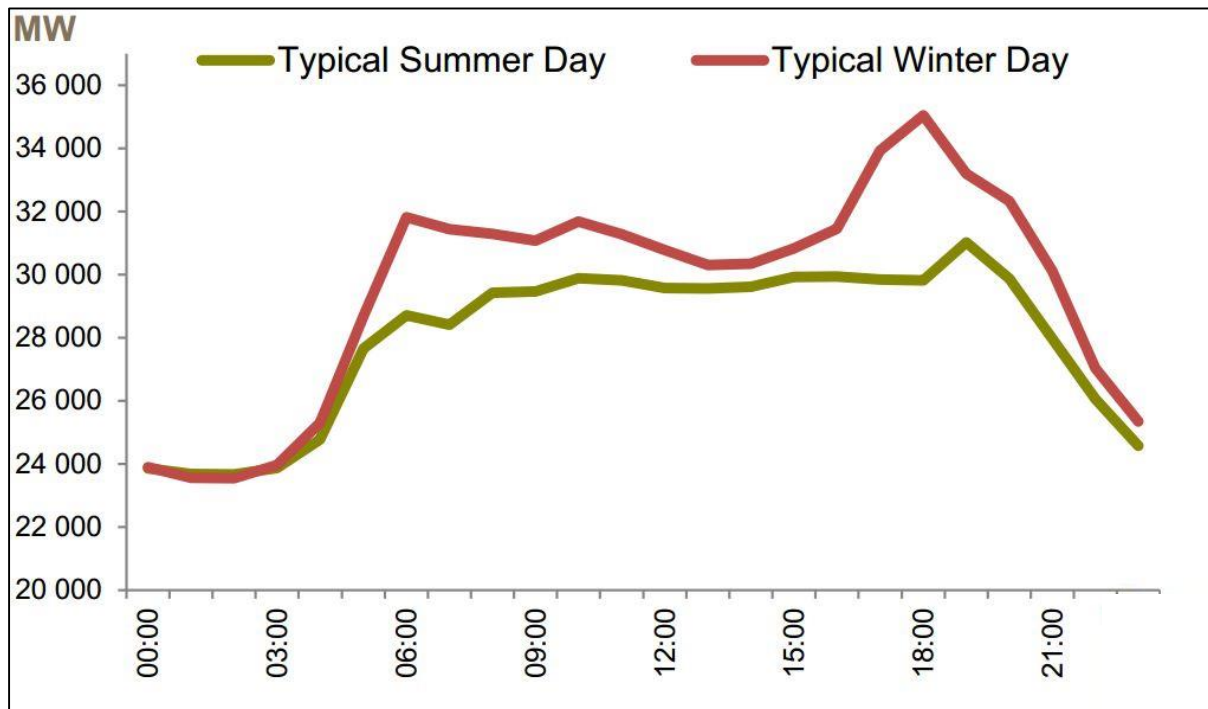


Figure 8: Typical daily load profiles

The ultimate goal of any EE/DSM intervention, therefore, would be to reduce the energy requirements of a certain process, thereby reducing the stress on the national supply network. The various EE/DSM methods and their targeted client-base determine their effects on the grid. As discussed, most EE/DSM interventions focus on reducing the peaks on the daily load profile, more specifically, the evening peak. This is simply because the evening peak results in the most drastic increase in demand.

Although there are initiatives being driven by Eskom to reduce the domestic demand, it is simpler to address large industries than address thousands of households [14]. The energy demand sector in SA is dominated by the usage from municipalities. According to the annual statistics made available by Eskom, a large sector of the demand, however, is attributable to industries and mining operations [16]. These are the sectors that generally receive more attention from ESCos. Their contribution to the total electricity demand in SA can be seen in Figure 9, below [10].

To address the issue of peak demand from large energy consumers, a time-of-use (TOU) tariff structure was introduced by Eskom. This TOU tariff structure charges different consumers at different rates, depending on the amount of electricity consumed during various time-slots.

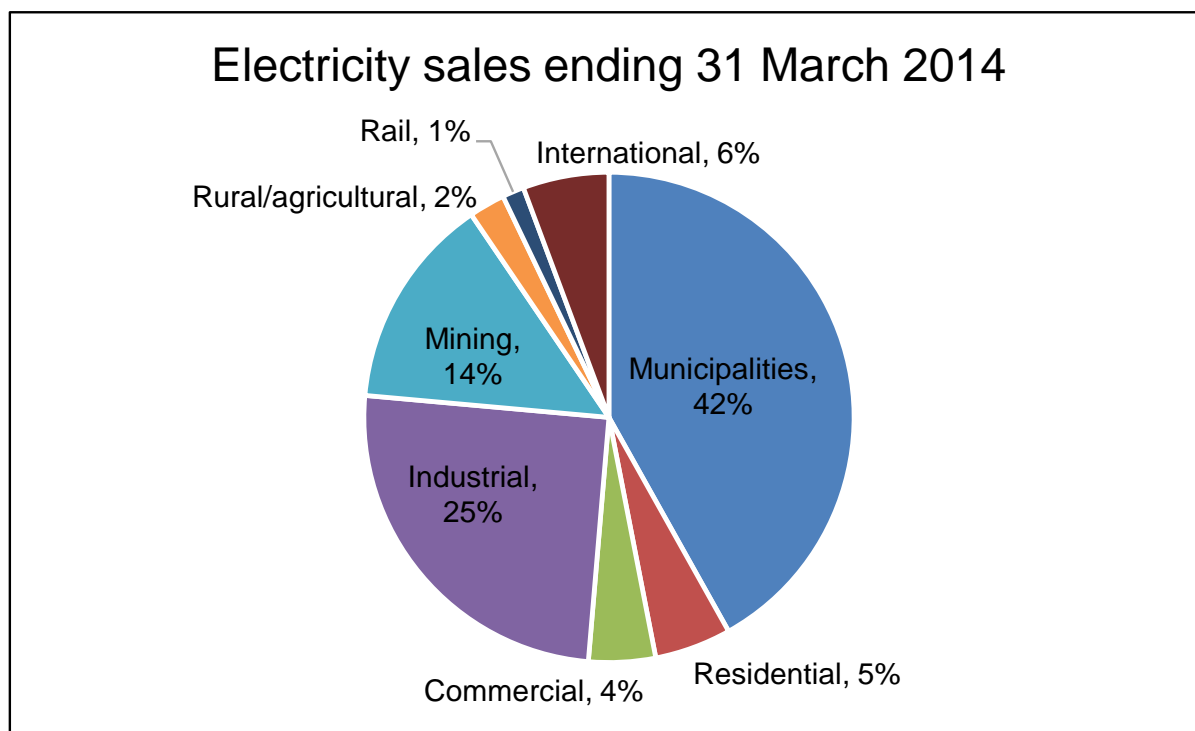


Figure 10: Electricity sales by sector

The TOU structure applicable to the years during which this study was commenced, is depicted in Appendix A-1. Here it can be seen that for Megaflex customers, as for most industrial and mining customers, it is more expensive to operate during peak times than during off-peak and standard times. Peak times are indicated as being between 07:00 and 10:00 (3 hrs) and 18:00 and 20:00 (2 hrs). A more detailed breakdown of different customer-sizes and their applicable tariffs can be found in Appendix A-2.

In combination with the TOU tariff structure, DSM interventions are implemented regularly under Eskom's DSM programme to reduce peak loads. EE/DSM interventions can be divided into the following different groups:

1. Load shifting
2. Peak clipping
3. Energy efficiency.

Load shifting is an energy-neutral intervention, as will be discussed in Chapter 2.4.3. In its most simple form, this implies that the energy "saved" during evening peak load-reductions (PLR), is made up for during other times of day. For instance, if it is decided that the energy saved during the load reduction period (E_p) must be recovered during the off-peak periods (t_{op}), it would mean that it is divided equally into these periods, as shown in Equation 1. This amount of energy (E_{ALop}) must then be added to the energy used prior to load shifting was implemented for that period (E_{BLoP}), to ensure the operations for the 24-hour period remain energy-neutral, as shown in Equation 1, below.

Equation 1

$$E_{ALop} = E_{BLOp} + (E_p \div t_{op})$$

$$\sum_{i=0}^{23} E_{BLi} = \sum_{i=0}^{23} E_{ALi}$$

$$\sum_{i=0}^{23} E_{BLi} = \sum_{j=0}^8 E_{ALopj} + \sum_{k=0}^{11} E_{BLSk} + \sum_{l=0}^5 E_{ALpl}$$

$$\sum_{i=0}^{23} E_{BLi} = \sum_{j=0}^8 [E_{BLOpj} + (E_p \div t_{op})] + \sum_{k=0}^{11} E_{BLSk} + \sum_{l=0}^5 E_{ALpl}$$

In these equations, the subscripts denote the following:

- *BL* – Before Load shift – which refers to the power or energy demand for the process at a specific period of the day before load shifting was implemented as a DSM intervention
- *AL* – After Load shift - which refers to the power or energy demand for the process at a specific period of the day after load shifting was implemented as a DSM intervention
- *op* – off-peak – which refers to the off-peak periods of a week-day, which total eight hours of a 24-hour day on the Megaflex TOU structure
- *s* – standard – which refers to the standard periods of a week-day, which total 11 hours of a 24 hour day on the Megaflex TOU structure
- *p* – peak – which refers to the peak periods of a week-day, which total five hours of a 24-hour day on the Megaflex TOU structure.

The period of day selected for recovery of the PLR energy can range from all other periods except for the peak period to the minimum amount of periods possible when the most energy-intensive pump configuration is used. The purpose of the baseline and scaled baseline is to ensure the evening peak-load reduction is calculated according to a pre-determined reference point [17], as will be made clear in Chapter 2.4.3. The amount of power required to recover the energy saved during the evening peak-load reduction (E_{ALop}), however, can only take place in fixed increments. These increments will be according to the power demands associated with the available pump configurations, unless technologies such as Variable Speed Drives (VSD's) are used..

If, for instance, $E_{ALop} = 3900 \text{ kW} + 975 \text{ kW} = 4875 \text{ kW}$, but the nearest larger power demand for a pump configuration is 4500 kW, then that configuration will have to run over a longer time than originally calculated. As another example, if the nearest larger power demand for a pump

configuration is 5100 kW, then that configuration will have to run over a shorter time than originally calculated. These examples are shown in Figure 10 and Figure 11, below.

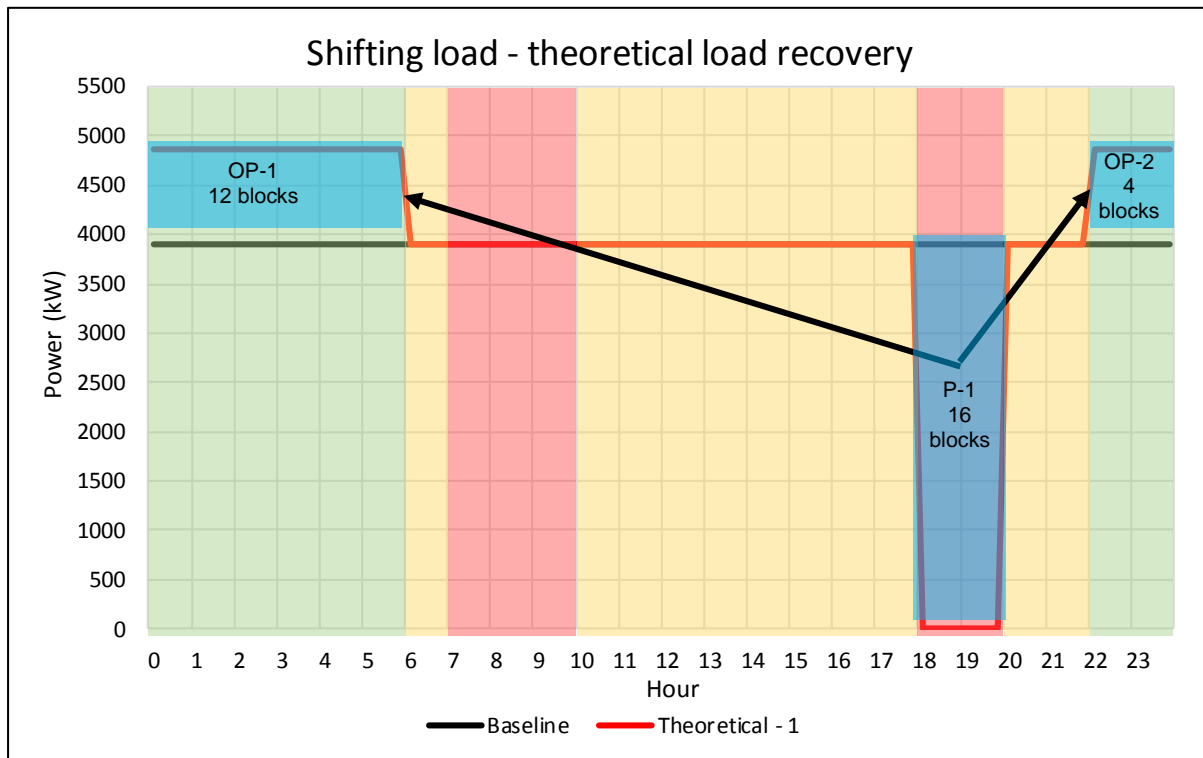


Figure 11: Shifting load – Theoretical load recovery

Figure 10 shows only the baseline and theoretical load shift. The theoretical load shift profile follows the red graph, where it is clear that the power load increase in the off-peak periods to recover the energy shifted from the evening peak period. This figure demonstrates that the area depicted by P-1 is the same size as the sum of areas in OP-1 and OP-2, leaving the load shift energy-neutral over 24 hours.

Figure 11 below shows the same pump station, with a load shift occurring according to the power loads associated with the actual pump configurations of the station. In this example, there are six possible pump configurations, with six separate power loads and flow rates. They are given in Table 1.

Table 1: Example pump configurations – power demands and flow rates

Nr	Configuration	Power (kW)	Flow rate (m ³ /s)	Specific energy (kWh/m ³)
1	0 Pumps	0	0	0.000
2	1 Pump	1500	1	0.417
3	2 Pumps	2700	1.7	0.441
4	3 Pumps	3900	2.4	0.451
5	4 Pumps	5100	3.1	0.457
6	1 small pump+1 large pump	4500	2.8	0.446

There is no pump configuration that will deliver the theoretically required 4875 kW in order to recover the shifted energy in the off-peak periods. The only two possible pump configurations that can recover this load are configuration 5 and 6. The power profiles for these two configurations are compared to the theoretical load shift profile in Figure 11.

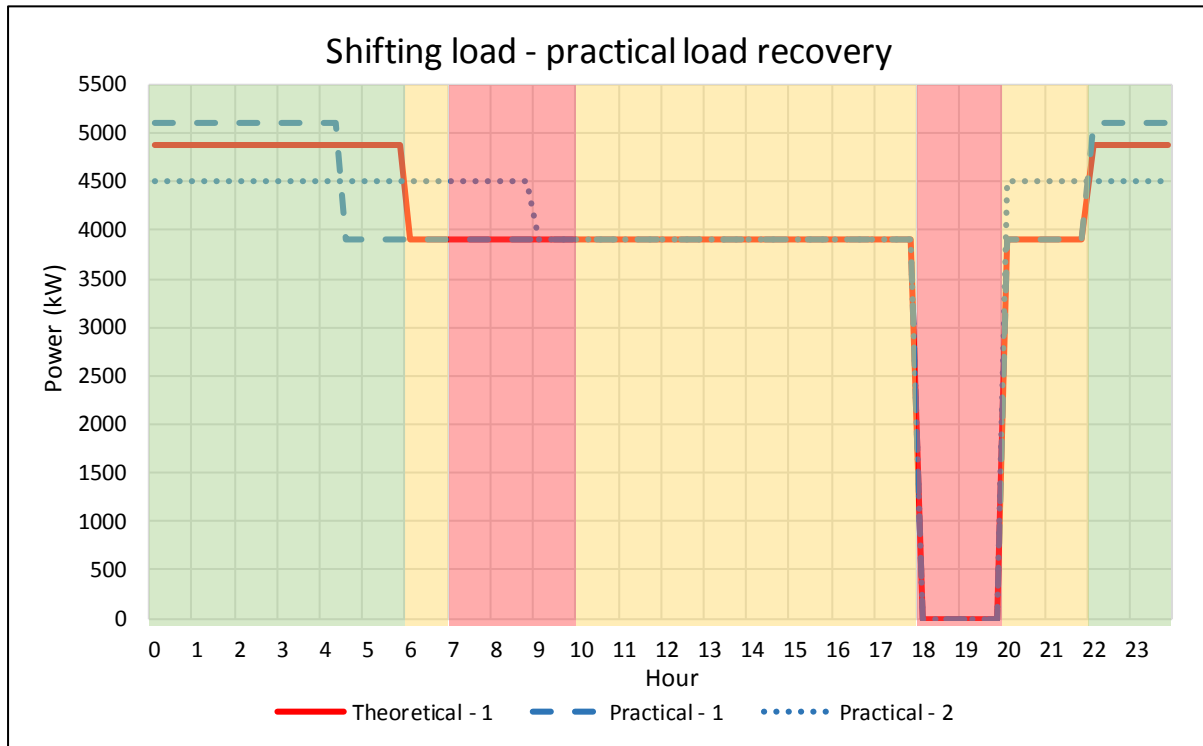


Figure 12: Shifting load – Practical load recovery

From these profiles, it can be seen that a longer time is required to recover the shifted energy for the Practical-2 graph, where the power demand for Configuration 6 is only 4500 kW. Configuration 5 has a power demand of 5100 kW, which results in a shorter time being required to recover the shifted energy. All three profiles in Figure 11 use the same amount of energy over a 24-hour period as the baseline in Figure 10, leaving all three energy-neutral.

Peak clipping is similar to load shifting, in the sense that it also focuses on lowering demand during peak times. However, as the name implies, the energy use during peak times is reduced, without it being moved to any other part of the day. This means that overall, less energy is consumed in a 24-hour period after peak clipping, than before.

It is therefore clear that peak clipping will lead to a loss or decrease in production with certain processes, over a 24-hour period. This, however, is not the case for all applications. In gold mines for example, a peak clip on the compressor system may take place during blasting, when no compressed air is required. In this way, no production loss or reduction will take place. Peak clipping, therefore, is more applicable to certain industrial operations than others.

Peak clipping is shown in Figure 12, below. It shows that the area under the peak clipped graph (energy consumed in a 24-hr day) is in total smaller than the area under the baseline period.

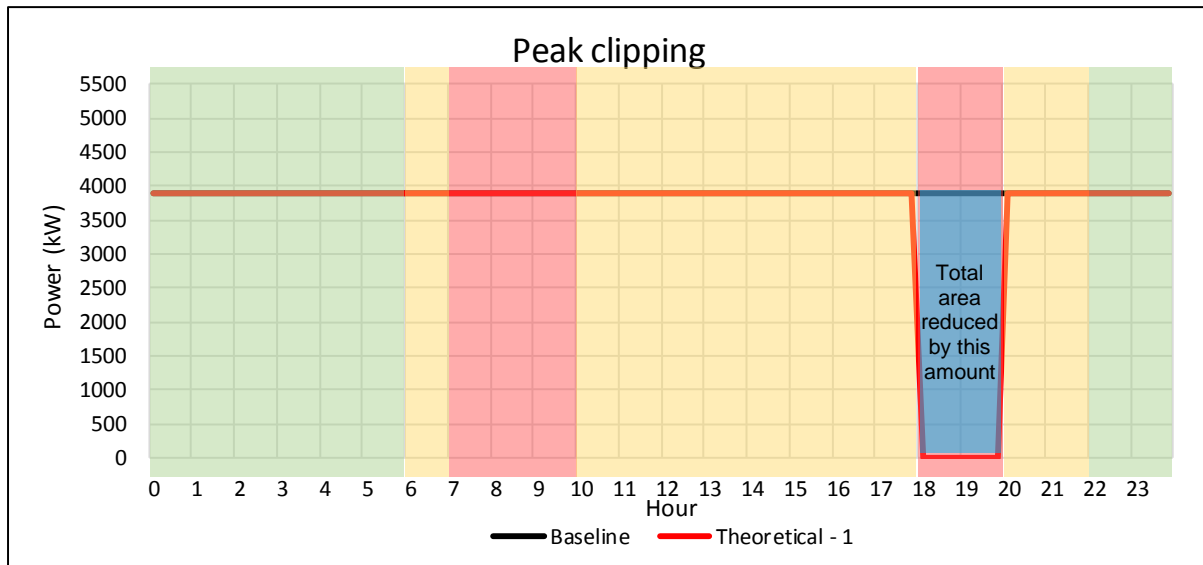


Figure 13: An example of a typical peak clip profile

Energy efficiency is different from both the above DSM-interventions, as it does not focus on a specific time of the day. This intervention aims to decrease the daily energy consumption of a process, without adversely impacting the production for a day. This is done by addressing inefficient sub-systems or machinery of a process, managing them more effectively or simply replacing them with more efficient ones.

The way EE impacts the energy consumption of a process can be seen in Figure 13. It is clear that the energy for a 24-hour period is lower after EE than before. It is also clear that it occurs throughout the whole day and does not lead to any form of “comeback load”.

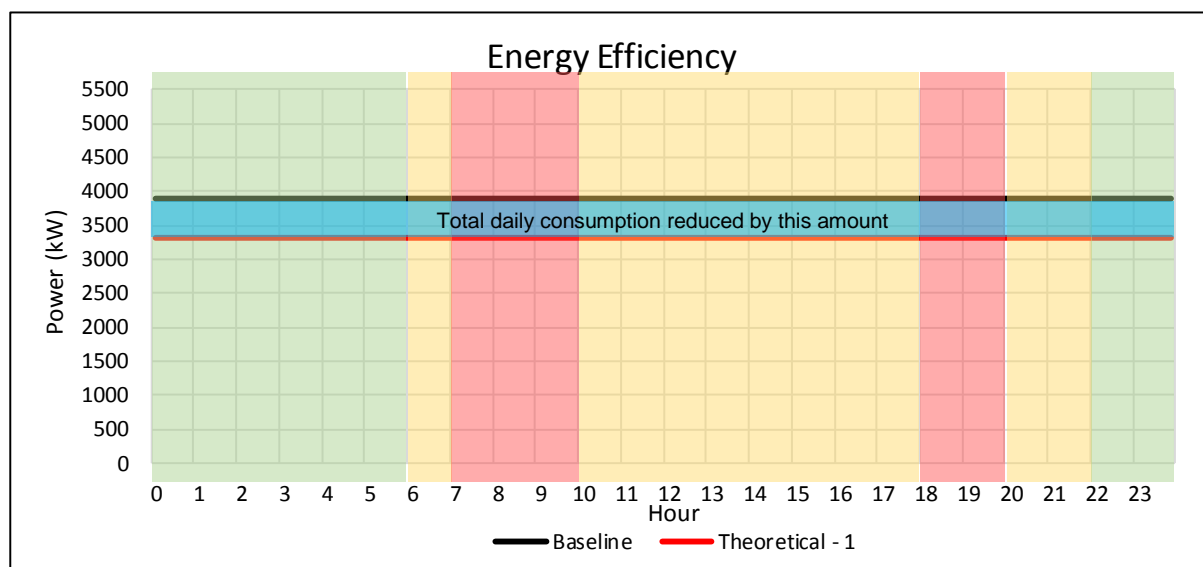


Figure 14: An example of a typical EE profile

1.4 Water schemes in South Africa

South Africa's water situation is characterised by substantial variations in water availability and storage capacity. This is because of SA's mostly semi-arid climate, and SA is in fact ranked as the 30th driest country in the world [18]. It has an average rainfall of 450 mm per annum, far less than the global average of 860 mm per annum [18]. Western parts of the country receive on average less than 100 mm/year, while the Eastern parts can have up to 1200 mm/year [19].

This sparse distribution of annual rainfall can be seen in Appendix A-3, for the period of July 2013 – January 2014. Appendix A-4 shows the distribution of all major dams in SA. Here it is obvious that most of the stored water capacity (surface water) is located in the Eastern parts as well. Figures A-3 and A-4 highlight the greatly unbalanced water distribution in SA.

The province with the most storage capacity is the Free State, with around 50% of SA's total surface water. The Gariep, Vanderkloof, Sterkfontein, Vaal and Bloemhof dams alone constitute nearly 47% of SA's total storage capacity. The distribution of surface water in SA can be seen in Figure 14 (adapted from [20]). The largest province, the Northern Cape, forming the West of the country, has less than 1% of the country's surface water, and this, while it makes up almost a third of the country's surface area.

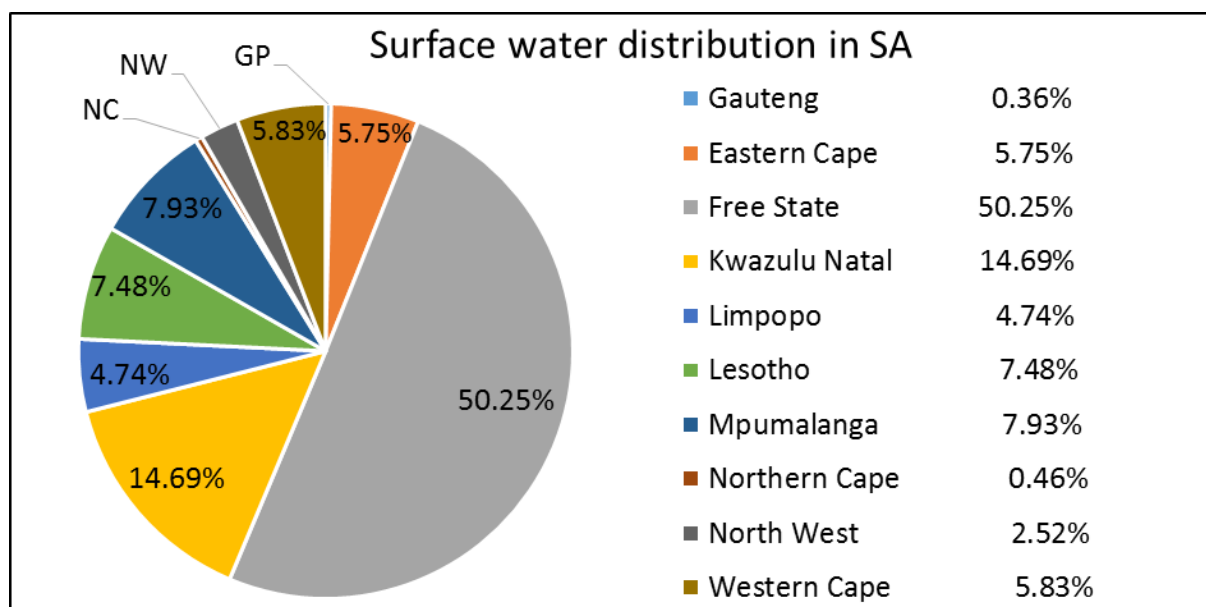


Figure 15: Surface water distribution in SA

From Figure 14, it is striking to notice that Gauteng, the province with the largest population (12.91 million) [21], has the absolute lowest level of surface water. This sparse distribution of water across the country led to the need for networks of large, integrated water schemes. Since most of SA's water usage consists of surface water (77%), it is obvious that these

sources need to be managed continuously and thoroughly [18]. This resource management comprises primarily of catchment- and river systems management, water storage, water abstraction and return-flow management.

To accomplish this, integrated management techniques are required to achieve the goal of water-resource protection and utilisation. This involved the building of a total of 794 large dams⁸, presently with a total capacity of over 31 billion m³, since the colonisation of South Africa [18]. These dams were built to increase the total storage capacity from 4 400 million m³ in 1956 to the level it is at present [22]. SA has a mean annual runoff (MAR) of 49 billion m³/a, of which only 10.24 billion m³/a is accessible at a relatively high confidence. This means that around two-thirds of SA's total MAR can be stored in manmade reservoirs[18].

The effective administration of these water-resources meant that they had to be divided into specific water management areas (WMA). They consist primarily of the largest draining rivers of a specific region. They are shown in Figure 15 [23], and are grouped into larger catchment areas.

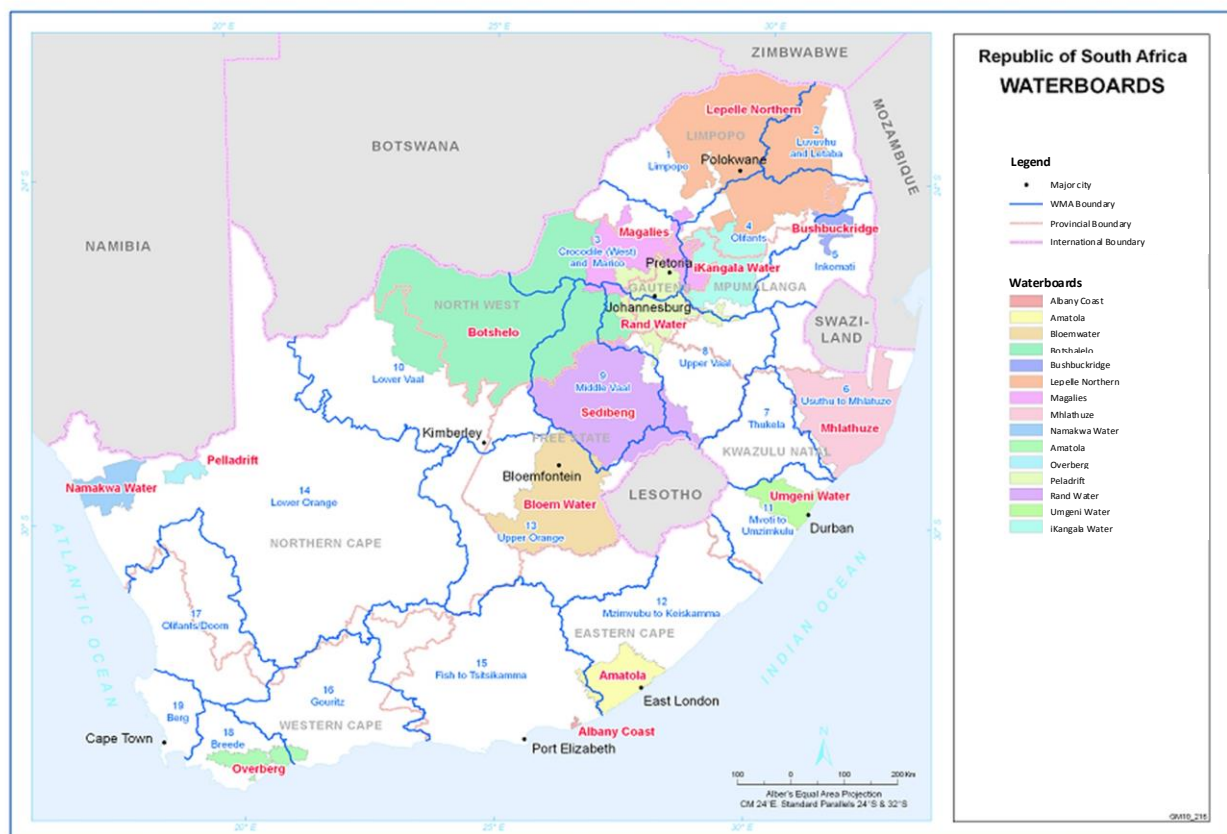


Figure 16: Water management areas and Waterboards of SA

⁸ Dams with a wall height of more than 15 m or between 5 m and 15 m and a FSC of more than 3 million m³.

These WMAs are mainly responsible for the following functions [18]:

- Developing strategies for water-resource management
- Developing and supporting various organisations for capacity building and conservancy
- Regulating water demand, including authorisation and billing management
- Managing information to support other water-resource management functions
- Implementing physical interventions such as conservation, demand management, infrastructure development and operation
- Auditing water-resources management strategies.

Because of the uneven distribution of water-resources in conjunction with uneven distribution of water demand, a main objective of these WMAs is to ensure sufficient water transfer. It is clear that Interbasin transfer schemes (IBT) form an integral part of managing water use and availability in SA. These schemes consist of an intricate network of dams, reservoirs, pump stations, pipelines and canals. Their aim is to transfer water from regions of abundance to those with great demands. There are a total of 28 IBT in South Africa, with total transfer capacity of more than 7 billion m³/a [18].

One of the earliest and largest IBT is Rand Water. Its origins are found in the early days of gold mining in the Witwatersrand area, where the demand for water was far from the source, namely the Vaal River and -Dam. Over time, the demand came not only from the mines, but also from the large populous of people congregating around these industries [24]. This highlights the fact that most economic, social and industrial development in SA actually takes place where water is not abundantly found [22].

A few IBT are given below, which form part of one of the largest catchment systems in South Africa, the Integrated Vaal River System (IVRS). Since the subject matter of this dissertation is DSM-interventions and water supply strategies, only IBT with pumping activities will be mentioned. There are however some IBT that make use solely of gravity feed, such as the famous Lesotho Highlands Water Project (LHWP). The LHWP transfers water from the Katse Dam (Lesotho) to the Ash River outfall in the Free State near Clarens. From there, it flows its natural route for about 200 km through the Ash, Liebenbergsvlei and Wilge Rivers, into the Vaal Dam near Vereeniging [25].

The IVRS comprises of various WMAs and Government Water Schemes (GWS). A layout of the IVRS can be found in Appendix A-5. A schematic of the annual transfers to and from the IVRS can be seen in Appendix A-6.

These figures demonstrate the large area serviced by the IVRS and great volumes of water transferred by it. A summary of these schemes and their installed capacities is given.

The Integrated Vaal River System

- Vaal River Eastern Sub-system Augmentation Project (VRESAP)

Source basin:	Vaal Dam	
Recipient basin:	Upper Olifants	
Consumer-base:	Industry (Sasol) and power stations (Matla, Khutala, Kriel)	
Transfer capacity:	5.07 m ³ /s	
Pump stations:	VRESAP - low lift (LL) and high lift (HL)	
Power demand (estimated):	550kW x 6 (LL) and 4 x 8000kW (HL)	[26]

- Grootdraai Dam Sub-system

Source basin:	Grootdraai Dam (Vaal River Basin)	
Recipient basin:	Upper Olifants	
Consumer-base:	Power stations (Thuthuka, Matla, Khutala and Kriel)	
Transfer capacity:	<i>see "Power demand" in brackets, below</i>	
Pump stations:	Grootdraai, Thuthuka, Grootfontein, Rietfontein	
Power demand (estimated):	Grootdraai: 4 x 1650 kW (4.13 m ³ /s)	[27]
	Thuthuka: 4 x 1725 kW (3.24 m ³ /s)	[27]
	Grootfontein: 5 x 2200kW (4.90 m ³ /s)	[27]
	Rietfontein: 4 x 3050kW (3.60 m ³ /s)	[27]

- Vaal Dam Sub-system - Rand Water

Source basin:	Vaal Dam	
Recipient basin:	Crocodile (West) and Marico	
Consumer-base:	Municipalities (City of Johannesburg, Ekurhuleni, Emfuleni, Tshwane, Midvaal, Govan Mbeki, Rustenburg)	
Transfer capacity:	<i>see "Power demand" in brackets, below</i>	
Pump stations:	Vereeniging WTP, Zuikerbosch WTP, Zwartkopjes, Eikenhof, Palmiet, Mapleton	
Power demand (estimated):	Vereeniging WTP: 13 => 39.42 MW	[28]
	(±31 m ³ /s)	[29]
	Zuikerbosch WTP: 36 => 86 MW	[28]
	(±51.60 m ³ /s)	[29]

Zwartkopjes:	11 => 30 MW	[30]
	(±8.10 m ³ /s)	[30]
Eikenhof:	17 => 33 MW	[30]
	(±13.89 m ³ /s)	[30]
Palmiet:	20 => 39 MW	[30]
	(±16 m ³ /s)	[30]
Mapleton:	11 => 12 MW	[30]
	(±8.30 m ³ /s)	[30]

- The Heyshope Scheme (Usutu GWS)

Source basin:	Usutu River Basin
Recipient basin:	Grootdraai Dam (Vaal River Basin) and Upper Olifants and Komati Basin
Consumer-base:	Industry (Sasol) and power stations (Kriel, Camden)
Transfer capacity:	<i>see "Power demand" in brackets, below</i>
Pump stations:	Heyshope, Geelhoutboom, Morgenstond, Jericho, Kliphoeck, and Camden
Power demand (estimated):	Heyshope: 4 x ±2915 kW (5.40 m ³ /s) [31]
	Geelhoutboom: 4 x ±8550 kW (4.74 m ³ /s) [32]
	Morgenstond: 6 x ±1300 kW (2.20-4 m ³ /s) [33]
	PS-A: 6 x ±3500 kW (3.30 m ³ /s) [34]
	PS-B: 4 x ±2400 kW (3.30 m ³ /s) [34]
	(booster)
	PS-C: 3 x ±2800 kW (1.77 m ³ /s) [34]

- The Zaaihoek Transfer Scheme (Slang River GWS)

Source basin:	Zaaihoek dam (Tugela Basin)
Recipient basin:	Vaal River Basin
Consumer-base:	Municipalities (Volksrust) and power stations (Majuba)
Transfer capacity:	3.20 m ³ /s
Power demand (estimated):	Zaaihoek: 4 x ±1875 kW

As stated previously, the above IBT are only a few of a great multitude of transfer schemes. There are many more water transfer schemes (WTS) within and between WMAs. These WTS can include municipal treatment plants and distribution networks, discussed later in Chapter 2.4.2. They in turn form part of the following larger systems [29]:

- The Middle Vaal Sub-system
 - Midvaal Water Company
 - Sedibeng Water
 - Bloemhof sub-system
- The Lower Vaal Sub-system
 - Riverton-Kimberley Scheme
 - Vaal-Gamagara GWS
 - Vaalharts Scheme
- Upper Orange Sub-system
 - The Caledon – Modder Transfer Scheme
 - The NOVO Transfer Scheme
 - The Mazelspoort Scheme
 - The Orange – Riet Transfer Scheme
 - The Orange – Fish Transfer Scheme
 - Orange-Vaal transfer scheme
- Lower Orange Sub-system
 - Douglas Irrigation Scheme
 - Middle Orange Irrigation Area
 - Boegoeberg Scheme
 - And many more, smaller rural supply schemes.

As seen in the IVRS alone, discussed in greater detail here above, the power demand of these IBT and other transfer schemes is very high. This is due to the large amounts of energy associated with pumping bulk volumes of water over great distances. The hydraulic power required to pump water is determined mainly by the flowrate and height (head) it must be pumped, and is given in Equation 2.

Equation 2

$$P = \rho g H Q$$

The head at which water is pumped depends greatly on the suction head, static head and pipe friction head [35]. Many of these transfer schemes pump water up to a reservoir or other dam at a much higher elevation and, in most cases, a considerable distance away. The resulting heads, coupled with high flow rates, lead to large power demands.

Pump stations play an intrinsic role in IBT since only in a few cases can high volumes of water be transferred solely by gravity. The high power demands of these pump stations and the almost year-round need for their operation make them ideal candidates for the implementation of DSM interventions. Load shifting in particular, is preferred, since in theory no perceived water-loss over time will take place. This means that with the effective operation of pump stations, PLR as well as electricity cost savings (ECS) can be achieved.

1.5 Problem statement

Before the implementation of any DSM-interventions, the AOA and its operating rules (WSS) directly determine how the water scheme is operated. As will be seen in Chapter 3, with the implementation of these interventions on a water scheme and its pump stations, its operation will be regulated not only by the WSS, but also by the DSM interventions. These DSM interventions, however, are both directly affected by various aspects of the water scheme itself, and indirectly through the AOA.

Figure 16 below, shows the current process interaction prior to any DSM being introduced at a WTS. It will show that a WTS is operated mainly according to the WSS it is supplied with, and the actual physical demands and constraints of the system. The interactions between the WSS and WTS are summarised in Chapter 3.2, as part of the methodology development.

Ultimately, it becomes clear that because the WSS and DSM interventions aim to regulate the operation of the same system, namely water transfer schemes, a need exists to evaluate how they might impact each other. This will then help to determine whether it is necessary to integrate the two processes, and if so, how.

The aim of this dissertation is to determine the mutual impacts WSS and DSM interventions have on each other. These impacts occur through the regulation of operations at the pump stations within these WTS. They will be analysed in the following way:

1. *Analyse* historical pumping trends for transfers by pump stations A, B and C.
2. Based on the characterised trends, *simulate* the following scenarios to obtain results of the performance indicators for the pump stations under historical low- and high transfer conditions:
 - 2.1. Pre-DSM Scenario
 - 2.2. Post-DSM Scenario

3. Based on the results for the same performance indicators of the case study during the implementation of DSM interventions in 2014, *verify* the results from the simulations.
4. Compare the results from the simulations and the case study to *validate* the need for this study by reaching *conclusions*.

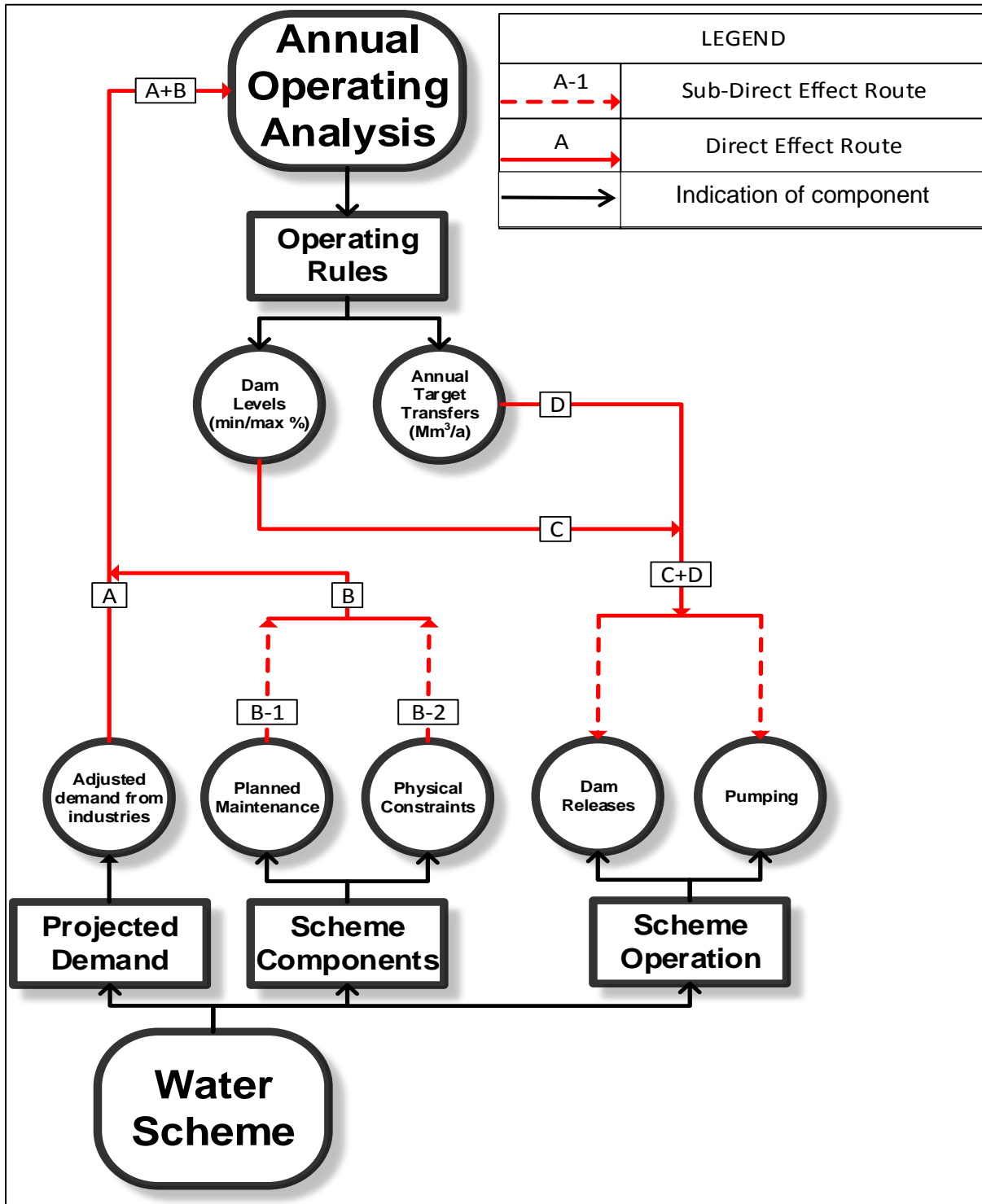


Figure 17: Pre-DSM process interactions

1.6 Introduction Conclusion

In this chapter, the power supply situation in South Africa and the events, decisions and policies leading thereto, was discussed. It became clear that the situation is far from desirable and that solutions are needed urgently. It was concluded that long-term solutions will take many years before their contribution to the supply network will be felt.

This leads to the need for faster solutions that would still have a measurable effect on the network. These solutions became known as DSM interventions and were aimed at reducing pressure on the national grid by addressing the demands of large power consumers. These interventions were divided into three types of projects:

- Energy efficiency projects
- Peak clipping projects
- Load shifting projects.

WTS play a major role in supplying the population and industries of South Africa with enough water. They, together with the enormous dams, long rivers and intricate distribution systems make up a vast and highly integrated water supply network. Critical to this network are the pump stations, which in many instances literally form the heart of the system.

This network requires careful management to successfully maintain the national system in a balanced and fully operational state. To manage all these systems collectively, water supply strategies (WSS) are implemented on each transfer within a WMA and its accompanying schemes.

These strategies determine the control philosophies by which the schemes are operated on an annual, and monthly basis. These strategies, therefore, can have an effect on DSM interventions (and intended savings) that have been implemented at pump stations. The mutual effects of these WSS on DSM interventions and -savings, and vice versa, and the integration thereof, form the foundation of this dissertation. It can be concluded that these impacts need to be studied and the integration of DSM practices and WSS needs to be investigated.

2. LITERATURE STUDY

Pump-motor sets at Pump station C⁹



⁹ C. Scheepers, photo taken at Pump station C, depicting the pumps and their driving motors.

2.1 Overview

This chapter intends to provide the reader with comprehensive insight into previous research conducted on similar subjects and the research done specifically for this study.

2.2 Water Transfer Schemes – Components and Design

In this sub-chapter, the infrastructure and design considerations of water schemes will be discussed. Attention will be given to functional requirements of water schemes and the consequent design principles used to achieve them. Finally, a breakdown of infrastructure and their respective functionalities will be given.

2.3 Water Supply Strategies in South Africa

This sub-chapter gives a detailed overview of water schemes and AOA, and how their results are used for water scheme management in SA. It will address how the national water network is an integrated series of schemes and why the need to manage these networks with WSS exists. The models used to determine and optimise these WSS will be described. How these WSS are interpreted and implemented on a practical level will be evaluated.

2.4 DSM Interventions on Water Pumping Systems

In Chapter 2.4, the focus will be placed on previous DSM interventions, which have been implemented on various water pumping systems. The differences in operational control philosophies, and the parameters which lead to them, will be highlighted. The way baselines and DSM savings are calculated for these projects, from an M&V perspective, will also be discussed.

2.5 Literature Study Conclusion

This sub-chapter gives a summary of what was discussed in Chapter 2, accompanied by a conclusion thereof, leading the reader to the next chapter and its subject matter.

2.2 Water Transfer Schemes – Components and Design

In this sub-section, the infrastructure and design considerations of water schemes will be discussed. The functions and design specifications, according to design constraints and -prerequisites will be evaluated. Attention will be given to functional requirements of water schemes and the consequent design principles used to achieve them. Finally, a breakdown of infrastructure and their respective functionalities will be given.

2.2.1 South African-specific requirements for transfer schemes

As mentioned in Chapter 1.4, South Africa is not only considered dry, but also suffers under the irregular and frequently questionable water-resource dispersal. This is recognised in the National Water Act of 1998, and underlines the importance of being able to ensure sustainable access to water under trying circumstances [36]. The purpose of WTS in the South African context is apparent.

The national government is therefore responsible for the spatial redistribution of water-resources within the country. This is aimed at ensuring continued growth and the general wellbeing of the country. This spatial redistribution of water may, however, only take place under clearly stated conditions. These conditions are summarised in a report for each WMA. These reports serve as overviews of the availability and utilisation of water-resources within the respective WMA [37]. A brief summary of these conditions is given below. They serve as a pretext to the considerations for the operational requirements of a water transfer scheme.

- The highest priority within a catchment is the allocation of water for its own reserve
- The redistribution of water away from its source-basin can only be justified if it results in a national net-benefit
- The environmental integrity of both the receiving and source catchments must be upheld
- IBT will only be considered a viable option if the receiving basin's water authorities implement the relevant demand management strategies
- IBT will not be considered if their sole purpose is the meeting of the requirements for the ecological component of the receiving basin's reserve
- Water reserves cannot be stored within or outside basins for extended periods for possible future use if that water can be utilised beneficially
- New water-resources, which have not yet been utilised, will be considered first when transfer volumes to outside catchments are determined
- Any operational costs associated with the transfer of water will be borne by the users of that water within the recipient basin
- The national government is responsible for planning, initiating and authorising IBT.

These guidelines are generally used for determining what the allowed annual transfer volume is out of the source basin and into the recipient basin. Based on these allowed transfers, technical specifications can be found for the design of transfer systems and more specifically, the pump stations within these systems.

2.2.2 Considerations for water transfer schemes

Generally, main pump stations that supply water into an integrated water distribution system, or WTS, are either near the water treatment plant (WTP) or raw water source, where it receives its water from. Pump stations that pump directly into transmission pipelines are usually referred to as main pump stations (MPS). Pump stations that are remote from MPS or WTP are called booster pump stations (BPS) and aim to increase the pressure in a system. This is usually necessary for systems with differential pressure zones due to varying topography [38].

WTS are usually designed to handle projected future increases in demands [39]. These demands can be determined by assessing the consumer base, which is to be supplied. This consumer base can consist of:

- Residential consumers
- Commercial consumers
- Industrial consumers
- Agricultural consumers
- Various combinations.

The projections for the demands from these consumer bases can be derived from historical and present consumption records. A summarised list of the required information for accurate projections is given below [40]:

- Current population and population growth estimates and projections
- Number of households, residential-, commercial- and industrial units
- Incomes (and fluctuations) related to residential units and economic growth of non-residential units
- Current levels of water service provided to, and consumption of residential and non-residential units
- Weather patterns and climatological changes and projections.

From these projections, the appropriate components of the WTS can be specified and selected. A component list for a typical MPS, within such a WTS, will be given. Their functionality, different available options and applicability to DSM intervention are given in the following sub-section.

2.2.3 Water transfer scheme components

Before a comprehensive overview of the components of a water scheme is given, the general considerations for all components requiring operation and maintenance will be discussed. Site selections for all components should be evaluated based on the following criteria [41]:

- Sites must be situated so as to prevent damage caused by regular flooding or natural occurrences
- The topography must be analysed to ensure the components used can handle the required static heads and friction losses
- The availability of electric power must be considered
- Access by means of road must be possible for operational and maintenance purposes
- The security of the site must be of such nature that it can be guaranteed
- Adverse impact to any surrounding occupied areas must be prevented.

Focus will now be placed on the most prominent components of a WTS. The sizing and specifications of each component depend on the combination of the major system elements. These elements comprise of the supply source, pumping, storage and distribution subsystems, depicted in Figure 17. For the purpose of this study, focus will only be placed on WTS, which do not include WTP, and whose main purpose is the redistribution of water-resources. The main components of a WTS, which is of relevance to this study, are the water source, the pumping infrastructure and the water storage.

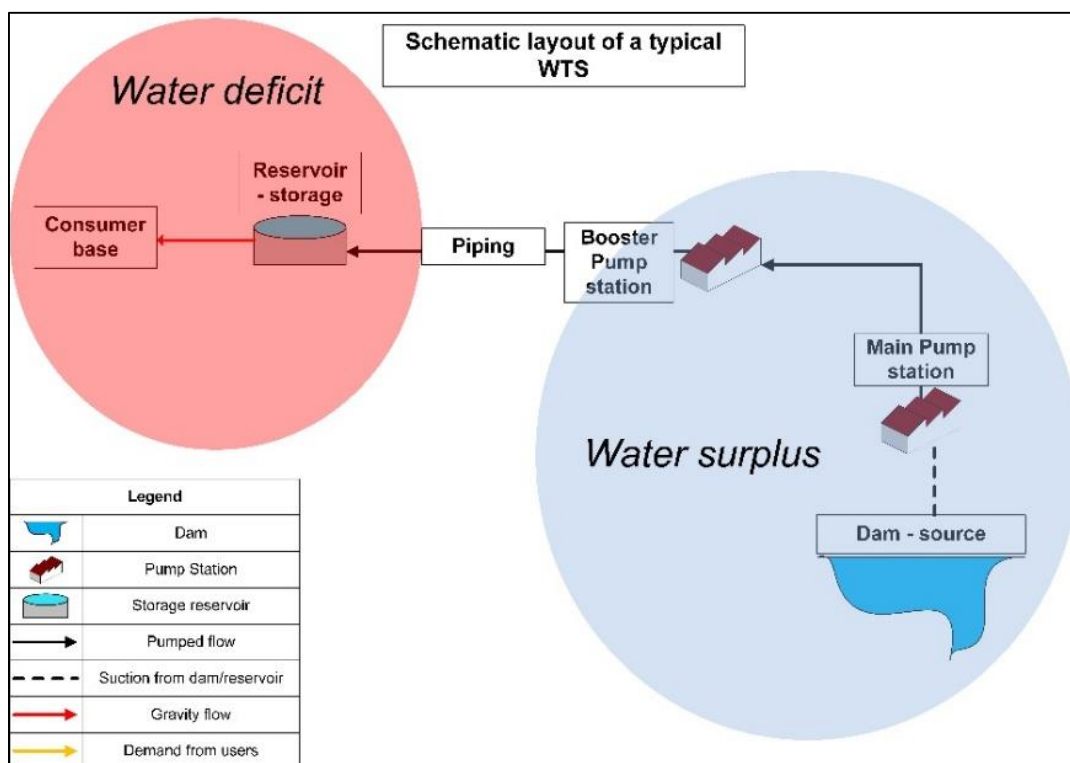


Figure 18: Schematic layout of a generic transfer scheme

Water source

In most cases, the water source forms part of a catchment. These sources are commonly rivers or dams within rivers. As mentioned in Chapter 1.4, these catchments have mean-annual runoffs (MAR), which result from the topography of the area, bring about streams, rivers and ground seepage. This MAR can be predicted and calculated, using two kinds of models: physically based models or black box models [42]. More detail on these models, and updated ones, will be given in Chapter 2.3.

The water source must be able to supply enough yield, ensuring spare capacity to supply the reserve of that catchment and its sub-systems. The yield from a water-resource system refers to the amount of water that can be abstracted at a predetermined rate on an annual basis, usually in million m^3/a (Mm^3/a). The reserve of a water source within a catchment system or subsystem is the amount of water required to supply the two main reserve components; the ecological- and basic human needs components. The yield of a water-resource system, therefore, is the remainder that can be abstracted after the supply of the reserve can be verified [37].

The ecological component represents the share of streamflow, which needs to remain in the rivers to safeguard the healthy functioning of natural aquatic ecosystems. The basic human needs component is the portion required to ensure the continued existence of the people located in the sub-system at an uncompromised standard of living, when compared to that prior to the commencement of abstractions and streamflow diversions [37].

The typical yield from a water source over a 12-month period is given in Figure 18 [37]. It shows how water must be stored during high flow months for use during low flow months.

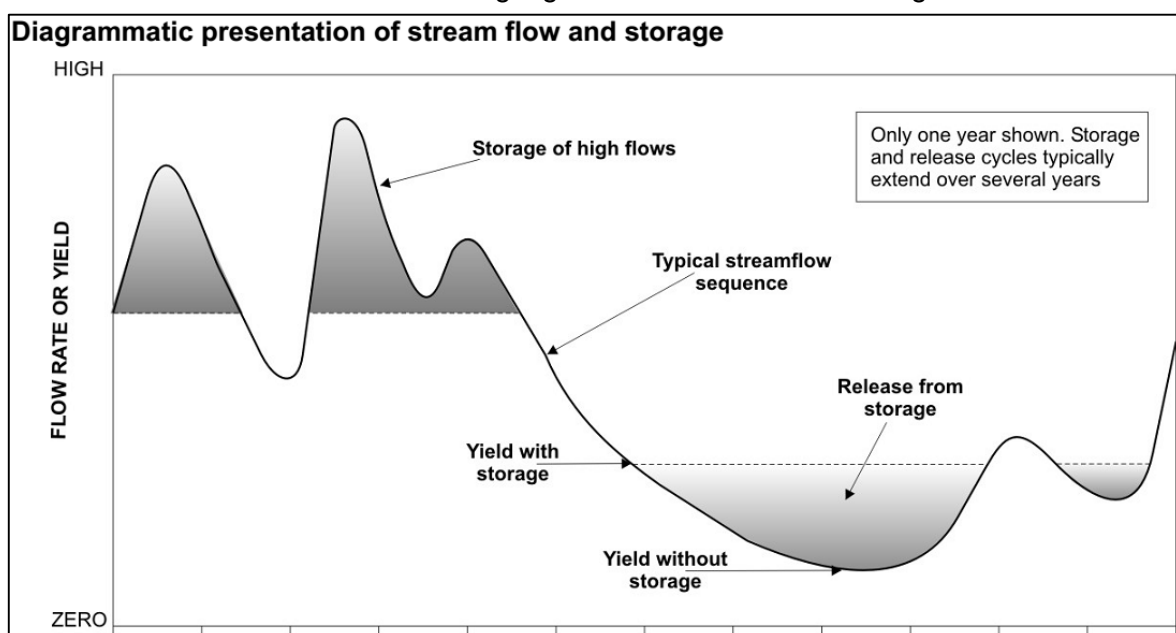


Figure 19: Typical annual yield from water -source

This will increase the assurance of available yield at higher abstraction rates over the entire storage-and-release cycle of water-resources.

It becomes clear that the more water can be stored within a catchment system or subsystem, the higher the assurance of yield availability during low flow periods. It also increases the assurance of reserve availability for that water-resource system. The higher the required assurance of a system, the higher the storage must be, or the smaller the yield of that system must be [37].

Water pumping infrastructure

This component of a WTS usually forms the heart of the system. It must be designed according to specifications derived from factors such as the distance the water must be pumped, the height it must be lifted and the rate at which it must be transferred. Various pump station design handbooks and guidelines [38] [41] state the major determining factors as being the location of the pumping- and intake infrastructure, and the anticipated heads and capacities.

The design head of a pump (or pump station) refers to its delivery pressure. This pressure is usually measured in metres, hence the term “head”. This system head ultimately determines the delivery pressure of a pump or MPS. It is determined by evaluating two key components; static head and friction head [43]. The static head is determined by the vertical height the pump must lift the water. The friction head refers to the resistance to flow in a piping system due to various factors such as pipe-surface friction, bend frictions and component frictions.

All these factors contribute to the resistance to flow of water through the system, and vary according to flow rates inside these systems. An example of a system curve is given in Figure 19 [38].

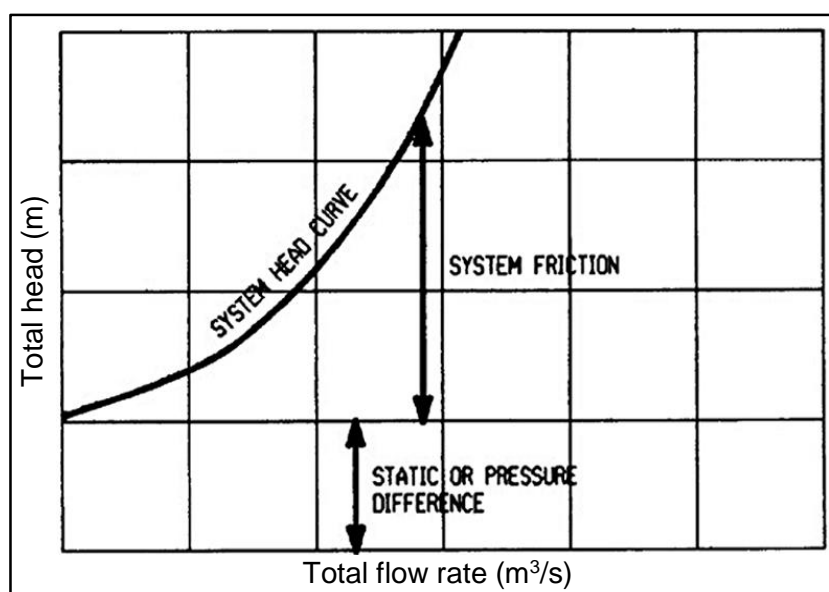


Figure 20: Example of system curve

Once the required flow rate and the applicable system head have been determined, pump selection can take place. Generally, there are two types of pumps in use for bulk water supply; vertical- and horizontal split case centrifugal pumps [41].

The centrifugal pump is the most popular type in the world. It is based on a simple principle where the fluid is led to an impeller hub and is thrown towards the outer edge of the impellers by the centrifugal force subjected to it. The construction is economical, robust and basic and its high rotation speed enables it to be connected directly to an asynchronous motor. It provides a steady liquid flow, and can be easily throttled without damaging the pump [44].

Horizontal split case centrifugal pumps (HSCCP) are generally used for their ease of access to pump components, such as the impellers, for maintenance purposes. An example of an opened HSCCP is given in Figure 21. This was taken at one of DWA's newer pump stations, located near the Vaal Dam, in Gauteng. They are usually placed in series with another HSCCP, shown in Figure 20. The purpose of this series configuration is for increased delivery pressures and to ensure sufficient suction pressure for the secondary pump [44]. Figure 20 shows the series configuration consisting of a single-suction HSCCP followed by a double-suction HSCCP.

Vertical split case centrifugal pumps (VSCCP) are generally used in applications with similar design conditions as HSCCP, but where space is limited. They are arranged as shown in Figure 22, taken at the abstraction works of the same WTS as Figure 21. It can be seen that the VSCCP takes up less floor-space, but requires more vertical height.

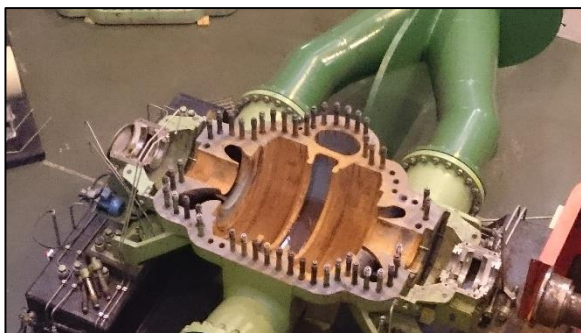


Figure 22: An open HSCCP



Figure 21: Two operational HSCCP in series

Figure 22 clearly demonstrates the advantage of lower required floor-space of a VSCCP, but also that it then requires more vertical space. In the case of VSCCP, the motor is positioned above the pump, compared to HSCCP where the motor is next to it. The motors used to drive these pumps will now be discussed. The pictures in Figures 19, 20 and 21 were taken by the author.



Figure 23: An operational VSCCP

The most common drive used for bulk water pumps is electric motors, more specifically, alternating current, squirrel-cage induction motors. These motors are specified based on the hydraulic power required to deliver the design flow rate at the design head, based on Equation 2 in Chapter 1.4. Motors can fail because of overload for extended periods and therefore motors are intentionally oversized to operate at only 75% to 80% of their full load capacity. At these loading levels, motor efficiencies and power factors remain rather high. However, when the motor load is lower than 25%, the efficiency and the power factor decrease drastically. It is therefore important to size the motor to ensure the associated losses are minimised [44].

Another important factor concerning pump-motors is how they are started and controlled. The three most popular methods of starting a motor are listed below [44]:

- Direct-on-line (DOL): It is started by connecting it directly to the power supply at rated voltage. DOL starting is suitable for stable supplies and mechanically rigid, and accurately dimensioned shaft systems, like pumps. It results in a high start-up torque and -current, but is the most simple and least costly.

- Soft starter: This refers to a device, which ensures a soft start of a motor by raising the voltage to a pre-set voltage within a specified raise time. The device is costly, but it reduces the start-up torque and -current drastically.
- Variable speed/frequency starting: This is similar to that of a soft starter, but doubles as a speed-regulating device for asynchronous motors. This means that except for managing the start-up current, it can be used to manage the delivered flow rate by varying the speed of the motor. This is a costly measure, but it can be used to operate a pump at the most efficient or required flow rates.

The manner in which these pump-motor sets are operated will determine the electricity costs associated with this operation. The water is generally pumped to a reservoir, or storage facility, from where it can gravitate into distribution networks or from where it can be used directly by industries.

Water storage infrastructure

Just as was the case for water sources such as dams and rivers, water storage units must be able to ensure a nominal supply to their consumer base. This implies that the volume must be enough to accommodate the annual daily average demand for 48 hours, without any inflow [40]. This basically serves as its reserve, as in the case of water sources. Not only must it be able to supply enough water during times of limited inflow, but it must be able to handle daily fluctuations in demand, specifically the peak demand for that consumer base. Reservoir levels are monitored by the supplying pumping station(s).

In many cases, reservoirs can supply a single industrial consumer. In South Africa, two of the largest industrial consumers are Eskom and Sasol Synfuels [45]. Both are located in the Vaal river system, with Eskom the main consumer of the water supplied by GWS-A in this study. In the case of Eskom, each power station has its own reservoir, and where levels are not directly monitored by the relevant pumping station, levels are reported in fixed intervals throughout the day.

Reservoirs can be built as open or closed structures. Open reservoirs are usually used for raw water storage, as they do not have to prevent any form of serious contamination. Closed reservoirs are used for potable water storage [46]. Closed reservoirs use air vents to regulate the release of air as the water-level inside fluctuates. Reservoir construction can vary from rectangular to cylindrical, based on spatial requirements. Other than the typical concrete reservoirs, open ground reservoirs with linings can also be a cost-effective option.

2.3 Water Supply Strategies in South Africa

This sub-chapter gives a detailed overview of water schemes and AOA, and how their results are used for water scheme management in SA. It will address how the national water network is an integrated series of schemes and why the need to manage these networks with WSS exists. The models used to determine and optimise these WSS will be described. How these WSS are interpreted and implemented on a practical level will be evaluated.

2.3.1 A need for water-resource management in South Africa

As is known at this stage, South Africa's integrated water resource systems are of the most complicated in the world. This is not only because of the low average annual rainfall and sparsely scattered resources, but because of the multitude of interlinked river systems and major IBT. As stated in Chapter 1.4, these IBT have the main purpose of ensuring water security in demand areas where the availability is low. One of the major problematic areas is the Integrated Vaal River System (IVRS), with its demand of approximately 3000 Mm³/a [47].

To address this problem, IBT are developed that provide water from various other basins outside that of the recipient basin, the IVRS. As can be seen in Figure 23, and Appendix A-6, there are many transfers from basins outside of the Vaal river basin into it.

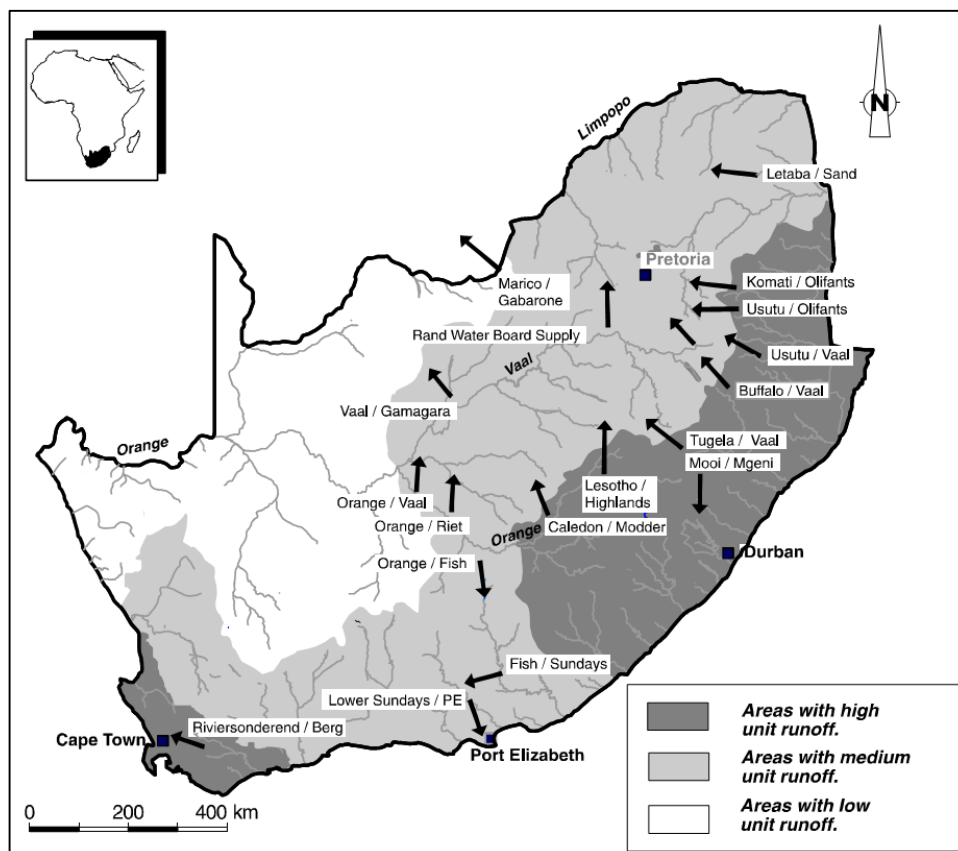


Figure 24: Map depicting IBT in South Africa

Many efforts have been made by the different water-users authorities to reduce demand, consumption and wastage due to leaks, as per the Water Conservation and Water Demand Management Strategy (WC/WDM) of 2004 [48]. It is quite obvious that if demand is significantly reduced by managing it in a sustainable fashion, the construction of more WTS can be postponed [49]. This would mean that the scarce water resources SA has to offer will be able to provide water at a greater assurance. This is because, as discussed in the previous section, if the abstraction rate out of a water source decreases, its assurance level will increase.

Except for effective WC/WDM strategies to reduce excessive consumption, proper supply management strategies are required. This implies that the transfers of water, water storage and water sources are monitored and managed effectively.

The IVRS, and the transfers to and from it, as well as a schematic of its integrated subsystems, are shown in detail in Appendix A-5 and A-6. The reason this study, and most AOA and resulting WSS focus on the IVRS, is because it is of national importance [47]:

- More than 80% of SA's electricity is generated in this area
- Two of SA's largest petro-chemical industrial plants are located in this region
- Many gold, platinum and coal mines are found in this area
- Over half of SA's population occupies homes in in this region
- More than half of the entire country's GDP is produced in the area.

The importance of the IVRS was underlined in 1983, when a massive evaluation of this water-resources system was commenced by DWAF. In light of the many high-demand centres and intricacy of the various inter-basin transfers, the need for a methodical and practical approach to the management of the water resources in South Africa was identified.

2.3.2 Modelling tools used to simulate water resource management

Different water-resource models were evaluated and it was concluded that the most fitting option was the adoption of the Canadian Acres Reservoir Simulation Program (ARSP). The ARSP was seen as the best model of its type on the market, making it a suitable starting point for the development of a new South African model [47].

The initial ARSP model was found to be lacking for South African application due to the complexity of the local water-resource networks and the varying climatic conditions. This required the use of stochastically generated streamflow sequences to attain realistic representations of actual system yields and their associated reliabilities. It was, however, selected by the DWA because it had a very flexible structure, making further upgrading and

modification possible. The most critical aspect of the model was its capacity to define a water-resource network and the related operating rules through a set of straightforward data files.

From this foundation, over the course of 18 years, the Water Resources Yield Model (WRYM) was developed. It makes use of many stochastically generated stream flow sequences as the input for the model. This enables water resource managers to analyse and simulate some of the most complex water-resource systems in a systematic way [47].

Based on the development of this WRYM for South African applications, a need was identified for a model that will aid in decision-making for future developments. The WRYM was limited in the sense that even though it modelled various system configurations, they were all based on respective static conditions. From these limitations, a more refined version of the WRYM was developed, which can evaluate changing system configurations over time. This meant that water demands, operating rules and certain water quality parameters could be varied over time. Finally, the Water Resource Planning Model (WRPM) was established.

Prior to the development of the above models, hydrological models, used to predict runoff and simulate water resource management, fell into two main groups: physically-based models and black-box models [42]. Physically-based models require lots of data to simulate different physical watershed-related processes. The black-box method extrapolates from non-linear relationships found between rainfall and runoff, without considering the physical processes.

Recently, the use of genetic algorithms (GA), to solve complex hydrological and water resource optimisation problems, was adopted. The possible applications of GA were clearly identified in a study performed in 2001 [50]. It was found that they can effectively be used in the determination of the most effective operating rules, without the need for human intervention during the calculation and evaluation phases [51]. This became necessary due to the large amount of data which had to be handled, required to optimise the management of the water resources. This necessity led to the follow-up study to the 2001 possible applications study, whereby various methods for the integration of GA into the current WRYM and WRPM were established [52].

In short, GA can be any mathematical procedure, which takes in certain data and modifies it in successive steps. The “genetic” or “evolutionary” methods in which the data is modified and evaluated, stem from Darwinian selection. This implies that the algorithms assess “populations” of stochastically generated stream flow sequences, based on how periodic differences due to environmental conditions impact “selective breeding” patterns.

The evolutionary nature, which these algorithms mimic, can be summarised in the following steps [53]:

- Commence with an initial population, which is randomly (stochastically) generated, but that contains the variability parameters characteristic of the population
- The fitness of each individual in the population is evaluated based on a fitness function
- The likelihood of each individual to survive is relative to its fitness
- The individuals of the next generation are selected according to this probability and through a genetic transformation process of crossover and mutation, thus, ensuring that the solution is not localised within the solution environment.

These GA basically assess the “fitness” or success of each set of operating rules from a population, based on stochastically determined stream flow conditions and varying demands [54]. The most successful operating rules, or water supply strategies (WSS), are then put through a genetic transformation process. This entails crossing over between different generations of WSS, mutating the most successful with each other or a combination of both transformations. Finally, the best WSS for the current, and most likely, future water-resource conditions are then selected.

A logical representation of this Darwinian process is given in the flow-chart in Figure 24 [55].

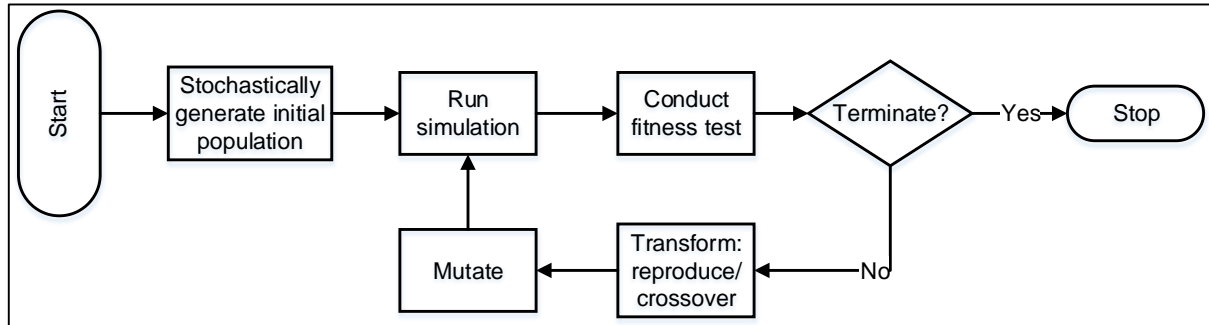


Figure 25: Flow diagram of logical steps taken by GA

2.3.3 Practical implementation of WSS

The WSS are selected based on subsystems within the larger drainage basin. The subsystems are very rarely isolated from each other. Boundaries, however, can be drawn between the interactions of these systems, based on a weighted penalty system [55]. These penalty systems form part of the GA discussed in Chapter 2.3.2, above, whereby a prioritised structure is developed.

This enables the simulations to place a priority on which streams, demands and reservoirs are most critical in their supply, under various available runoff scenarios. If the allocated penalty to a required runoff is higher than that of a priority allocated to a certain transfer route, that

transfer route will be voided and the next higher priority transfer route will be evaluated. If this transfer route's priority is higher than the penalty, then transfers through it will be allowed [56].

The physical manifestations of these WSS, derived from the weighted penalty system and GA optimisation of the WRYM and WRPM discussed above, are a set of operating rules. These operating rules can be categorised according to two groups; water transfer rules and water storage rules. Water transfer can refer to any mode of transport for water due to pressure differences, such as pipelines, rivers or canals. Water storages refer to any form of repository in which water can be held, such as lakes, dams, and various kinds of reservoirs, tanks, ponds or even weirs in rivers.

These operating rules, or WSS, are given in a document called an annual operating analysis (AOA). The period in which the operation and state of water-resources within a catchment area is monitored and reported on, is from each April to the following May. These AOAs state the basic assumptions made for the analysis and simulations, the water storage starting conditions, the projected demands and results of the previous 12 months. Based on these results, the relevant WSS for the current storage conditions are given. The information on how these WSS are presented, interpreted and executed by operational personnel, is derived from AOAs for the past six years [57]–[63].

Limits are placed on how much annual average flow is required through a water transfer channel based on the forecasted demand by the consumer base on the receiving end thereof, as discussed earlier. These limits can be a reflection of the minimum required transfer rate through a channel to be able to satisfy the demand. This type of limit is generally referred to as a lower limit for required transfers.

Transfer limitations can also be based on the maximum supply capacity from the source, referred to as upper limits. This supply capacity can be limited due to various physical constraints such as the flow rate through the pipeline or canal before it chokes or overflows [64]. It can also be due to the physical size of the pumps delivering the flow. Another major constraint on supply capacity is the amount of water, which can be abstracted safely without negatively impacting the reserve of the supply source, as discussed in Chapter 2.2.1.

Furthermore, limitations can be placed on the water storages. Source- and recipient storages will most often have a full storage level (FSL) and a dead storage level (DSL). These levels act as boundaries within which the storage must be operated. Generally, if the storage is operated above the FSL, water can be seen as under-utilised. As a more serious

consequence, above FSL operation can lead to spilling or flooding, and consequently damaging of the storage infrastructure or surrounding environment [65].

Operation near the DSL boundary can lead to water shortages and ultimately drought conditions. This will obviously adversely affect the supply of water to the consumer base, leading to socio-economic consequences, as well as retard the catchment's ability to provide supply for its reserve [66]. If the reserve capacity of a storage facility within a catchment is compromised, ecological disasters can occur, and the WTS will fail at its most important task [67].

WSS focusing on water storage play another very important role. That is to ensure balanced draw-down of the entire system within a catchment area. Balanced draw-down of water sources is important to enable an acceptable level of certainty for supply. This stems from the fact that if a recipient dam drops below its DSL, while its source dam remains between FSL and DSL, it will take too long for it to refill. In this time, ecological as well as socio-economic issues will arise in the recipient dam's catchment area and consumer base. When transfers commence, depending on the source's storage capacity, its storage levels will drop at high rates, which can lead to the same issues now arising at the source.

WSS therefore require a WTS to deliver a certain amount of water (target transfers) on an annual or monthly basis, to a consumer base. Simultaneously, the sustainable storage of water must be ensured by balancing the draw-down of these bulk storages. These WSS will be discussed in the methodology and results of this study, in Chapters 3 and 4.

2.4 DSM Interventions on Water Pumping Systems

Water pumping systems can vary based on their purpose and the type of transfers associated with these requirements. Pumping systems are actively employed in the following industries:

- Mine dewatering [68] [69] [70] [71] [72]
- Municipal water treatment plants (WTP) and distribution utilities [73] [74]
- Bulk water transfer schemes (including IBT). [27] [75] [76]

The main purpose of each of these systems depends on the nature of the pumping taking place. These differences in purpose will determine the manner in which the pumping systems are operated and according to which parameters. Overviews of the functional requirements and operation of these systems, due to their inherent differences, will be discussed. The baseline scaling and savings calculations on such systems will also be addressed.

2.4.1 Water pumping systems – operational control philosophies

Mine dewatering

There are two major sources of water in mines in South Africa; chilled water sent down shafts for cooling purposes and naturally befalling fisher water [72]. These sources result in large volumes of water congregating in the depths of mines, which need to be pumped to the surface. The water is usually cooled in a series of fridge plants and cooling towers on the surface, before it is sent to mining operations underground [70].

The purpose of water pumping systems in mines is to extract this water from underground back to the surface. This involves a series of cascading pumping stations on multiple levels along the shaft [68]. This cascading system can be split into two flows; chilled water, being sent down, and hot water, being pumped up. These pumping stations, on the different levels, regularly have reservoirs named “hot- and cold dams”. Accompanying these dams are a series of multistage centrifugal pumps, which pump the water out of the hot dams, up to the next dewatering level [77]. An example of such a dewatering system is given in Appendix A-8.

From Appendix A-8, it is apparent that there is no explicit demand, which the pumps need to supply on the hot-water side of the transfers. The hot water is, however, most often treated, chilled and sent down again in a “closed-loop” fashion. There is nevertheless the problem of excess fisher water. This implies that more water must be pumped out of the mine than was sent down for cooling purposes. The determining factor in the operation of these pumps are the levels of the hot and cold dams [68]. The cold-dam levels will impact how much water must be sent down from the cooling system. The hot-dam levels will dictate how many pumps must be in operation.

Both the hot and cold dams have operational ranges in which they must be kept. These levels insure that the cold dams do not drop below a certain required level, compromising the supply of chilled water to the mining operations underground. They also ensure that the hot dams do not overflow, resulting in flooding, damages and possible injuries and/or loss of life [71].

Municipal WTP and distribution utilities

Municipal water supply refers to the supply of water for commercial, residential and industrial use within a municipal area. The DWA, in conjunction with local and metropolitan municipalities and waterboards, are responsible for the quality and provision of this water [45]. WTP and the distribution systems following them, are used to provide these services. A schematic layout of the municipal water-supply value chain is given in Figure 25 [18].

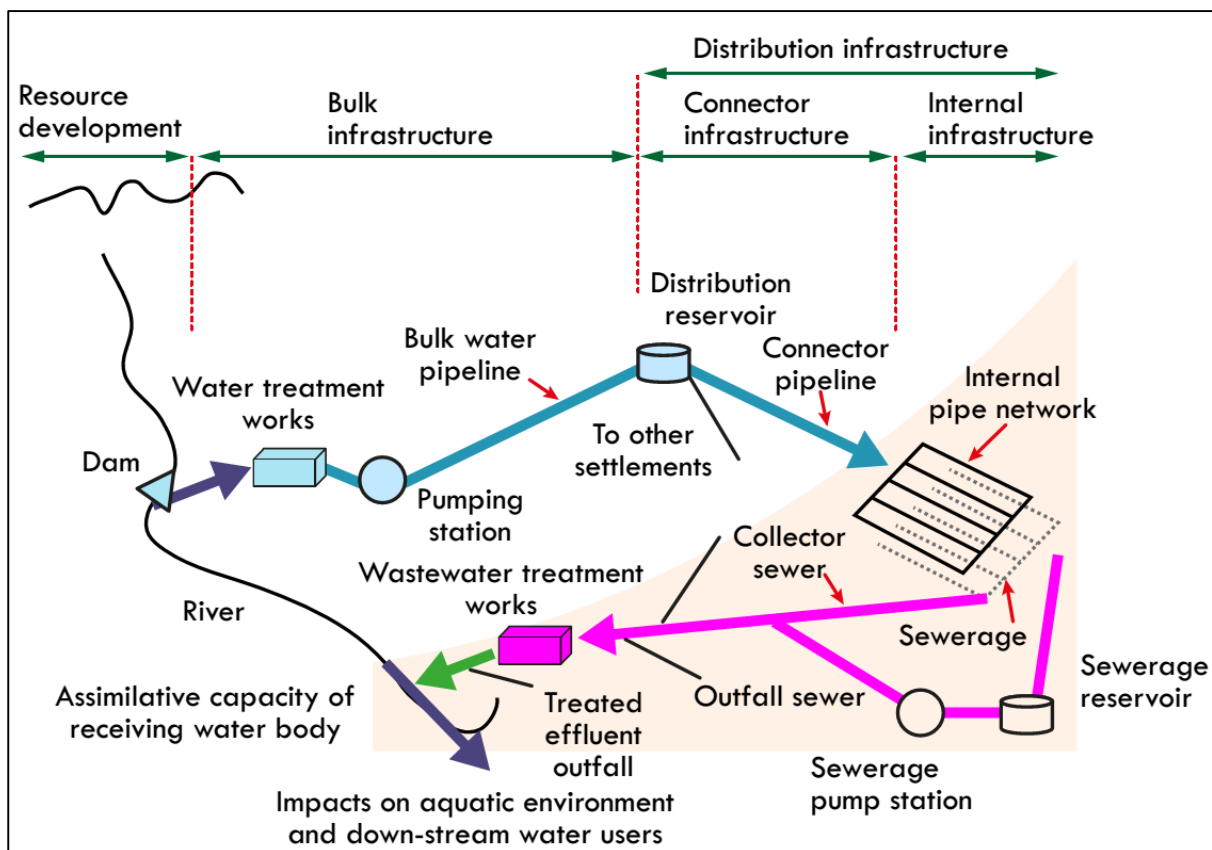


Figure 26: Schematic layout of the municipal water-supply value chain

The largest energy consumers in this supply network are the pumping systems at the WTP, MPS and BPS [78] [79] [80]. This is because large amounts of hydraulic energy must be added to the water for it to overcome height differences between the source and distribution network. In cases where the water is pumped directly into a pressurised distribution network, energy is also required to increase pressure so as to prevent backflow.

In a similar fashion to mine dewatering systems, the WTP and their MPS must keep the reservoirs downstream in the network at a certain level. As discussed in Chapter 2.2.2, reservoirs are designed to store a reserve amount, so as to be able to supply water into the network for up to 48 hours in the case of constrained supply. This means that these reservoirs need to be kept above a certain level, ensuring enough volume is available for such conditions. Another difficulty found was that if the reservoirs dropped too low, at times of high demand, the MPS at WTP would not be able to refill them if there were any constraints on their supply capacity.

The WTP and distribution utility need to ensure ample supply to the consumer base. This is reflected by the distribution-reservoir levels preceding the internal supply network depicted in Figure 25, above. These water-pumping systems are therefore operated according to the demand for water, and the level of the distribution reservoirs.

Bulk water transfer schemes and IBT

These transfers were discussed in detail in Sections 2.2 and 2.3. Since their main purpose is the transfer of water from basins with a water surplus to those with a deficit, they are mainly operated at a more constant load. This is because in many cases they do not supply a consumer base directly. This, however, is not the case for all bulk water transfers. The layouts for different types of WTS are given in Figure 26.

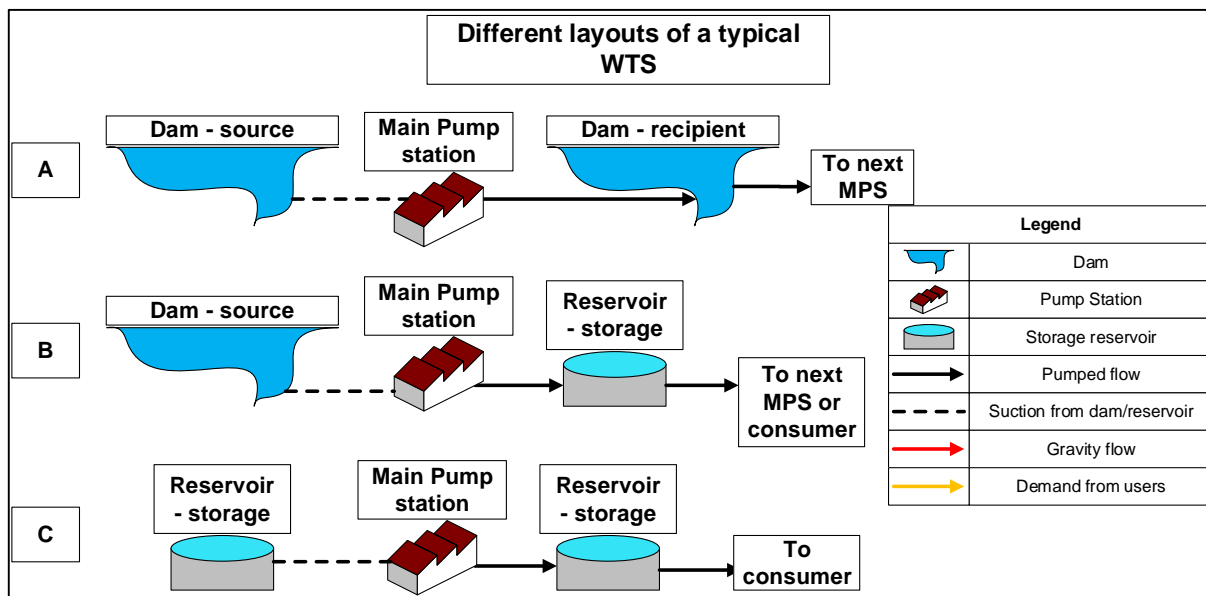


Figure 27: Schematic of different layouts for WTS

From Figure 26, it can be seen that each layout will supply according to different requirements. In layout A, water will only be supplied to the recipient dam if its level is below the specified level, as discussed in Chapter 2.3. When transfers do occur for layout A, they will not supply

an immediate demand directly, and will continue until the recipient dam has reached its upper level, as stated in the relevant WSS.

Layout B shows that the MPS in that WTS will most likely supply a required average daily transfer rate, in order to keep the reservoir at specified levels. This operation can therefore be intermittent, depending on the fluctuations of the reservoir. The same holds true for layout C, where transfers occur between two reservoirs. The main goal of that MPS will be to insure that the receiving reservoir levels remain within its specified range.

2.4.2 Previous DSM interventions on water pumping systems

Mine dewatering

As seen in Figure 9 Chapter 1.3, the mining sector represents around 14% of the national electricity consumption, of which another 14% is attributed directly to the mines' dewatering systems [70]. These systems have therefore been the subject of many DSM projects. Load shift projects can be implemented without the addition of any new infrastructure, since it only requires that the already existing systems be operated according to an optimised schedule.

In many cases, however, it is required that certain of the existing infrastructure be upgraded. This is necessary to insure that the rescheduling of the operations can take place without too much human input. These projects would typically consist of upgrading the pump station automation infrastructure [71]. This would usually imply that infrastructure such as control systems, communication systems, monitoring systems and supervisory control and data acquisition systems (SCADA) are either introduced or upgraded.

All this infrastructure would be employed to start and stop dewatering pumps in accordance with an optimised control philosophy [68]. These control philosophies optimise pump operation with the goal of reducing peak loads, while simultaneously monitoring dam levels. The dam levels would be prepared for load shifting by filling cold dams and draining hot dams prior to reducing peak loads [71]. By doing this, load could be reduced in peak times, resulting in DSM savings.

In some cases, DSM interventions can be implemented to not only reduce peak load, but also daily energy consumption [72] [71]. This would be termed a load shift and energy efficiency project. The water cooling system would be used to build up reserves of chilled water, and in combination with the use of turbines on the chilled-water side and optimised pump scheduling, the total energy consumption was reduced.

For all these factors to be taken into consideration to optimise pump operation, an energy management system (EMS) is employed [81]. Such an EMS will take all the required parameters into consideration and then either issue a pumping schedule to be implemented by an operator or automatically control the pumps. It has been shown that automatic control realises greater and more sustainable savings, since human error can be negated [71].

In the case of load shift projects, the same amount of electricity, or more, will most likely be used over a 24-hour period [71]. This is because the peak load must be recovered, as discussed in Chapter 1.3. DSM savings for load shift projects on mine dewatering systems can range from 2 MW to 6 MW, depending on the constraints of the systems. A summary of six load shift impacts at six South African mines is given in Table 2.

Table 2: Summary of DSM results at six mines in SA

Mine	Installed Capacity [MW]	Flow delivered [M ³ /day]	Load Shift Impact Achieved [MW]
Mine 1	26.0	23.0	4.5
Mine 2	27.2	22.0	3.5
Mine 3	23.8	65.0	7.0
Mine 4	18.8	11.0	4.0
Mine 5	11.0	19.0	3.8
Mine 6	47.2	45.0	11.0

From this table, it can be concluded that load shifting projects have been implemented extensively on mines around South Africa.

Municipal WTP, distribution utilities and bulk transfers

The installed power capacities of various bulk water pumping systems were reviewed in Chapter 1.4. These were not only limited to WTP, but included large IBT. For this reason, both municipal WTP and distribution utilities, as well as bulk transfers will be discussed in this section.

DSM interventions have also been implemented extensively on such systems. In a similar fashion to that of mine dewatering systems, load shifting does not necessitate any new infrastructure. It only necessitates the rescheduling of pump operation. As in the case of mine dewatering systems, infrastructure upgrades may be required at times to ensure correct integration between the existing SCADA systems and an EMS [73].

Municipal WTP and distribution utilities typically operate according to the demand from the consumers, as reflected in the distribution reservoir levels. This approach is typically referred to as “reservoir control”, or “res-control”. As for mine dewatering systems, these distribution reservoirs need to be operated between specified levels.

Distribution reservoirs have capacities in excess of 90,000 m³ and can reach volumes of 980,000 m³ [73]. This implies that their reaction to changes in inflow and outflow rate will be less sensitive than the smaller balancing reservoir located at BPS. These balancing reservoirs, located at the BPS itself, have capacities of around 20,000 m³. These balancing reservoirs’ levels therefore need to be in the right range for load shifting to proceed. This usually means that their levels need to be low in order to accommodate for inflow from the WTP upstream [73]. This is only applicable in cases where load shifting is implemented solely on the BPS within a distribution system, and not on the MPS at the WTP.

In cases where load shifting is implemented on the MPS at the WTP, the water treatment process needs to be taken into account. This process usually consists of a raw-water pump station, a raw-water reservoir, the treatment facility, a clear water reservoir and the MPS [74]. The MPS gets its water from the clear water reservoirs and pumps it to the distribution reservoir or BPS downstream from it. The MPS will therefore be operated according to the level of the clear water reservoir, as well as the level of the distribution reservoir to which it pumps [74].

The average DSM saving achieved on four BPS forming part of the largest distribution utility in SA, located in Gauteng, was 15.4 MW. This was done by using the balancing reservoirs at the BPS in order to prepare for load shifts during peak times [73].

Results from load shifting at a WTP, located in the North-West province, showed savings of 2.21 MW. This might seem much smaller than that of the BPS mentioned above, but it must be taken into account that the installed capacity of the pump-motor sets at the MPS was only around 3.75 MW [74]. Load shifts were achieved through the scheduling of the pump operation, while maintaining the clear water- and distribution reservoir levels within the acceptable ranges.

Load shift projects have also been implemented at pump stations forming part of an IBT. These projects were focused on the pump stations, which extract water from the Grootdraai Dam, and pump water to the Eskom power stations located in Mpumalanga. They form part of the Usutu-Vaal transfers. Two of the pump stations pump water between dams and the third pumps water directly to reservoirs located at the power stations [27].

A combined load shift of 12.6 MW was achieved between the three pump stations.

2.4.3 Baseline- and DSM savings calculations

Baselines are used as a reference of energy consumption patterns prior to DSM interventions being implemented. In the case of water pumping systems, it will characterise the operation of the pump-motor sets. This characterisation serves as a reference point from which the DSM savings of implemented projects can be calculated [82]. There are various approaches to baseline development, depending on which DSM intervention is implemented, as discussed in Chapter 1.4. This dissertation only focuses on the implementation of daily scaled, energy-neutral load shifts.

To determine an accurate representation of pumping and the associated electricity consumption, verifiable data is required. In most cases, metered data is preferred, since the validity thereof is simpler to trace. This data should be established for a period of at least three months of continuous operation. Data should not be too old, as it will give a false indication of operation if any infrastructural changes have occurred in the meantime. It should, however, also not be so recent that it might already reflect the impact DSM interventions [72].

Data from the following sources can be used [72]:

1. Metered data in 30-minute intervals of the total pumping system
2. Metered data of individual pumps in 30-minute intervals, which can be added up for a total load profile
3. Operational schedules in the form of log sheets or SCADA data and the operational load of the individual pumps or pump configurations.

Baseline development

All available load profile data can be considered. The dataset can then be analysed and irregular behaviour, which cannot be explained by the M&V, ESCo or client, must then be removed. The most recent set of consecutive power data prior to any form of ESCo involvement can then be selected [72].

The data should be split in 30-minute intervals and then allocated in weekday, Saturday and Sunday groupings. The average weekday load can then be calculated from all the weekdays for the selected three-month period. The same must be applied for the Saturday and Sunday profiles, respectively. These profiles represent the baselines of energy consumption for the weekdays, Saturdays and Sundays [72]. The M&V weekday baselines for the case study of GWS-A can be seen in Appendix B1 and B2.

Baseline scaling

Service level adjustments, or scaling factors, can now be used to adjust or scale the baseline according to each day's electricity consumption, after the implementation of load shifting. The scaling of the baseline will make it possible to see a more realistic representation of the energy demand after load shifting. This is done to adjust for changes in operational requirements at the pump station, making sure that the net impact of the load shift is energy-neutral on a daily basis [83].

For this to be the case, it must be assumed that the system efficiencies remain the same after the implementation of load shifting as before. The calculations below will result in the total electricity consumption for the scaled baseline being equal to that of the actual electricity consumption for that 24-hour period. The steps required to perform energy-neutral daily scaling are given below [83] [72]:

1. Calculate the total 24-hour electricity consumption for the baseline load profile, where;

E	= Energy	(kWh)
P	= Power value	(kW)
subscript B	= Baseline	
subscript i	= hour of the day	(0 to 23, 00:00 to 23:00, for a 24-hour day)

Equation 3

$$E_B = \sum_{i=0}^{23} P_{Bi}$$

2. Determine the total electricity consumption separately for each day after load shifting has been implemented, where;

subscript AL	= Actual, after load shifting
--------------	-------------------------------

Equation 4

$$E_{AL} = \sum_{i=0}^{23} P_{ALi}$$

3. With the above two total electricity consumptions, calculate the scaling factor (SF);

Equation 5

$$SF = \frac{E_{AL}}{E_B}$$

4. Multiply the scaling factor with each power value (kW) of the baseline to scale it up or down, depending on whether more or less electricity was consumed on the day in question;

subscript SB = scaled baseline

Equation 6

$$P_{SBi} = SF \times P_{Bi}, i \in \mathbb{Z}, 0 \leq i \leq 23$$

DSM savings calculations

The DSM savings for each day, due to the implementation of a load shift, can now be calculated with respect to the scaled baseline. The scaled baseline now serves as a reference from which to measure by what amount the power load was reduced during the evening peak period (EPP). The EPP refers to the two hours from 18:00 to 20:00, i.e. the 18th hour and the 19th hour. The Megaflex time-of-use (TOU) chart in Appendix A-1 will aid in visualising this time slot. The following equation is used to calculate the DSM saving, where;

\bar{P} = Average power value (kW)

subscript PLR = peak load-reduction (kW savings)

Equation 7

$$P_{PLR} = \bar{P}_{SBi} - \bar{P}_{ALi}, i \in \mathbb{Z}, 18 \leq i \leq 19$$

For simple notation, the hours over which the average is calculated, are taken as integers (\mathbb{Z}). This does not have to be the case; if the time intervals between metered power values are five minutes, then the average will be taken over all 24, 5-minute intervals, instead of over two 1-hour intervals. This DSM saving calculation is demonstrated in Figure 27.

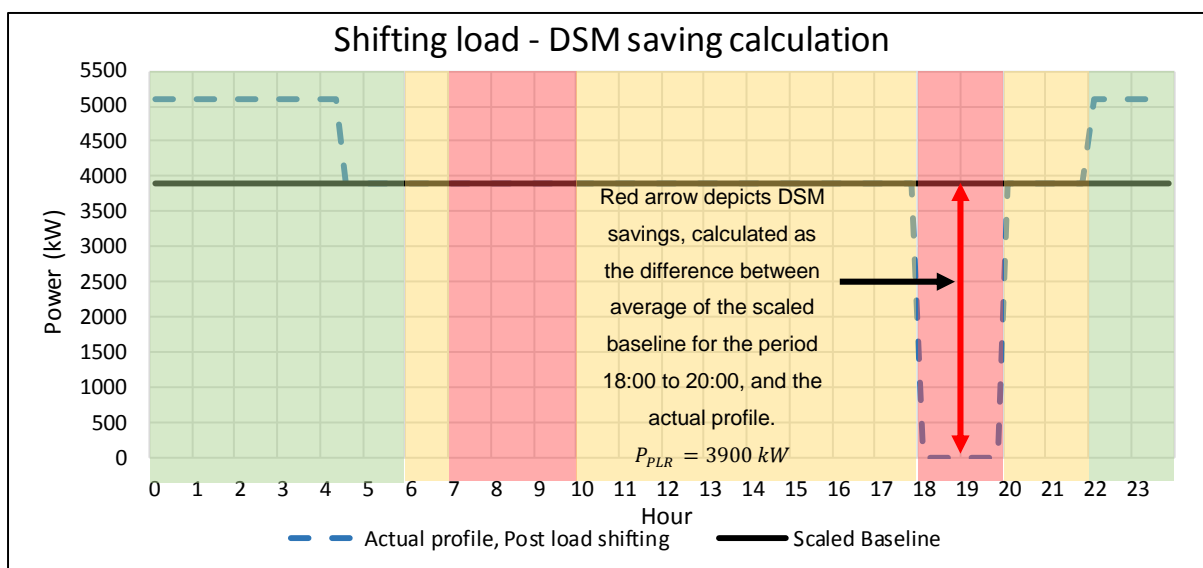


Figure 28: Shifting load – DSM savings calculations

2.5 Literature Study Conclusion

In this literature study, the need for transfer schemes in South Africa was reviewed. The factors that are taken into consideration when planning a WTS were also given. The functionality of the different sub-systems within a WTS was discussed.

From the need for WTS came a need to manage them. Their large sizes, both geographically and in terms of transfer capacities, necessitated that their interaction with the water resources they rely on be simulated and regulated. The results from these simulations are summarised in an annual operating analysis, and from these, operating rules or WSS are stipulated.

Finally, DSM interventions on other water pumping systems were reviewed. It was found that load shifting is practical and achieves high peak-load reduction. These peak-load reductions and the projects resulting in them, must however be approached from an operational point of view and take the system infrastructure into account. The methods used by an ESCo and an M&V team, to calculate DSM savings for load shift projects, were shown.

3. METHODOLOGY

Y-Junction in a bulk water supply line leading to Davel reservoirs¹⁰



¹⁰ C. Scheepers, photo taken at Davel reservoirs, large-diameter supply lines.

3.1 Overview

This chapter intends to provide clear insight into the background and historical information used in the implementation of previous WSS and AOAs. This will serve as a prelude to the methods used to quantify the interactions between WSS and DSM interventions.

3.2 Introduction to Methodology

This introduction gives an overview of the approach used to consider the interactions between the processes that form the basis of this study, namely DSM interventions and WSS.

3.3 Case Study Site Description – GWS-A

After the reasoning behind the methodology used has been discussed, the reader will be familiarised with the water scheme, which serves as the case study. This will include a brief overview of the WMA in which it is found and the components which form part thereof. In the following chapter, the WSS that were supplied for the GWS-A will be examined.

3.4 Summary of Past AOA – GWS-A

With the background of GWS-A given in Chapter 3.3, the reader will now be presented with an overview of the past six years' AOA. The goals of these AOAs, their targets and a breakdown of how much of these annual targets were achieved, will be given.

3.5 Methodology Conclusion

The detail discussed in Chapter 3 will be summarised and the relevance thereof in terms of the following chapter will be underlined.

3.2 Introduction to Methodology

The aim of this dissertation is to provide insight into how DSM interventions and water supply strategies affect each other. Based on these effects, a foundation will be laid to investigate integrating these two processes in a mutually beneficial manner. The diagram in Figure 28 shows the various interactions between the WSS, the WTS, which they regulate, and the load shifting implemented on them.

As the title of this dissertation states, the two processes being integrated are the WSS and DSM interventions. A key factor, however, and the objective of both of these processes, is the water transfer schemes on which they are implemented. The manner in which these two processes interact with each other, through the WTS, will be discussed in detail below.

Direct effects

A. The actual demand of a water scheme can directly impact how achievable the annual target set by the AOA for a water scheme is. This is so because, although the demand of a scheme and its fluctuations are taken into account during the simulations for the AOA, it can be influenced by various external factors, most notably:

A-1. Maintenance performed on other water schemes, which the scheme in question delivers the bulk of its supply to, or which it can supplement or augment to when required, can have an impact. Planned maintenance is taken into account during the AOA, as discussed in Chapter 2.2.2, while unplanned maintenance or shutdowns have a more adverse impact on the scheme's demand, or supply thereof.

A-2. Seasonal changes are taken into account during the simulations from which the AOA are derived. Unexpected seasonal changes such as El Niño's, which commonly lead to droughts in the southern hemisphere, and their effects on rainfall, can however not be predicted with as much certainty as the normal annual weather and rainfall patterns [84].

A-3. The water quality of certain dams can vary based on rainfall (and resulting floods), surrounding sediments, farming activities and industrial activities, just to name a few. These unforeseen changes can influence which sources are used to supply water to nearby power stations, as the water quality has an impact on the lifespan of their water reticulation systems.

B. The components of a water scheme can also directly affect the DSM interventions enacted on a pump station. Although most aspects regarding these components are

taken into account in as much detail as possible during the simulations for the AOA, certain unplanned events and constraints can have an impact on how achievable the annual target is, as well as how achievable the DSM savings are.

B-1. As discussed above, planned maintenance on a scheme, and the limitations on capacity resulting therefrom, are taken into account during the simulation for the AOA. Unplanned maintenance on components such as canals, pipelines, electrical infrastructure, pumps and even communications systems, can limit the capacity available to pump water. This has a direct effect on DSM interventions.

B-2. The components that form part of a water scheme all have certain physical constraints. Pipelines have a design-specified flow rate and pressure which cannot be exceeded. Motor-pump sets can only deliver a rated flow at a specific RPM and head. The transformers that supply electricity to the pump stations at the required voltages and ampere also have a specified design capacity. All these aspects directly affect how much flow rate can be delivered by a scheme, and any unplanned changes in one of these will have an effect on the feasibility of DSM interventions.

C. The minimum and maximum dam levels stated by the AOA, which are determined with the simulations discussed in Chapter 2.3.2, will directly determine when a scheme, or subsystem within a scheme, operates or stops. These upper and lower bounds stated in the operating rules for a specific year are in place to ensure that there is always a reserve amount of water available at an acceptable certainty level. When dams or reservoirs near this level, water will either not be transferred from it any more, or water will be transferred to it from another scheme or subsystem. This will directly affect whether DSM interventions may take place or not at a pump-station.

D. Finally, the baselines and how they are selected, grouped and scaled, directly impact the savings of DSM interventions imposed at a pump station.

D-1. The boundaries of a baseline determine which components and energy systems are taken into account when determining a benchmark for pre-DSM energy and power consumption. It is determined by various aspects, as discussed in Chapter 2.4.3. This grouping of baselines will determine what savings are achievable at a pump station.

D-2. The method used to scale a baseline is of cardinal importance to the longevity of the savings intended to be achieved by the DSM interventions [85]. Not only does

it affect the longevity, but also the immediate savings, and how they are affected by changes in the water scheme as a whole and changes at the pump station itself.

Indirect effects

- A₁ The fluctuations in actual demand have an indirect effect on the savings achieved by DSM interventions, through impacting the annual target, as set out in the AOA. If the actual demand that a water scheme needs to supply decreases drastically, for example due to higher than expected rainfall, the water scheme in question will not have to supply as much water. This means that fewer pumps will be running, or when VSDs are in use, they will be running at lower speeds, both resulting in a below-target saving. This will be demonstrated in detail through the case study, in Chapter 4.
- B₁ The scheme components and their limitations will indirectly affect how achievable the annual volume target is for the water scheme in question, by directly impacting the DSM interventions performed. If the limitations are not taken into account with regard to the annual target, and DSM interventions, such as load shifting, are performed, comeback loads, for example will not be possible and the annual target will gradually be missed over time. This will be discussed in detail through the case study, in Chapter 4.
- B₂ These components and their limitations will also have an indirect effect on the savings of DSM interventions performed on a pump station within a water scheme. By limiting the capacity of the scheme in question to a certain point, DSM interventions such as load shifting might not be achievable at all, and no or minimum savings will be possible.

From the description of process interactions above, the diagram in Figure 28 was constructed. In this figure, it becomes clear that there exist two points of cause-and-effect concentrations; at the savings of DSM interventions and at the AOA target transfers for a water scheme. It is these two aspects that therefore require the most attention when a cause-and-effect analysis is done, and when the integration of this entire system is considered.

To consider the inter-process effects holistically, they must be examined in further detail. In this methodology, a comprehensive analysis of interactions between the two processes is conducted. The ultimate goal of this analysis will be to quantify these effects. The results from this analysis can then be used to understand the interactions and draw conclusions on how to manage both processes sustainably.

To analyse the interactions between the two processes, the goals of each must be prioritised. This is necessary ultimately to justify whether the effect of the lower priority process on the higher one is such that it will affect the goals set by the higher priority process. Accordingly, if this is the case, then the higher priority process will be qualified and the lower one will not, for a specific scenario.

Secondly, the interactions between the WSS and WTS, and between DSM interventions and WTS must be characterised. To do this, the way in which the two processes are intended to operate individually must be understood. Thus, the ideal pre-DSM scenarios, demonstrating how the WSS and water scheme are supposed to interact under high- and low transfer conditions, will be considered. Hereafter an ideal post-DSM scenario, demonstrating how the DSM interventions are supposed to interact with the same high- and low transfer conditions, will be evaluated.

The results from the simulations used to quantify the pre- and post-DSM scenarios will then be verified. This will be done by comparing them to results from the actual performance assessment phase of a load shift project implemented on pump stations within GWS-A. The verified results of the ideal and actual scenarios will then be compared to each other and conclusions will be drawn based thereon. These conclusions will then help to understand the mutual effects DSM interventions and WSS have on each other.

The methodology used to evaluate the process interactions depicted in Figure 28, below, is given as:

1. The *analysis* of historical pumping tendencies at Pump stations A, B and C.
2. *Simulate* pre- and post-DSM scenarios to compare results of the performance indicators for the pump stations under low- and high transfer conditions:
3. *Verify* the results from the simulations by comparing them with results from the case study during the implementation of DSM interventions in 2014.
4. Discuss the results from the simulations and the case study to *validate* the need for this study by reaching *conclusions*.

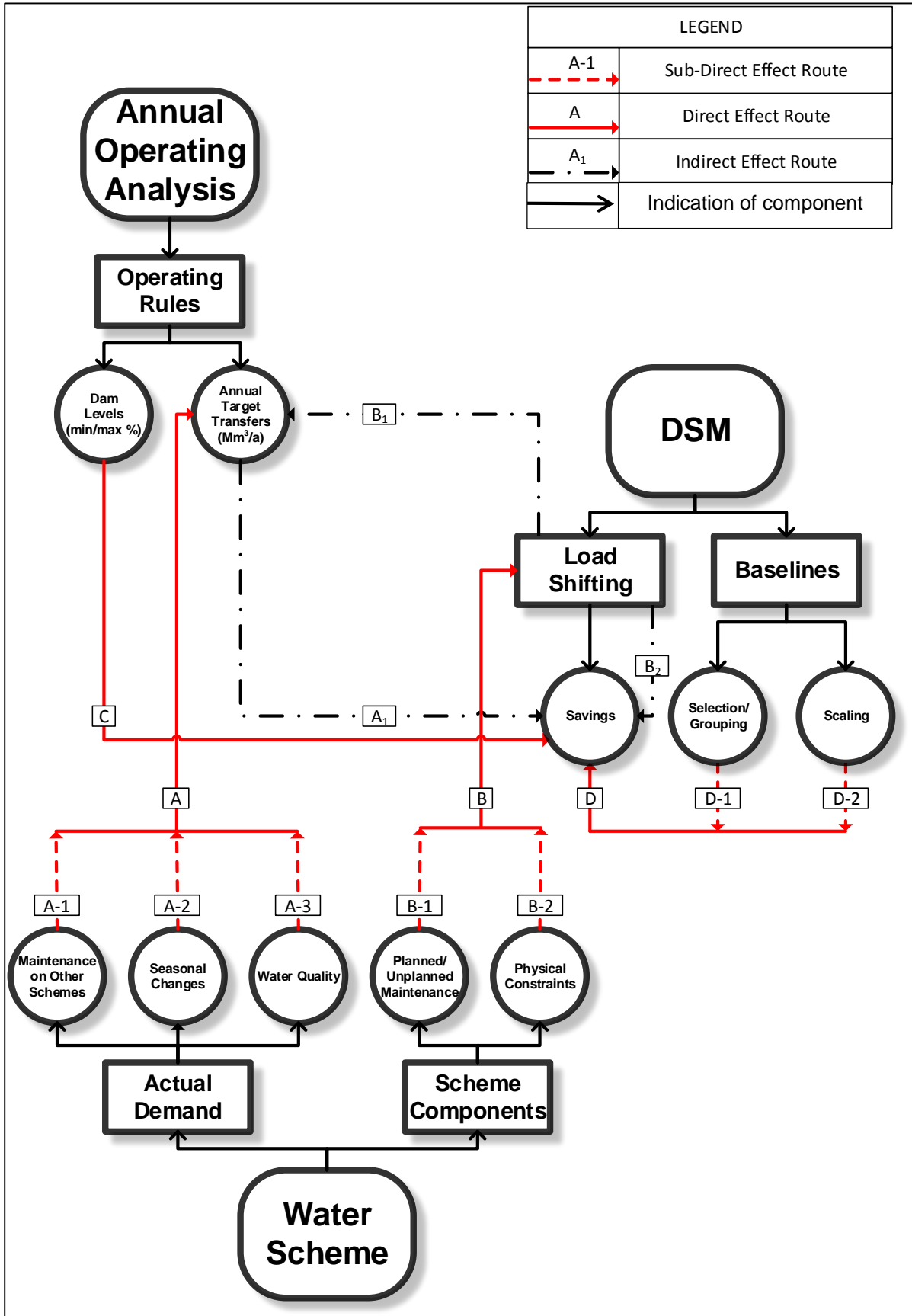


Figure 29: Post-DSM process interactions

3.3 Case Study Site Description – GWS-A

The case study used in this dissertation is a Government Water Scheme located in Mpumalanga, South Africa. It will be referred to as GWS-A from this point onward in this study. It is found in the Usutu-Mhlathuze WMA. Its main drainage basin is in catchment area W, the Mfolozi basin (Appendix A-7) and consists of the Usutu- and Pongola Rivers, which have their confluence before entering Mozambique as the Maputo River. The sub-catchment area in which GWS-A is found, is the Upper Usutu. GWS-A transfers water from the Upper Usutu to the Upper Vaal and Upper Olifants WMA's. Transfers may also be made to the Inkomati WMA, when needed, as shown in Figure 29 (Adapted from [86]).

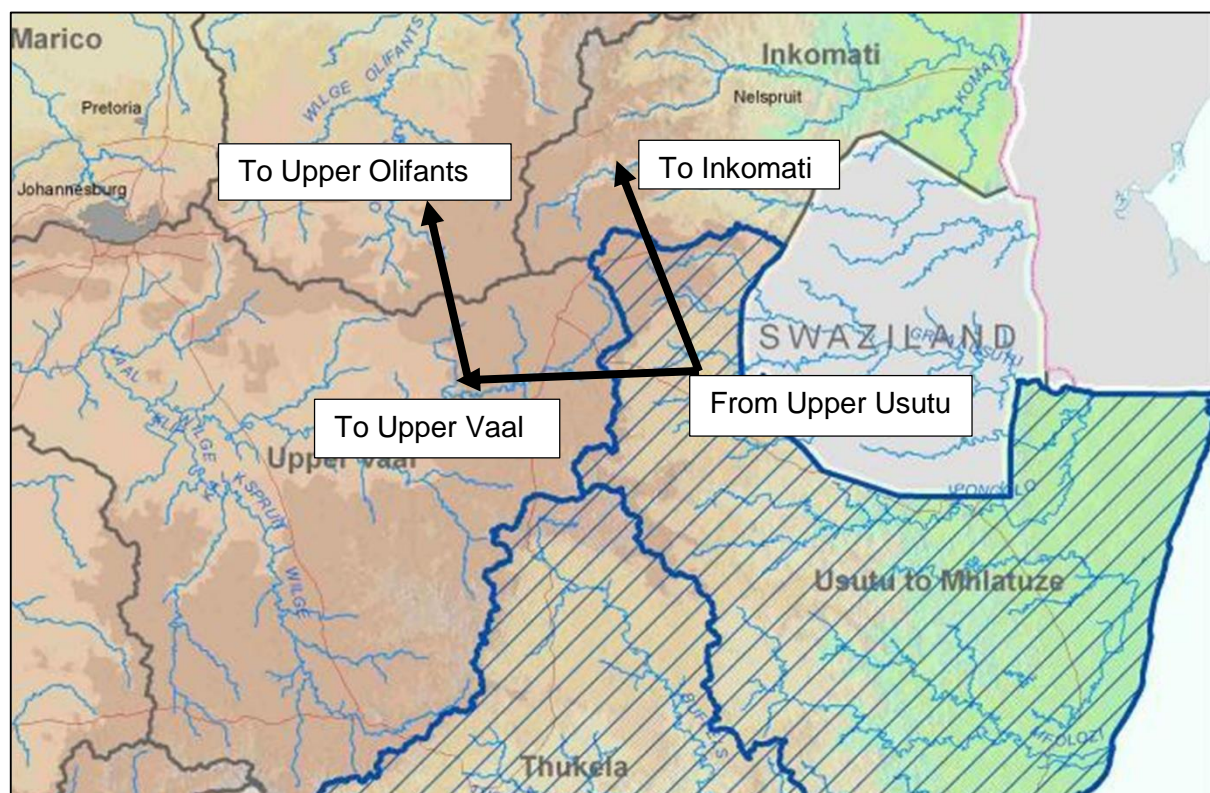


Figure 30: Map showing transfers by GWS-A

The scheme consists of four main pump stations, three main supply dams and a series of balancing reservoirs. They are depicted in the layout in Figure 30. Load shift projects were implemented at Pump stations A, B and C, and they form the basis of the case study and simulations. Pump station D was not included in the original load shifting projects, as it was not in use at the time of project implementation. This is because of the WSS in operation at that time, which will be discussed in Chapter 3.4.

Figure 30 shows how water is transferred by the pump stations between dams and reservoirs. More detailed layouts of the pump stations themselves are given in Appendix C-1, C-2 and C-3.

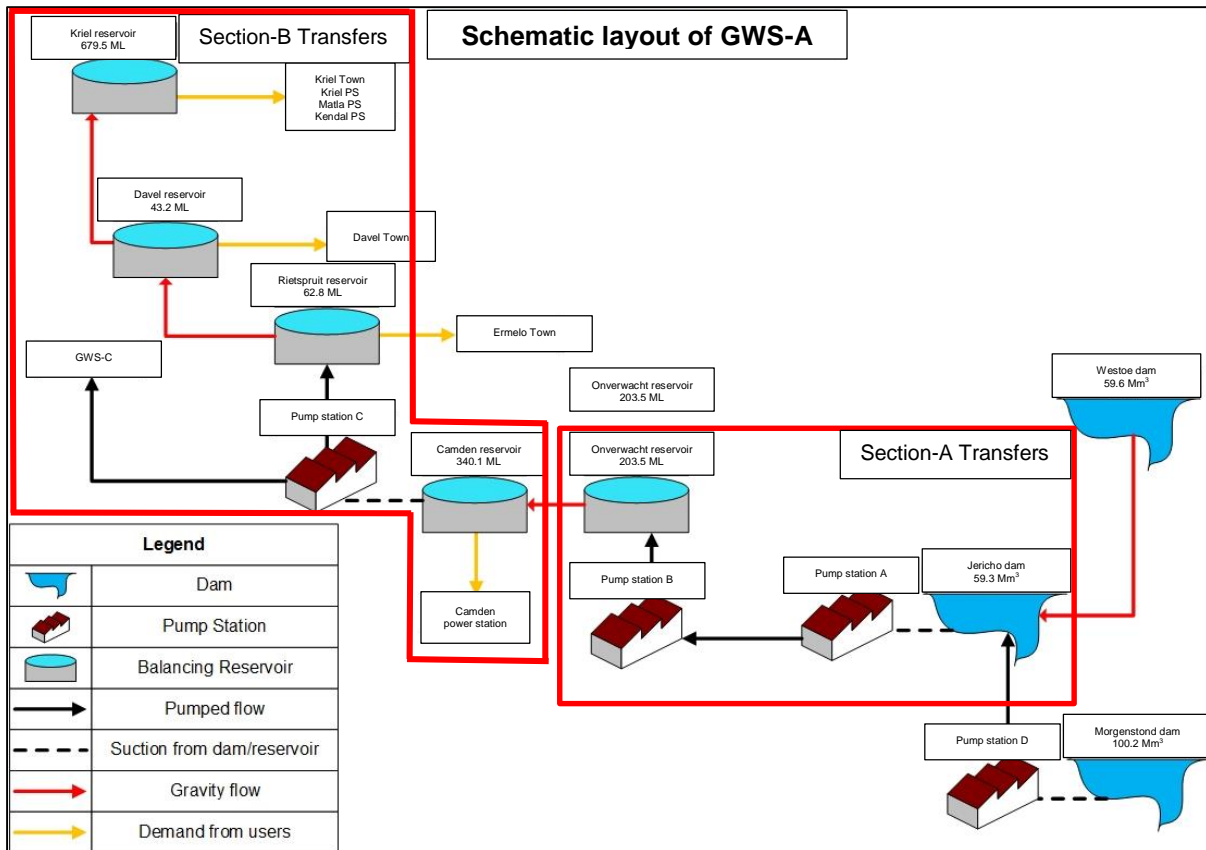


Figure 31: A schematic layout of GWS-A

Brief overviews of the installed pump-motor sets and plant capacities are given in Table 3 and Table 4, below.

Table 3: Brief overview of pump-motor sets

Pump station	Number of pumps	Max in operation	Installed power rating
Pump station A	6 (4 small and 2 big)	4	3455 kW & 3650 kW
Pump station B	4	2	2400 kW
Pump station C	3	2	2813 kW

Water is pumped from Jericho dam to the Onverwacht reservoirs. Between Pump station A and Onverwacht, the water passes through a booster pump station, Pump station B. Pump station B is mainly used to charge pipelines after maintenance has been performed or when Onverwacht reservoir's levels have dropped to critically low levels. Pump station B can only be operated when two pumps at Pump station A are pumping into the same line. There are two pipelines from Pump station A, called the North and the South lines. Because of pipe friction, when two pumps pump into the same line (in parallel), the flow achieved is lower than

when two pumps are running on separate lines. The booster pumps at Pump station B increase the delivery pressure to Onverwacht. It slightly increases the flow rate delivered by Pump station A as well, as demonstrated in Figure 31.

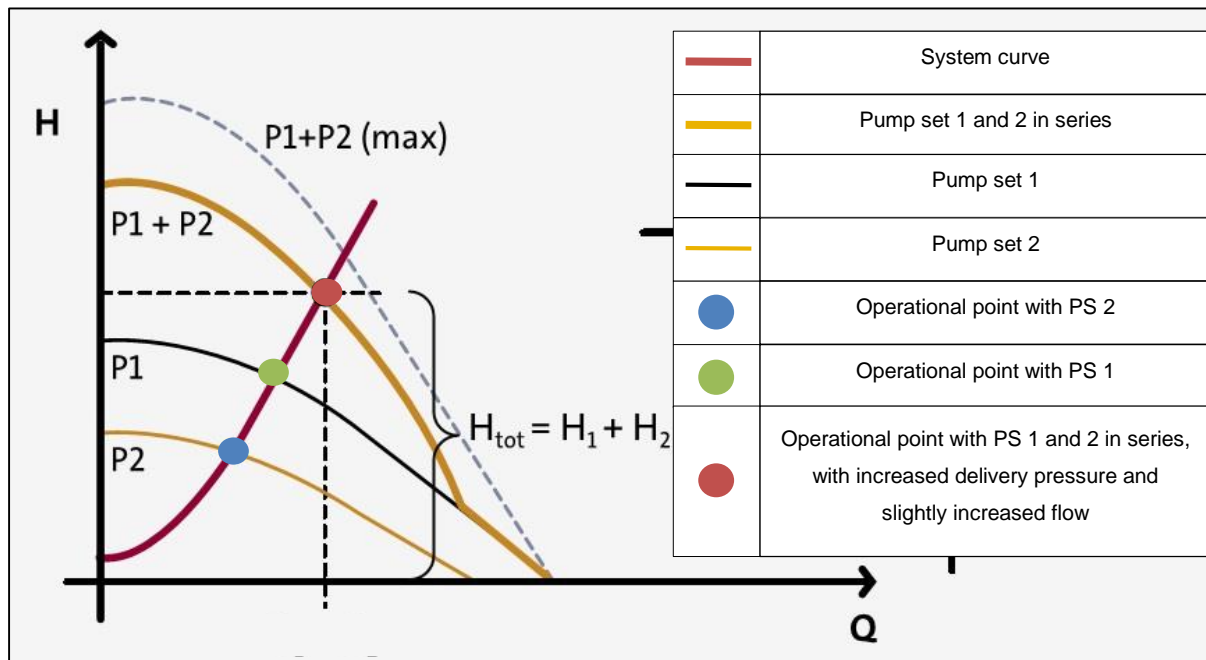


Figure 32: Pump- and system curve for series operation

From Figure 31, it is clear that if the booster pumps are in operation downstream from Pump station A, they increase the delivery pressure to Onverwacht. For an unchanged system curve, however, the flow will be higher than if the pump configuration at Pump station A were in operation alone. Table 4 gives the operational parameters for the different possible pump configurations between Pump station A and B and for Pump station C.

Table 4: Pump stations A, B and C operational parameters

Description	Total Flow (m ³ /s)	Pump station A (kW)	Pump station B (kW)	Pump station C (kW)
1 A, no B	0.92	3777	0	3777
2 A on different lines, no B	1.72	7000	0	7000
2 A on same line, no B	1.1	5690	0	5690
2 A + 1 B	1.66	6600	2500	9100
3 A, no B	2.02	9200	0	9200
3 A + 1 B	2.8	10100	2500	12600
4 A, no B	2.2	12000	0	12000
4 A + 1 B	3	12300	2500	14800
4 A + 2 B	3.3	13200	5000	18200
1 C	1.61	0	0	2500
2 C	2.56	0	0	5000

Pump station C delivers most of its water to the Rietspruit reservoir, from where it gravitates to Davel reservoir and finally Kriel Reservoir. From the Rietspruit reservoir, water is also drawn

off to the town, Ermelo. The water from Davel is mostly used to supply the Kriel, Kendal and Matla power stations. When Pump station C runs two pump-sets, it can deliver water to the Inkomati scheme, through what is known as the Usutu-Inkomati (UK) pipeline. This water is transferred to the Nooitgedacht Dam, to supplement the water from within the Inkomati scheme.

Further upstream in the water supply, water is drawn from Heyshope Dam. This water is pumped to Geelhoutboom Dam, from where it is then pumped to Morgenstond Dam. This is supposed to occur when Morgenstond reaches 80% FSC [57]–[63]. Heyshope, however, does not only supply Morgenstond Dam, but also Grootdraai Dam, when Grootdraai is below 75% FSC. This will be discussed in more detail in Chapter 3.4.

All these operating rules apply to the greater Usutu and Usutu-Vaal areas, and have an impact on how the water is distributed, according to dam levels. In addition to these rules, there are further WSS, which stipulate the required average flow rate by the different sections of GWS-A, as discussed in Chapter 2.3.2. The past six years' AOA results and operating rules are summarised in Chapter 3.4.

3.4 Summary of Past AOA – GWS-A

Aim of an Annual Operating Analysis

An Annual Operating Analysis aims to assess the previous year's operation, in light of that year's WSS, and provides a set of operating rules for a water scheme for the next year. The AOA and the simulations from which it is derived, are based on the demand and runoff, for that WMA, the restrictions of the system and the yield of the specific catchment area. As discussed in Chapter 2.3.2, the operating rules or water supply strategies (WSS) serve as a guide to manage multiple resources to achieve maximum supply from the system. Part of managing these resources is to guarantee the supply of water with continuously changing water requirements over the foreseen planning period in a sustainable way.

In the introduction of each year's AOA, the following statement is made:

“The purpose of this report is to present information on the storage-state and long-term sustainability of the water resources of the Integrated Vaal River System (IVRS). Analyses were undertaken over the period 1 May 2008 to 30 April 2025, using 1 000 stochastically generated streamflow sequences, to test the impact of an updated set of water requirement projections and various operating scenarios on the system's overall assurance of supply.”[57]

Operating rules

The operating rules can be seen as strategies to regulate the supply and demand of water. These water supply strategies (WSS) consist of a set of limits on dam levels, dam draw-down sequences and annual transfer volumes in millions of m³ per year.

For the GWS-A, these WSS must regulate the levels of four large dams, the annual flow out of them and ultimately the supply to the various towns, industries and other water schemes. The supply of these dams must be guaranteed to prevent the entire system reaching a critically low state. GWS-A has a complex customer base, including power stations, farmers, towns and other water schemes on an augmenting basis. With this in mind, the annual target transfers aim to ensure enough supply to this consumer base and the continuously growing demand. Demand-growth forecasts, however, are supplied by municipalities, industries (power stations) and other major users [57]–[63], discussed in Chapter 2.2.2.

A breakdown of the annual targets and the actual transfers per reporting period, is given in Table 5, further below. The graphs depicting these annual volumes are given in Appendix C-4 to C-10, but are discussed in this chapter. Upon examination of these summarised results,

it can be seen that, for certain target transfers, they are either under- or overachieving annually. The deviations from target should, however, be evaluated in more detail.

Past target transfers versus actual transfers

Heyshope Dam to Grootdraai Dam

Firstly, the reason why this transfer is included in the examination of annual target- and actual transfers is because transfers to Morgenstond Dam can only take place when transfers are made to Grootdraai Dam. This is simply because transfers from Heyshope Dam occur via a canal system, with a diversion structure to Morgenstond Dam. Water can only be diverted to Morgenstond Dam if the canal is full enough to supply water to Grootdraai Dam. The layout of this section of the scheme is given in Figure 32.

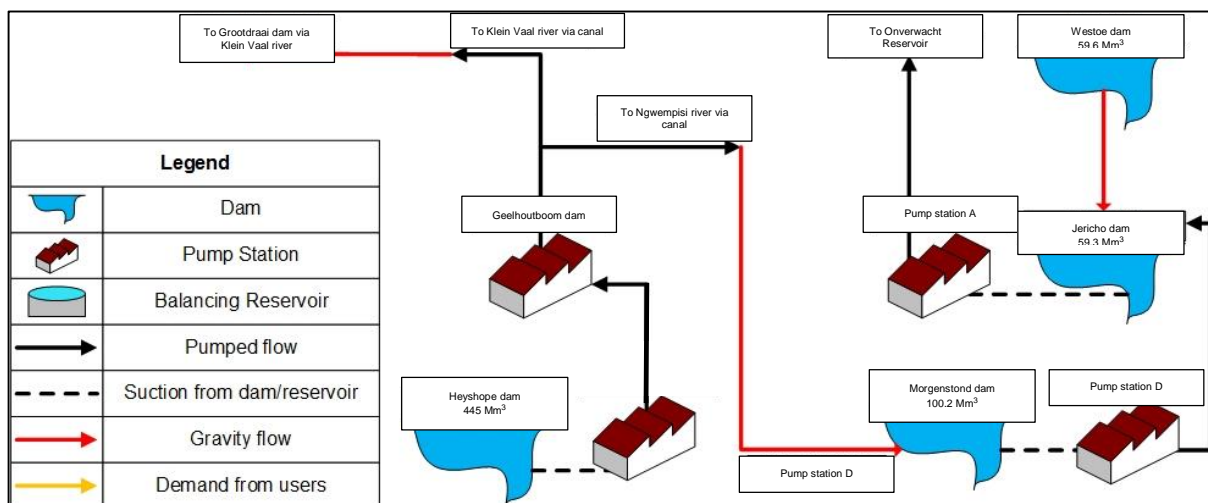


Figure 33: A schematic layout of the upper sections of GWS-A

The targets set for transfers from Heyshope Dam to Grootdraai Dam are based on the latter's dam levels. This means that transfers should only occur from Heyshope Dam to Grootdraai Dam when Grootdraai Dam is below a certain level. If transfers must occur, the target transfers given in the WSS only serve as a maximum annual transfer, translating into a maximum average flow rate in m^3/s , i.e., an *upper limit*.

This target therefore only serves as a guide to prevent excessive transfer, and not as a *minimum* transfer that *must* be achieved, i.e. a *lower limit*. This means that the target is not an annual pre-requisite and does not *have* to be achieved. The rule usually states that transfers must take place when Grootdraai Dam reaches 75% FSC. This principle and practice can clearly be seen, as only 23% (2008) and 35% (2012 and 2013) of the annual target transfers were reached.

Heyshope Dam to Morgenstond Dam

Heyshope Dam transfers water to Morgenstond Dam on the same principle as those for transfers to Grootdraai Dam. This means that the transfers to Morgenstond Dam also only take place when Morgenstond Dam reaches a certain level. The annual target transfers are therefore a maximum limit, and are only applicable when the dam-level transfer conditions require it.

These transfers should only happen when Morgenstond Dam reaches 80% FSC. Hence, it does not *have* to be achieved annually, and is once again an upper limit. Just as was the case with transfers to Grootdraai Dam, this principle can be seen since only 33% (2008) and 8% (2012 and 2013) of the annual target transfers to Morgenstond Dam were achieved. It is clear that transfers from Heyshope Dam to Morgenstond Dam coincide with transfers to Grootdraai Dam.

Morgenstond Dam to Jericho Dam

The transfers to Jericho Dam, from the Westoe- and Morgenstond Dams, take place according to the “*Inter-reservoir transfer rules for Usutu the Usutu Sub-system*” [57]–[63]. These transfer rules can be seen in Figure 33, and are supplied in every year’s AOA. In these graphical rules, the draw-down stages of these three dams are given. The sequence-numbers in red circles indicate in what order the transfers are to happen from the each dam.

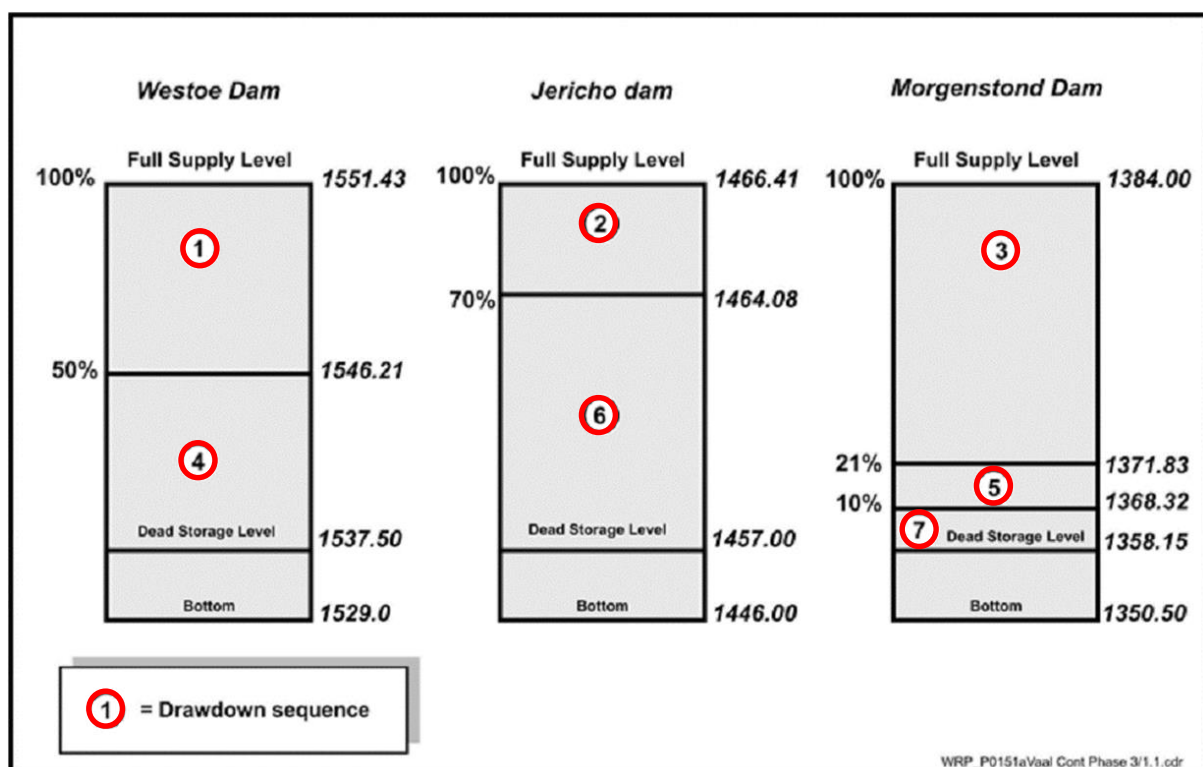


Figure 34: Inter-reservoir transfer rule for the Usutu Sub-system

This diagram indicates the following to scheme operators:

1. Transfer from Westoe Dam to Jericho Dam until Westoe Dam reaches 50%.
2. Then continue with transfers from Jericho Dam until it reaches 70%.
3. Thereafter start to transfer from Morgenstond Dam to Jericho Dam until Morgenstond Dam reaches 21%.
4. If transfers cannot take place from Heyshope Dam to Morgenstond Dam, continue with transfers from Westoe Dam to Jericho Dam until Westoe Dam reaches dead storage level (DSL).
5. Continue with transfers from Morgenstond Dam until it reaches 10%.
6. Draw Jericho dam down to DSL.
7. Transfer from Morgenstond Dam to Jericho Dam to continue supply from Jericho Dam, until Morgenstond Dam reaches DSL.

While the above inter-reservoir transfers take place, the respective annual target transfers serve as the rules in operation. When transfers take place from Morgenstond Dam to Jericho Dam it must not exceed the set maximum target of 100.42 Mm³/a. The FSC of Morgenstond Dam is 100.2 Mm³, which means that this is the absolute maximum amount of water that can be transferred from Morgenstond Dam.

This would, however, result in it being drawn down to its DSL if no transfers were made to it from Heyshope Dam. This target, therefore, does not *have* to be achieved on an annual basis, as it is rather an upper limit. The actual transfer volumes achieved are 74% (2008), 9% (2009), 31% (2010), 24% (2011) 33% (2012) and 33% (2013).

The higher percentage reached in 2009 was due to Westoe Dam being near the 50% level, resulting in Morgenstond Dam having to supply most of the water requirements to Jericho Dam. Once good rains fell in early 2009, Westoe was able to commence transfers to Jericho Dam, although Morgenstond Dam continued to supply water. In the following period (2009-2010), supply was commenced from Westoe, and halted from Morgenstond Dam, as stated in the Inter-reservoir transfer rules in Figure 33.

Westoe Dam to Jericho Dam

The transfers from Westoe Dam to Jericho Dam follow the rules set out in the Inter-reservoir transfer rules in Figure 33, as discussed above. The annual target transfers also serve as an upper limit for transfers, and are based greatly on the level of Westoe Dam at the beginning of the planning period. It also depends on planned maintenance on the supply line from Westoe Dam to Jericho dam, or the line from Morgenstond Dam to Jericho Dam. This means

that the maintenance, which is planned on these lines, is taken into account when determining the annual target or maximum transfer from a dam.

In this case, in the period 2010 to 2011, Westoe Dam's annual target was much lower than that of other years, at 16.83 Mm³/a instead of near 50 Mm³/a. This is because there was scheduled maintenance on the gravity line from Westoe Dam to Jericho Dam. For this reason, Morgenstond Dam had to supply most of the water in this period, even though Westoe Dam was full most of the year. The percentage of the target transfers for the past six years were 22% (2008), 59% (2009), 65% (2010), 40% (2011), 79% (2012) and 80% (2013).

All the above annual target transfers were subject to the respective reservoir/dam-level rule in place. This meant that these target transfers served rather as *upper* limits for annual transfers between the respective dams. These targets, therefore, were not based solely on a demand, which they had to accommodate, although the demand from Jericho Dam (discussed below) is taken into account.

This is evident in the fact that the supplies from Heyshope Dam through Morgenstond Dam to Jericho dam and from Westoe Dam to Jericho Dam aim to keep Jericho dam at a balanced level; between 70% and 75%. These supplies, and the order in which they take place, are entirely dependent on the levels of the respective dams. These transfers, therefore, can be distinguished as ***inter-reservoir transfer rules***, aiming to ensure a balanced draw down of storage, instead of aiming to accommodate a certain demand.

The following transfers which are going to be discussed, are from Jericho Dam. They differ from the above transfers in the fact that they are based on the demand, which they need to supply, and are not affected by any other dam's level throughout the planning period. The following WSS, therefore, can be called ***consumer-demand transfer rules***. These demands, and how they are derived, were discussed in more detail in Chapter 2.2.2, but are referred to in the following paragraphs.

Jericho Dam to Onverwacht reservoir (Section-A Transfers)

The transfers from Jericho Dam to Onverwacht reservoir occur via two pipelines with a maximum of four pumps at Jericho Dam. As discussed in Chapter 3.3, theoretically Pump station A (at Jericho Dam) is designed to be able to operate four pumps, in conjunction with two pumps at Pump station B, delivering a maximum flow rate of 3.30 m³/s. However, during the time of this study, only 1 pump was available to operate at Pump station B, and three pumps at Pump station A, resulting in a maximum flow rate of 2.80 m³/s.

From Onverwacht reservoir, water gravitates to the reservoirs at Camden power station, along three lines. Flow is regulated according to the level of the Camden reservoirs by means of valves.

The supply to Onverwacht reservoir, therefore, accounts for the gross supply to the Eskom power stations, towns, irrigation and other schemes. This is evident in Table 5, where the sum of the supplies from Camden to the power stations and the Inkomati scheme, equals the total annual supply from Jericho Dam to Onverwacht reservoir. Further examination of Table 5 and the graph in Appendix C8 makes it clear that the annual target for transfers from Jericho Dam to Onverwacht reservoir declined. This is due to mounting constraints on the installed infrastructure at Pump stations A, B and C and the fact that the targets are refined over time, according to updated pumping capacities. This is in contrast to the fact that demand from the power stations and towns in the area is to increase with time, as discussed in Chapter 2.2.2.

The decrease in annual target transfers over time, lead to a higher percentage of it being achieved; 62% (2008), 69% (2009), 84% (2010), 73% (2011), 83% (2012) and 83% (2013). This is an important note, since it may be interpreted wrongly that the water scheme achieved a greater percentage of its targets due to increased capacity, which is not the case.

Onverwacht reservoir to Eskom power stations (Section-B Transfers)

As seen in Figure 30, Chapter 3.3, from Onverwacht reservoir, water gravitates to the Camden reservoirs, found at Camden power station and Pump station C. From the Camden reservoirs, water is supplied to Camden power station and also pumped to Rietspruit reservoir. Rietspruit reservoir supplies the Ermelo municipality as well as Davel reservoir. Davel supplies water to Davel town and Kriel reservoir. Kriel reservoir supplies Kriel town and Kriel power station. Water can also be supplied from Kriel to Kendal power station.

The power stations within the Usutu-Vaal catchment receive a share of its full demand from GWS-A, in the Usutu catchment. The rest of their demand is supplied from GWS-B within the Usutu-Vaal catchment (Grootdraai Dam) itself. The supply distribution for these power stations is given in the Venn-diagram, in Figure 34. The average supply percentages of these stations from GWS-A and GWS-B for the past 6 years are also given in Figure 34, in brackets.

These supplies may vary, based on scheduled maintenance on the various schemes, leading to shortfalls that need to be augmented by the other scheme. Such was the case in the 2010 – 2011 planning period, when GWS-A had to supply 100% of Kriel and Kendal's demand, where it usually only needed to supply a portion of the total demand.

This portion does, however, fluctuate on an annual basis according to water quality and annual yield of the different schemes. The values given in Figure 34 are averages taken over the past six years.

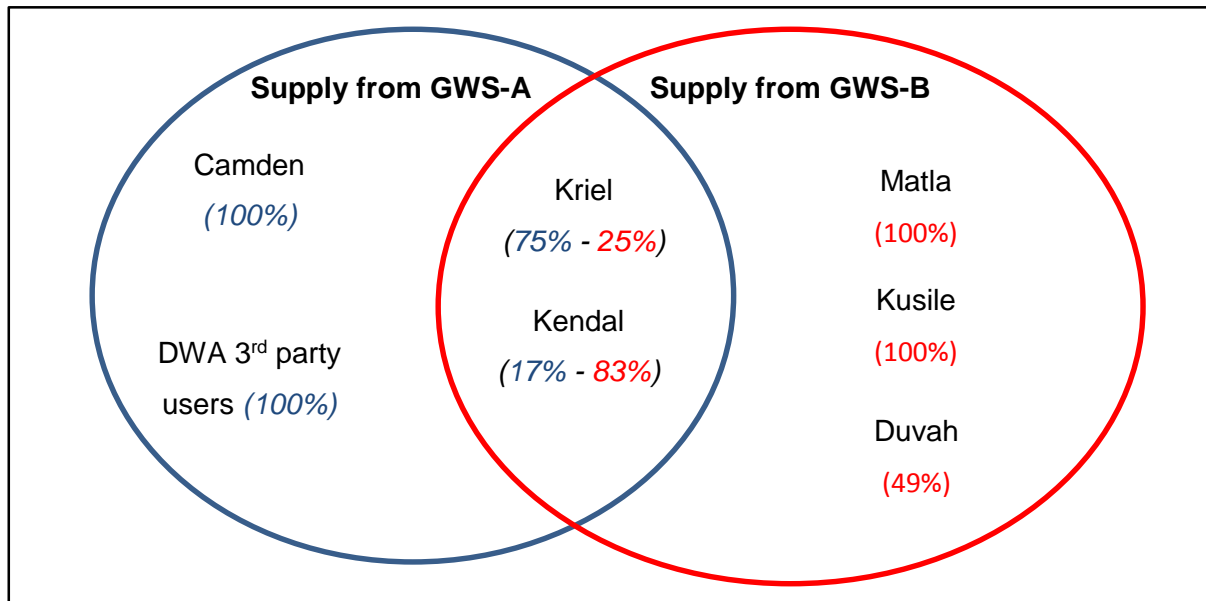


Figure 35: Supply-distribution from the Usutu and Usutu-Vaal Catchments

Eskom, along with other large industrial and municipal consumers, provide regular demand projections for use in the AOA, as discussed in Chapter 2.2.2. These demands are generally regarded as the determining factor for the operation of a pump station within a GWS. The physical manifestations of these demands are the levels of the reservoirs from which water is drawn. If demand for water were to increase dramatically, reservoir levels would naturally fall, and vice-versa. The reservoirs, whose levels are critical to monitoring the demand of water from the Eskom power stations, and their storage capacities, are listed below:

- Onverwacht 203.536 ML
- Camden 340.1 ML
- Rietspruit 62.8 ML
- Davel 43.2 ML
- Kriel 679.5 ML

Over the past six years, the following percentages of the annual target transfers to the Eskom power stations were achieved; 95% (2008), 104% (2009), 97% (2010), 105% (2011), 111% (2012) and 111% (2013). Since more than 100% of the target is achieved in four out of the past six years, it becomes evident that this supply line is over-stressed. This is due to the Eskom power stations using on average slightly more water than predicted.

It must also be noted, as in the previous transfer examined, the increase in percentage target achieved, is due to a decrease in annual targets, not only an increase in total pump station

annual transfers or transfer capacity. Other problems, such as communications failures to valves and satellite pump stations, can also lead to reservoirs overflowing, which could also explain the overconsumption.

Onverwacht reservoir to Nooitgedacht Dam (Section-B Transfers)

GWS-A can also supply water to Nooitgedacht Dam, which forms part of the GWS in the Inkomati WMA (GWS-C). The purpose of this supply line is to aid GWS –C in times of low internal supply capacities. This rule is similar to the first four scenarios, where supply to Nooitgedacht Dam occurs according to its level. If Nooitgedacht is above 90% capacity, GWS– A does not need to supply any water. Restrictions on the availability of pumps, due to maintenance issues, at Pump station C have also placed limitations on this transfer. The percentage annual targets reached for the past six years are 13% (2008) and 49% (2012 and 2013). As before, this increase is not only due to an increase in total annual transfer, but also due to a decrease in annual target, as seen in Appendix C10.

The transfers discussed above are given in Table 5 [57]–[63]. They are grouped according to planning period, which usually stretches from 1 May to 30 April every calendar year. This table should be examined with the layouts in Figure 30 and Figure 32 as reference. The values in brackets refer to the storage capacities of the reservoir or dam in question and are given to understand the large annual transfers that take place better.

The consumer-demand transfer rules, in the form of annual, and monthly targets, along with the inter-reservoir transfer rules, will be referred to collectively as the *water supply strategies* (WSS). These WSS and their mutual interactions with DSM interventions on the pump stations within this scheme will be evaluated in the following sections.

Table 5: Annual targets and actual transfers for '08 to '14

Period	From	To	Annual Target transfer (Mm ³)	Actual reported transfer (Mm ³)	Percentage of annual target transfer
May'08-Apr'09	Heyshope (445 Mm ³)	Grootdraai	140.31	32.31	23%
	Heyshope (445 Mm ³)	Morgenstond (100.2Mm ³)	44.18	14.74	33%
	Jericho (59.3 Mm ³)	Onverwacht (0.203Mm ³)	98.93	61.55	62%
	Morgenstond (100.2 Mm ³)	Jericho (59.3 Mm ³)	100.42	74.27	74%
	Onverwacht (NA)	Cd, Kendal, Kriel (NA)	58.77	55.82	95%
	Camden (NA)	Komati (NA)	45	5.73	13%
	Westoe (59.6m ³)	Jericho (59.3 Mm ³)	51.12	11.05	22%

May09-Apr10	Heyshope (445 Mm ³)	Grootdraai	140.31	0	0%
	Heyshope (445 Mm ³)	Morgenstond (100.2 Mm ³)	44.18	0	0%
	Jericho (59.3 Mm ³)	Onverwacht (0.203Mm ³)	98.93	68.09	69%
	Morgenstond (100.2 Mm ³)	Jericho (59.3 Mm ³)	100.42	8.99	9%
	Usutu (NA)	Cd, Kendal, Kriel (NA)	65.67	68.09	104%
	Usutu (NA)	Komati (NA)	30	0	0%
	Westoe (59.6m ³)	Jericho (59.3 Mm ³)	61.12	36.23	59%
May10-Apr11	Heyshope (445 Mm ³)	Grootdraai	135.07	0	0%
	Heyshope (445 Mm ³)	Morgenstond (100.2 Mm ³)	44.18	0	0%
	Jericho (59.3 Mm ³)	Onverwacht (0.203Mm ³)	89.94	75.89	84%
	Morgenstond (100.2 Mm ³)	Jericho (59.3 Mm ³)	100.42	30.8	31%
	Usutu (NA)	Cd, Kendal, Kriel (NA)	71.74	69.9	97%
	Usutu (NA)	Komati (NA)	17.77	0	0%
	Westoe (59.6m ³)	Jericho (59.3 Mm ³)	16.83	10.93	65%
May11-Apr12	Heyshope (445 Mm ³)	Grootdraai	135.07	0	0%
	Heyshope (445 Mm ³)	Morgenstond (100.2 Mm ³)	44.18	0	0%
	Jericho (59.3 Mm ³)	Onverwacht (0.203Mm ³)	89.94	65.88	73%
	Morgenstond (100.2 Mm ³)	Jericho (59.3 Mm ³)	100.42	24.26	24%
	Usutu (NA)	Cd, Kendal, Kriel (NA)	63	65.88	105%
	Usutu (NA)	Komati (NA)	11.95	0	0%
	Westoe (59.6m ³)	Jericho (59.3 Mm ³)	51.12	20.35	40%
May12-Apr13	Heyshope (445 Mm ³)	Grootdraai	135.07	47.44	35%
	Heyshope (445 Mm ³)	Morgenstond (100.2 Mm ³)	44.18	3.39	8%
	Jericho (59.3 Mm ³)	Onverwacht (0.203Mm ³)	87.16	72.28	83%
	Morgenstond (100.2 Mm ³)	Jericho (59.3 Mm ³)	100.42	32.7	33%
	Usutu (NA)	Cd, Kendal, Kriel (NA)	51.22	57.02	111%
	Usutu (NA)	Komati (NA)	31.42	15.26	49%
	Westoe (59.6m ³)	Jericho (59.3 Mm ³)	46.78	37.04	79%
May13-Apr14	Heyshope (445 Mm ³)	Grootdraai	135.07	47.57	35%
	Heyshope (445 Mm ³)	Morgenstond (100.2 Mm ³)	44.18	3.39	8%
	Jericho (59.3 Mm ³)	Onverwacht (0.203Mm ³)	87.16	72.41	83%
	Morgenstond (100.2 Mm ³)	Jericho (59.3 Mm ³)	100.42	32.69	33%
	Usutu (NA)	Cd, Kendal, Kriel (NA)	51.22	57.03	111%
	Usutu (NA)	Komati (NA)	31.42	15.38	49%
	Westoe (59.6m ³)	Jericho (59.3 Mm ³)	46.78	37.2	80%

After evaluation of the annual transfers above, it becomes clear that the WSS given for a scheme cannot be used explicitly as a performance indicator. This is because the nature of transfers are not all the same and do not all have common goals. The WSS, which can be classified as consumer-demand transfer rules are, however, more of an indication of how successful a scheme is at achieving its goal. They are still only a guide and not a fixed, explicit pre-requisite for successful operation.

The two goals for successful operation of a pump station within a water scheme can be summarised as:

- The continuous, uninterrupted and sufficient supply of water to the consumer-base, and
- The stable, sustainable management and utilisation of storage capacity.

One of the most practical ways to monitor how successful a water scheme, or more specifically a pump station, is at achieving its goal on a daily basis, is reservoir-level monitoring. For this to be understood, it must first be clear that the level of a reservoir reacts directly to the demand, which that reservoir is supplying. This is explained in Equation 8, which refers to the Law of Mass Conservation for an incompressible fluid.

Equation 8

$$\Delta_t V = t(Q_i - Q_o)$$

Equation 8 states that for an incompressible fluid such as water, the change in volume ($\Delta_t V$) of a storage over a certain time interval (t) is equal to the difference between the rates of inflow (Q_i) and outflow (Q_o) for that same time interval.

The effective monitoring of reservoir response is, therefore, a simple parameter to observe in real time and one that will indicate if the pump station in question is succeeding or not.

Ideally, the outflow from these reservoirs should be monitored as well, to understand the reactions of the reservoirs. None of these values were logged during the implementation of this project. For this reason, another method of quantifying and understanding the water demand supplied by the pump stations in the case study, and passing through a reservoir, needed to be found.

This can be done with the aid of the past six years' AOA and the monthly breakdown of the annual target transfers, and actual transfers. The transfers that are of importance for this study are listed below:

- From Pump station A to Onverwacht Reservoir.
- From Pump station C to GWS-C.

- From Pump station C to the power stations in the Usutu-Vaal WMA.

These transfers are given in each year's AOA from May of that year to April of the next year. Each month's target and reported actual transfers are given in an appendix of that year's AOA. With the aid of these logged transfers, the manner in which there is pumped, for various target transfers, can be characterised.

For the sake of simplicity, this monthly characterisation is done in the following chapter. The reasons for the monthly fluctuations will be discussed where possible, as given in that year's AOA. These monthly actual transfers will then be used to understand the different circumstances under which the pump stations need to operate and will serve as a basis for the input parameters for the simulations to come in Chapter 4.

3.5 Methodology Conclusion

The reasoning behind why the mutual effects between DSM interventions and WSS are to be analysed was outlined by the methodology. It serves as a prelude to the actual analyses that follow in the next chapter. The previous years' AOAs, their results and the conditions leading to these results were analysed on an annual basis.

The specific transfers on which this study focuses will be characterised in Chapter 4.2. This will help to characterise the practical execution of each transfer-section's target, as given by the WSS for that period and that section of the scheme.

This will also aid in selecting appropriate months to serve as the basis conditions in the simulations. The mutual effects between DSM interventions and WSS will be analysed, as laid out in Chapter 1.5 and summarised in Chapter 3.1

The results of the simulations and the observed interactions during the implementation of the load shift projects will provide insight into how the two processes in question impact each other. The understanding of these interactions can then be used to reach conclusions and suggest ways to integrate them.

4. ANALYSIS AND RESULTS

Rietspruit reservoir¹¹



¹¹ C. Scheepers, photo taken at Rietspruit reservoirs, showing the large concrete reservoir.

4.1 Overview

In this section, the methods discussed above and analyses performed will be followed in detail. These analyses aim to simulate the implementation of WSS at WTS. This will be done to evaluate pre- and post-DSM conditions. The results from these analyses will then be verified against those obtained during the implementation of the project in 2014.

4.2 Characterising Interactions between WSS and Water Schemes

The previous year's monthly operation for each transfer section will be examined to establish a set of basis input parameters. These parameters will serve as high- and low transfer conditions with corresponding pumping trends. They will serve as basis conditions under which load shifting is to be implemented.

4.3 Analysis of Interactions between WSS and Water Schemes

Based on the appropriate input transfer rates selected in Chapter 4.2, these conditions will be simulated for Section-A transfers (Pump stations A and B) and Section-B transfers (Pump station C). This is done to establish boundaries between which load shifting can successfully take place. It will determine the DSM savings and operational indicators associated with the different transfer conditions.

4.4 Analysis and Comparison of 2014 GWS-Case Study

The conditions under which the load shifting projects were implemented will be discussed as prelude to the case study analysis. The specific results studied in Chapter 4.3, applicable to the case study, will then be summarised for comparison in the conclusion.

4.5 Analysis and Results Conclusion

An overview of the chapter and the results discussed will be given.

4.2 Characterising Interactions between WSS and Water Schemes

To evaluate the mutual effects that the WSS discussed in Chapter 3.4 have on load shifting at pump stations, and vice-versa, what both processes require from the WTS they aim to regulate, must be clearly defined.

- WSS require a water scheme to deliver a certain amount of water (target transfers) annually or monthly to the consumer base. At the same time, the sustainable storage of water must be ensured by balancing the draw-down of these bulk storage dams. These requirements lead to the pump stations, which form part of the water scheme, being operated according to specific guidelines.
- DSM interventions, particularly load shifting, require that these pump stations be operated according to a predetermined schedule. This schedule depends on the tariff structure imposed by the electricity-supply utility. The implementation of this schedule leads to a pump station being operated in accordance with yet another set of guidelines.

Since both load shifting and the WSS aim to regulate the operation of the pump stations in different ways, it becomes clear why they would affect each other. This is shown in Figure 28, Chapter 3.2. Before characterising how both processes affect the operation of the pump stations within a water scheme, the goals of each need to be evaluated and prioritised.

Goals of water supply strategies for water schemes

As stated in Chapter 3.4, the two goals for successful operation of a water scheme can be summarised as:

- Continuous, uninterrupted and sufficient supply of water to its consumer-base and
- Stable, sustainable storage management and utilisation.

Since these are the exact same goals as the WSS aim to achieve, it is clear that the interaction between WSS and the water scheme carries the higher priority.

Goals DSM interventions have for water schemes

Load shifting, as a DSM intervention, aims to reduce peak-time electricity consumption. This will result in ECS, as discussed in Chapter 1.3. Since this goal does not correspond to the goals of the water scheme, it carries a lower priority in the operation of the pump stations within the water scheme. The fact that the goals differ, but are not in direct contradiction with each other, means that a way can be found to implement both successfully.

It can therefore be concluded that first and foremost, the water scheme must succeed in its purpose to supply water to the consumer-base. Only after this can be guaranteed, can load shifting be considered an acceptable practise to implement. For this to be the case, the effects load shifting will have on the water scheme, and its ability to follow the WSS, must be small enough not to compromise its operational goals.

Below, the historical interactions between WSS and water schemes will be characterised. These historical results will be used to determine average high- and low demand operational conditions for the pump stations forming part of the case study. To demonstrate the results of such interactions, a Pre-DSM scenario will be simulated. The relevant output parameters, which can serve as performance indicators will then be examined. A post-DSM scenario will then be simulated to investigate the effect load shifting will have on a water scheme under the different operational requirements. The same parameters will then be evaluated and the results will be discussed.

4.2.1 Section-A transfers

As seen in Figure 30, Chapter 3.3, Pump station A pumps to Onverwacht reservoirs. This occurs in conjunction with the booster pump station at Pump station B. Pump station B can only operate when two pumps per line are running at Pump station A, and increases the flow rate, as discussed in Chapter 3.3. For these reasons, the two stations can be simplified as one large station, delivering a combined flow into a common line. The measured transfer rates and pump power demands for the different pump-configurations between the two stations are given in Table 4, Chapter 3.3, and will be collectively referred to as *Section-A transfers*.

Figure 36 shows the average monthly actual transfer rates, normalised to the target transfer rate for that month. It shows that the actual monthly average transfer rate for the past six years seldom exceeds the target. Of the total 72 months, only four of them either reached or exceeded their target. The years that came the closest to reaching the annual target were 2012 and 2013, falling on average 18% short of the average annual target, as indicated by the numbers in bold above each year's column-cluster.

Figure 35 is similar to Figure 36, with the average *monthly* actual transfer rates being normalised to the average *annual* actual transfer rate of that planning period. This gives an indication of how far each month's average transfer rate deviates from the average transfer rate for that planning period.

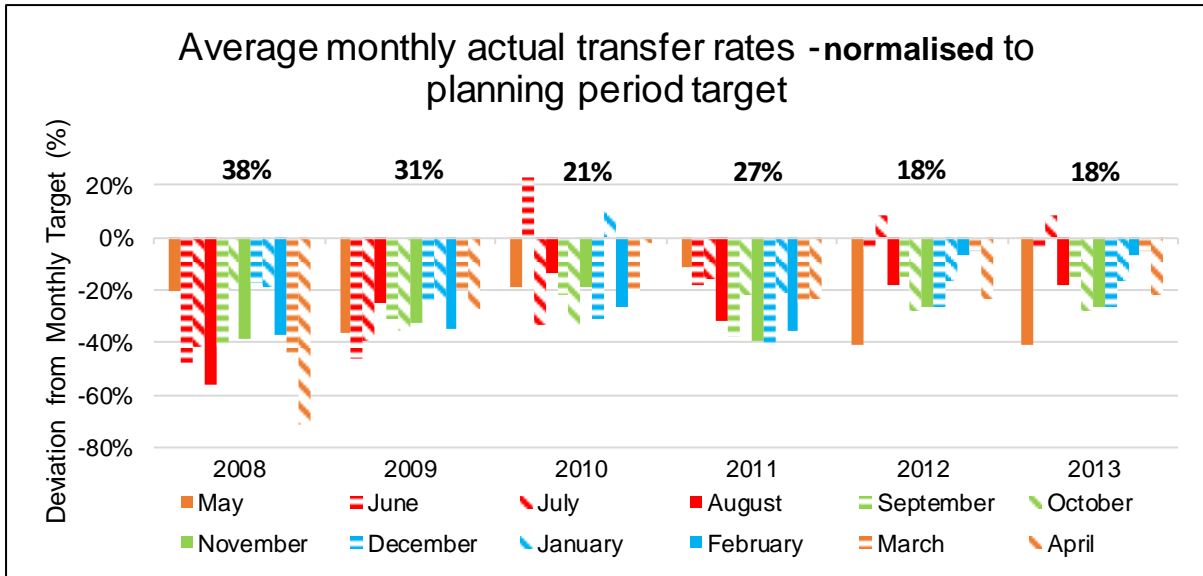


Figure 37: Section-A average monthly actual transfer rates - normalised to target

There is unfortunately no recurring pattern of increased or decreased pumping coinciding with a specific season. This is because the determining factor for total volume supplied by the pump station depends more on the capacity of the station or system than the demand which must be supplied.

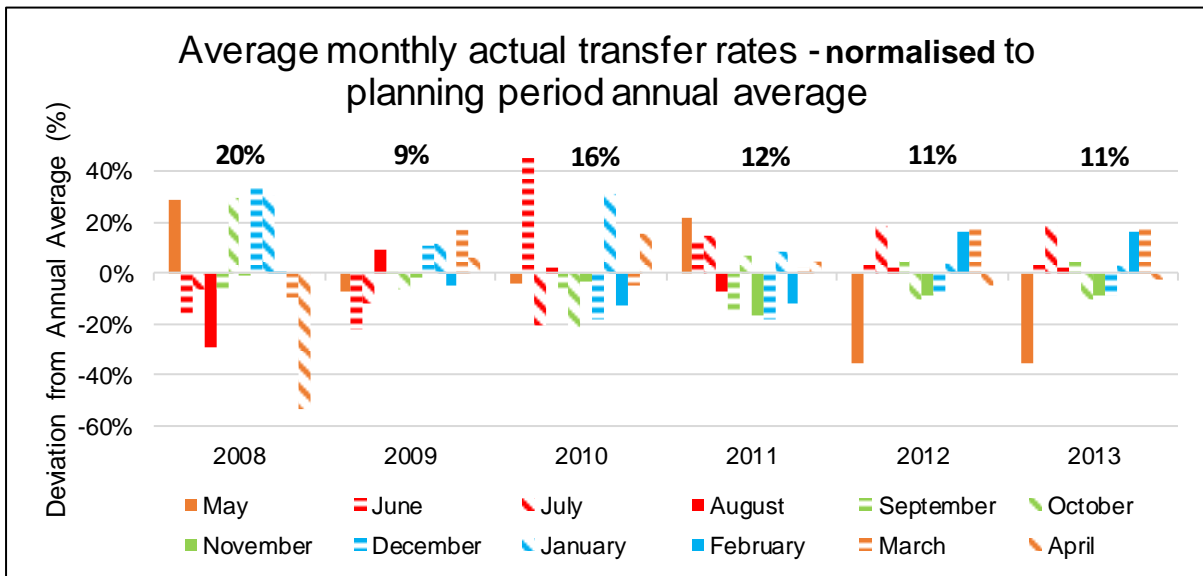


Figure 36: Section-A average monthly actual transfer rates - normalised to annual average

The supply capacity of the system in turn depends greatly on maintenance performed on infrastructure and the down-time that is experienced with it. It does, however, point out to what extent each month deviates from the average pumping for a year. From this, it can be seen that 2009 has the least deviation from that year's average, at 9%, and that 2012 and 2013 follow a close second. It is notable that if the one outlier for 2012 and 2013 was half of what it actually is, this deviation from the annual average would also only be 9%.

From the above two graphs, it can be concluded that the years with the smallest deviation from their average transfer rate, i.e. the years with the most uniform pumping are 2009, followed by 2012 and 2013. It can also be concluded that the years which came closest to achieving their respective targets were 2012 and 2013. Based on these two observations, the two years, which are most preferential to be used as base scenarios for the simulations are 2012 and 2013.

The planning period for May 2012 to April 2013 is also the same year that was used to gather baseline data for the load shift project at Pump stations A, B and C. This power data can now be used to characterise the pumping in this period. The daily power data can also be used to understand which daily pumping profiles led to the monthly transfers, as indicated in the AOA results for these months.

The pumping data, pumping logbook and measured flow rates for the various pump-configurations were used to determine the monthly and daily transfers for this period. Table 4 in Chapter 3.4 shows the average power values and matching average flow rates measured for the different pump configurations. The power data available for Pump stations A and B are complete for 1 March 2012 to 31 July 2012. This divides the power data into two planning periods, namely 2011-2012 (March and April) and 2012-2013 (May to July), since AOA planning periods run from every May to the next April.

By calculating the transfer rates of Pump station A for the power data from 1 March 2012 to 31 July 2012 based on the method above, the following total average monthly transfer rates were found. They are compared to the monthly transfer rates reported in the AOA's for 2011/2012 and 2012/2013 in Figure 37. The percentage difference from the reported transfer rates are given in bold above the respective month.

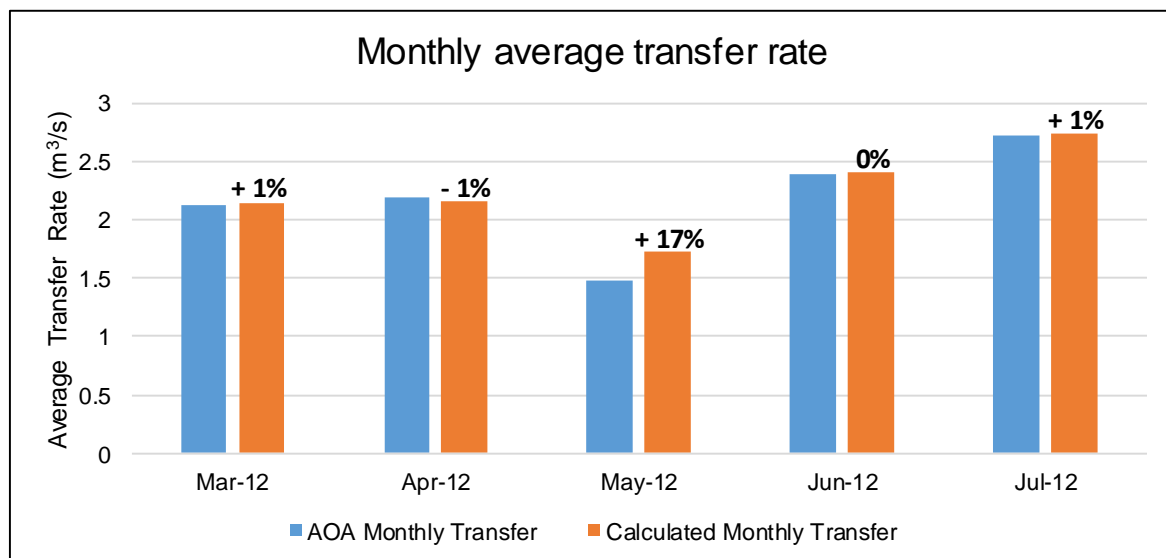


Figure 38: Section-A calculated and reported monthly average transfer rates

As seen from the previous paragraphs, the calculated transfer rate of the outlier, May 2012, also differs the most from the reported average transfer rate. The other four months only differ with $\pm 1\%$ from the reported average transfer rate, thereby *verifying* the methods used to calculate transfer rates based on power data. It can therefore be safely assumed that the reported transfer rate for May 2012 might be incorrect. It should be closer to within $\pm 1\%$ of the calculated transfer rate of $1.73 \text{ m}^3/\text{s}$ rather than the reported rate of $1.48 \text{ m}^3/\text{s}$.

Based on Figure 36, Figure 35 and Figure 37, a selection can now be made of two months to serve as high and low monthly transfer conditions for further simulations. *July 2012* will serve as the *high transfer conditions* scenario (Section-A, Pre-DSM – Subcase A). *May 2012* will serve as the *low transfer conditions* scenario (Section-A, Pre-DSM - Subcase B).

4.2.2 Section-B transfers

Transfers from Pump station C can occur to Rietspruit reservoir and to Nooitgedacht Dam. This can take place at either a rate of $1.61 \text{ (m}^3/\text{s)}$ or $2.56 \text{ (m}^3/\text{s)}$, as discussed in Chapter 3.3. Water is, however, also abstracted from Camden reservoirs to Camden power station by Eskom, and does not form part of the pumping at Pump station C. The transfers resulting from pumping at Pump station C, with the portion abstracted by Camden power station negated, will be referred to as *Section-B transfers*.

The actual transfers logged in the AOA from Pump station C are described as “Jericho (Onverwacht) to Nooitgedacht” and “Jericho to Camden, Kriel, Kendal PSs & DWAF third-party users “. In this dissertation, these transfers will be referred to as “Camden to Nooitgedacht” and “Camden to power stations”, respectively, and as Section-B transfers, collectively.

Figure 38 is an excerpt from the 2012-2013 AOA, showing the format in which the target and actual transfers for a reporting period is given. It is important to note that the transfers given

Jericho to Onverwacht (Maximum transfer capacity is $3.135 \text{ m}^3/\text{s}$) - WRPM Channel 36 (Channels 27 and 39 transfers plus Channel 168 transfer) (DWA Jericho pumped)														
Target	m^3/s	2.450	1.801	1.601	1.601	1.601	1.455	1.601	1.601	1.601	1.601	1.601	2.800	1.775
	Million m^3/m	6.56	4.67	4.29	4.29	4.15	3.90	4.15	4.29	4.29	3.91	4.29	7.26	56.03
	Cumulative	6.56	11.23	15.52	19.80	23.95	27.85	32.00	36.29	40.57	44.48	48.77	56.03	
Actual	m^3/s	1.301	0.834	1.291	1.310	1.426	1.856	1.456	1.289	1.162	1.658	1.563	1.307	1.370
	Million m^3/m	3.48	2.16	3.46	3.51	3.69	4.97	3.77	3.45	3.11	4.05	4.19	3.35	43.24
	Cumulative	3.48	5.64	9.10	12.61	16.31	21.28	25.05	28.50	31.62	35.66	39.85	43.24	
Jericho (Onverwacht) to Nooitgedacht - WRPM Channel 168 (DWA UK Link)														
Target	m^3/s	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.404	0.597	0.111
	Million m^3/m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.08	1.55	2.63
	Cumulative	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.08	2.63	
Actual	m^3/s	0.000	0.000	0.000	0.000	0.070	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006
	Million m^3/m	0.00	0.00	0.00	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18
	Cumulative	0.00	0.00	0.00	0.00	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Jericho to Camden, Kriel, Kendal PSs & DWAF 3rd Party Users - WRPM Ch 27+ 39 (DWA Jericho subtract UK Link)														
Target	m^3/s	2.450	1.801	1.601	1.601	1.601	1.455	1.601	1.601	1.601	1.601	1.196	2.203	1.692
	Million m^3/m	6.56	4.67	4.29	4.29	4.15	3.90	4.15	4.29	4.29	3.91	3.20	5.71	53.40
	Cumulative	6.56	11.23	15.52	19.80	23.95	27.85	32.00	36.29	40.57	44.48	47.69	53.40	
Actual	m^3/s	1.301	0.834	1.291	1.310	1.355	1.856	1.456	1.289	1.162	1.658	1.563	1.307	1.364
	Million m^3/m	3.48	2.16	3.46	3.51	3.51	4.97	3.77	3.45	3.11	4.05	4.19	3.35	43.05
	Cumulative	3.48	5.64	9.10	12.61	16.12	21.09	24.87	28.32	31.43	35.48	39.67	43.05	

Figure 39: Excerpt from 2012 AOA - Target and actual transfers

for “Camden to power stations” are calculated by subtracting the “Camden to Nooitgedacht” transfers from the Jericho Dam to Onverwacht Reservoir transfers. This will be better understood if Figure 30, in Section 3.3 is referenced while studying the above excerpt.

This means that the actual transfer values given for the “Camden to power station transfers” include the water supplied to Camden power station itself. This could be confusing since it might give the impression that this portion of water is pumped by Pump station C as well, while it is not.

The total annual volume water to be supplied to Camden power station is given as 19.63 million m³, in the 2012-2013 AOA. A monthly breakdown for transfers to achieve this annual volume is not given. The average daily flow rate required to reach this volume over a 365.25-day calendar year is 0.62 m³/s. When this is subtracted from the actual reported transfers for Pump station C, a more realistic transfer rate is found, as discussed below.

Since the total volume pumped from Jericho Dam by Pump stations A and B is ultimately pumped by Pump station C, save the amount used by Camden power station, the same months will be used for Section-B transfers’ simulations. This means that May and July 2012’s pumping profiles will serve as the basis conditions to be simulated. These average monthly transfers are given in Figure 39 below, comparing the reported average transfer rates, the adjusted transfer rates and the calculated transfer rates with each other.

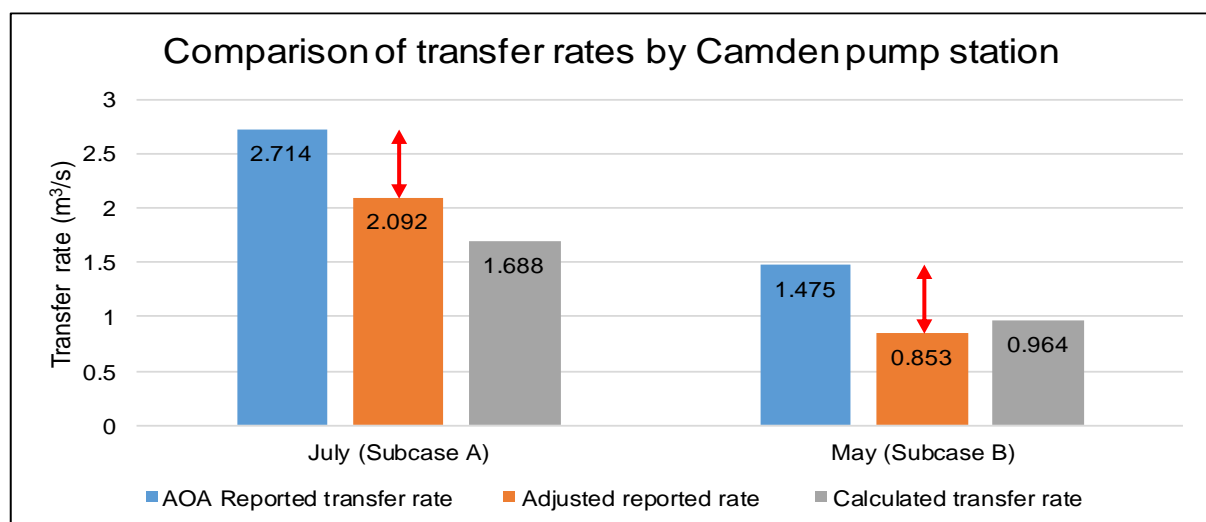


Figure 40: Comparison of transfer rates by Pump station C

The calculated transfer rate was determined on the same basis as in Chapter 4.2.1, based on the parameters given in Table 4, Chapter 3.3. The estimated portion of water used by Camden power station is deducted from the AOA reported transfer rate, and indicated by the red arrows. This gives the adjusted reported transfer rate, which clearly brings it closer to the calculated transfer rate.

It is clear that the July calculated transfers are lower than the adjusted reported transfer rate. It is safe to assume that because July is a “high demand” season, the power station would use more water. The May calculated transfers are higher than the adjusted reported transfer rates. May is considered a “low demand” period for Eskom, therefore the usage by Camden power station will be lower. This can explain the difference for both subcases.

The estimated portion to Camden power station could not be verified for each month separately. It therefore will be assumed that the transfer rates to be simulated for Pump station C are based on the calculated transfer rates, given in Figure 39.

4.3 Analysis of Interactions between WSS and Water Schemes

The aim of these simulations will be to demonstrate how pumping takes place under pre-DSM and post-DSM conditions. For this reason, there will not be focussed on the reservoir levels upstream or downstream of the pump station in question. The reasoning behind this is twofold:

1. The same amount of water pumped by Pump stations A and B to Onverwacht, is pumped away by Pump station C, or used by Camden power station, leaving the reservoirs with a balanced in- and out flow, reflected in Figure 38.
2. The reservoir levels for the water scheme were not logged and therefore cannot be used in the simulations, as discussed in Chapter 3.4.

To effectively evaluate the mutual effects that the WSS and DSM interventions have on the operation of pump stations, and vice-versa two scenarios will be evaluated in this chapter:

- Pre-DSM Scenario: Ideal interactions between WSS and the operation of water schemes, *without DSM interventions*, based on the high- (Pre-DSM A) and low (Pre-DSM B) transfer conditions in Chapter 4.2.1.
- Post-DSM Scenario: Ideal interactions between WSS and the operation of water schemes, *with DSM interventions*, based on the high-(Post-DSM A) and low (Post-DSM B) transfer conditions in Chapter 4.2.2.

Simulation assumptions

For the simulations of the Post-DSM Scenario, it is assumed that the DSM intervention implemented on the sites is limited to energy-neutral load shifting, as discussed in detail in Chapter 1.4. The basis assumption for both scenarios is that the WSS given by the AOA are implemented as they were for the months selected. In order for this to be the case, the following supplementary assumptions must be made to ensure these transfer rates are achievable:

Actual Demand – Assumptions

The transfer rates simulated for Pre-DSM Scenarios A and B are given in the introduction of Chapter 4.3.1 and Chapter 4.3.2, respectively. This led to the below assumptions being made:

- No other maintenance on other water schemes, which may affect the scheme in question, took place during period being simulated
- No unexpected seasonal rainfall changes occurred during period being simulated
- No changes in water quality of the scheme in question or surrounding schemes occurred during period being simulated.

Scheme components – Assumptions

All constraints are as originally supplied for the period being simulated, which implies the following;

- All pumps are in good, functioning condition during the period being simulated and are available for operation
- All pipelines/canals are available for water transfer during the period being simulated
- All other infrastructure required for the operation of the water scheme, the pump station in particular, are in good, functioning condition during period being simulated.

Parameters used to quantify WSS

Upon examination of the WSS given by the past six years' AOA, the following parameters can be identified to play a role in the operation of the three pump stations. It is clear that the WSS, which have the greatest impact on the operation of Pump stations A, B and C are the annual target transfers, or *consumer-demand transfer rules*. The *inter-reservoir transfer rules* do not directly affect these pump stations. This study focuses on the pump stations on which DSM interventions were implemented in 2014, these rules therefore do not need to be taken into consideration in the simulations.

Layout and simulation description

Pump station A (Section-A transfers):

- The pump configurations and accompanying flows and power demands are given in Table 4, Chapter 3.3
- They all draw out of a common line from Jericho Dam
- Pump 4 and 5 pump into a common line (South Line) to Onverwacht
- Pump 1 and 2 pump into a common line (North Line) to Onverwacht.

Pump station B (Section-A transfers):

- Pump station B operates as indicated in Table 4, Chapter 3.3.

Pump station C (Section-B transfers):

- Pump station C operates as indicated in Table 4, Chapter 3.3
- This implies that either 1.61 m³/s or 2.56 m³/s can be pumped to either Rietspruit reservoir or Nooitgedacht Dam. The destination of the water pumped will be disregarded for the purpose of these simulations, as discussed above. It will be assumed that the total water pumped to the receiving reservoirs equals the water extracted therefrom, as demonstrated in Figure 38.

Key performance indicators (KPI)

For each day, the following KPI will serve as the outputs of the simulations and will ultimately be used to characterise the impact of load shifting:

- Daily average transfer rate achieved
- Daily total electricity consumption
- Daily total electricity cost
- Daily DSM saving achieved (applicable to Post-DSM scenarios).

The average daily transfer rate will indicate how much water was pumped and therefore establish how the pump station performed in terms of the WSS. The total electricity consumption will show how the pump stations operated from an energy perspective. The total daily electricity cost will show the intended impact load shifts have on the operational costs of a pump station. Finally, the DSM saving achieved after load shifts are simulated will show how successful the intervention was and how the operation of the pump station impacted it.

4.3.1 Pre-DSM scenario, Section-A transfers

The simulations performed for the pre-DSM scenario are based on the months selected in Chapter 4.2.1. Subcase A will refer to the high transfer conditions, while Subcase B will refer to low transfer conditions. Simulations will be performed for each day of these months, to evaluate the difference in pump-station operation for different average daily transfer rates.

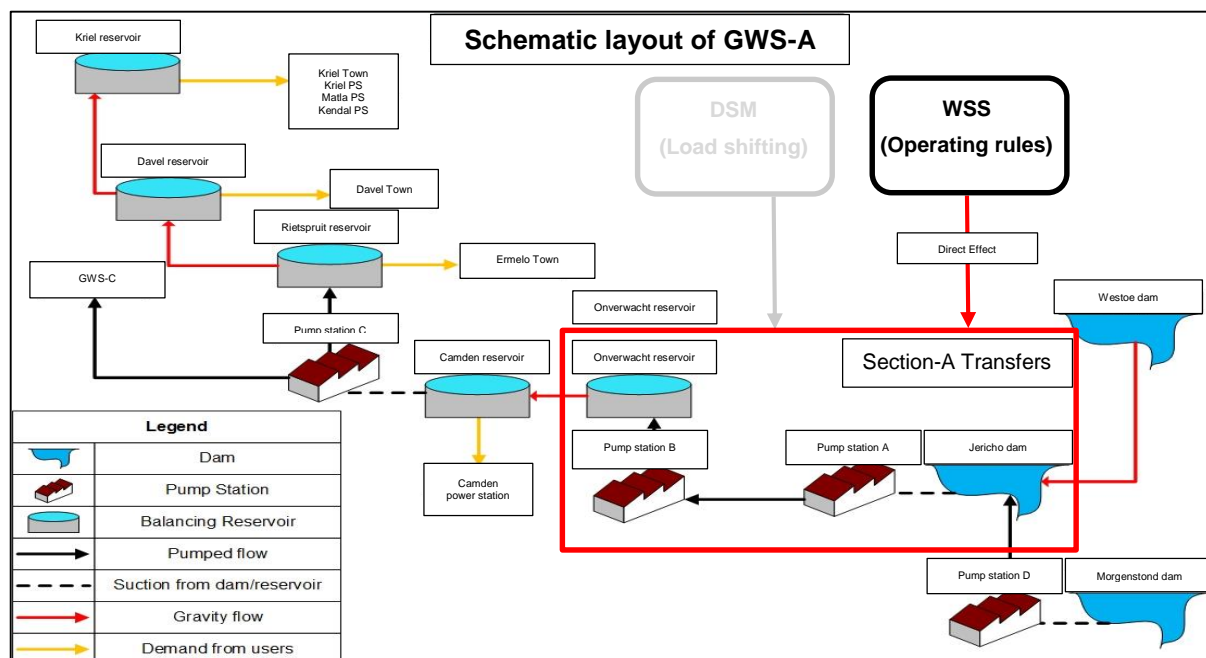


Figure 41: Schematic of GWS-A, Section-A transfers, pre-DSM

The performance indicators mentioned in Chapter 4.3 will be summarised for each day. The transfer section, and the process interactions being evaluated are shown in Figure 40, above.

Pre-DSM, Section-A daily average transfers

The daily average transfer rates for the high- and low transfer conditions are compared to each other in Table 6

Table 6: Section-A transfers, Pre-DSM transfer rates

Weekday nr.	Subcase A (high) (m ³ /s)	Subcase B (low) (m ³ /s)
1	2.80	1.10
2	2.58	1.22
3	2.09	2.02
4	2.55	2.42
5	2.83	1.39
6	3.30	2.00
7	3.30	1.77
8	3.30	2.02
9	3.15	2.80
10	3.00	2.80
11	2.80	2.21
12	2.80	0.30
13	2.57	0.96
14	2.28	0.81
15	3.00	0.92
16	2.18	0.92
17	2.12	1.29
18	2.46	0.96
19	2.43	1.11
20	2.80	1.90
21	2.11	2.91
22	2.80	2.85
Total average (m ³ /s)	2.69	1.67

The daily average transfer rates summarised in Table 6 are given in Figure 41. In Figure 41, they are ordered from low- to high flow rates and are not representative of flow rates on specific days. Figure 41, below, shows that the average daily transfer rate for the month of Subcase A is much higher, at 2.69 m³/s, than that of Subcase B, at 1.67 m³/s.

This is reflected clearly by the fact that the lowest transfer rate for Subcase A is only 2.09 m³/s, where for Subcase B it is as low as 0.30 m³/s. This combined range of daily average transfer rates covers a good deal of the possible transfer rates achievable by Pump stations A and B; between 0.00 m³/s and 3.30 m³/s.

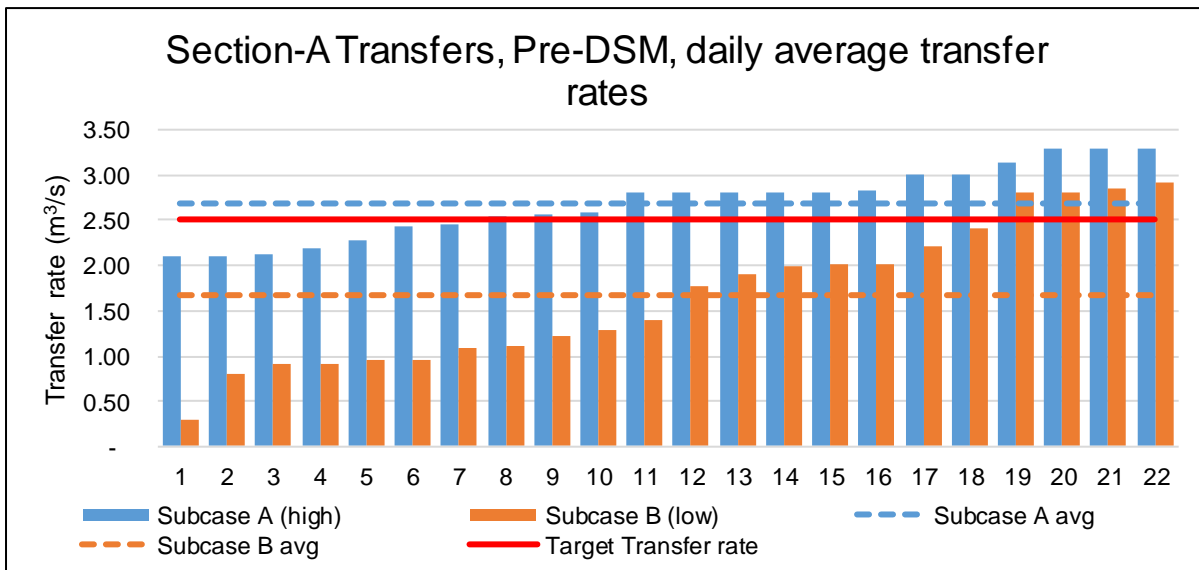


Figure 42: Section-A transfers, Pre-DSM transfer rates

Furthermore, it is apparent that Subcase A is a good example of high transfer conditions since 15 of the 22 weekdays (68%) in the month exceeded the target transfer rate of 2.50 m³/s. In Subcase B, only four of the 22 weekdays (18%) exceeded the target transfer rate. These differences highlight the point made in Chapter 3.4 that the target transfer rates (both annual and monthly) only serve as a guideline and not an explicit prerequisite for successful operation.

Pre-DSM, Section-A electricity consumption

The daily total electricity consumptions are summarised in Table 7, below. They are also given per weekday number for each subcase's respective month. This means that weekday 1 refers to the first weekday of that month, irrespective of what day of the week it is. In the same way, weekday 22 refers to the last weekday of the respective month.

The total monthly electricity consumption for Subcase A is 69.8% more than that of Subcase B. Generally, the higher daily average transfer rates result in a higher consumptions. This can be because of two factors;

- The higher daily average transfer rate inherently means a higher total daily volume transfer, requiring more energy in total, and
- The total daily energy consumption associated with the total daily volume transferred depends greatly on which combination of pump configurations was employed. This means that a combination of high specific energy consumption (SEC) configurations might have been used where lower SEC ones would have achieved the same total daily volume transfer.

Table 7: Section-A transfers, Pre-DSM electricity consumption

Weekday nr.	Subcase A (high) (kWh)	Subcase B (low) (kWh)
1	302,400	136,560
2	279,450	147,090
3	226,718	220,800
4	276,050	262,450
5	320,050	177,610
6	436,800	206,150
7	436,800	204,673
8	436,800	224,822
9	395,150	302,400
10	355,200	302,400
11	302,400	240,350
12	302,400	32,540
13	290,375	96,487
14	257,950	80,261
15	365,300	90,648
16	260,850	90,648
17	248,000	127,432
18	277,075	115,814
19	273,375	131,216
20	302,400	218,780
21	242,400	332,500
22	302,400	316,550
Total sum (kWh)	6,890,343	4,058,180

The increase in energy consumption for increased daily average transfer rate is reflected in Figure 42, below. Both subcases have been plotted on the same graph, as one large data-set. Their results, however, distinguished between the two different ranges in which transfers took place.

Subcase A clearly only had transfers from 0.30 m³/s to 2.91 m³/s, where Subcase B had transfers from 2.09 m³/s to the maximum transfer rate of 3.30 m³/s. The differences in total electricity consumption can be seen clearly. It is noteworthy that the R-squared value for linear regression, for the daily energy consumption associated with the daily average transfer rates is 0.96.

This indicates that there is a strong linear relation between the total daily energy consumed and the daily transfers achieved, prior to load shifts being performed. This will be discussed further below.

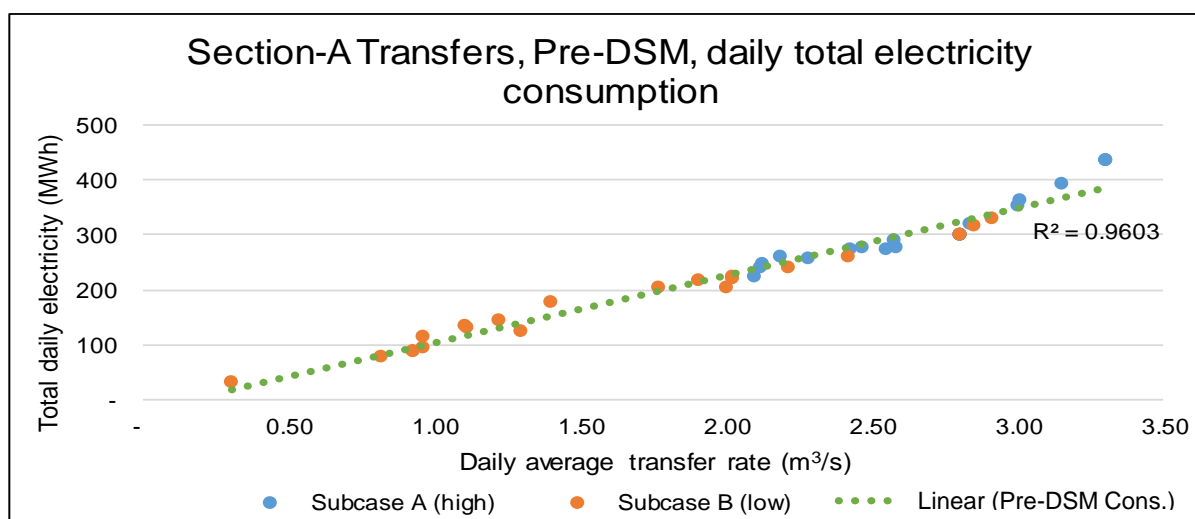


Figure 43: Section-A transfers, Pre-DSM electricity consumption

Pre-DSM, Section-A electricity costs

The daily total electricity costs are summarised in Table 8. They are also given per weekday number for each subcase's respective month.

Table 8: Section-A transfers, Pre-DSM electricity costs

Weekday nr.	Subcase A (high) (R)	Subcase B (low) (R)
1	269,310	121,617
2	245,509	126,552
3	193,025	196,639
4	241,148	233,008
5	286,592	158,126
6	389,003	187,587
7	389,003	178,535
8	389,003	214,284
9	352,634	269,310
10	316,332	269,310
11	269,310	203,812
12	269,310	19,463
13	256,785	81,250
14	222,336	76,918
15	332,298	80,729
16	226,692	80,729
17	220,598	113,391
18	237,534	100,017
19	233,395	123,052
20	269,310	193,533
21	198,786	294,960
22	269,310	274,791
Total sum	6,077,223	3,597,611

The total monthly electricity costs for Subcase A is 69.9% more than that of Subcase B. This is once again attributable to the total greater amount of energy required to achieve higher daily average transfer rates. Where the greater amounts of energy associated with higher daily average transfer rates depends on two aspects, the daily cost depends on a third as well. Except for the same two aspects mentioned above, it is also affected by the time of day during which pumping occurs. This is due to the TOU structure in place for energy consumption on weekdays.

Two days might have the exact same average total daily transfer, as well as the same total electricity consumption, but based on when – during which times of the day – the most or most energy-intensive pumping was done, the total daily costs can differ greatly. The graph in Figure 43 below once again demonstrates a strong linear relationship between the electricity costs associated with the energy consumption for different daily average transfer rates.

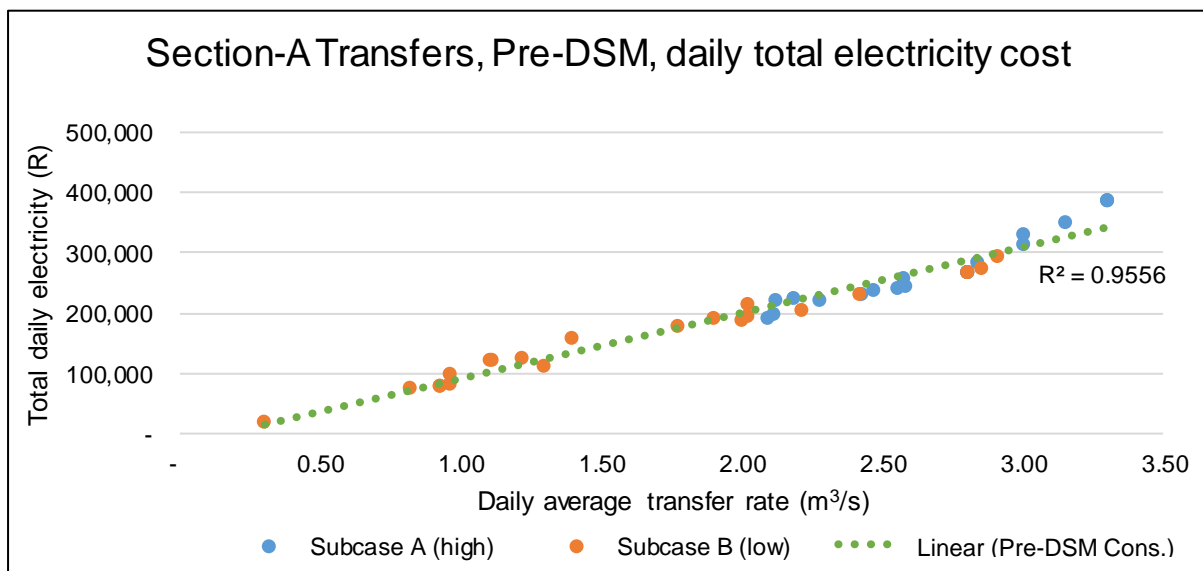


Figure 44: Section-A transfers, Pre-DSM electricity cost

The deviances from the linear regression line can be due to multiple factors. Restrictions on pump availability and maintenance issues can result in decreased pump station capacity. This will lead to lower total consumptions and energy costs. High demands will again result in high transfer rates, which require full pump availability. High required daily transfer rates will also result in less profile variation over 24 hours, due to lower average transfer rates which would occur if lower flow-rate pump configurations are used.

Low daily transfer rates therefore will result in flexibility in terms of which combinations of pump configuration will be able to result in a high enough average daily transfer rate. The more the pumping profile varies in a day, the greater the impact on the linear relation between the energy consumption and -cost, and the daily average transfer rate achieved. The variation in pump configurations will also result in a mixture of high- and low SEC pump configurations

being employed. This, in turn, will also contribute to the variation in energy consumption and cost.

4.3.2 Post-DSM scenario, Section-A transfers

In the following two sections, load shifting will be simulated on the pump stations forming part of Section-A and B transfers. These simulations will quantify the impact thereof on the transfers under the high- and low transfer conditions given in Subcases A and -B. The impact will not only be investigated in terms of the actual transfers achieved during the subcase in question, but also the target transfers for the subcase. Load shifts will be implemented on an energy-neutral basis, as discussed in Chapter 1.4. The baseline data, which was used for the project in the subsequent case study, will serve as the baseline according to which the daily profiles will be scaled. The transfer section, and the process interactions being evaluated are shown in Figure 44.

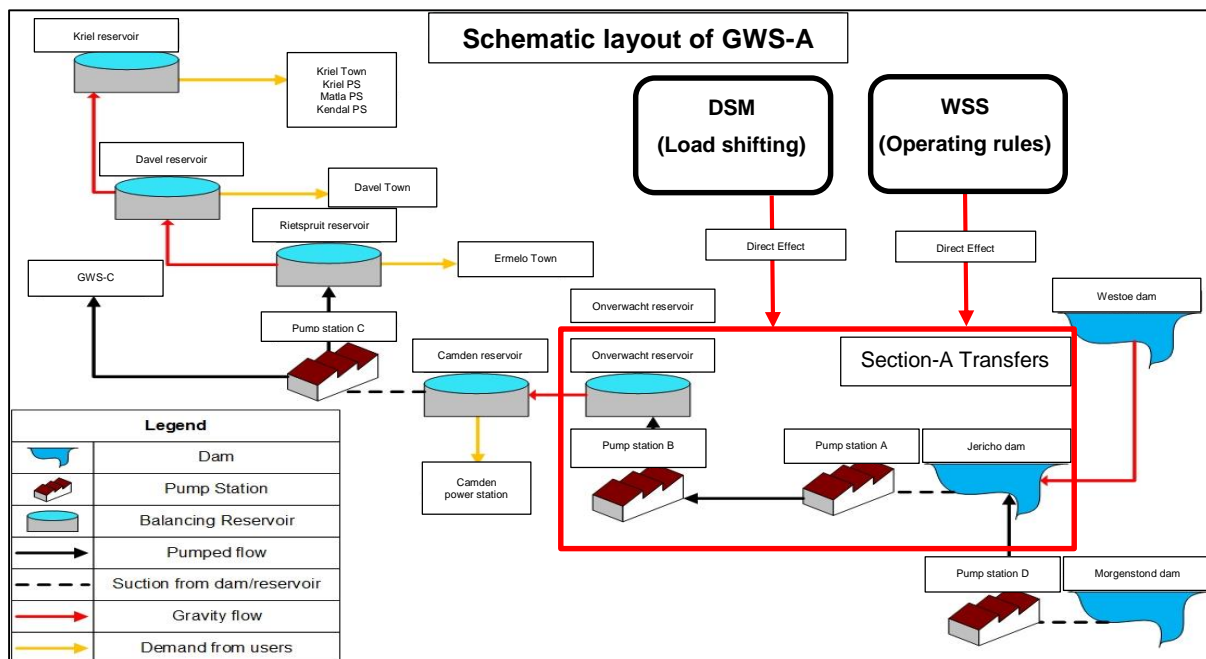


Figure 45: Schematic of GWS-A, Section-A transfers, post-DSM

This baseline data can be seen in Appendix B-1 and the graphs for the weekday profiles in Appendix B-2. For the Scenario 2 simulations, load shifts were executed to achieve only the required target, as specified in the M&V plan for the DSM projects [87] [88]. The target contractual DSM savings for the case study for the pump stations forming part of Section-A transfers are given in Table 9, below.

Table 9: Contracted DSM savings – Section-A Transfers

Pump station A	4.00 MW
Pump station B	2.42 MW
Total	6.42 MW

Load shifts will be carried out in such a manner as to attempt to recover the energy saving of the evening peak load-reduction (PLR) before the next day. This means that whatever energy is “saved” during the PLR, must be recovered within the 24 hours of that specific day. This ensures that the load shifts are energy-neutral on a daily basis, since the scaled baseline are scaled according to daily consumptions, as discussed in Chapter 2.4.3.

Since the simulations were executed to investigate the combined impact on both Pump station A and B, as discussed in Chapter 4.2.1, an evening PLR of 6.42 MW between the two stations was simulated for. If the load shift requires a power load for which there is no pump configuration at the pump station(s) in question, the possibility of achieving a greater PLR will be explored. If the energy reduction associated with this greater PLR would not be recoverable within the 24-hour time scale of that day, the next smaller PLR will be simulated. The impact of this load shift on the transfers, energy consumption and target stipulated in the AOA for that month will be evaluated in the succeeding sections.

Post-DSM, Section-A daily average transfers

The daily average transfer rates for the high- and low transfer conditions, after the implementation of energy-neutral load shifts, are compared to each other in Table 10.

Table 10: Section-A transfers, Post-DSM transfer rates

Weekday nr.	Subcase A (high) (m ³ /s)	Subcase B (low) (m ³ /s)
1	2.76	1.09
2	2.67	1.16
3	1.97	1.96
4	2.56	2.29
5	2.76	1.54
6	3.30	1.77
7	3.30	2.00
8	3.30	1.78
9	3.20	2.76
10	2.94	2.76
11	2.76	2.24
12	2.76	0.27
13	2.57	1.12
14	2.39	0.76
15	3.00	0.87
16	2.17	0.87
17	1.90	1.14
18	2.41	1.19
19	2.31	1.20
20	2.71	1.66
21	2.20	2.79
22	2.71	2.78
Total average	2.67	1.64

To compare the impact load shifting had on the daily and monthly transfers, Subcase A and B are shown on different graphs. They are compared in a similar way as done in Chapter 4.3.2 for the Pre-DSM results. The daily average transfers after load shifting are compared to each day on which load shifting was simulated, and ordered from low- to high based on the Pre-DSM transfer rates.

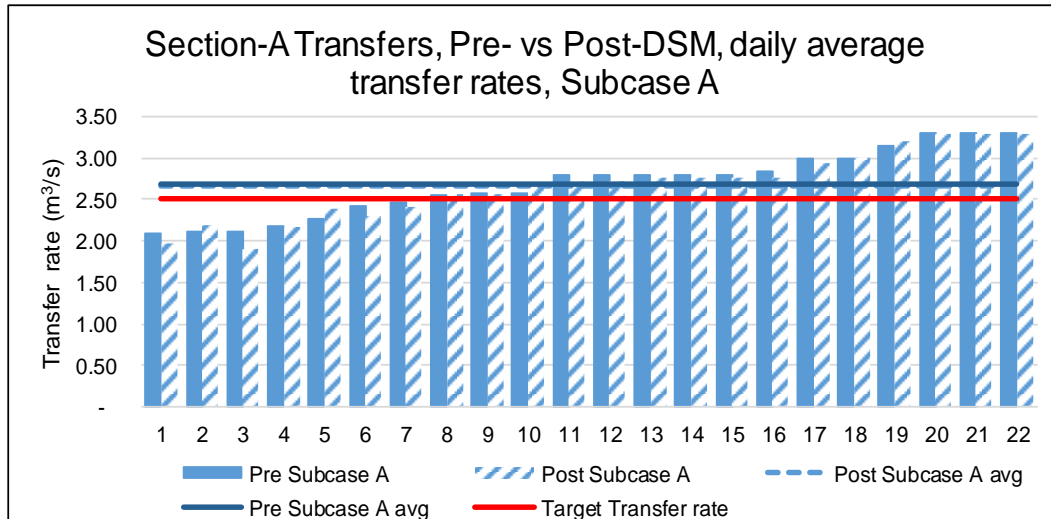


Figure 46: Section-A transfers, Subcase A Pre- vs. Post-DSM transfer rates

As can be seen in Figure 45, for the high transfer conditions of Subcase A, there are slight variances in the day-to-day average transfer rates. Some Post-DSM transfer rates are slightly higher and others slightly lower than the Pre-DSM transfer rates. The average daily transfer rate for the entire month, however, is virtually the same as that of the Pre-DSM monthly average, as seen in Table 10, above. The Pre-DSM monthly average transfer rate is 2.69 m³/s, while the Post-DSM rate is 2.67 m³/s.

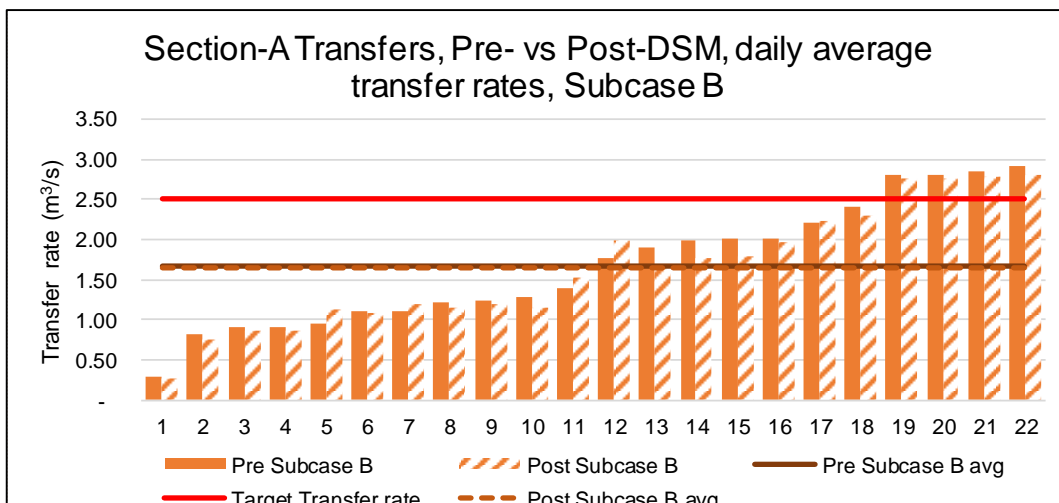


Figure 47: Section-A transfers, Subcase B Pre- vs. Post-DSM transfer rates

This clearly demonstrates that at high transfer conditions, if all pump configurations are available, energy-neutral load shifts will not negatively impact the transfers of a pump station.

The same comparisons were done for Subcase B, the low transfer conditions, in Figure 46, above. It shows that there are greater differences between the Pre-DSM and Post-DSM average daily transfers. Ultimately, the Pre-DSM monthly average transfer rate is 1.69 m³/s, while the Post-DSM rate is 1.64 m³/s. There is clearly a very small difference between the two, as was the case for the high transfer conditions. The greater inter-day differences between Pre- and Post-DSM pump station operation for Subcase B can be attributed to the fact that the required transfer rates were lower.

As mentioned in Chapter 4.3.1 above, the lower required transfer rates result in flexibility in pump configuration selection. This in turn leads to greater variance of the pumping profile since a variety of pump configurations can be combined throughout the day to reach a required daily average transfer rate.

On days where the Post-DSM transfers are substantially higher, the pump configuration employed for the CL has a lower SEC than the pump configurations used in the Pre-DSM pumping. That means that when it is used to recover the energy saved during the PLR, more water is pumped than if the original configuration was used.

The same is true for days when the Post-DSM transfers are lower than the Pre-DSM ones. On these days, the pump configuration used for the CL had a higher SEC. This in turn meant that when the configuration was used to recover the saved energy, less water was pumped for the same amount of energy used.

Post-DSM, Section-A electricity consumption

The total daily electricity consumption for the Post-DSM results are summarised in Table 11, below. The Post-DSM total monthly consumptions for Subcases A and -B are 0.02% less and 0.09% more than that of the Pre-DSM consumptions, respectively. This is more clearly demonstrated in Figure 47 and Figure 48, below.

Figure 47 shows that the inter-day difference between the Pre- and Post-DSM total electricity consumptions is low, peaking at 5% for Subcase A. The Pre- and Post-DSM accumulative electricity consumptions over the month are virtually the same for both subcases.

This shows that the load shifts were simulated successfully as energy-neutral. The greater day-to-day differences between Pre- and Post-DSM consumptions for Subcase B are once again attributable to the lower required transfer rates, as discussed above. The days which had the greatest difference in consumption, are the same as those whose daily average transfer rates differed the most. The reason for this is also the differences in SEC for different pump configurations, as discussed above.

Table 11: Section-A transfers, Post- vs. Pre-DSM electricity cons.

Weekday nr.	Subcase A (high) (kWh)	Subcase B (low) (kWh)
1	302,580	137,115
2	292,680	139,220
3	220,457	221,154
4	278,130	251,954
5	312,030	189,235
6	436,800	181,800
7	436,800	225,032
8	436,800	199,622
9	408,750	303,800
10	355,700	303,800
11	302,580	246,304
12	302,580	29,707
13	289,825	118,293
14	270,855	77,968
15	365,300	90,746
16	252,454	90,746
17	231,050	118,682
18	270,405	140,244
19	264,529	146,885
20	302,954	193,580
21	255,204	326,180
22	302,954	322,330
Total sum (kWh)	6,891,417	4,054,397

The Pre- and Post-DSM electricity consumptions for Subcase A are compared to each other in Figure 47.

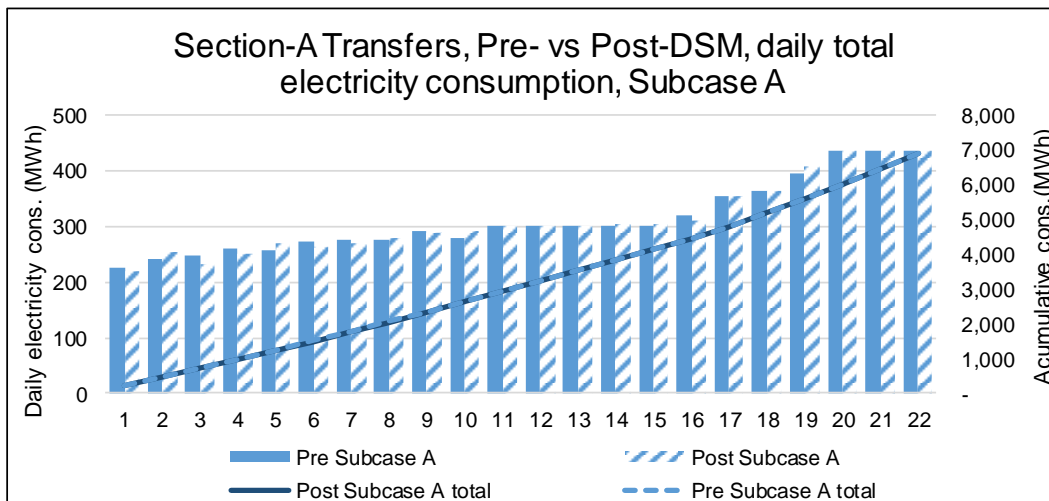


Figure 48: Section-A transfers, Subcase A Pre- vs. Post-DSM electricity cons.

The Pre- and Post-DSM electricity consumptions for Subcase B are compared to each other in Figure 48.

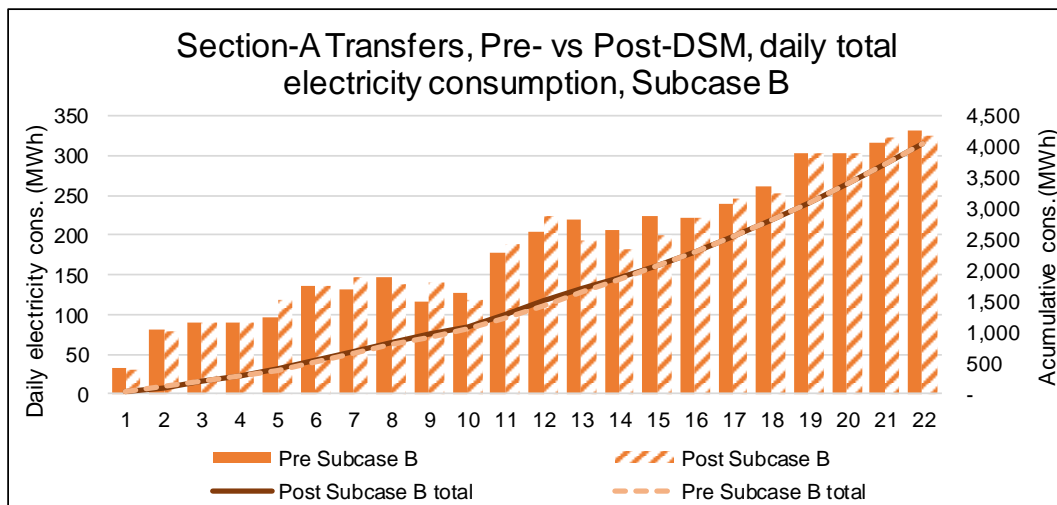


Figure 49: Section-A transfers, Subcase B Pre- vs. Post-DSM electricity cons.

The strong linear relation between the daily average transfers and the daily electricity consumptions, after load shifts were simulated, is shown in Figure 49. Figure 49 further shows that the load shifts were successfully simulated to be energy-neutral over a 24 hour period. The load shifts did not compromise the strong linear relationship between the amounts of

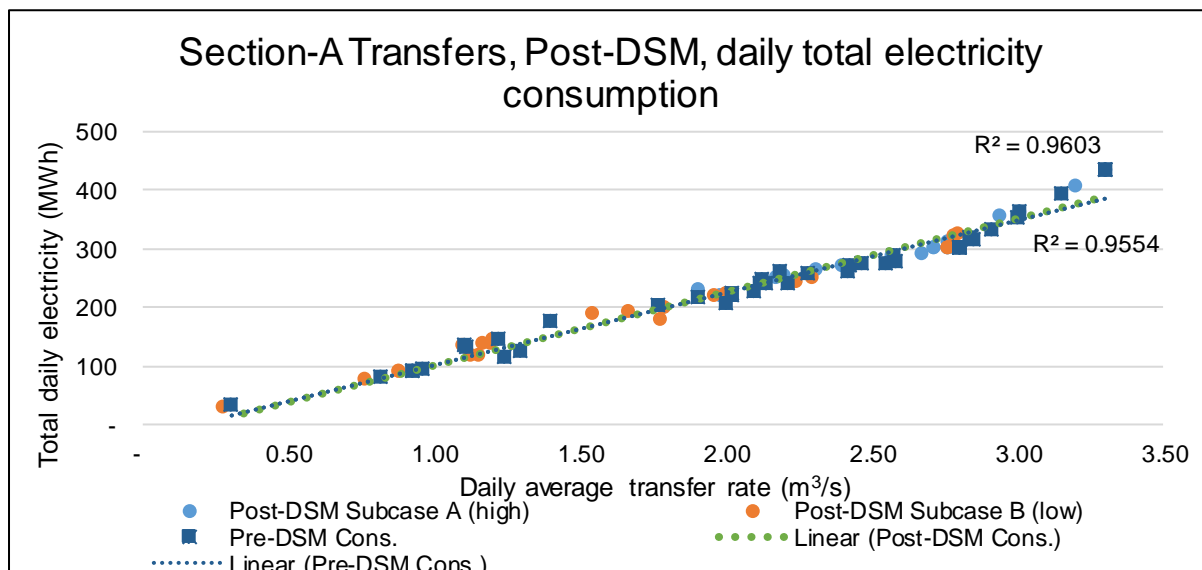


Figure 50: Section-A transfers, Pre- vs. Post-DSM electricity cons.

energy associated with daily average transfer rates. If the load shifts were not energy-neutral, it would reflect in this graph as well as the two preceding it. This becomes clear when the post-DSM energy daily consumptions are compared to the pre-DSM consumptions, above. It therefore can be concluded that the simulated load shifts did not adversely affect the energy consumptions or the total daily transfers.

Post-DSM, Section-A electricity cost

The monthly simulated costs for Pre- and Post-DSM conditions are compared to each other for the two subcases in Figure 50 and Figure 51.

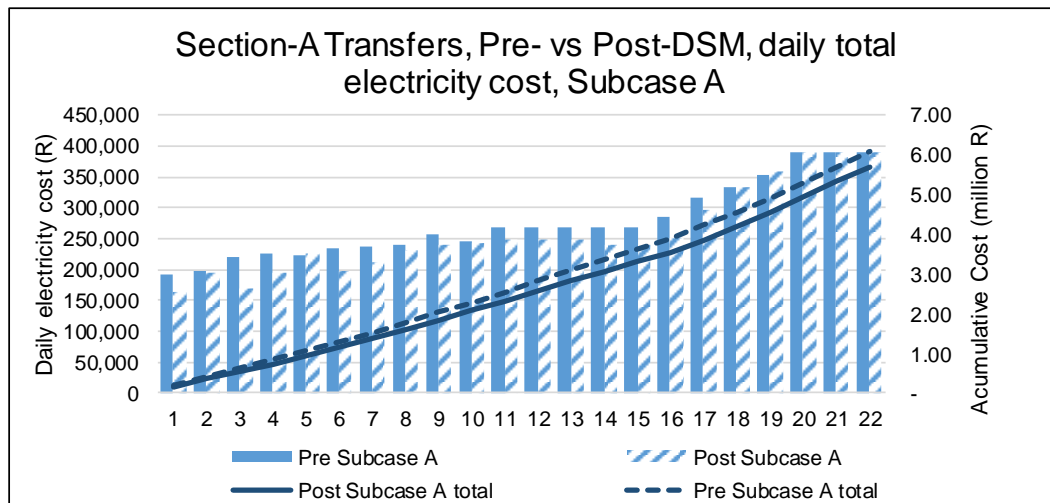


Figure 51: Section-A transfers, Subcase A Pre- vs. Post-DSM electricity costs

Both figures clearly show that the Post-DSM daily electricity costs are lower than the Pre-DSM costs. This is because of the ECS due to lower consumption in the more expensive EPP and higher consumptions during the cheaper standard and off-peak periods. Subcases A and B achieved ECS of 6.12% and 12.72%, respectively.

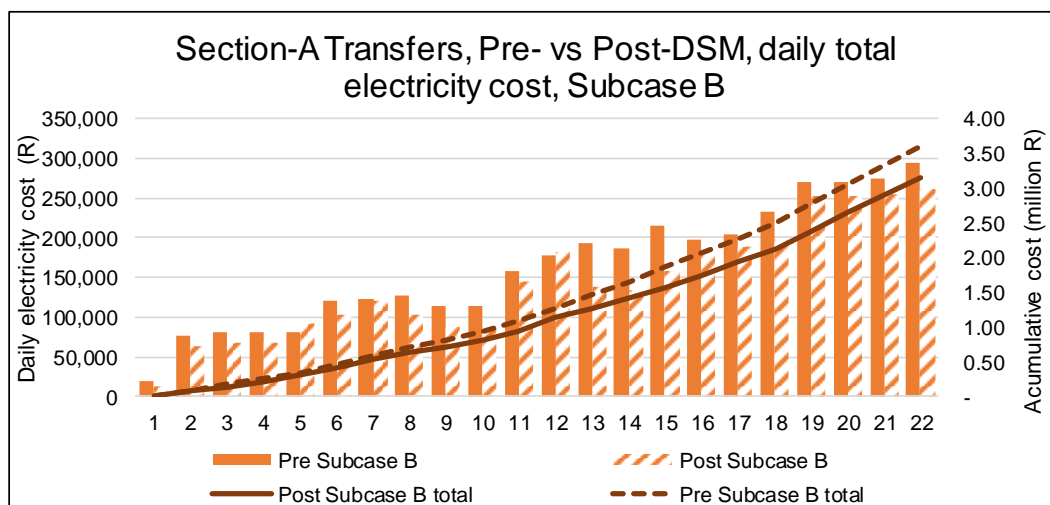


Figure 52: Section-A transfers, Subcase B Pre- vs. Post-DSM electricity costs

The strong linear relationship between the total daily costs for daily average transfer rates can be seen in Figure 52, and are similar to those of the Pre-DSM results. As expected, based on Figure 50 and Figure 51, the post-DSM electricity costs are lower than for the pre-DSM results. This shows the value of implementing load shifting at pump stations in WTS, as they can reduce operational costs.

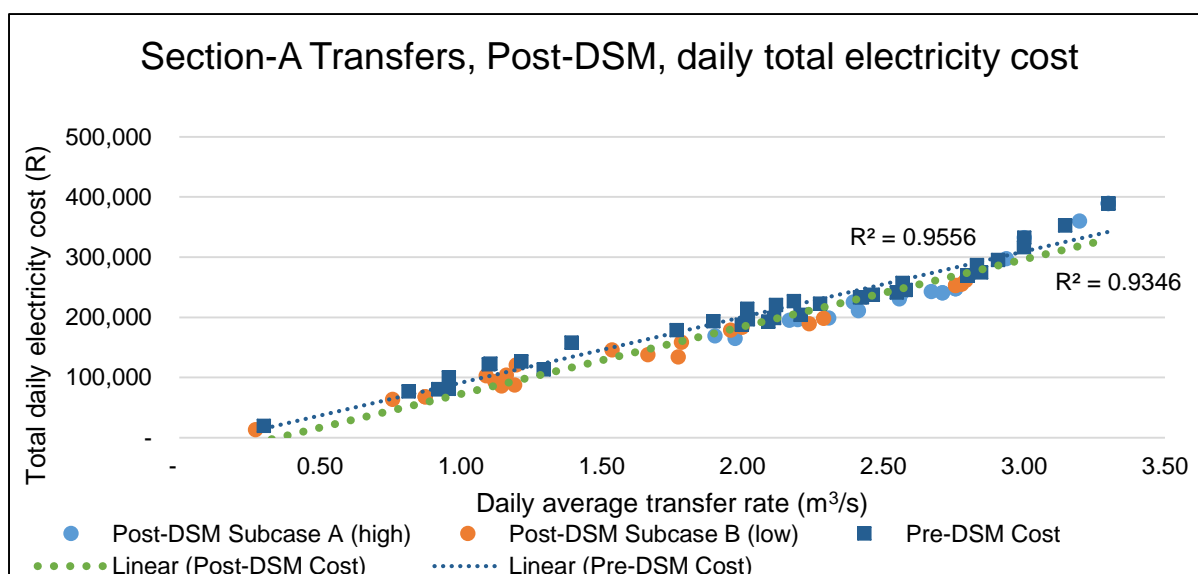


Figure 53: Section-A transfers, Pre- vs. Post-DSM electricity costs
Post-DSM, Section-A DSM savings

The daily savings achieved for both subcases are summarised in Table 12.

Table 12: Section-A transfers, DSM savings

Weekday nr.	Subcase A (high) (MW)	Subcase B (low) (MW)
1	6.95	5.82
2	6.54	5.46
3	9.21	6.75
4	5.93	7.91
5	7.35	7.60
6	0.05	5.63
7	0.05	8.34
8	0.05	5.69
9	2.28	5.69
10	5.76	6.51
11	6.95	1.24
12	6.95	4.94
13	5.11	3.26
14	5.63	3.79
15	(2.94)	3.79
16	6.77	4.96
17	9.65	5.86
18	5.61	6.14
19	7.28	8.09
20	8.88	7.94
21	6.89	7.78
22	8.88	6.57
Total average (MW)	5.45	5.90

From Table 12, above, it is apparent that the average monthly DSM saving for Subcase A (high transfer conditions) were 7.63% lower than those for Subcase B. It is also evident that there were more low-savings days for Subcase A than for Subcase B. This stems from the fact that at higher transfer rates, higher power demands are required. This in turn means that if a day's average transfer rate is so high that the scaled baseline is too high for any available pump configuration to be able to recover energy above it, a load shift cannot take place.

This fact is demonstrated in Figure 53, which shows the DSM savings achieved at the different daily average transfer rates for both subcases.

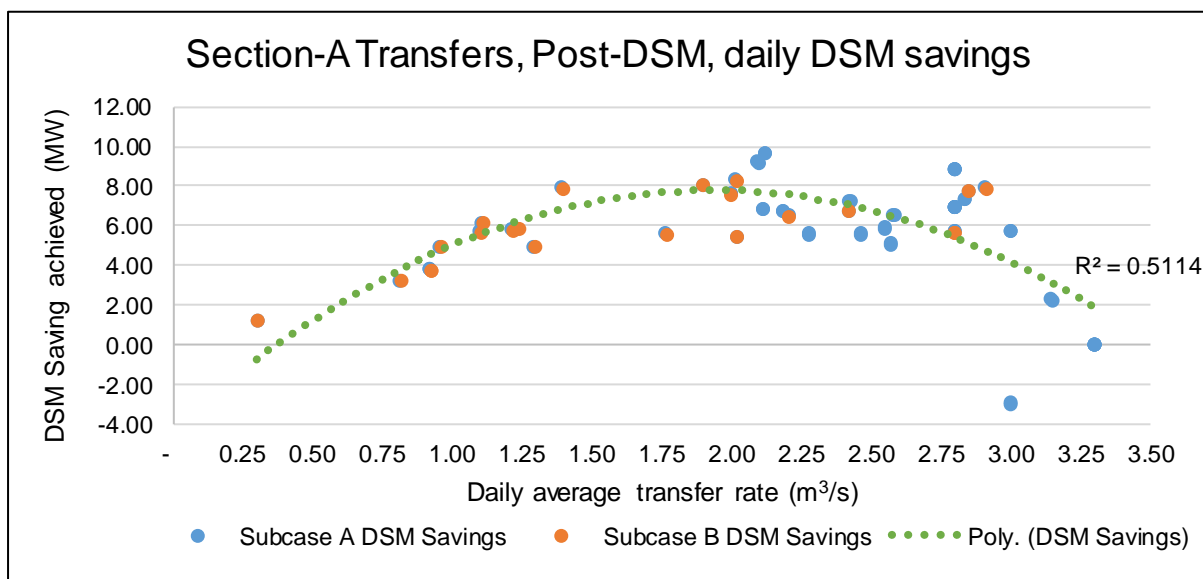


Figure 54: Section-A transfers, DSM savings

Figure 53 shows that there is a squared polynomial relation between the amount of savings that can be achieved and the daily transfer rates. It makes sense that at very low transfer conditions, lower savings can be achieved since the scaled baseline according to which the savings are calculated, will be low. The same logic applies to very high transfer rates. If the average daily transfer rate is so high that there is no possibility for a comeback load, then there will be lower savings or none at all.

The higher the daily average transfer rate, and the higher the power demand associated with it, the less possible it becomes to achieve large savings. In truth, if the power demand and transfer rate are very high in the times near the EPP, the possibility of doing a load shift becomes lower. This is simply because in combination with a high scaled baseline, there exists no spare capacity at the pump station to execute any form of comeback load.

Therefore, for Pump stations A and B, with their combined pump configurations, flow rates and power demands, there exists an optimal daily average transfer range for DSM savings. Within this range, the highest possible DSM savings can be achieved. For Pump stations A

and B, the range in which they can achieve collectively the 6.42 MW evening PLR is between 1.25 m³/s and 2.80 m³/s.

The graph does, however, appear to have its extreme point off-centre to the right, where there is a large grouping of high savings between 2.75 m³/s and 3.00 m³/s. These high transfer rates result in high daily energy consumption. This in turn results in the baseline being scaled upwards, and therefore higher DSM savings being calculated. At transfer rates above this range, however, there is no comeback capacity available to ensure daily scaled energy-neutral load shifting. This leads to a drastic reduction in achievable DSM savings at daily average transfers above this optimum range. This is further evident in the fact that at lower average transfer rates, the scaled baseline will be low. This will result in lower calculated DSM savings even though there is ample comeback capacity.

Post-DSM, Section-A results summary

It can be concluded that the simulated load shifts did not have a negative effect on the Pre-DSM transfers, electricity consumption and costs. They did, however, lead to lower monthly electricity costs and therefore decreased the unit production costs (UPC) of the water transferred. These values are compared to each other as a summary of the results discussed in Chapter 4.3.1 and Chapter 4.3.2.

Table 13: Section-A transfers, Subcase A Post- vs Pre-DSM summary

Monthly values	Pre-DSM	Post-DSM	% Difference
Avg. Transfers (m ³ /s)	2.69	2.67	-1.04%
Electricity cons. (MWh)	6,890.34	6,891.42	0.02%
Electricity cost (R)	6,077,223.44	5,705,511.27	-6.12%
Avg. DSM Saving (MW)	-	5.45	N/A
SEC (kWh/m ³)	1.35	1.36	1.05%
UPC (R/m ³)	1.19	1.13	-5.41%

Table 14: Section-A transfers, Subcase B Post- vs Pre-DSM summary

Monthly values	Pre-DSM	Post-DSM	% Difference
Avg. Transfers (m ³ /s)	1.68	1.64	-2.50%
Electricity cons. (MWh)	4,058.18	4,054.40	-0.09%
Electricity cost (R)	3,612,019.47	3,152,727.10	-12.72%
Avg. DSM Saving (MW)	-	5.86	N/A
SEC (kWh/m ³)	1.27	1.30	2.41%
UPC (R/m ³)	1.13	1.01	-11.70%

The results clearly show that the simulated energy-neutral load shifts resulted in 85% to 91% of the targeted DSM savings being reached for high- and low transfer conditions, respectively. This resulted in reduced UPC without adversely affecting the transfers of Pump stations A and B.

4.3.3 Pre-DSM scenario, Section-B transfers

The simulations performed for the pre-DSM scenario are based on the months selected in Chapter 4.2.1. Subcase A will refer to the high transfer conditions, while Subcase B will refer to low transfer conditions. Simulations will be performed for each day of these months, to evaluate the difference in pump-station operation for different average daily transfer rates. The performance indicators mentioned in Chapter 4.3 will be summarised for each day. The transfer section, and the process interactions being evaluated, are shown in Figure 54.

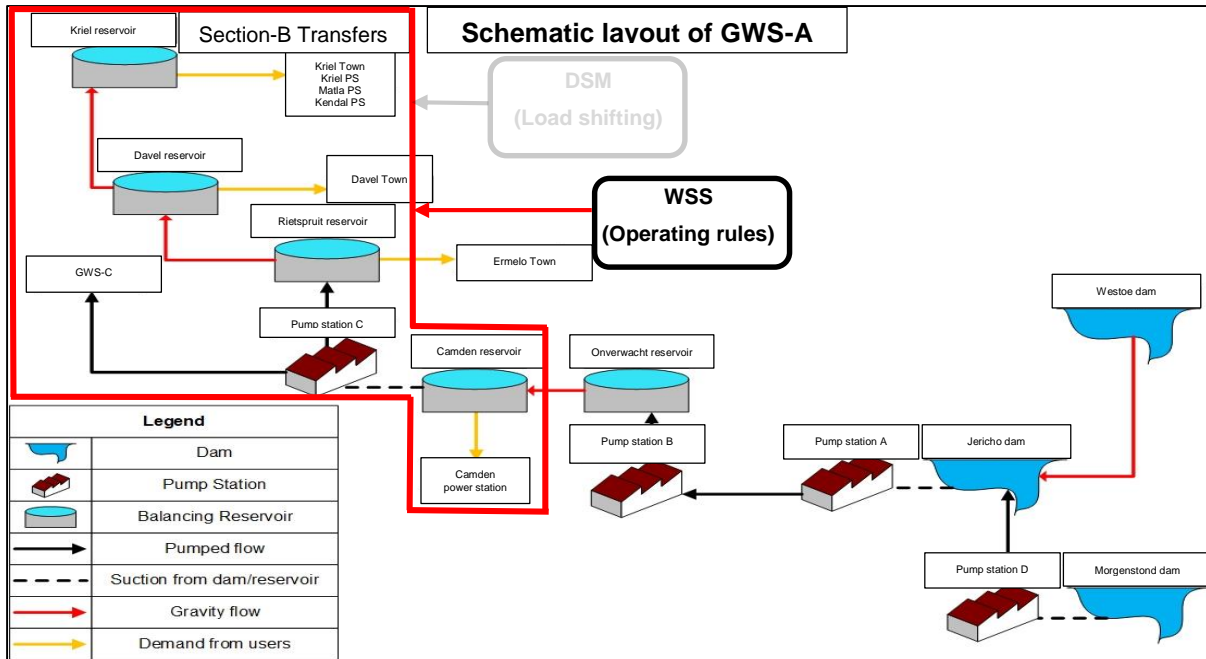


Figure 55: Schematic of GWS-A, Section-B transfers, pre-DSM

Pre-DSM, Section-B daily average transfers

The daily average transfer rates for the high and low transfer conditions are compared to each other in Table 15 and Figure C 55, below.

Table 15: Section-B transfers, Pre-DSM transfer rates

Weekday nr.	Subcase A (high) (m ³ /s)	Subcase B (low) (m ³ /s)
1	1.75	0.79
2	0.70	1.03
3	1.03	1.49
4	1.79	1.58
5	1.86	1.42
6	2.08	1.49
7	2.47	1.34
8	1.76	1.48
9	1.57	1.43
10	1.70	1.61
11	1.81	0.63
12	1.71	-

Weekday nr.	Subcase A (high) (m ³ /s)	Subcase B (low) (m ³ /s)
13	1.75	-
14	1.78	-
15	2.16	0.13
16	1.54	0.27
17	1.97	0.13
18	0.94	0.15
19	1.28	0.57
20	1.69	1.71
21	1.60	1.60
22	1.69	2.38
Total average	1.66	0.96

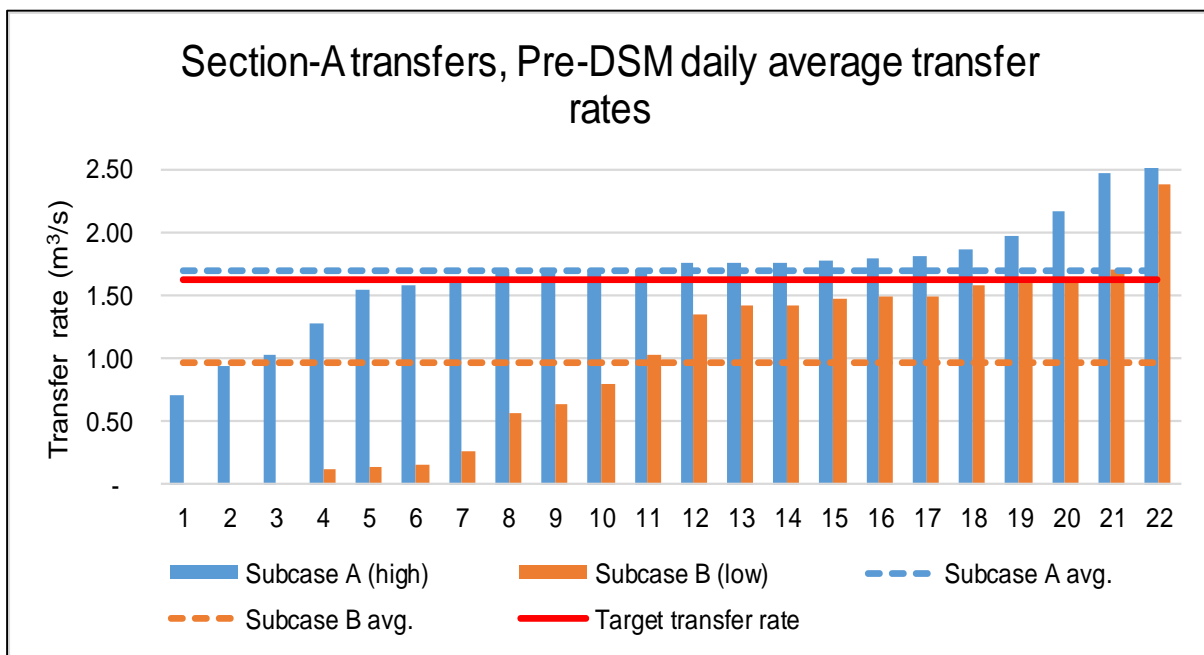


Figure 56: Section-B transfers, Pre-DSM transfer rates

The transfer rates once again are ordered from low to high for each subcase. It shows that the average daily transfer rate for the month of Subcase A is much higher, at 1.66 m³/s, than that of Subcase B, at 0.96 m³/s. This demonstrates that the months selected are good representations of high- and low transfer conditions.

This range of daily average transfer rates covers a good deal of the possible transfer rates achievable by Pump station C; between 0.00 m³/s and 2.56 m³/s. Subcase A exceeds the transfer target for that month 68% of the time, while Subcase B exceeds it only twice. This demonstrates how differently the two subcases performed in terms of the AOA monthly targets.

Pre-DSM, Section-B electricity consumption

The daily total electricity consumptions are summarised in Table 16, below. They are also given per weekday number for each subcase's respective month, as before. The total monthly electricity consumption for Subcase A is 84.5% more than that of Subcase B. Generally, the higher the average daily transfer rates result in a higher consumptions. This is because of the same two factors discussed in Chapter 4.3.1 for Section-A transfers.

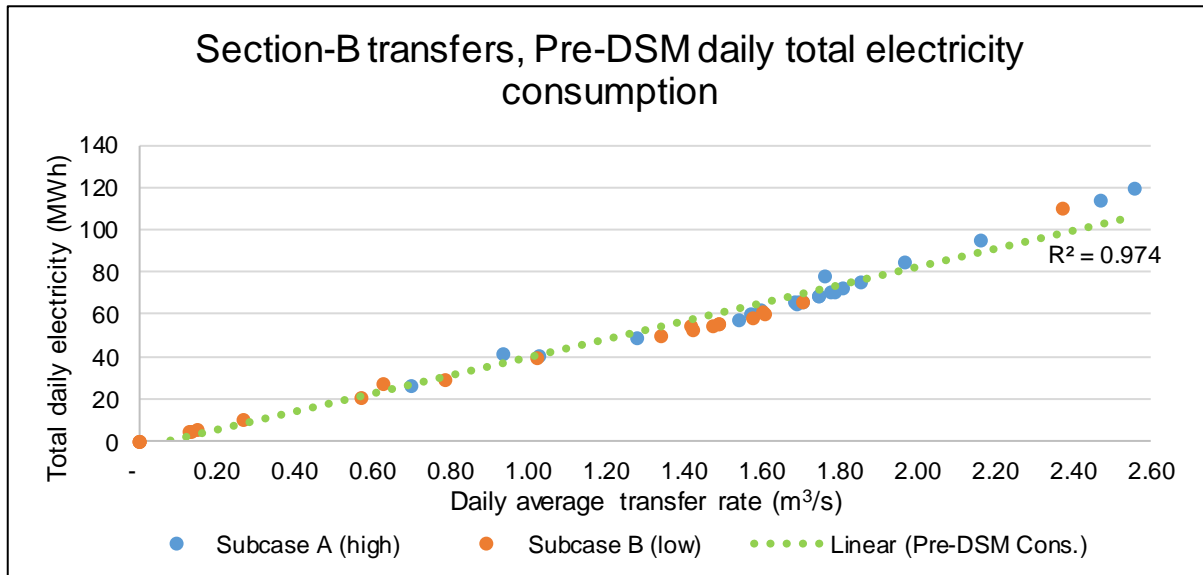


Figure 57: Section-B transfers, Pre-DSM electricity cons.

The increase in energy consumption for increased daily average transfer rate is reflected in Figure 56. Both subcases have been plotted on the same graph, as one large data-set. Their results, however, are distinguished between to show the two different ranges in which transfers took place.

Table 16: Section-B transfers, Pre-DSM electricity cons.

Weekday nr.	Subcase A (high) (MWh)	Subcase B (low) (MWh)
1	68.75	29.38
2	26.88	40.00
3	40.63	55.63
4	71.25	58.75
5	75.63	54.38
6	120.00	55.63
7	114.38	50.00
8	78.75	55.00
9	60.63	53.13
10	65.63	60.00
11	72.50	27.50
12	66.25	-
13	68.75	-
14	70.63	-
15	95.00	5.00

Weekday nr.	Subcase A (high)	Subcase B (low)
16	57.50	10.00
17	85.00	5.00
18	41.25	5.63
19	48.75	21.25
20	66.25	66.25
21	61.88	61.25
22	65.00	110.63
Total sum (MWh)	1,521.25	824.38

Subcase B clearly had transfers from 0.13 m³/s to 2.38 m³/s, where Subcase A had transfers from 0.70 m³/s to the maximum transfer rate of 2.56 m³/s. The differences in total electricity consumption can clearly be seen. It is noteworthy that the R-squared value for the energy consumption associated with the daily average transfer rates is 0.97. This indicates that there is once again a strong linear relation between the energy consumed and the transfers achieved, prior to load shifts being performed.

The relationship between the increased energy consumption associated with increased average daily transfer rates will not be discussed again. The relationship is as discussed in Chapter 4.3.1.

Pre-DSM, Section-B electricity cost

The daily total electricity costs are summarised in Table 17. They are also given per weekday number for each subcase's respective month.

Table 17: Section-B transfers, Pre-DSM electricity cost

Weekday nr.	Subcase A (high) (R)	Subcase B (low) (R)
1	64,119	20,929
2	19,637	35,543
3	32,319	51,639
4	61,193	52,976
5	64,904	50,417
6	106,869	47,612
7	104,805	39,989
8	69,709	50,456
9	52,887	45,734
10	57,215	53,435
11	59,928	10,853
12	57,254	-
13	58,362	-
14	58,668	-
15	88,881	2,788
16	47,912	5,958
17	76,396	2,979
18	30,096	3,018

Weekday nr.	Subcase A (high) (R)	Subcase B (low) (R)
19	50,070	16,217
20	58,207	59,945
21	55,839	55,038
22	64,480	103,429
Total sum	1,339,748	708,953

The total monthly electricity costs for Subcase A is 84.5% more than that of Subcase B. This is once again attributable to the total greater amount of energy required to achieve higher average daily transfer rates.

Where the greater amounts of energy associated with higher daily average transfer rates depended on two aspects, the daily cost depends on a third as well, as discussed in Chapter 4.3.1. Figure 57, again, demonstrates a strong linear relationship between the electricity costs associated with the energy consumption for different transfer rates. The deviances from the linear regression line can be due to the same factors discussed in Chapter 4.3.1, and will not be repeated.

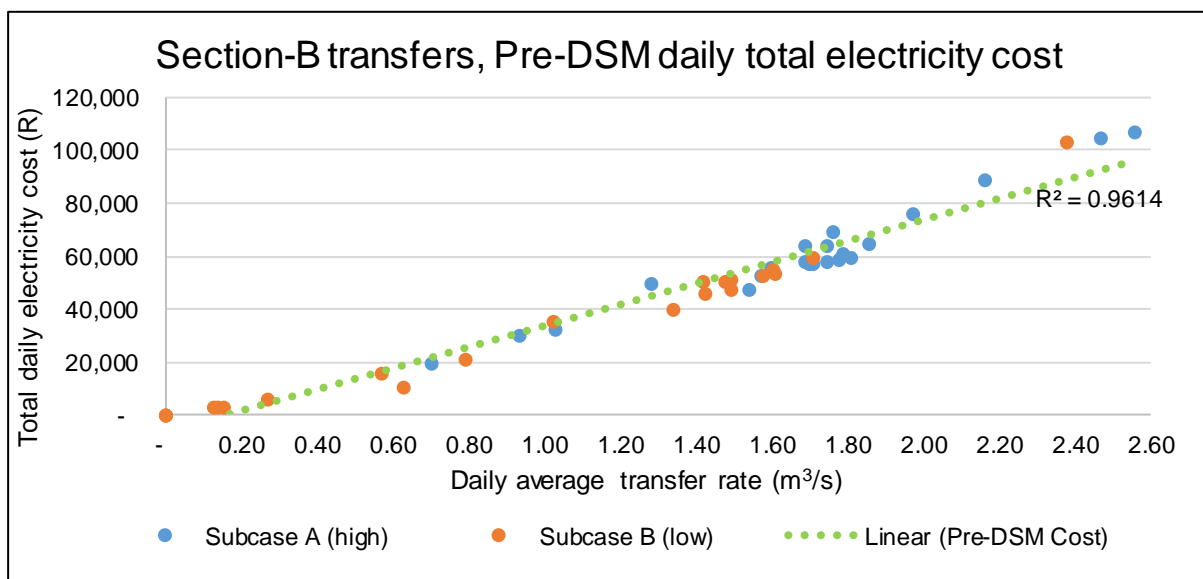


Figure 58: Section-B transfers, Pre-DSM electricity cost

4.3.4 Post-DSM scenario, Section-B transfers

The same assumptions and simulation conditions and methodology, discussed in Chapter 4.3.2, for Section-A transfers, are applicable to the simulations for Section-B transfers. The contractual DSM saving, which is to be achieved through the implementation of load shifting, is 2.33 MW [89]. The transfer section, and the process interactions being evaluated are shown in Figure 58.

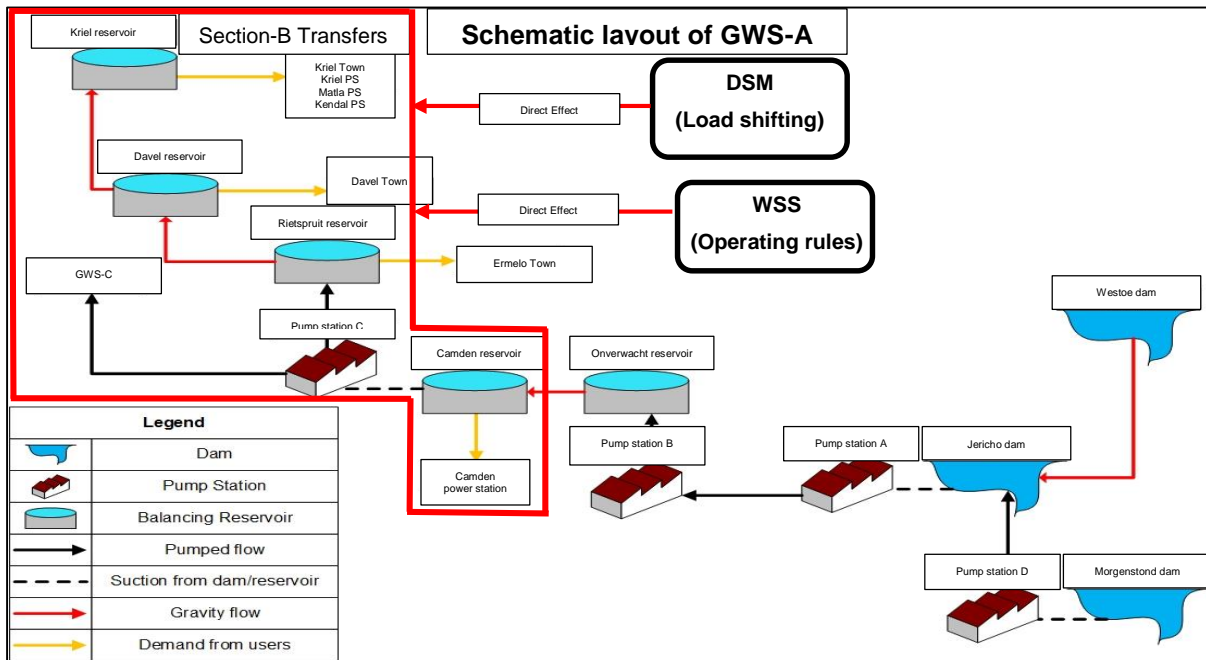


Figure 59: Schematic of GWS-A, Section-B transfers, post-DSM

Post-DSM, Section-B daily average transfers

The daily average transfer rates for the high- and low transfer conditions, after the implementation of energy-neutral load shifts, are compared to each other in Table 18.

Table 18: Section-B transfers, Post -DSM transfer rates

Weekday nr.	Subcase A (high) (m ³ /s)	Subcase B (low) (m ³ /s)
1	1.65	0.83
2	0.90	0.93
3	0.94	1.47
4	1.78	1.53
5	1.88	1.35
6	2.56	1.47
7	2.47	1.27
8	1.76	1.42
9	1.44	1.36
10	1.68	1.56
11	1.79	0.83
12	1.69	-
13	1.74	-
14	1.70	-

Weekday nr.	Subcase A (high) (m ³ /s)	Subcase B (low) (m ³ /s)
15	2.09	0.13
16	1.56	0.27
17	1.76	0.13
18	1.10	0.15
19	1.19	0.55
20	1.73	1.67
21	1.56	1.57
22	1.66	2.38
Total average	1.67	0.95

To compare the impact load shifting had on the daily and monthly transfers, Subcase A and B are shown on different graphs. They are compared in a similar way as done in Chapter 4.3.3 for the Pre-DSM results. The average daily transfers, after load shifting, are compared to each day on which load shifting was simulated for, and ordered from low to high based on the Pre-DSM transfer rates. These graphs can be seen in Figure 59 and Figure 60.

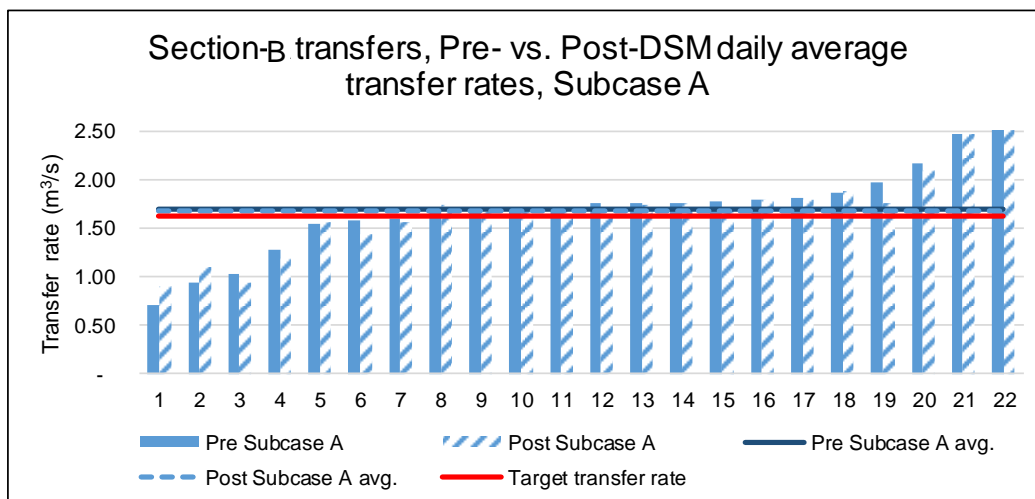


Figure 60: Section-B transfers, Subcase A, Post -DSM transfer rates

As can be seen in Figure 59, the average daily transfer rate for the entire month is virtually the same as that of the Pre-DSM monthly average, as seen in Table 18, above. The Pre-DSM monthly average transfer rate is 1.66 m³/s, while the Post-DSM rate is 1.67 m³/s.

Figure 60, below, shows the average daily transfer rate for the entire month is again basically the same as that of the Pre-DSM monthly average, as seen in Table 18, above. The Pre-DSM monthly average transfer rate is 0.96 m³/s, while the Post-DSM rate is 0.95 m³/s.

The simulations therefore clearly demonstrate that at both high- and low transfer conditions, if all pump configurations are available, energy-neutral load shifts will not negatively impact the transfers of a pump station.

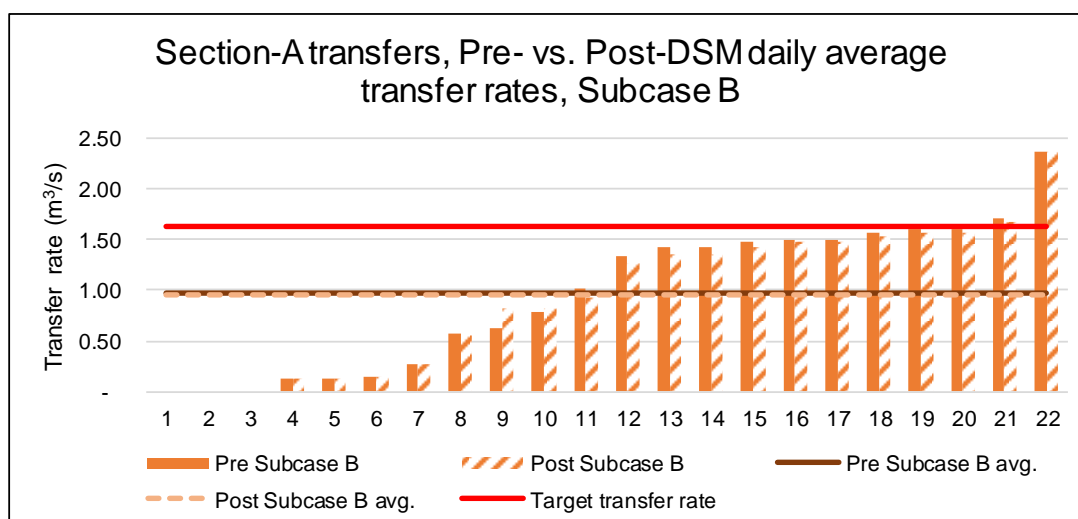


Figure 61: Section-B transfers, Subcase B, Post -DSM transfer rates

Post-DSM, Section-B electricity consumption

The total daily electricity consumption for the Post-DSM results are summarised in Table 19. The Post-DSM total monthly consumptions for Subcases A and B are 0.86% and 1.29% more than that of the Pre-DSM consumptions, respectively, as shown in Figure 61 and Figure 62, below.

Table 19: Section-B transfers, Post -DSM electricity cons.

Weekday nr.	Subcase A (high) (kWh)	Subcase B (low) (kWh)
1	66.25	31.88
2	34.38	37.50
3	38.75	56.88
4	74.38	59.38
5	76.88	53.75
6	120.00	56.88
7	114.38	48.75
8	78.75	55.00
9	55.63	52.50
10	68.13	60.63
11	75.00	35.00
12	68.75	-
13	71.88	-
14	69.38	-
15	90.00	5.00
16	60.63	10.00
17	75.00	5.00
18	48.75	5.63
19	46.25	20.63
20	71.25	67.50
21	63.13	62.50
22	66.88	110.63
Total sum (kWh)	1,534.38	835.00

The Pre- and Post-DSM accumulative electricity consumptions over the month are therefore virtually the same for both subcases, as shown in Figure 61 and Figure 62, below. This shows that the load shifts were successfully simulated as energy-neutral.

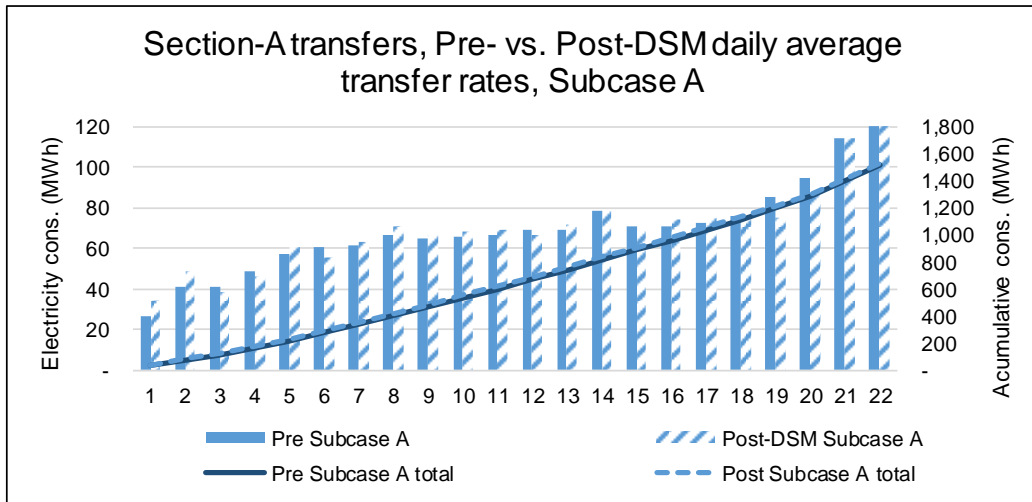


Figure 62: Section-B transfers, Subcase A, Post -DSM electricity cons.

Both figures clearly show that the total monthly electricity consumption for the Pre- and Post-DSM results are close matches. Furthermore, there are less inter-day differences in daily average transfer rates or electricity consumptions. This is because there are only two possible pump configurations, which can be used to achieve these transfer rates and comeback loads.

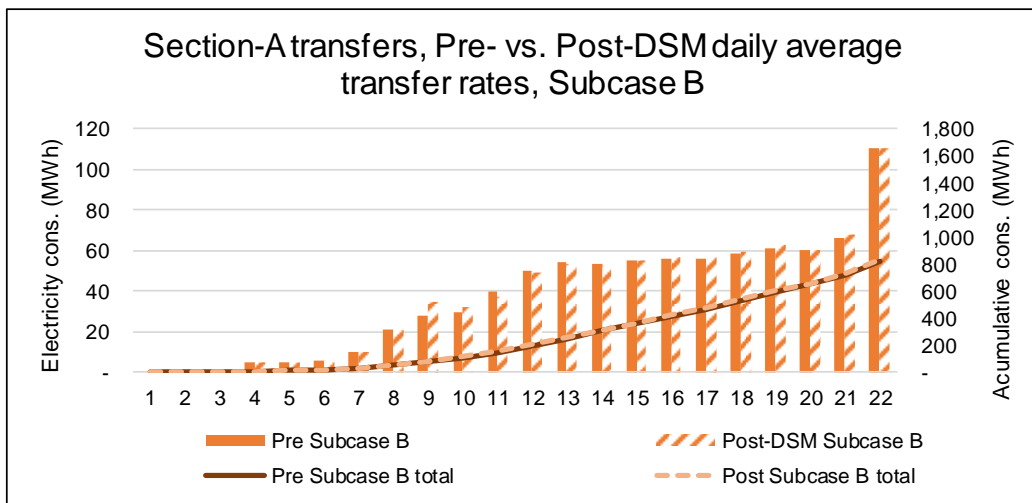


Figure 63: Section-B transfers, Subcase B, Post -DSM electricity cons.

Figure 63, below, once again shows the strong linear relationship between the electricity consumption and daily average transfer rate. From it can also be seen that the Pre- and Post-DSM daily consumptions are in the same range and have the same strong linear relationship. This further shows that the load shifts were simulated as daily scaled energy-neutral.

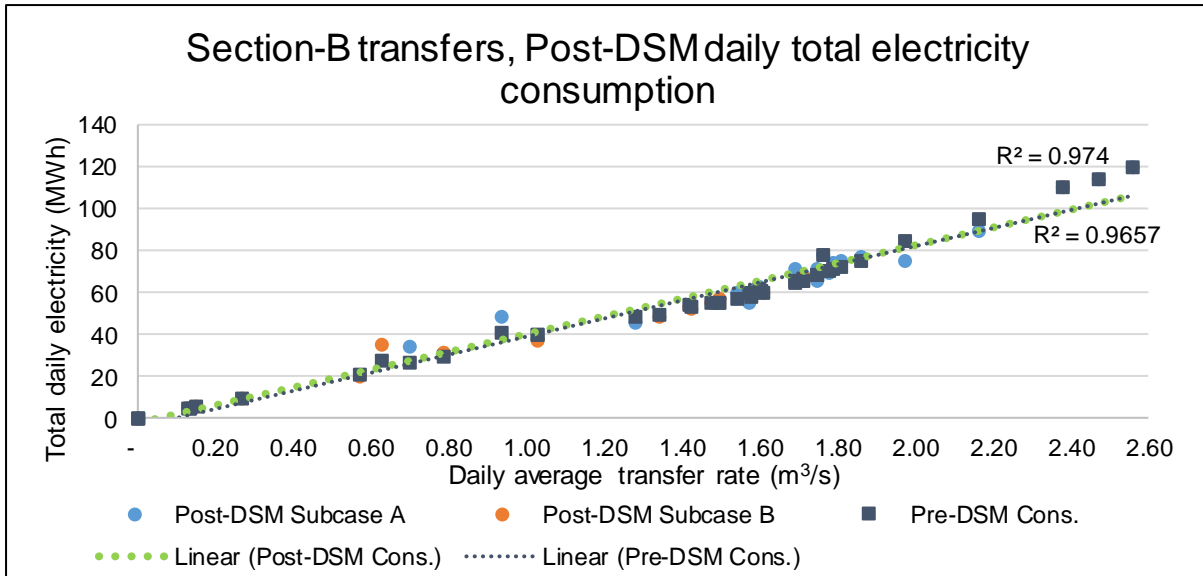


Figure 64: Section-B transfers, Pre- vs. Post -DSM electricity cons.

Post-DSM, Section-B electricity cost

The monthly simulated costs for Pre- and Post-DSM conditions are compared to each other for the two subcases in Figure 64 and Figure 66, below.

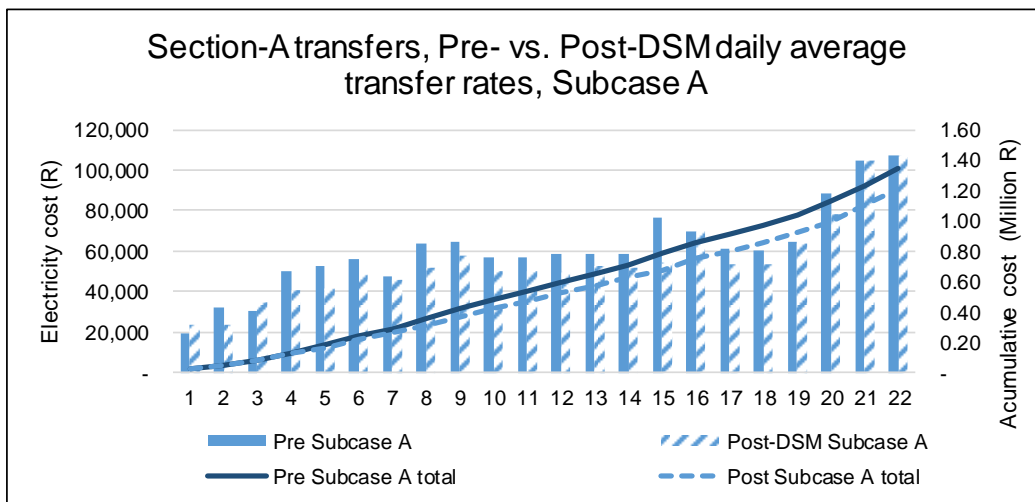


Figure 65: Section-B transfers, Subcase A, Post -DSM electricity cost

Both figures clearly show that the Post-DSM daily electricity costs are lower than the Pre-DSM costs. This is because of the ECS due to lower consumption in the more expensive EPP and higher consumptions during the cheaper standard and off-peak periods. Subcases A and B achieved ECS of 9.83% and 11.38%, respectively.

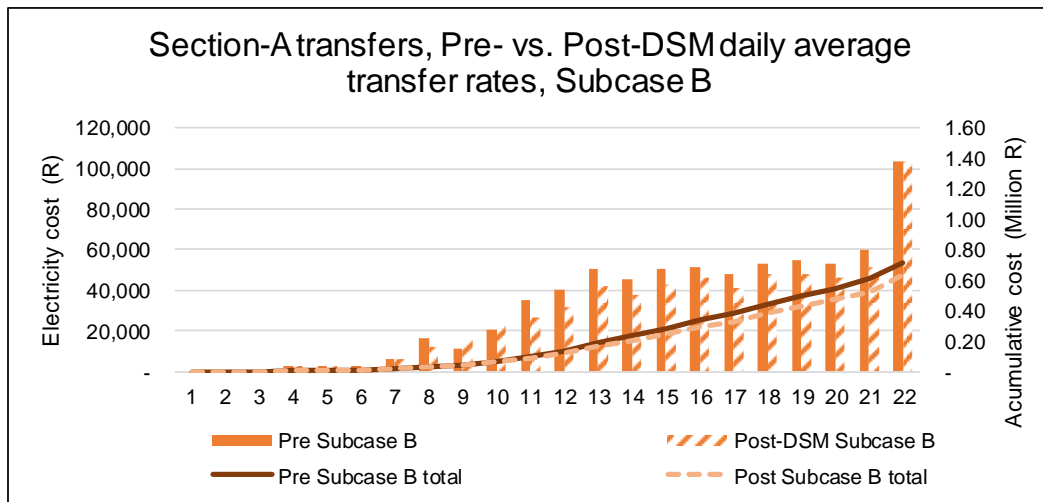


Figure 67: Section-B transfers, Subcase B, Post -DSM electricity cost

The linear relationship between the total daily costs for daily average transfer rates can be seen in Figure 65, and is similar to that of the Pre-DSM results and those for Section-A transfers. As was the case for Section-A transfers in Chapter 4.3.2, it can be seen that the simulated load shifts resulted in an overall decrease in daily electricity costs.

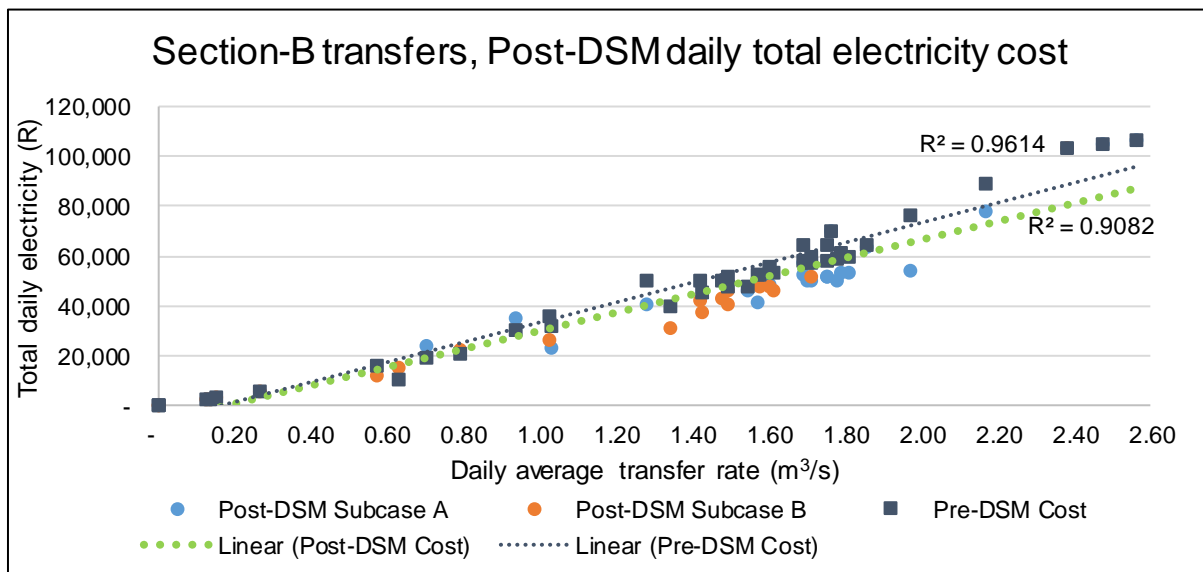


Figure 66: Section-B transfers, Pre- vs. Post-DSM electricity cost

Post-DSM, Section-A DSM savings

The daily savings achieved for both subcases are summarised in Table 20, below. It can be seen that the average monthly DSM savings for the high transfer conditions (Subcase A) were 69.25% higher than those for the low transfer conditions. It is also evident that there were more low-savings days for Subcase B than for Subcase A. This stems from the fact that for many of the days in Subcase B the daily average transfer rates were so low that the scaled baseline was also too low to result in higher DSM savings.

Since there are only two pump configurations, very low daily average transfer rates imply that the configurations run for shorter periods. This is because the flow rates which are

Table 20: Section-B transfers, Post -DSM savings

Weekday nr.	Subcase A (high) (MW)	Subcase B (low) (MW)
1	2.93	1.41
2	1.52	1.66
3	1.71	1.89
4	3.29	2.00
5	0.90	2.38
6	0.31	2.52
7	0.06	2.16
8	2.55	2.43
9	2.46	2.32
10	3.01	2.68
11	3.32	1.55
12	3.04	-
13	3.18	-
14	3.07	-
15	1.48	0.22
16	2.68	0.44
17	3.32	0.22
18	2.16	0.25
19	2.05	0.91
20	3.15	2.99
21	2.79	2.76
22	2.96	-0.11
Total average (MW)	2.36	1.39

delivered by the configurations are high, at either 1.61 m³/s or 2.56 m³/s. If there were more configurations that could deliver lower flow rates, there could have been more options available to run during low required transfer conditions. This in turn would lead to more daily energy consumption, but a higher scaled baseline for DSM savings.

If a day's average transfer rate is so high that there is no spare capacity to recover the transfers, and therefore power load, a load shift cannot take place.. This is the opposite case of that for the low average daily transfer rates, discussed above. Once again, there are only two pump configurations, and if the baseline consists mainly of two pumps in operation, there is now comeback capacity to recover saved energy. This becomes clear in Figure 67, below.

The shape of the graph is once again that of an asymmetric quadratic polynomial. This is the same shape found for Section-A transfers and the rationale behind it is similar. It is noteworthy that there is again a grouping of high DSM savings off-centre to the right of the extreme. The reasoning for this will not be repeated and is discussed in Chapter 4.3.2.

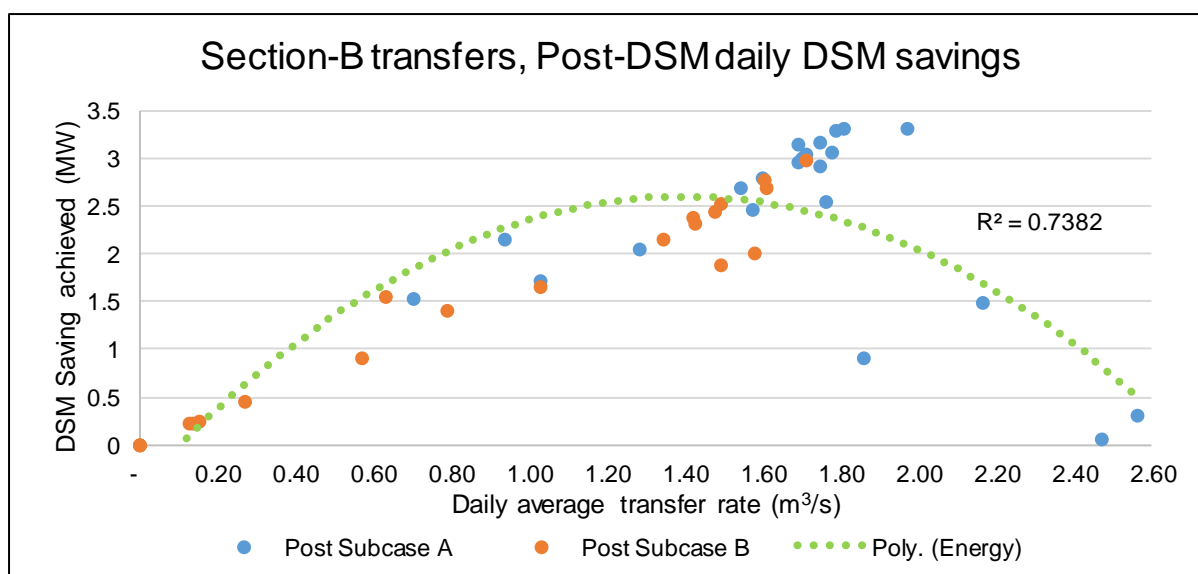


Figure 68: Section-B transfers, Post -DSM savings

Post-DSM, Section-B results summary

It can be concluded that the simulated load shifts did not have a negative effect on the Pre-DSM transfers, electricity consumption and costs. It did, however, lead to lower monthly electricity costs and therefore decreased the unit production costs (UPC) of the water transferred. These values are compared to each other as a summary of the results discussed in Chapter 4.3.3 and Chapter 4.3.4.

The results clearly show that the simulated energy-neutral load shifts resulted in 60% to 101% of the DSM targets being reached for high- and low transfer conditions, respectively. This resulted in reduced UPC without adversely affecting the transfers of Pump station C.

Table 21: Section-B transfers, Subcase A Post- vs Pre-DSM summary

Monthly values	Pre-DSM	Post-DSM	% Difference
Avg. Transfers (m ³ /s)	1.69	1.67	-1.20%
Electricity cons. (MWh)	1,521.25	1,534.38	0.86%
Electricity cost (R)	1,339,747.88	1,207,991.44	-9.83%
Avg. DSM Saving (MW)	-	2.36	N/A
SEC (kWh/m ³)	0.47	0.48	2.07%
UPC (R/m ³)	0.41	0.38	-8.75%

Table 22: Section-B transfers, Subcase B Post- vs Pre-DSM summary

Monthly values	Pre-DSM	Post-DSM	% Difference
Avg. Transfers (m ³ /s)	0.96	0.95	-1.57%
Electricity cons. (MWh)	824.38	835.00	1.29%
Electricity cost (R)	708,953.44	628,309.88	-11.38%
Avg. DSM Saving (MW)	-	1.39	N/A
SEC (kWh/m ³)	0.45	0.46	2.36%
UPC (R/m ³)	0.39	0.35	-10.44%

4.4 Analysis and Comparison of 2014 GWS-Case Study

The load shift project was implemented on Pump stations A, B and C in 2014. Power data is available from May 2014 to September 2014. This falls within the 2014/2015 planning year. The data used for the performance assessment (PA) period, verified by the relevant M&V team, however, will be used [90] [91]. This is for the months of July, August and September 2014. The same method previously used to determine daily and monthly average transfer rates, based on power data, in Chapter 4.2 and 4.3 was employed for 2014.

4.4.1 2014 Case study – Section-A transfers

The same results used to quantify the simulated impact of load shifting on the KPI of the pump stations, will be used to examine the impact for the three months of the PA period of 2014. The linear relationship between the monthly energy consumption and cost, and the average daily transfer rates, will be used to estimate these results. The approximated polynomial relationship between DSM savings and the average monthly transfer rate will be used to predict the DSM savings for the transfer rates calculated during the PA period.

DSM savings and transfers

The total monthly transfers calculated from the power data for Pump stations A and B, of Section-A transfers, are compared to the AOA reported transfers and AOA targets for the same months. These values are given in Figure 68.

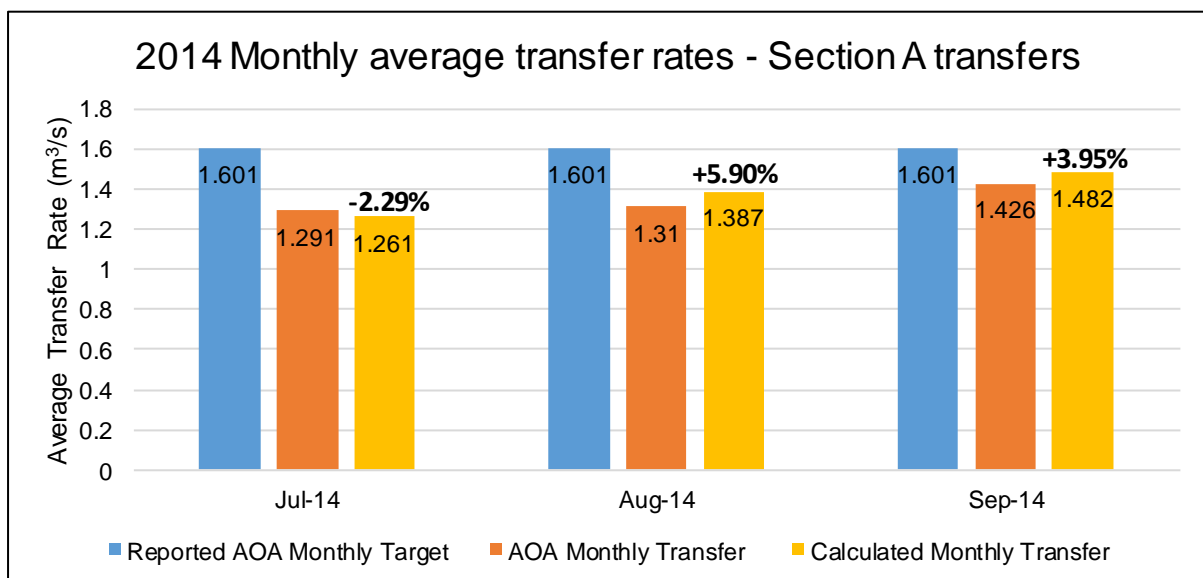


Figure 69: Section-A transfers – Case study transfers

From Figure 68, above, it can be seen that the calculated monthly transfers compare relatively well to the monthly transfers reported in the 2014/2015 AOA. The power data used for the

case study was verified by the independent M&V team, with a summary supplied in Appendix B-3 and B-4.

It should be noted that the average monthly transfer rates for 2014 are much lower than those for either the high- or low transfer conditions of Subcase A and B in Chapter 4.3.1. The low transfer conditions of Subcase B, Chapter 4.3.1 are $1.67 \text{ m}^3/\text{s}$, which are still 12.33% higher than the highest calculated transfer rate for September 2014. This means that the results of the actual load shifts performed during this time will most likely be more comparable with those of Subcase B. They should however be even lower, according to the observations made for the relationship between DSM savings and average daily transfer rates.

The quadratic polynomial used to visualise the relationship between DSM savings and average daily transfer rates for Section-A transfers, results in much higher savings for the daily flow rates calculated. For this reason, a grade four polynomial equation was used to determine the approximated results, shown in Figure 69, and given in Appendix D-1, D-2 and D-3. Figure 69 shows the approximated and actual results for the DSM savings during the three-month PA period.

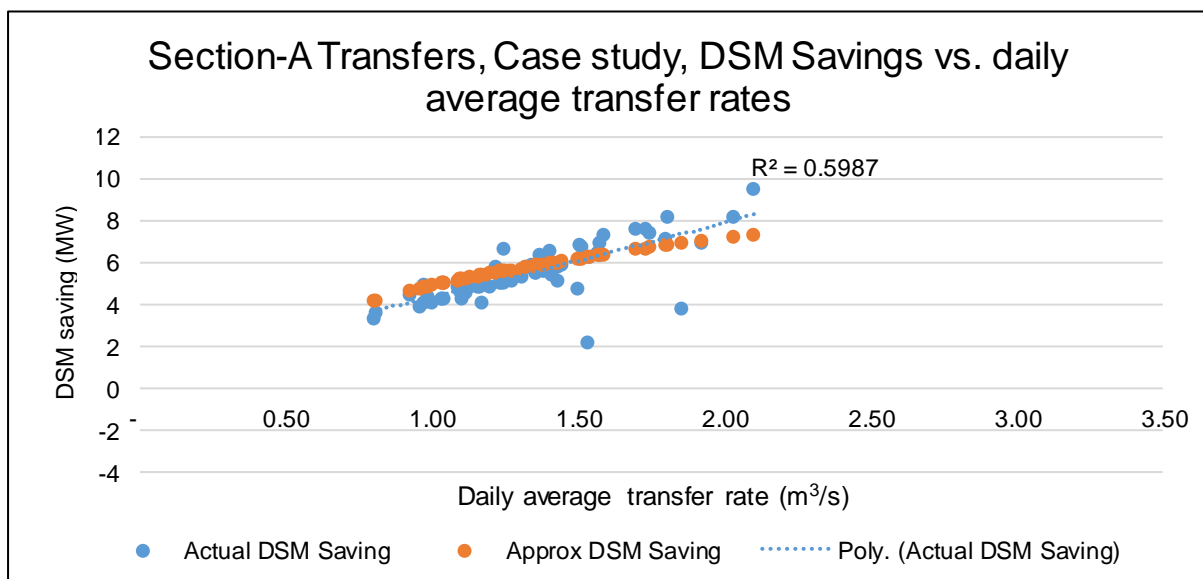


Figure 70: Section-A transfers – Case study DSM savings

The orange points show the predicted approximate DSM savings, based on the grade four polynomial mentioned above, and the blue shows the actual daily DSM savings for the 2014 case study. They will follow a gradual slope, appearing to be linear, but this is because of the small range of daily transfers in which savings were achieved. The actual DSM savings fall relatively close to these predicted approximations, verifying the model and method used to execute the simulations in Chapter 4.3.2.

The predicted total average DSM saving for the three-month period differs with only 4.62%, as can be seen in Appendix D-1. If the two outliers were removed, this percentage difference of the three-month period would be only 2.7%. These outliers are most likely due to low reservoir levels on those specific days, resulting in high transfers, but low DSM savings, to prevent the reservoir levels from falling too far.

The polynomial trend line shown above is once again quadratic. Its quadratic polynomial R-squared value of 0.60 compares well to those found in the simulated results of 0.51. It must firstly be noted that the range of daily average transfer flows for the case study fall between 0.8 m³/s and 2.1 m³/s, where those used in the simulations fall between 0.3 m³/s and 3.3 m³/s. This makes the comparisons relevant, since they are within the simulated range. If the two outliers far below the trend line in Figure 69 are removed from the population, the R-squared value would be 0.71, once again verifying the simulations used.

The transfer capacity, however, was much lower during the case study due to maintenance issues, at only 2.2 m³/s and occasionally 2.8 m³/s. The range of average transfer rates for the case study fall on the upward slope of the polynomial, far below the limited maximum transfer capacity of Pump stations A and B.

It therefore becomes clear that if the target transfers decrease due to decreased demand, the DSM savings will be more easily achieved, but will also be lower, due to lower scaled baselines. Furthermore, if the target transfers decrease due to decreased pumping capacity, the DSM savings will be harder to achieve, and will also be lower due to lower baselines.

Electricity consumption and cost

The actual and approximated results for the case study electricity consumption and cost are given in Appendix D-2 and D-3. They are also compared to each other in Figure 70 and Figure 71, below. The orange points once again show the approximated values. The linear trend line in both cases refers to the actual measured data for the case study period of July to September 2014.

The percentage differences between the actual and approximated total energy consumptions and costs for the three-month PA period are 2.38% and 2.52%, respectively. This further verifies the methods and model used to simulate the impact load shifting will have on the operation of Pump stations A and B.

Figure 70 shows that the predicted total daily electricity consumptions, according to the case study average daily transfer rates, correlate well with the actual measured power data and electrical consumptions.

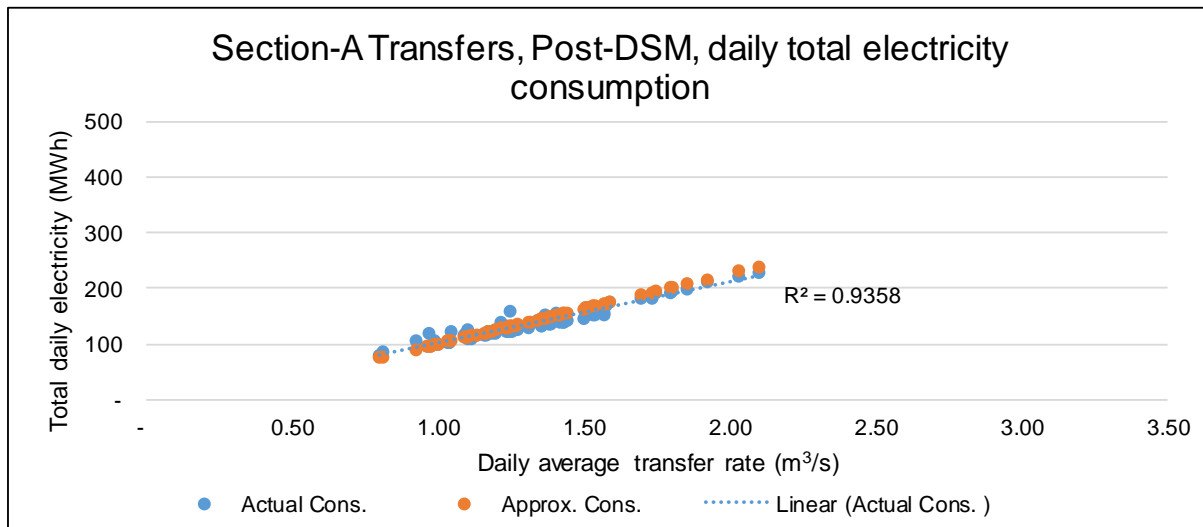


Figure 71: Section-A transfers – Case study electricity cons.

The linear R-squared value for actual measured power data and the linear trend line is 0.94, very close to the simulated value of 0.95.

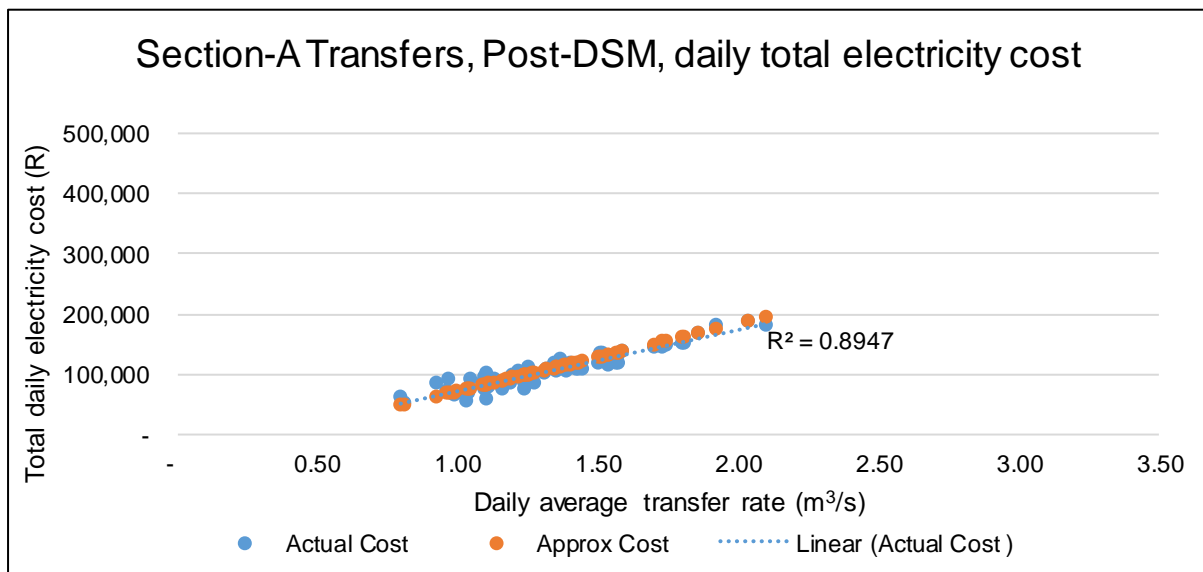


Figure 72: Section-A transfers – Case study electricity cost

Figure 71 shows the linear relationship between the measured average daily transfer rates and the electricity costs calculated for them. The linear R-squared value of 0.89 is slightly lower than that of the simulated value of 0.93. This can be because of the fact that the range of the population is much smaller than that of the simulations. The available pump configurations during the case study were limited to a maximum flow rate of 2.2 m³/s and an associated power demand of 12,000 kW.

This means that high power demand configurations could not be used to pump water, resulting in an uneven distribution within the population of points, concentrating near the lower transfer rates and lower costs.

It can be concluded from these actual results that the model used to simulate load shifts at Pump stations A and B are within acceptable accuracy. Furthermore, the lower transfer conditions obviously lead to lower electricity consumptions and equivalent costs, just as the simulations have shown.

Case study vs. simulations – summary

Based on the installed and available transfer capacities, and the required transfers of Pump stations A and B, depicted in Figure 72, the following conclusions can be made:

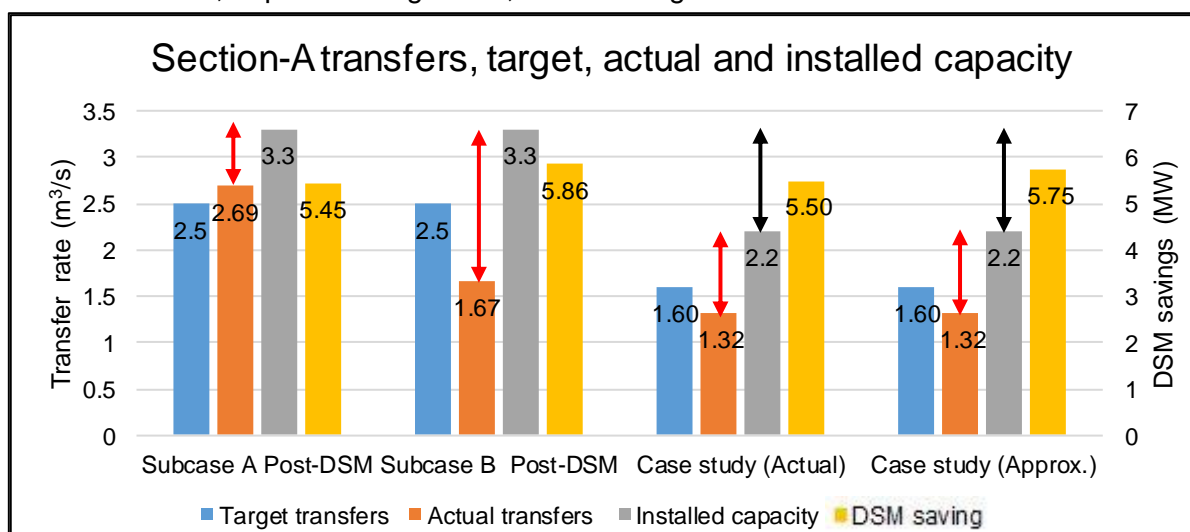


Figure 73: Section-A transfers – Case study summary

- Subcase A post-DSM simulation results show that even though the transfer rates are higher, the limited spare capacity (red arrows) prohibits very high DSM savings due to limited comeback capacity
- Subcase B post-DSM simulation results show that even though the transfer rates are lower, the excessive spare capacity allows for very high DSM savings due to high available comeback loads
- Actual case study results show that with much lower average transfer rates, and limited available installed capacity (black arrows), high DSM savings were still achieved. Even though the available installed capacities were below maximum, it was still high enough to ensure comeback loads. The overall very low required transfer rates also alleviated pressure from having to recover all “saved” energy and associated transfers in the same day
- The transfer results from the predicted case study approximations are exactly the same as those for the actual case study, with only the predicted DSM savings being slightly

higher. This is because the simulations used to determine the relationship between DSM savings and required average daily transfers accounted for a CL on every day of load shifting. This CL would consequently make the scaled baseline higher, resulting in more DSM savings.

This, however, was not the case for every weekday during the case study. On many occasions, load would not be recovered due to various factors, most notable of which is the perceived lack of need for such load recovery under the operators. This stems from the fact that the reservoir levels rarely decrease drastically in the two hours of the EPP. They would, however, decrease the following day when usage increased.

The great differences in average transfer rates for the simulations and actual case study complicate the determination of the impact that load shifts have on the operation of the pump stations. Based on the fact that the results from the simulated load shifts are verified by those measured during the case study, it can be concluded that energy-neutral load shifts on Pump stations A and B will not negatively affect their operation.

It must, however, be noted that these simulations lack the capacity to include the impact of daily reservoir level fluctuations on required transfer rates and subsequently on possible DSM savings. Furthermore, it should be noted that the simulations were carried out for explicitly daily scaled energy-neutral load shifts. This means that if load shifts were carried out in practice, without the required load recovery, the DSM savings will be lower and the impact on pump station operation will most likely be negative. It would result in decreased transfers over time, further preventing the pump stations from reaching their targets and possibly leading to supply shortfalls.

Energy-neutral load shifts in most cases result in most of the “saved” transfers (water) being recovered. It will therefore not negatively affect the pump stations’ operation in terms of achieving the required target transfers stipulated in the AOA.

4.4.2 2014 Case study – Section-B transfers

The same results used to quantify the simulated impact of load shifting on the KPI of the pump stations, will be used to examine the impact for the three months of the PA period of 2014. The linear relationship between the monthly energy consumption and cost, and the average daily transfer rates, will be used to estimate these results. The approximated polynomial relationship between DSM savings and the average monthly transfer rate will be used to predict the DSM savings for the transfer rates calculated during the PA period.

DSM savings and transfers

The total monthly transfers calculated from the power data for Pump station C, of Section-B transfers, are compared to the AOA reported transfers and AOA targets for the same months. These values are given in Figure 73.

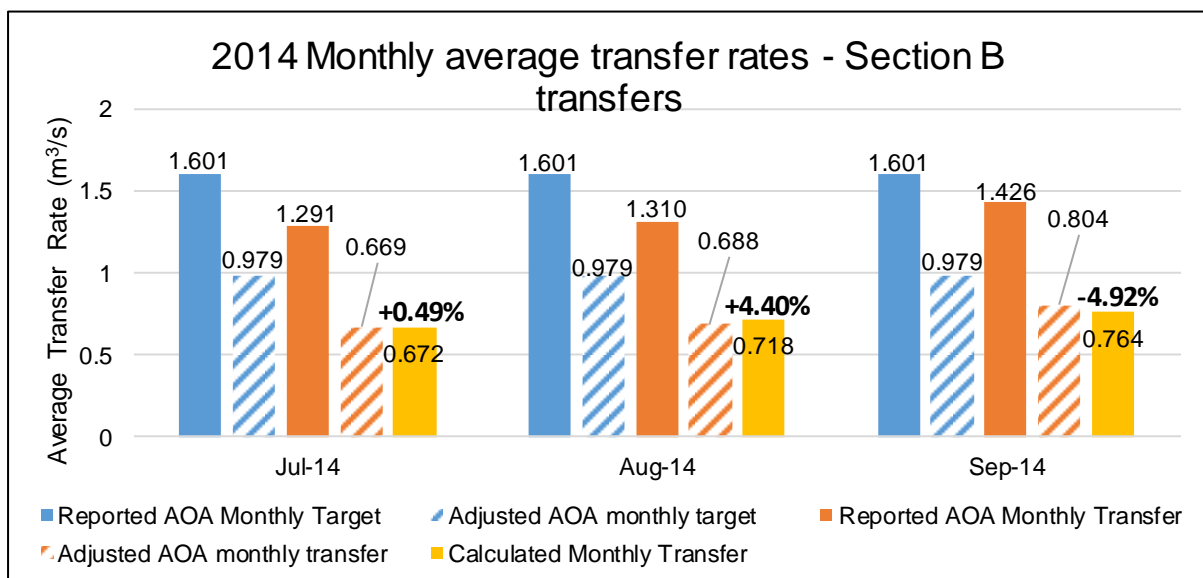


Figure 74: Section-B transfers – Case study transfers

Figure 73 shows the reported and adjusted AOA monthly transfers and targets. These adjustments are made as discussed in Chapter 4.2.2. The calculated flow rates compare well with the adjusted transfer rates from the 2014/2015 AOA. The power data used for the case study was verified by the independent M&V team, with a summary supplied in Appendix B-5 and B-6.

The average monthly transfer rates for 2014 are much lower than those for either the high- or low transfer conditions of Subcase A and B in Chapter 4.3.3. The low transfer conditions of Subcase B, Chapter 4.3.3 are 0.96 m³/s, which is still 25.59% higher than the highest calculated transfer rate for September 2014. This means that the results of the actual load shifts performed during this time will most likely be more comparable with those of

Subcase B. They should, however, be even lower, according to the observations made for the relationship between DSM savings and average daily transfer rates.

The quadratic polynomial used to visualise the relationship between DSM savings and average daily transfer rates for Section-B transfers, results in much higher savings for the daily flow rates calculated. For this reason, a grade four polynomial equation was used to determine the approximated results, shown in Figure 74, and given in Appendix D-4, D-5 and D-6. Figure 74 shows the approximated and actual results for the DSM savings during the three-month PA period.

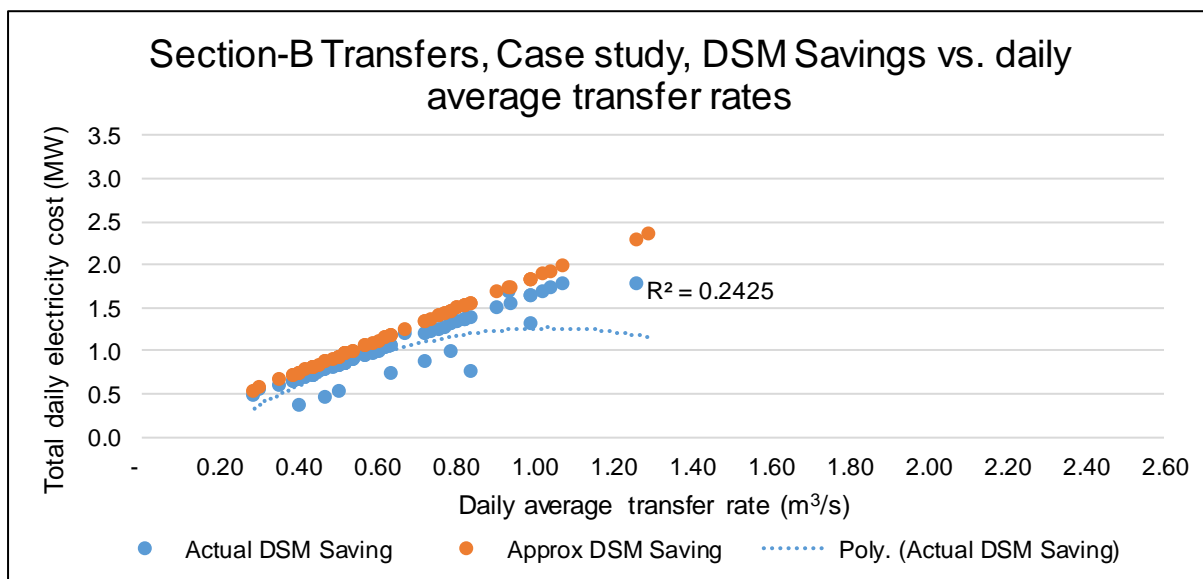


Figure 75: Section-A transfers – Case study DSM savings

The orange points show the predicted DSM savings, based on the grade four polynomial mentioned above, and the calculated actual daily transfers for the 2014 case study. They will follow a gradual slope, appearing to be linear, but this is because of the small range in which savings were achieved. The actual DSM savings fall relatively close to these calculated predictions, verifying the model and method used to execute the simulations in Chapter 4.3.2.

The predicted total average DSM saving for the three-month period differs with 28.52%, as can be seen in Appendix D-4. This difference is much greater than that for Pump stations A and B, in Chapter 4.4.2 above. The actual savings are mostly lower than the predicted savings, for the same transfer rates. This is an indication that the actual load shifts were carried out differently than how they had been simulated. From the graphs in Appendix B-4, it can be seen that the pumps were operated very erratically. This is because of the limitation of only one pump being available most of the time at Pump station C.

This prevents comeback loads from being performed, resulting in lower scaled baselines and lower savings for the same transfer rates. Demands in general were lower, due to good rainfall

in the Inkomati catchment. This meant that Pump station C did not have to augment any supply to the Nooitgedacht Dam, as discussed in Chapter 4.2.2. Pump station C, therefore, operated its single available pump only according to the reservoir levels at Rietspruit reservoir. This led to erratic pumping throughout the day, contributing to the lower DSM savings, and poor correlation with the quadratic polynomial trend.

The polynomial trend line shown above is once again quadratic. Its quadratic polynomial R-squared value of 0.24 compares poorly to that found in the simulated results of 0.74. It must be noted firstly that the range of daily average transfer flows for the case study falls between 0.29 m³/s and 1.29 m³/s, where those used in the simulations fell between 0.13 m³/s and 2.56 m³/s. This makes the comparisons relevant, since they are within the simulated range. It should be emphasised that the limited pump availability and lower demands discussed in the previous paragraph contribute greatly to this poor correlation between the predicted and actual DSM savings.

Once again, it is clear that if the transfer requirements decrease due to decreased demand, the DSM savings will be more easily achieved, but will also be lower, due to lower scaled baselines. Furthermore, if the required transfers decrease due to decreased pumping capacity, the DSM savings will be harder to achieve, and will also be lower due to lower baselines.

It should be noted that there are only two pump configurations available at Pump station C, namely one pump at 1.61 m³/s and two pumps in parallel at 2.56 m³/s. This means that the pump station has a low “pumping resolution”. This low resolution leads to limitations in terms of CL and associated CT. It also means that limitations on pump availability due to maintenance will have more drastic impacts on the operation of the pump station. This makes the pump station more “sensitive” to capacity restrictions. This higher sensitivity results in lower possible DSM savings under such restrictions of any nature.

Electricity consumption and cost

The actual and approximated results for the case study electricity consumption and cost are given in Appendix D-5 and D-6. They are also compared to each other in Figure 75 and Figure 76, below. The orange points once again show the predicted values. The linear trend line in both cases refers to the actual measured data for the case study period of July to September 2014. The percentage difference between the actual and predicted total energy consumptions for the three-month PA period is 4.21%. This further verifies the methods and model used to simulate the impact load shifting will have on the operation of Pump stations C.

Figure 75 shows that the predicted total daily electricity consumptions, according to the case study average daily transfer rates, correlate very well with the actual measured power data and electrical consumptions.

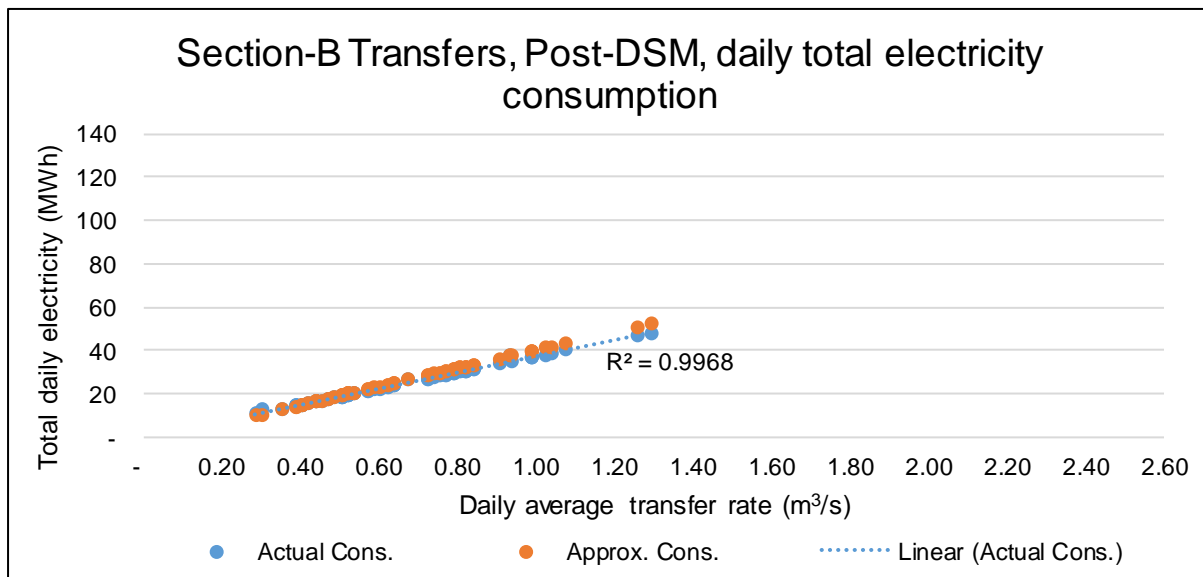


Figure 76: Section-A transfers – Case study electricity cons.

The R-squared value for the linear relationship between the daily energy consumption and daily transfers is extremely high, at 0.99, comparing well to the simulated value of 0.97.

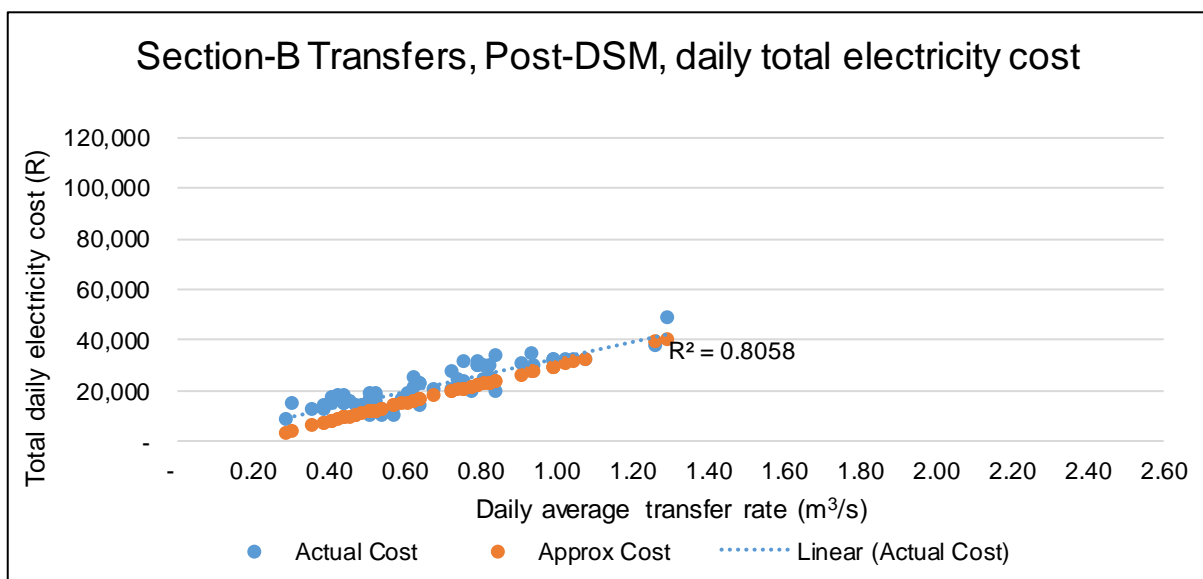


Figure 77: Section-A transfers – Case study electricity cost

Figure 76 shows that the predicted values for the daily electricity costs are generally lower per daily average transfer rate than the actual measured costs. This can be explained in conjunction with the figure in Appendix B-4, where it can be seen that for the three months, the pumps were operated mostly from 07:00 to 17:00. This means that even though their operation was erratic and restricted to only one pump and a low power demand, their operation during the more expensive morning peak period and standard times of the day resulted in high

electricity costs. The erratic operation led to the linear R-squared value of 0.81 being much lower than the simulated value of 0.91.

Case study vs. simulations – summary

Based on the installed and available capacity, and the required transfers of Pump station C, depicted in Figure 77, the following conclusions can be made:

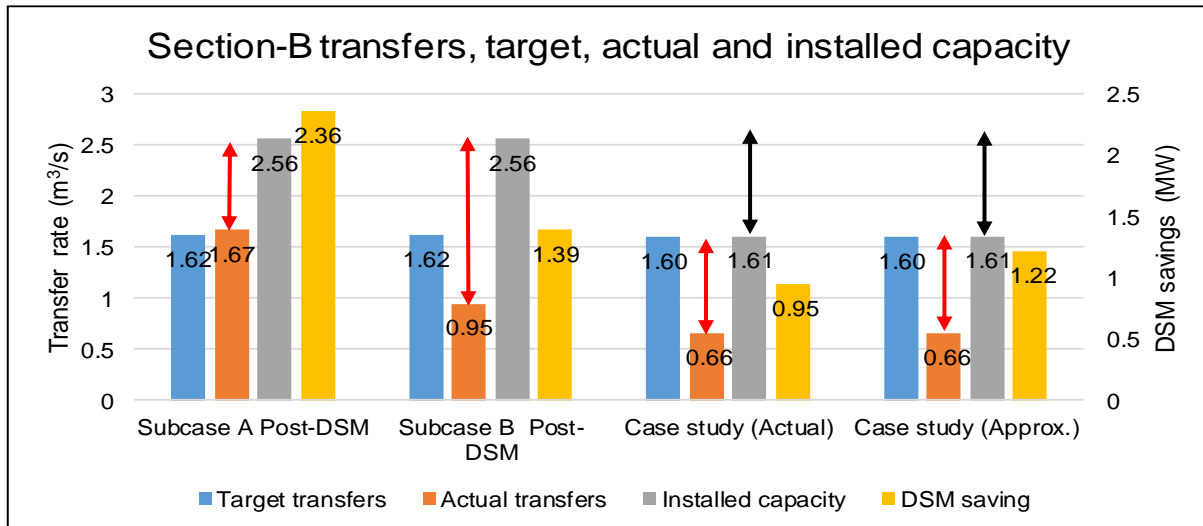


Figure 78: Section-A transfers – Case study summary

- Subcase A Post-DSM results show that even though the transfer rates are higher, the ample spare capacity (red arrows) allows for very high DSM savings due to sufficient comeback capacity
- Subcase B Post-DSM results show that even though the spare capacity is in excess, the low transfer rates result in low scaled baselines, which will mean low DSM savings, irrespective of high enough comeback capacity
- Actual case study results show that with much lower transfer rates, and limited spare capacity, only low DSM savings were possible. This was because of the fewer possible pump configurations, meaning that the reduction in installed capacity (black arrows), would have a greater effect on CL than was the case for Section-A transfers. Once again, as was the situation for Subcase B, the ample spare capacity cannot make up for the low scaled baselines resulting from the low transfer rates
- The transfer results from the predicted case study approximations are exactly the same as those for the actual case study, with only the predicted DSM savings being higher. This is because the simulations used to determine the relationship between DSM savings and required average daily transfers accounted for a CL on every day of load shifting. This CL would consequently raise the scaled baseline, resulting in more DSM savings. The erratic pumping throughout the day, with only one available pump, lead to

CL not being employed on a regular basis. This resulted in the much lower DSM savings than predicted.

The average transfer rates differ greatly between the simulated subcases and actual case study. This complicates the determination of the impact that load shifts have on the operation of the pump stations under the rules set out in the AOA. Based solely on the fact that the results from the simulated load shifts are verified by those measured during the case study, it can be concluded that energy-neutral load shifts on Pump station C will not negatively affect their operation.

It must, however, be noted, that just as was the case for Section-A transfers, these simulations lack the capacity to include the impact of daily reservoir level fluctuations on required transfer rates and subsequently on possible DSM savings. Furthermore, it should be noted that the simulations were carried out for explicitly energy-neutral load shifts. This means that if load shifts are carried out, but are not accompanied by the required load recovery, the DSM savings will be lower and the impact on pump station operation will most likely be negative. It would result in decreased transfers over time, further preventing the pump stations from reaching their targets and possibly leading to supply shortfalls over time.

Energy-neutral load shifts do in most cases result in most of the “saved” transfers (water) being recovered, and will therefore not negatively affect the pump stations operation in terms of the achieving the required target transfers stipulated in the AOA.

4.5 Analysis and Results Conclusion

Chapter 4 covered the analyses performed to establish the impact of load shifting on the operation of pump stations in a WTS. The interaction between the WSS and WTS, prior to any DSM being implemented, was first characterised. From the data obtained from the past six years' AOA, it was concluded that the planning year of May '12 to April '13 came the closest to its monthly targets. It was also concluded that during this period there was the least deviation from the annual average. This indicated that this period would serve as an accurate depiction of pre-DSM operation, according to the WSS supplied for that period.

Hereafter, daily pumping was first simulated to determine the KPIs associated with pre-DSM operation. Measured power data and associated flow rates, along with the AOA targets for these months were used to do this. Daily scaled energy-neutral load shifts were then simulated on the pump stations within GWS-A. The target DSM savings were simulated on a daily basis in order to determine the impact thereof on the KPIs of the pump stations. In the simulations, daily power data was used from high- and low transfer months. This ensured the results from the simulations would characterise the Pre- and Post-DSM KPIs for as great an operational range as possible; from minimum daily transfers to maximum.

With the results from the simulations serving as a theoretical depiction of Pre- and Post-DSM operations, the results from the case study could now be compared. The measured and verified power data, and the associated flow rates, were used to determine the actual KPIs for the case study. It was found that the results from the simulations were an accurate indication of both Pre- and Post-DSM operation. Not only did the results show the same relationships for different daily average transfer rates, but they were in the same range of values as were found for the case study. This verified the simulated results and the assumptions made.

It was concluded that daily scaled energy-neutral load shifts would have no adverse effect on the operation of a pump station within a WTS, governed by WSS and operating rules. If there were limitations on pump availability, it would result in poor DSM savings, or lower transfers achieved by the pump station if maximum load shifts were performed. It was further found that a greater selection of available flow rates and power demands, for different pump configurations, would result in a lower sensitivity to pump availability, and therefore have a lower impact on achievable DSM savings.

5. CONCLUSION AND RECOMMENDATIONS

End-user product¹²



¹² Stock photography image

5.1 Conclusion

In Chapter 1, an introduction was given. This included information on the power supply situation in South Africa and its causes and the interim solutions brought forward by Eskom as the national electricity-supply utility. Thereafter, background was given into WTS in South Africa. Finally, a problem statement was formulated:

The mutual effects of these WSS on DSM interventions and savings, and vice versa, and the integration thereof, form the foundation of this dissertation. It can be concluded that these impacts need to be studied and the integration of DSM practices and WSS needs to be investigated.

Chapter 2 gave a review of relevant literature. This included the background on the need for, and requirements and component of, WTS in South Africa. The following section covered the necessity for water-resource management and the modelling tools and methods used. The manner in which the results from these simulations are practically interpreted and implemented, as a set of operating rules and water supply strategies, was also discussed. Finally, a review was given of the considerations for implementing DSM strategies on water pumping systems, previous load shift projects implemented and how the baselines are calculated and scaled in order to determine the DSM savings.

The methodology in Chapter 3 served as an introduction to characterise the interaction between the different aspects of the three processes. This was concluded by establishing a cause-and-effect process interaction diagram, showing the mutual impacts between WSS, WTS and DSM interventions. The site where load shifting projects were implemented on three pump stations was described. The past six years' AOA results and operating rules were discussed and summarised for the site and surrounding sub-sections of the greater WTS.

In Chapter 4, the simulations performed for the site were discussed. The process used to determine which years and months would serve as an accurate representation of the pre-DSM pumping conditions was reviewed. Calculations were performed to determine the average daily transfer rates for the selected periods, by measuring the power data for different pump configurations and their associated flow rates. Based on these observations and numerical relationships, a simulation model was built. With this model, it was possible to simulate the effect daily scaled energy-neutral load shifting would have on the operations of the pump stations.

The months analysed were selected to reflect low- and high transfer conditions, in order to cover the entire flow rate range of the separate transfer sections. This made it possible to

characterise the operation of the pump stations for transfers ranging from maximum to minimum. With the characterisation complete for pre-DSM operation, and the results given and discussed, daily scaled energy-neutral load shifts were carried out for each day of the selected two months' operations.

It was found that there exists a linear relationship between the total daily electricity consumed and total daily average transfer rate achieved for a pump station. A linear relation was also found between the total daily electricity costs and total daily average transfer rate for a pump station. Furthermore, it was noted from the Post-DSM simulations that there exists an asymmetric, quadratic polynomial relationship between the DSM savings, which can be achieved for a pump station having to deliver a certain daily average transfer rate. All these results were evaluated for both Pre- and Post-DSM conditions, for all three pump stations forming part of GWS-A.

The same KPIs were then analysed for the period during which load shifting was implemented at the pump stations. These results also demonstrated that there exist the same linear relationships between the daily electricity consumption and cost, and the daily average transfer rates. The same asymmetric, quadratic polynomial relationship between the DSM savings that can be achieved and daily average transfer rates, was found in the case study's results. The case study results verified the results obtained from the simulations.

These results are summarised in Figure 78, Figure 79 and Figure 80, below.

From the results, it became clear that there exist a range of daily average transfers, in between which the highest DSM savings can be achieved. It was concluded that at daily average transfer rates below the range, the scaled baseline would be too low to result in high DSM savings being calculated. Furthermore, at daily average transfer rates above the optimal range, there was no capacity for a CL, which would effectively result in a peak-clip taking place, instead of a load shift. This meant that at transfer rates above which no higher power loads were available for a CL, load shifting would not take place at all.

Furthermore, it could be seen that the pump-resolution available at a pump station would also impact the relationship between DSM savings and delivered daily average transfer rates. It was noted that since Section-A transfers had nine available pump configurations, CLs could be more easily attained at higher transfer capacities. This, is in comparison to Section-B transfers, which only had two available pump configurations and associated power loads and -flow rates.

This brings the *final conclusion*; that daily, energy-neutral load shifting, as a DSM intervention, will have no adverse effect on the successful operation of a pump station being operated according to the target transfers stipulated by the WSS. Furthermore, if the target transfers, or actual required transfers for a pump station within a WTS are too high, load shifting will not be possible, and DSM savings will be negatively affected. These closing conclusions *validate* the necessity for the study, and the results from the simulations.

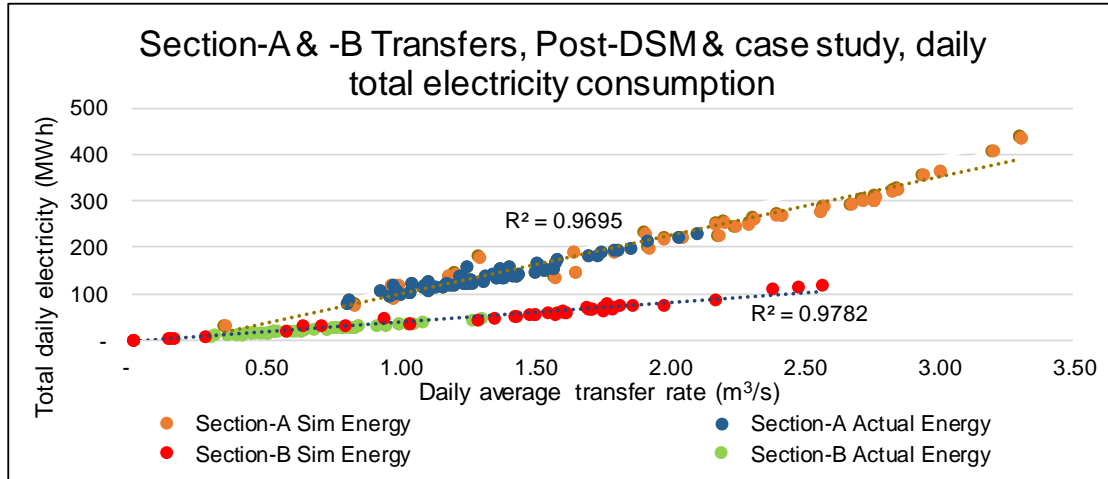


Figure 79: Case study vs Simulation electricity results - Summary

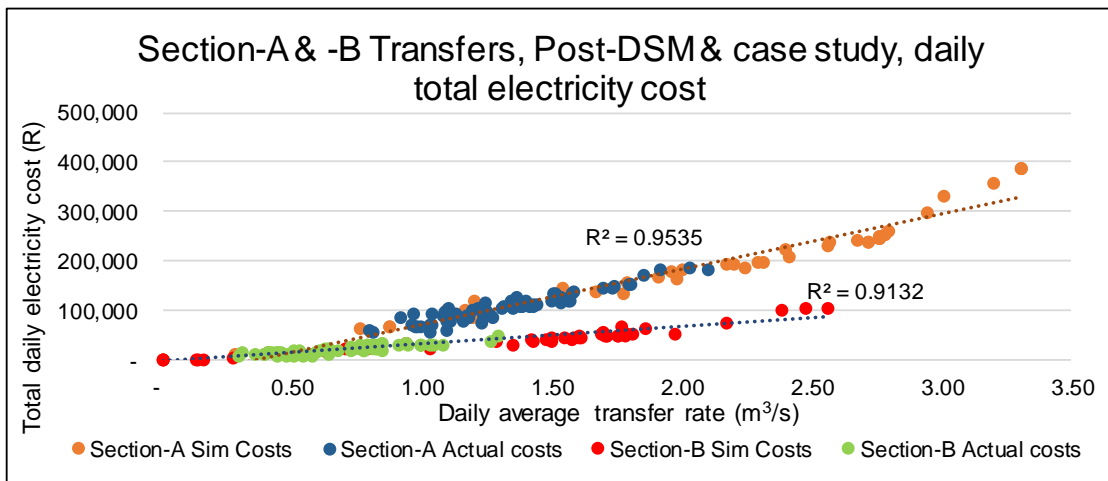


Figure 81: Case study vs Simulation cost results - Summary

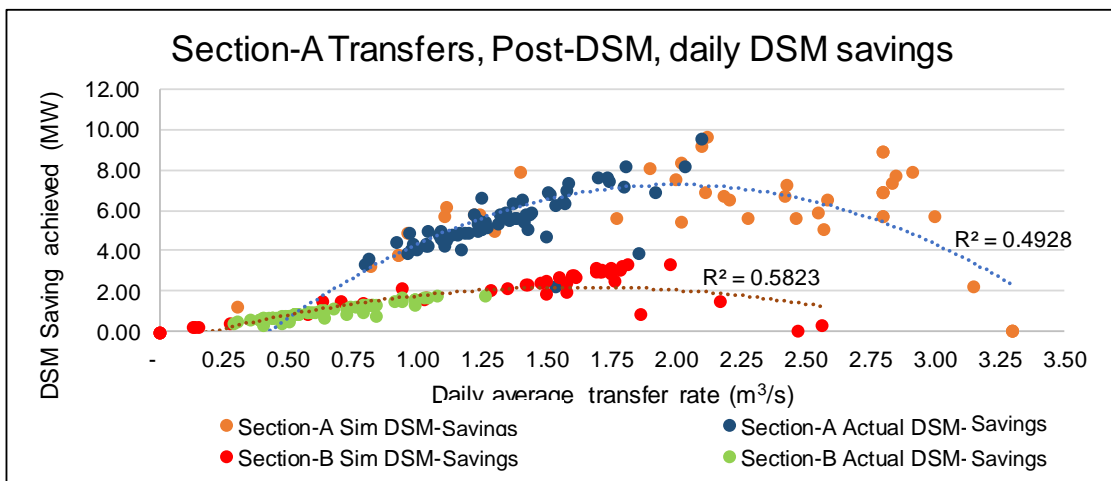


Figure 80: Case study vs Simulation DSM Savings results - Summary

5.2 Recommendations

From the simulations, measurements and finally the conclusions reached throughout this study, the following recommendations can be made for improvements and further studies:

- Find more suitable mathematical relationships between the DSM savings achievable at different daily average transfer rates. It is noted that the quadratic polynomial used to characterize this relationship is lacking. It would rather appear that the relationship consists of two separate polynomials; a linear, positive sloped one for the first range (up to the maximum point), and a linear, negative sloped one for the second range.
- The development of a generic model that can be used to determine the optimum range for transfer rates in order to achieve maximum DSM savings from load shifting. This model should be versatile in order to accommodate different pump station layouts and resulting pump configurations. It should also be robust so that it can be used to evaluate the feasibility of future, planned load shift projects on bulk water pumping systems.
- Develop a model that can optimise the operation of pumps by prioritising the selection of pumps configurations in a pump station based on the specific energy consumption of each configuration. This will result in an improvement in the energy efficiency of the pump station. In addition to this, such a model can also be used to adjust operation according to running time, for effective pump cycling, and according to pump availability under maintenance constraints.
- Include in following simulations the effects of downstream reservoir levels and resulting reservoir control at the pump station on DSM savings.
- Investigate the possible implications of implementing load shifts volume neutral, instead of energy-neutral on a daily basis. This would imply that a CL is calculated based on “water loss” during EPP load reductions, instead of “energy saved”. The results from the simulations show that there are slight differences, but that daily scaled energy-neutral load shifts result in very close to the same amount of water being pumped after load shifting as before.
- Expand the study to include pump stations, which form part of sub-sections of WTS classified as “inter-reservoir transfers”, depicted as Layout A in Figure 26, Chapter 2.4.1. This would then include the WSS, which regulate inter-reservoir transfers, discussed in Chapter 3.4. These WSS were not included in this study, as no DSM interventions have been implemented on such pump stations, and the pump stations forming part of the case study for this dissertation were only regulated according to consumer-demand transfer rules and -targets.

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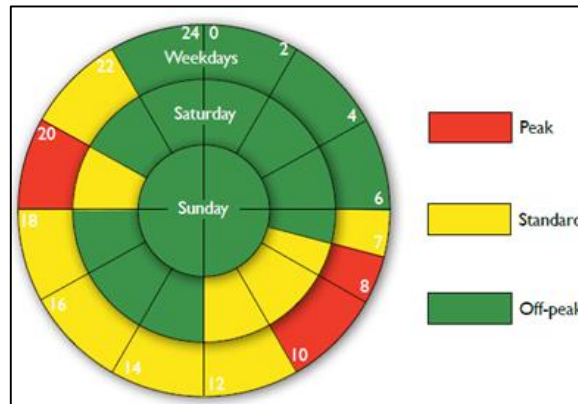
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APPENDIX A

A-1: Eskom's TOU structure for Megaflex, Miniflex and Ruraflex customers [92].



A-2: Eskom's 2014/2015 Megaflex-tariffs for local authorities [92].

MEGAFLEX – Non local authority rates

Active energy charge (c/kWh)															
Transmission zone	Voltage	High demand season (Jun-Aug)						Low demand season (Sep-May)						Transmission network charges (R/kVA/m)	
		Peak		Standard		Off peak		Peak		Standard		Off peak		VAT excl.	VAT incl.
		VAT excl.	VAT incl.	VAT excl.	VAT incl.	VAT excl.	VAT incl.	VAT excl.	VAT incl.	VAT excl.	VAT incl.	VAT excl.	VAT incl.	VAT excl.	VAT incl.
≤ 300km	< 500V	220.91	251.84	67.21	76.62	36.69	41.83	72.34	82.47	49.92	56.91	31.82	36.27	R 6.32	R 7.20
	≥ 500V & < 66kV	217.44	247.88	65.87	75.09	35.77	40.78	70.93	80.86	48.82	55.65	30.97	35.31	R 5.78	R 6.59
	≥ 66kV & ≤ 132kV	210.56	240.04	63.78	72.71	34.64	39.49	68.69	78.31	47.27	53.89	29.99	34.19	R 5.63	R 6.42
	> 132kV*	198.45	226.23	60.11	68.53	32.65	37.22	64.74	73.80	44.55	50.79	28.27	32.23	R 7.11	R 8.11
> 300km and ≤ 600km	< 500V	222.71	253.89	67.48	76.93	36.64	41.77	72.65	82.82	50.01	57.01	31.73	36.17	R 6.37	R 7.26
	≥ 500V & < 66kV	219.61	250.36	66.53	75.84	36.13	41.19	71.65	81.68	49.30	56.20	31.28	35.66	R 5.83	R 6.65
	≥ 66kV & ≤ 132kV	212.63	242.40	64.41	73.43	34.97	39.87	69.36	79.07	47.73	54.41	30.28	34.52	R 5.67	R 6.46
	> 132kV*	200.43	228.49	60.72	69.22	32.96	37.57	65.37	74.52	44.99	51.29	28.54	32.54	R 7.18	R 8.19
> 600km and ≤ 900km	< 500V	224.93	256.42	68.13	77.67	36.99	42.17	73.38	83.65	50.50	57.57	32.03	36.51	R 6.45	R 7.35
	≥ 500V & < 66kV	221.81	252.86	67.20	76.61	36.49	41.60	72.36	82.49	49.80	56.77	31.59	36.01	R 5.88	R 6.70
	≥ 66kV & ≤ 132kV	214.79	244.86	65.07	74.18	35.33	40.28	70.06	79.87	48.22	54.97	30.59	34.87	R 5.71	R 6.51
	> 132kV*	202.45	230.79	61.32	69.90	33.31	37.97	66.04	75.29	45.45	51.81	28.84	32.88	R 7.28	R 8.30
> 900km	< 500V	227.19	259.00	68.84	78.48	37.38	42.61	74.12	84.50	51.01	58.15	32.37	36.90	R 6.47	R 7.38
	≥ 500V & < 66kV	224.02	255.38	67.86	77.36	36.84	42.00	73.07	83.30	50.28	57.32	31.90	36.37	R 5.95	R 6.78
	≥ 66kV & ≤ 132kV	216.95	247.32	65.72	74.92	35.68	40.68	70.76	80.67	48.71	55.53	30.90	35.23	R 5.75	R 6.56
	> 132kV*	204.43	233.05	61.96	70.63	33.66	38.37	66.72	76.06	45.93	52.36	29.16	33.24	R 7.33	R 8.36

* >132kV or Transmission connected

Distribution network charges						
Voltage	Network access charge (R/kVA/m)		Network demand charge (R/kVA/m)		Urban low voltage subsidy charge (R/kVA/m)	
	VAT excl.	VAT incl.	VAT excl.	VAT incl.	VAT excl.	VAT incl.
< 500V	R 12.56	R 14.32	R 23.81	R 27.14		
≥ 500V & < 66kV	R 11.52	R 13.13	R 21.85	R 24.91		
≥ 66kV & ≤ 132kV	R 4.11	R 4.69	R 7.61	R 8.68	R 10.14	R 11.56
> 132kV / Transmission connected					R 10.14	R 11.56

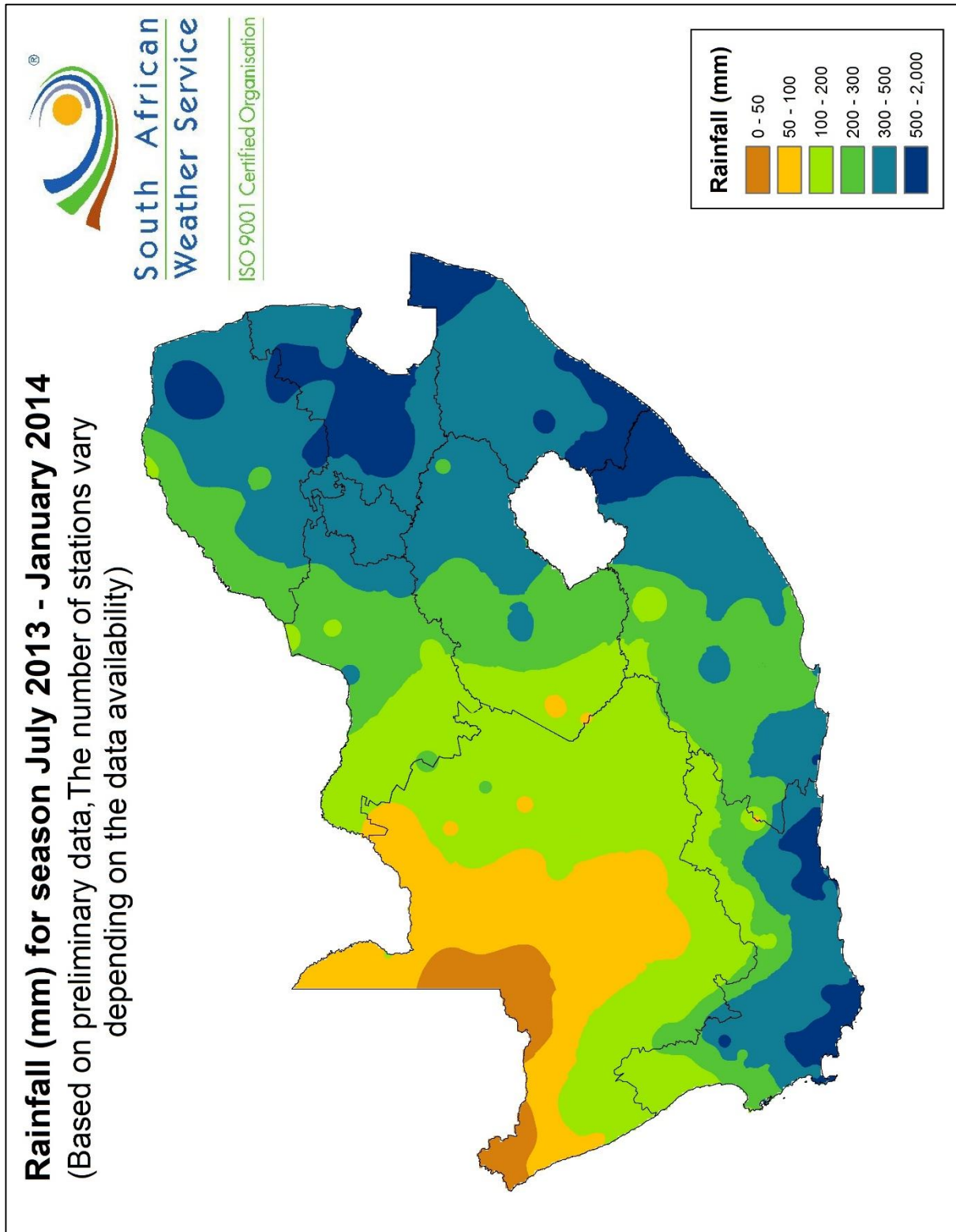
Voltage	Reliability service charge (c/kWh)		Customer categories	Service charge (R/Account/day)		Administration charge (R/POD/day)		Electrification and rural network subsidy charge (c/kWh)	Affordability subsidy charge (c/kWh)
	VAT excl.	VAT incl.		VAT excl.	VAT incl.	VAT excl.	VAT incl.		
< 500V	0.29	0.33	> 1 MVA	R 144.18	R 164.37	R 64.98	R 74.08	All seasons VAT excl. VAT incl. 5.62 6.41	Only payable by non-local authority tariffs All seasons VAT excl. VAT incl. 2.24 2.55
≥ 500V & < 66kV	0.28	0.32	Key customers	R 2 825.34	R 3 220.89	R 90.23	R 102.86		
≥ 66kV & ≤ 132kV	0.27	0.31							
> 132kV*	0.25	0.29							

* >132kV or Transmission connected

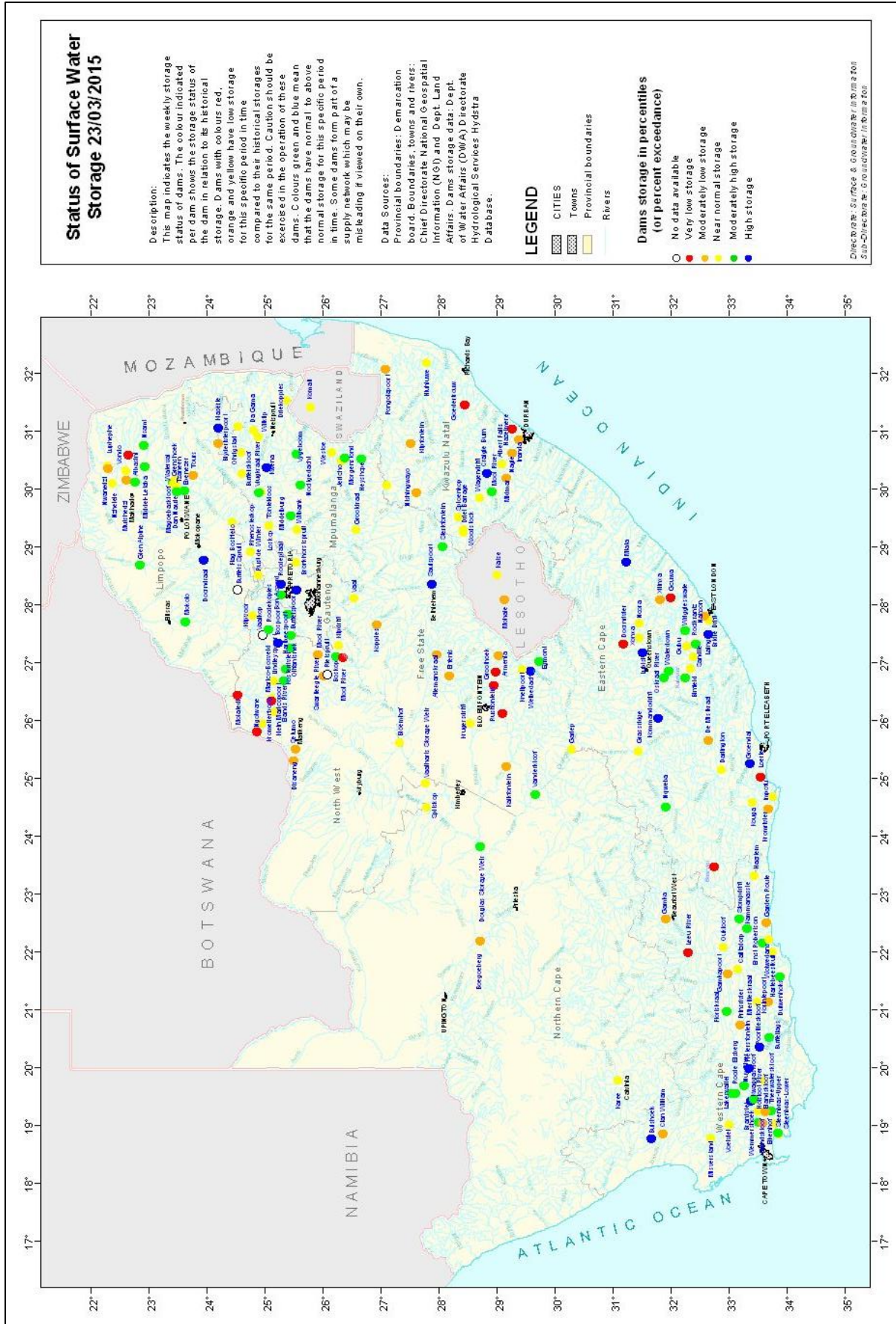
Reactive energy charge (c/kVAh)			
High season	Low season		
	VAT excl.	VAT incl.	
10.15	11.57		

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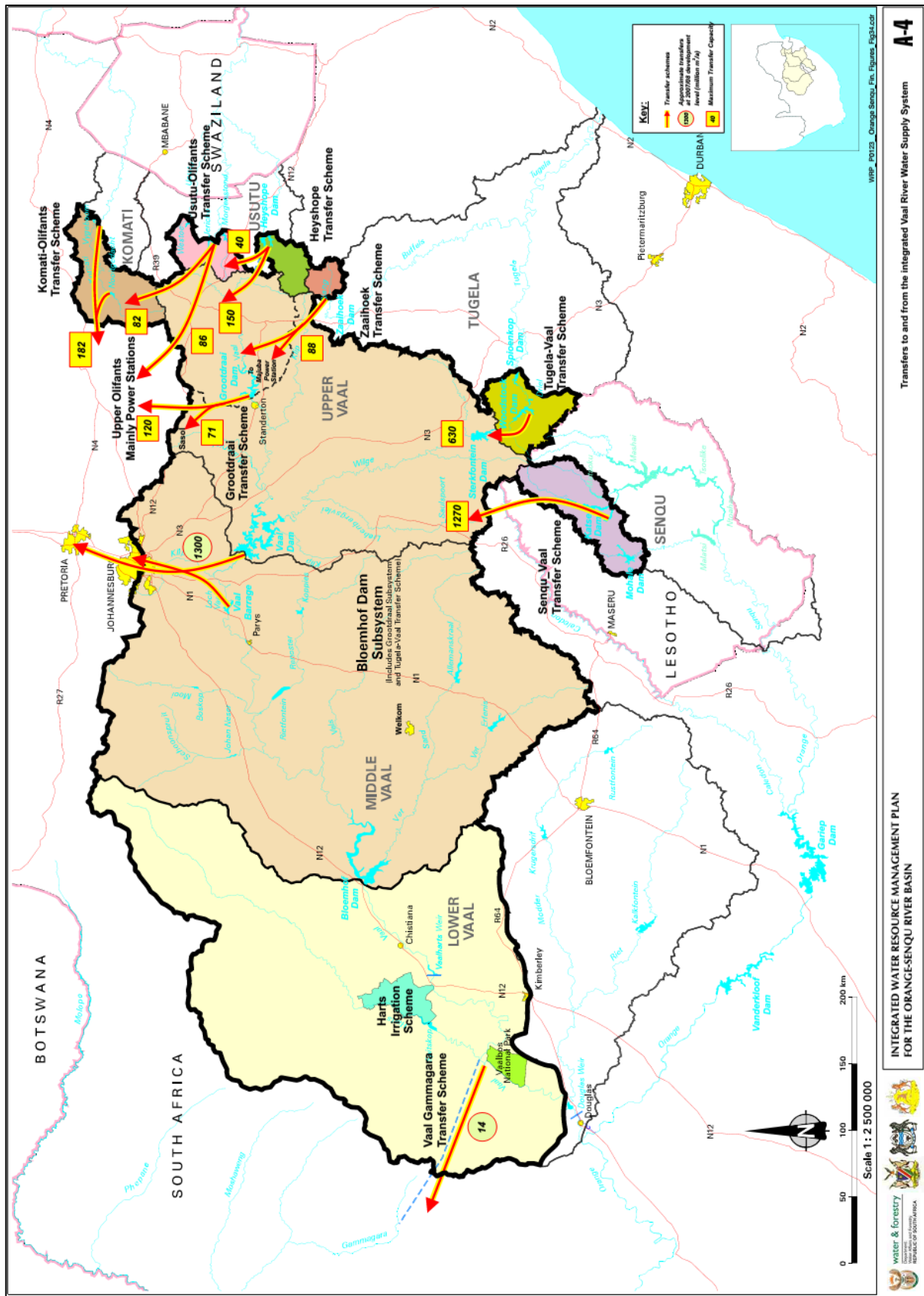
A-3: Map showing annual rainfall in South Africa for July 2013- January 2014 [93]



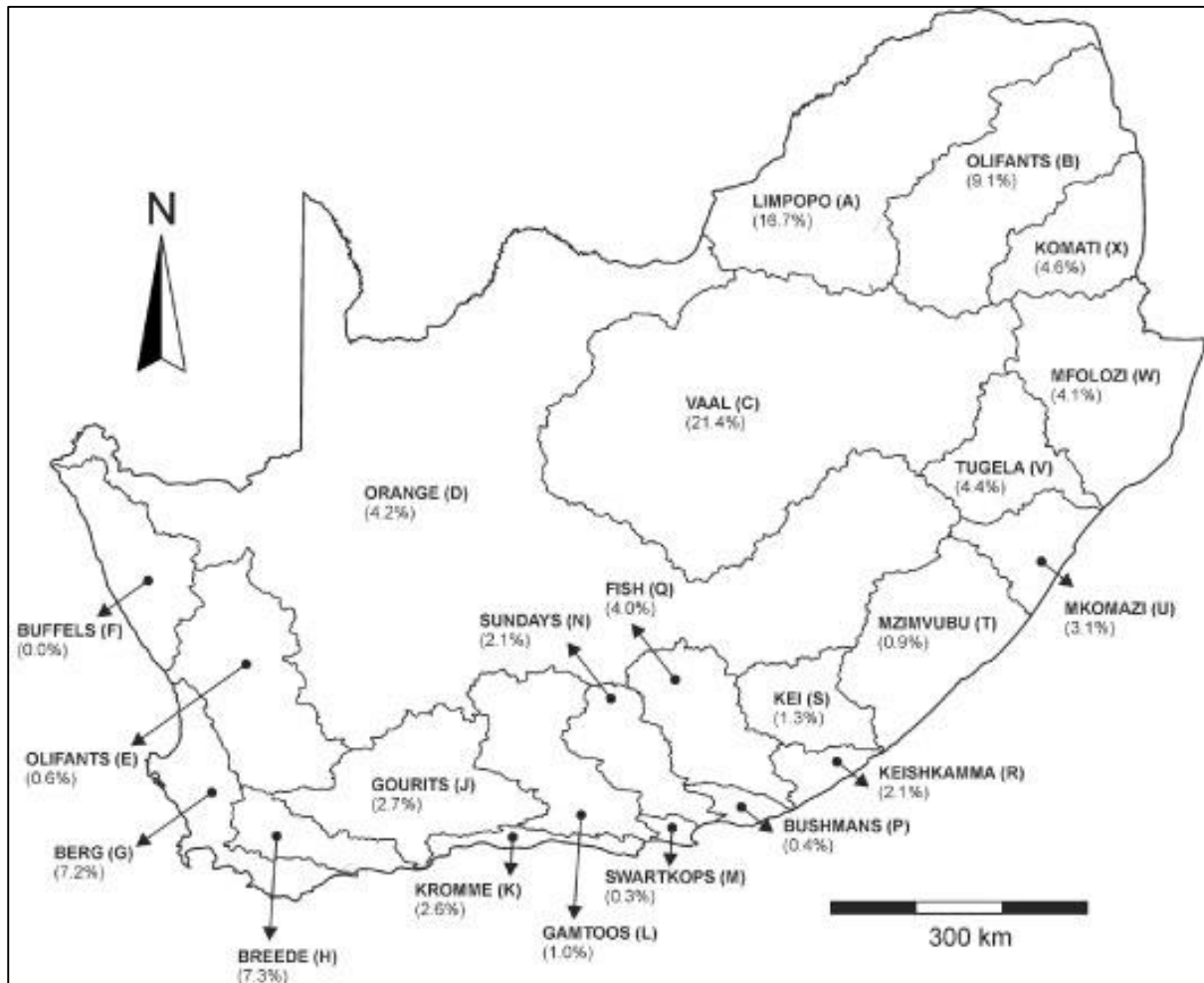
A-4: Map showing the status of South Africa's surface water storage on 23/03/2015 [94]



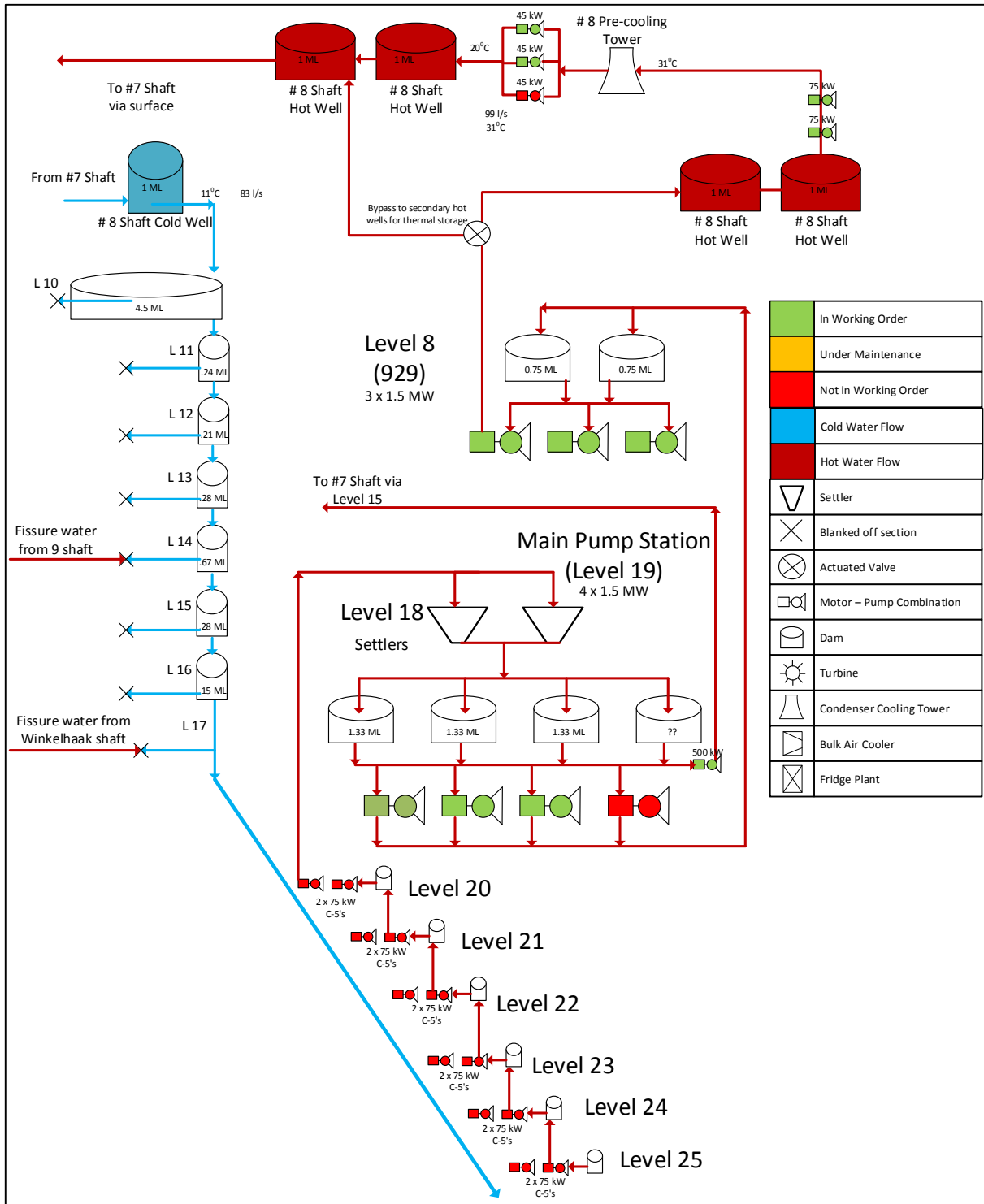
A-6: Schematic of transfers to and from the Integrated Vaal River System [29].



A-7: A map showing the main drainage regions of South Africa [95].



A-8: A layout of a dewatering system at a gold mine in Mpumalanga, South Africa



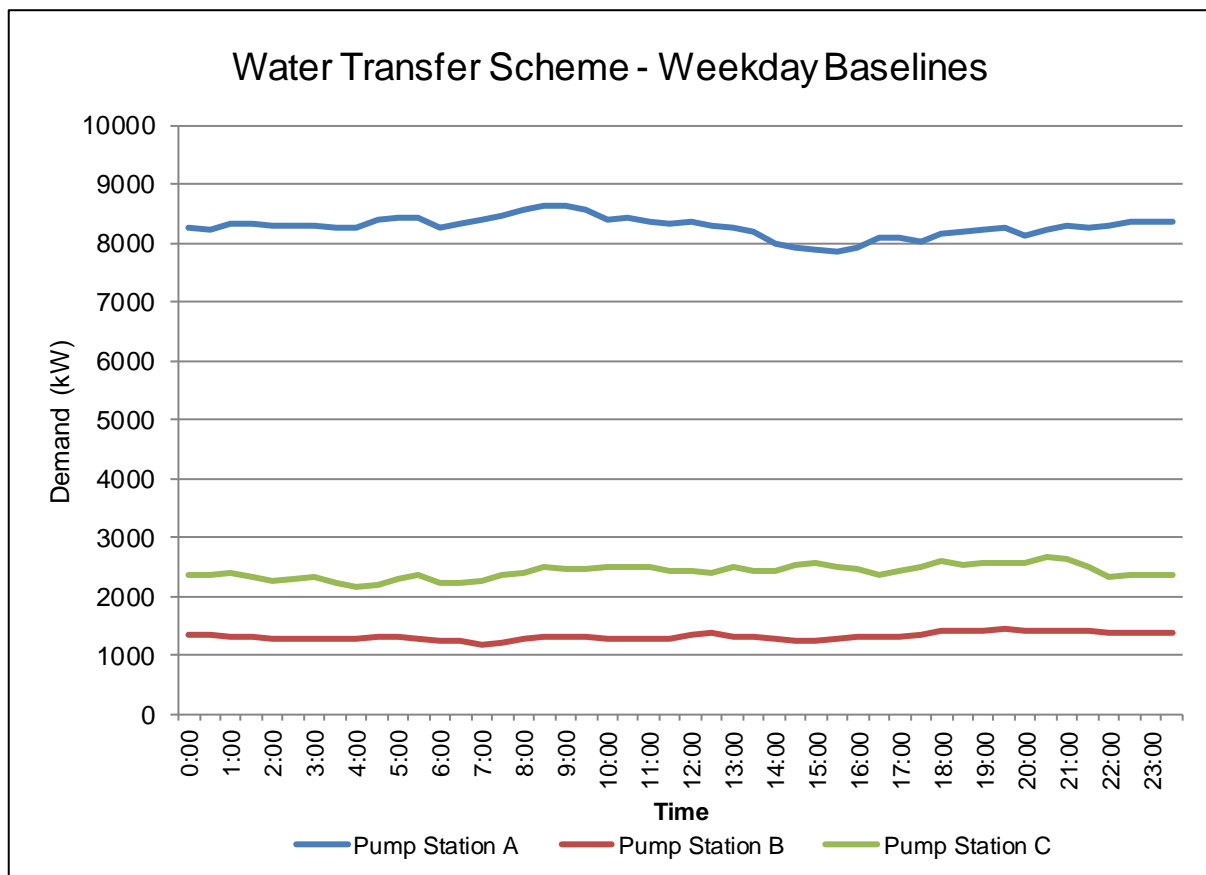
APPENDIX B

B-1: Water transfer scheme power baseline values

Time	Pump Station A (kW)			Pump Station B A (kW)			Pump Station C A (kW)		
	Weekday	Saturday	Sunday	Weekday	Saturday	Sunday	Weekday	Saturday	Sunday
0:00	8,251.97	8,839.13	8,260.72	1,359.10	2,136.58	1,974.81	2,365.76	2,509.12	2,531.46
0:30	8,228.92	8,176.85	8,264.54	1,339.27	2,016.87	1,976.81	2,373.69	2,436.11	2,401.91
1:00	8,310.85	7,651.54	8,202.35	1,328.77	1,930.86	1,976.37	2,387.00	2,397.17	2,320.18
1:30	8,315.21	7,530.95	8,083.30	1,313.16	1,930.59	1,977.74	2,318.04	2,297.74	2,322.24
2:00	8,299.58	7,533.65	8,059.57	1,289.05	1,931.29	1,973.21	2,269.35	2,231.28	2,316.26
2:30	8,297.61	7,532.44	7,774.46	1,288.25	1,932.05	1,975.63	2,308.69	2,081.24	2,319.43
3:00	8,295.64	7,537.18	7,777.63	1,288.06	1,932.58	1,977.50	2,319.38	2,216.76	2,322.15
3:30	8,270.39	7,538.37	7,783.61	1,288.11	1,932.48	1,977.70	2,213.50	2,146.50	2,323.90
4:00	8,268.39	7,536.30	7,773.20	1,287.40	1,931.53	1,975.74	2,151.12	1,833.68	2,394.71
4:30	8,408.46	7,569.00	7,768.96	1,308.17	1,930.56	1,974.22	2,186.23	2,246.87	2,402.91
5:00	8,429.38	8,397.37	7,773.03	1,325.28	1,931.01	1,973.45	2,309.44	2,655.65	2,613.39
5:30	8,434.21	8,543.16	7,779.61	1,295.19	1,776.52	1,974.13	2,348.98	2,687.33	2,711.28
6:00	8,255.64	8,494.27	7,765.85	1,253.03	1,725.78	1,971.17	2,230.05	2,729.85	2,398.16
6:30	8,317.40	8,478.64	7,459.27	1,233.50	1,724.34	1,964.54	2,225.90	2,649.50	2,072.41
7:00	8,378.15	8,665.68	7,469.73	1,182.48	1,725.84	1,967.67	2,254.92	2,739.20	2,075.27
7:30	8,471.86	8,866.94	7,477.86	1,200.21	1,724.76	1,966.68	2,367.05	2,897.22	2,182.32
8:00	8,547.24	8,781.64	7,510.65	1,275.79	1,724.48	1,969.22	2,399.17	2,810.18	2,464.56
8:30	8,633.23	9,062.96	7,704.83	1,310.87	1,803.43	1,970.81	2,493.67	2,507.77	2,318.10
9:00	8,615.34	9,191.90	7,833.61	1,319.14	1,931.20	1,973.01	2,466.60	2,296.57	2,137.11
9:30	8,550.00	9,190.04	7,852.93	1,308.74	1,931.25	1,975.96	2,480.38	2,322.53	2,225.49
10:00	8,411.40	9,192.71	7,843.69	1,295.84	1,931.74	1,973.28	2,498.71	2,447.36	2,319.06
10:30	8,413.93	9,189.56	8,179.53	1,296.26	1,931.87	1,974.28	2,484.91	2,291.31	2,319.27
11:00	8,366.96	9,250.61	8,422.15	1,275.21	2,093.67	1,969.94	2,508.15	2,280.81	2,273.93
11:30	8,343.55	9,175.20	8,414.19	1,272.90	2,131.42	1,970.96	2,437.15	2,108.86	2,105.76
12:00	8,371.45	8,987.55	8,412.11	1,355.56	2,128.68	1,971.55	2,436.95	2,442.73	2,108.06
12:30	8,300.24	8,988.56	8,405.10	1,382.95	2,129.96	1,972.22	2,401.37	2,880.79	2,109.39
13:00	8,247.80	9,005.98	8,403.84	1,310.48	2,133.06	1,973.49	2,489.49	2,796.27	2,110.17
13:30	8,190.27	9,011.95	8,404.79	1,305.97	2,135.94	1,973.42	2,446.61	2,716.58	2,108.91
14:00	7,985.94	9,008.50	8,742.00	1,270.39	2,136.55	1,974.17	2,444.29	2,747.57	2,109.87
14:30	7,908.36	9,008.12	8,953.06	1,264.44	2,131.94	1,974.29	2,519.59	2,875.60	2,181.55
15:00	7,881.18	9,115.62	8,940.03	1,243.89	2,129.28	1,970.00	2,577.65	2,674.88	2,340.56
15:30	7,840.09	9,042.56	8,922.26	1,278.47	2,129.80	1,968.05	2,495.91	2,527.54	2,867.84
16:00	7,934.80	8,864.64	8,922.91	1,321.43	2,127.53	1,966.54	2,456.89	2,526.83	2,813.02
16:30	8,097.00	8,840.83	8,925.71	1,300.04	2,003.97	1,967.47	2,375.82	2,530.78	2,563.91
17:00	8,090.97	8,817.87	8,795.07	1,321.17	1,968.99	1,970.36	2,423.65	2,525.11	2,275.72
17:30	8,037.52	8,836.26	8,483.64	1,359.09	1,967.54	1,967.01	2,501.60	2,520.56	2,097.93
18:00	8,144.53	8,875.41	8,434.19	1,415.06	1,968.40	1,968.65	2,600.46	2,409.09	2,187.98

18:30	8,182.52	8,898.20	8,455.58	1,424.31	1,972.67	1,969.82	2,527.59	2,313.88	2,390.65
19:00	8,211.78	8,934.67	8,474.11	1,428.79	1,979.18	1,972.17	2,567.96	2,320.98	2,211.36
19:30	8,252.52	8,922.43	8,486.58	1,445.46	1,977.06	1,976.62	2,566.43	2,521.99	2,079.78
20:00	8,127.17	8,773.45	8,467.29	1,430.35	1,975.88	1,975.69	2,569.79	2,684.64	2,077.54
20:30	8,219.13	8,655.24	8,469.84	1,429.92	1,979.58	1,980.70	2,681.97	2,724.66	1,965.18
21:00	8,304.32	8,624.01	8,447.38	1,432.81	1,975.62	1,977.48	2,622.70	2,622.47	1,767.11
21:30	8,267.67	8,515.61	8,437.01	1,431.23	1,978.88	1,977.07	2,505.66	2,507.63	1,900.55
22:00	8,307.92	8,304.87	8,422.56	1,392.20	1,976.23	1,978.79	2,319.13	2,506.11	2,039.68
22:30	8,361.39	8,302.41	8,389.40	1,392.43	1,976.56	1,975.89	2,361.30	2,257.85	2,284.55
23:00	8,367.63	8,294.10	8,373.74	1,391.48	1,979.68	1,974.65	2,356.40	2,278.47	2,292.71
23:30	8,352.84	8,272.68	8,385.03	1,389.43	1,976.80	1,979.06	2,348.87	2,531.42	2,374.82

B-2: Water transfer scheme - Weekday baselines

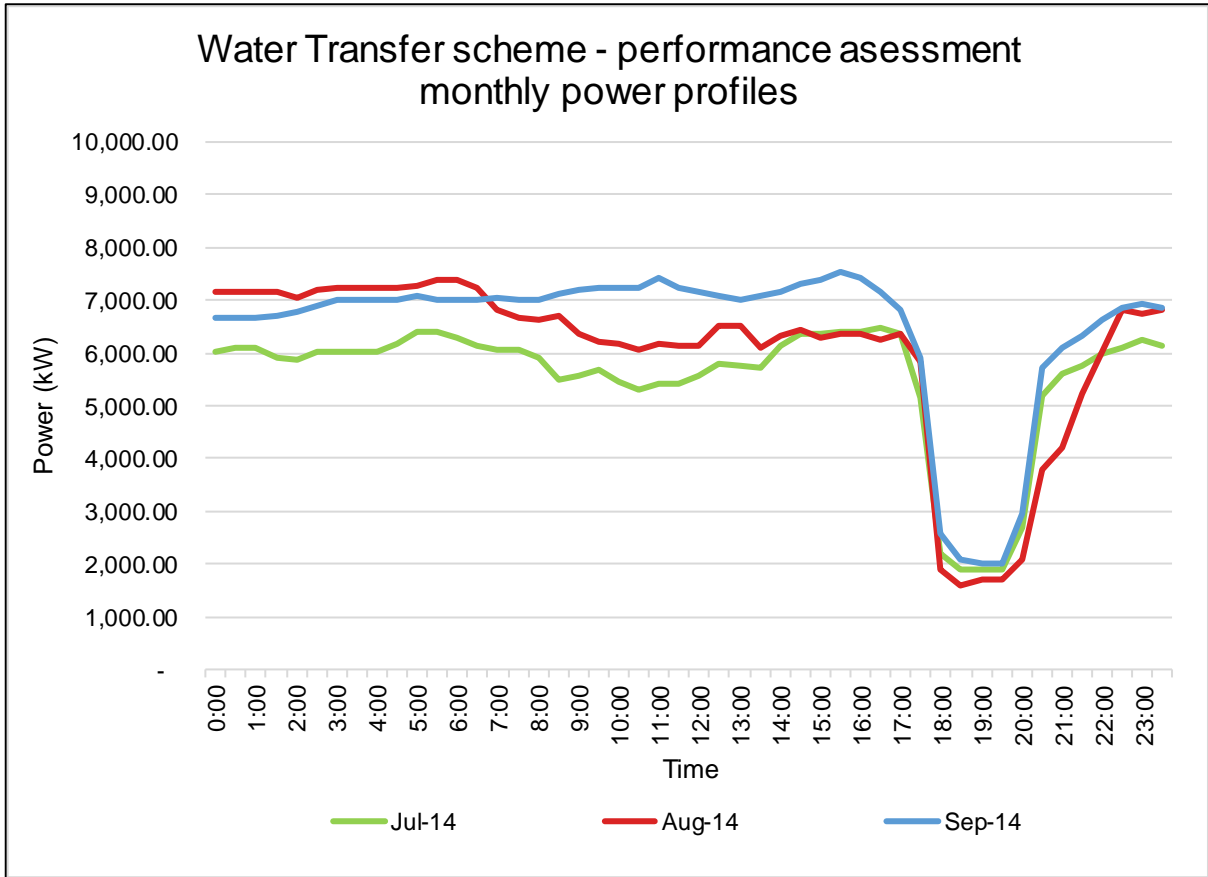


B-3: Section-A transfers, 2014 monthly performance assessment power values

Time	Pump Station A+B (kW)		
	Jul-14	Aug-14	Sep-14
0:00	6,028.61	7,157.77	6,669.53
0:30	6,090.32	7,157.77	6,669.53
1:00	6,090.32	7,157.77	6,669.53
1:30	5,915.39	7,157.77	6,691.37
2:00	5,884.53	7,053.81	6,786.53
2:30	6,019.35	7,193.26	6,903.53
3:00	6,019.35	7,228.74	6,989.13
3:30	6,019.35	7,228.74	7,010.97
4:00	6,019.35	7,228.74	7,010.97
4:30	6,163.44	7,228.74	7,010.97
5:00	6,411.48	7,290.45	7,064.68
5:30	6,411.48	7,403.68	7,001.73
6:00	6,286.39	7,403.68	6,992.50
6:30	6,132.58	7,243.10	6,992.50
7:00	6,045.11	6,834.79	7,029.17
7:30	6,049.74	6,683.18	6,990.28
8:00	5,924.65	6,643.39	7,022.17
8:30	5,506.03	6,721.13	7,122.93
9:00	5,572.37	6,353.39	7,195.12
9:30	5,673.08	6,221.50	7,248.83
10:00	5,460.52	6,160.58	7,248.83
10:30	5,298.10	6,073.11	7,248.83
11:00	5,419.94	6,188.87	7,406.62
11:30	5,419.94	6,121.87	7,245.95
12:00	5,564.48	6,141.60	7,151.12
12:30	5,811.42	6,497.19	7,088.17
13:00	5,769.16	6,497.19	7,009.67
13:30	5,707.92	6,106.84	7,088.17
14:00	6,121.18	6,322.26	7,156.38
14:30	6,373.85	6,426.23	7,311.93
15:00	6,378.48	6,283.92	7,370.43
15:30	6,387.74	6,364.52	7,555.98
16:00	6,387.74	6,369.15	7,417.48
16:30	6,491.71	6,262.32	7,143.03
17:00	6,374.18	6,352.65	6,817.08
17:30	5,138.68	5,850.89	5,912.62
18:00	2,186.66	1,907.18	2,577.42
18:30	1,891.00	1,584.97	2,081.42
19:00	1,891.00	1,698.19	2,018.47
19:30	1,891.00	1,698.19	2,018.47
20:00	2,683.74	2,063.71	2,940.62
20:30	5,203.11	3,782.39	5,737.58
21:00	5,597.06	4,222.13	6,080.58

21:30	5,746.18	5,232.60	6,324.30
22:00	5,991.29	6,036.48	6,645.80
22:30	6,087.69	6,817.16	6,872.13
23:00	6,245.81	6,760.55	6,935.90
23:30	6,120.71	6,812.53	6,850.30

B-4: Section-A transfers, 2014 monthly performance assessment power graphs

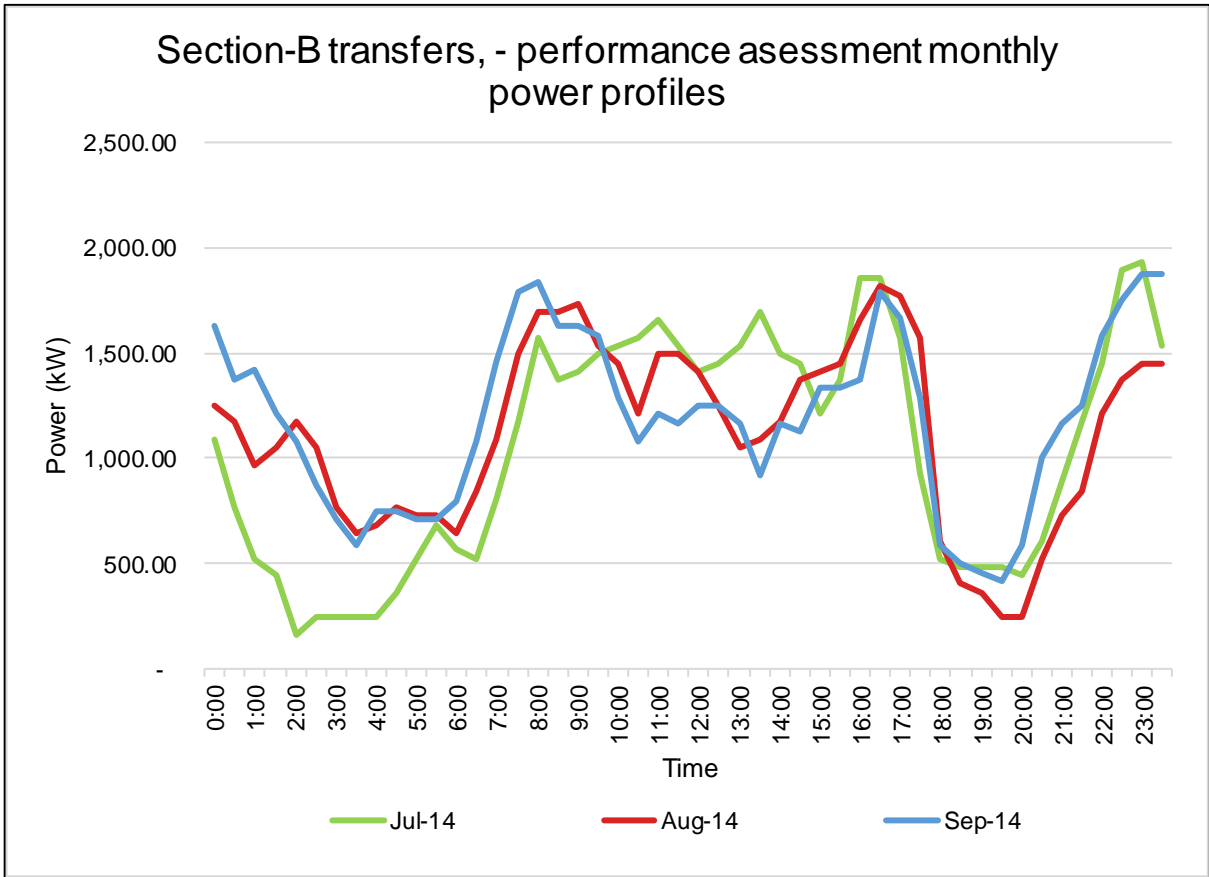


B-5: Section-B transfers, 2014 monthly performance assessment power values

Time	Pump Station C (kW)		
	Jul-14	Aug-14	Sep-14
0:00	1,088.71	1,250.00	1,625.00
0:30	766.13	1,169.35	1,375.00
1:00	524.19	967.74	1,416.67
1:30	443.55	1,048.39	1,208.33
2:00	161.29	1,169.35	1,083.33
2:30	241.94	1,048.39	875.00
3:00	241.94	766.13	708.33
3:30	241.94	645.16	583.33
4:00	241.94	685.48	750.00
4:30	362.90	766.13	750.00
5:00	524.19	725.81	708.33
5:30	685.48	725.81	708.33
6:00	564.52	645.16	791.67

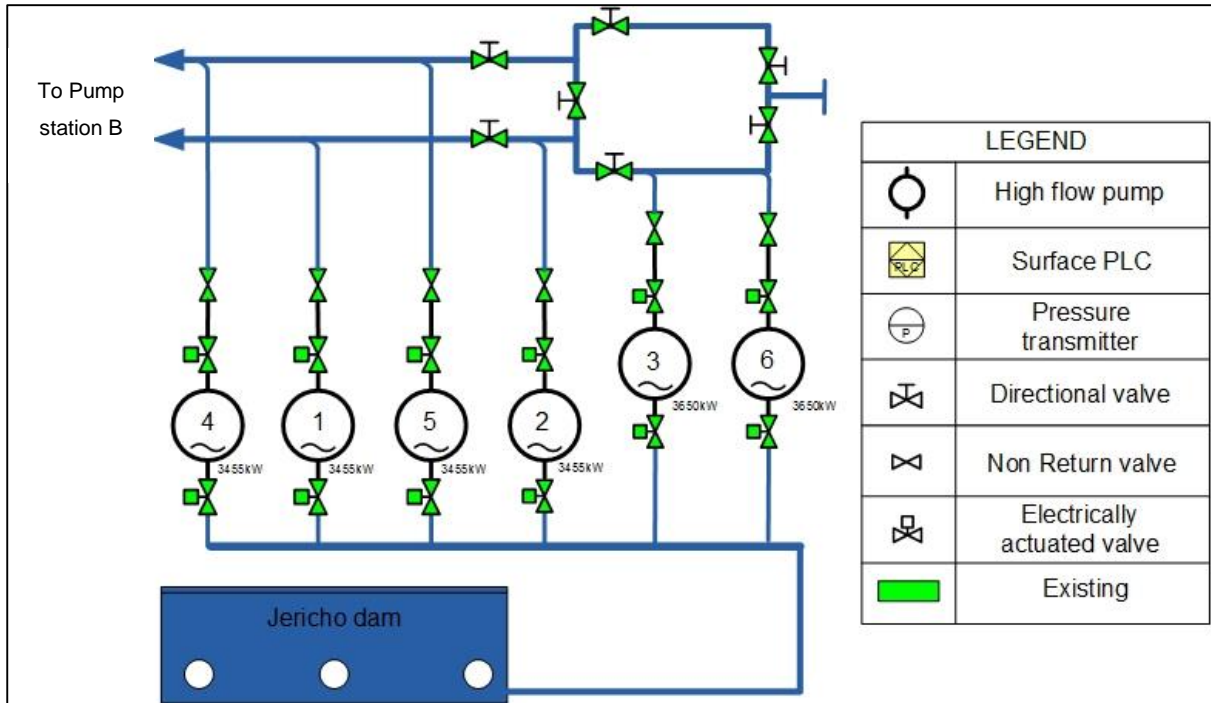
6:30	524.19	846.77	1,083.33
7:00	806.45	1,088.71	1,458.33
7:30	1,169.35	1,491.94	1,791.67
8:00	1,572.58	1,693.55	1,833.33
8:30	1,370.97	1,693.55	1,625.00
9:00	1,411.29	1,733.87	1,625.00
9:30	1,491.94	1,532.26	1,583.33
10:00	1,532.26	1,451.61	1,291.67
10:30	1,572.58	1,209.68	1,083.33
11:00	1,653.23	1,491.94	1,208.33
11:30	1,532.26	1,491.94	1,166.67
12:00	1,411.29	1,411.29	1,250.00
12:30	1,451.61	1,250.00	1,250.00
13:00	1,532.26	1,048.39	1,166.67
13:30	1,693.55	1,088.71	916.67
14:00	1,491.94	1,169.35	1,166.67
14:30	1,451.61	1,370.97	1,125.00
15:00	1,209.68	1,411.29	1,333.33
15:30	1,370.97	1,451.61	1,333.33
16:00	1,854.84	1,653.23	1,375.00
16:30	1,854.84	1,814.52	1,791.67
17:00	1,572.58	1,774.19	1,666.67
17:30	927.42	1,572.58	1,291.67
18:00	524.19	604.84	583.33
18:30	483.87	403.23	500.00
19:00	483.87	362.90	458.33
19:30	483.87	241.94	416.67
20:00	443.55	241.94	583.33
20:30	604.84	524.19	1,000.00
21:00	887.10	725.81	1,166.67
21:30	1,169.35	846.77	1,250.00
22:00	1,451.61	1,209.68	1,583.33
22:30	1,895.16	1,370.97	1,750.00
23:00	1,935.48	1,451.61	1,875.00
23:30	1,532.26	1,451.61	1,875.00

B-6: Section-B transfers, 2014 monthly performance assessment power graph

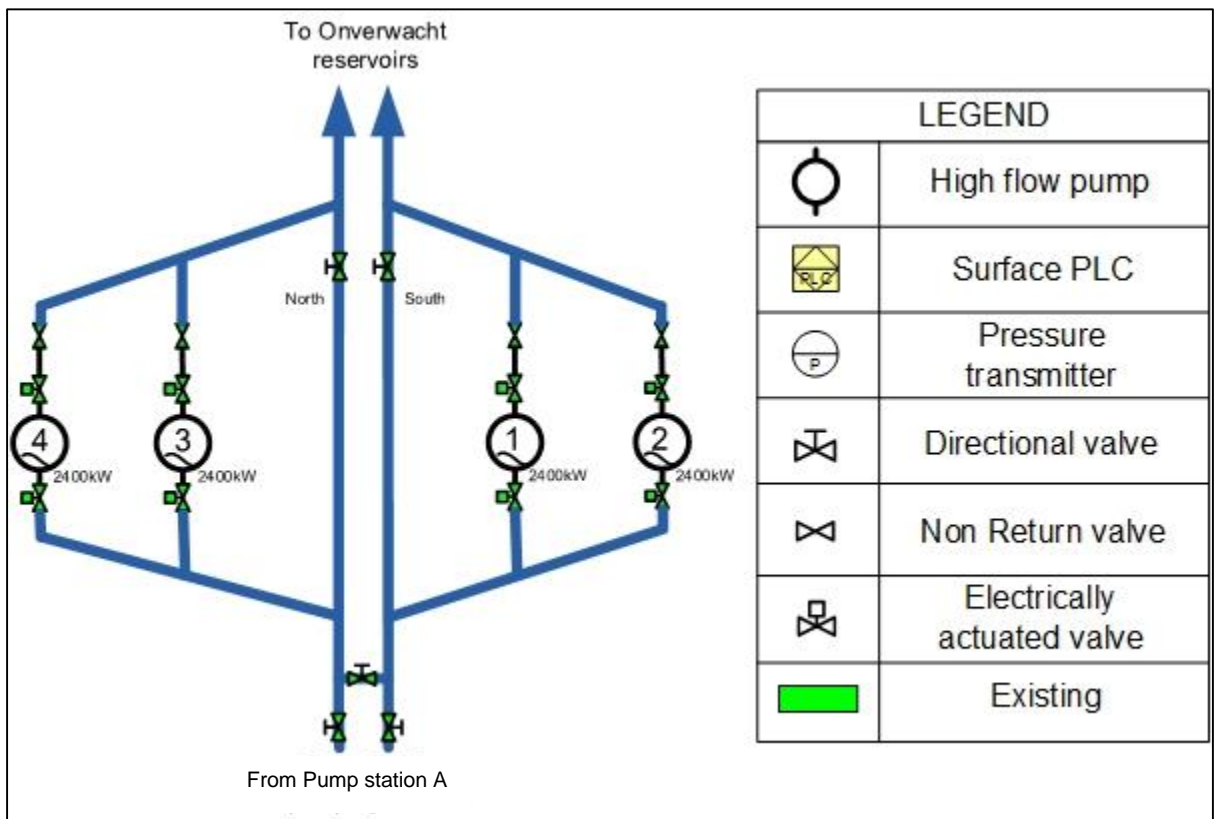


APPENDIX C

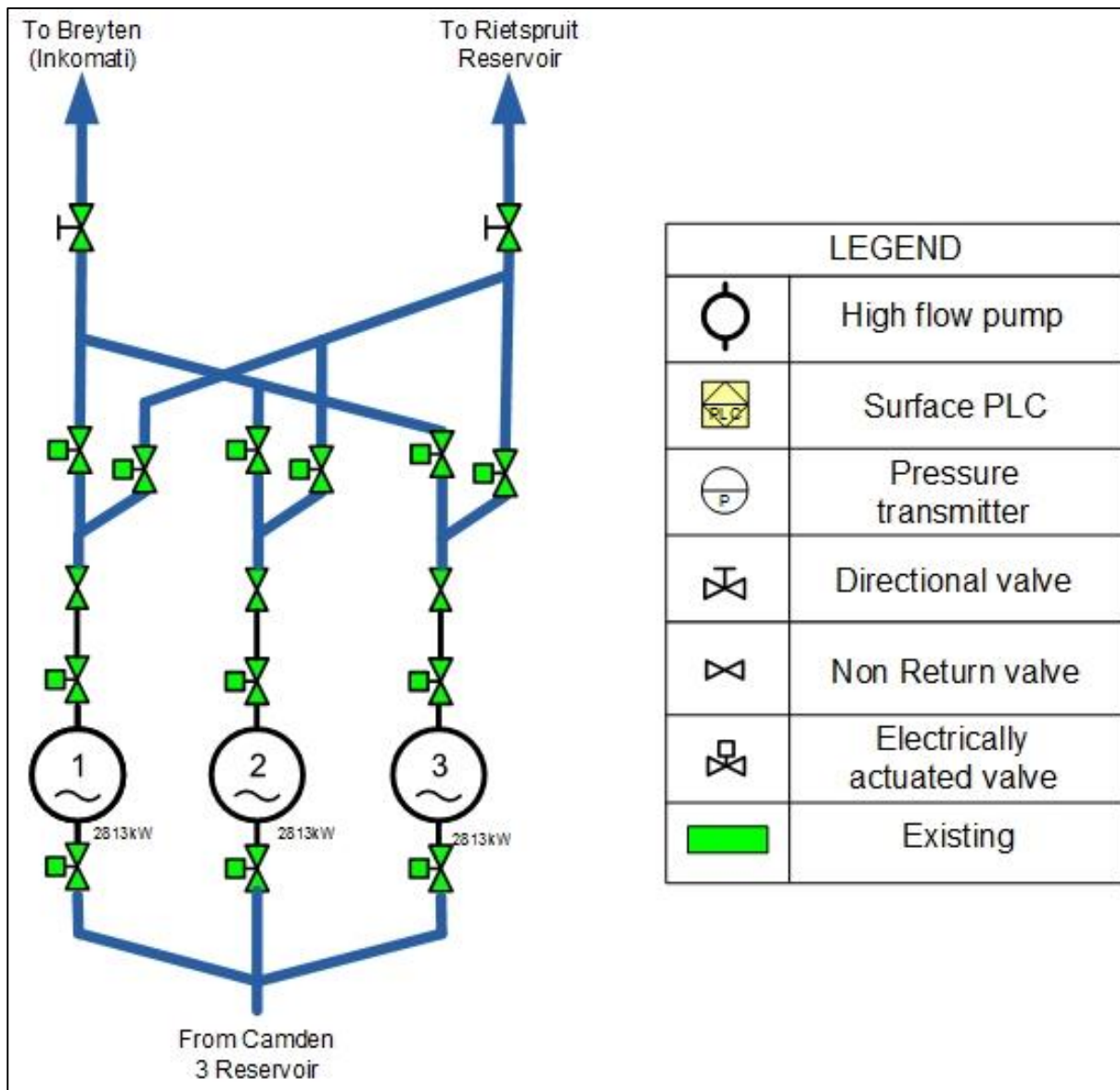
C-1: Layout of Pump station A.



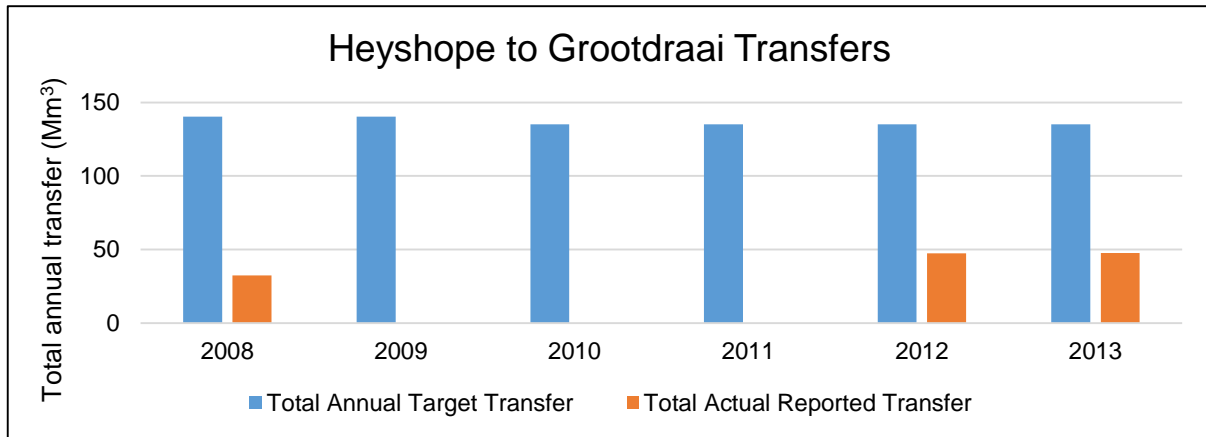
C-2: Layout of Pump station B.



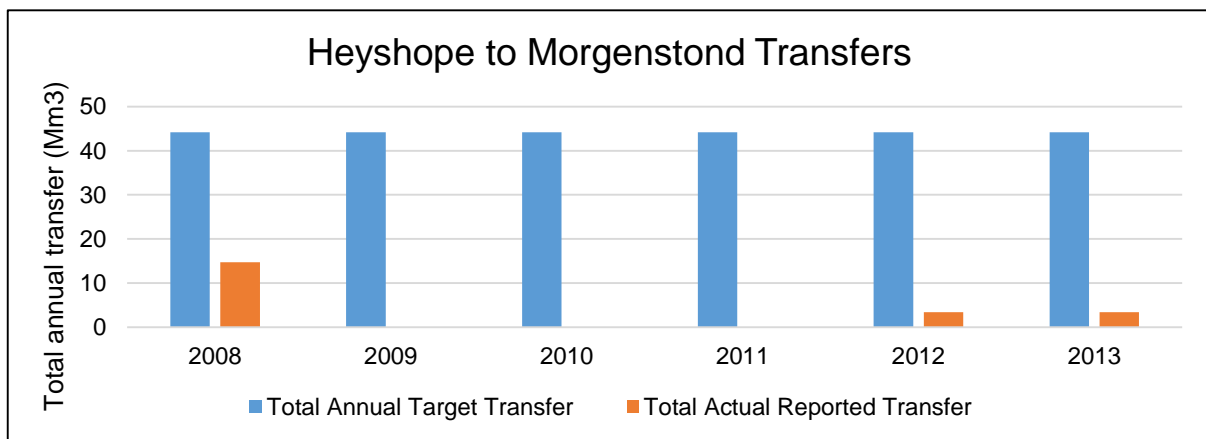
C-3: Layout of Pump station C.



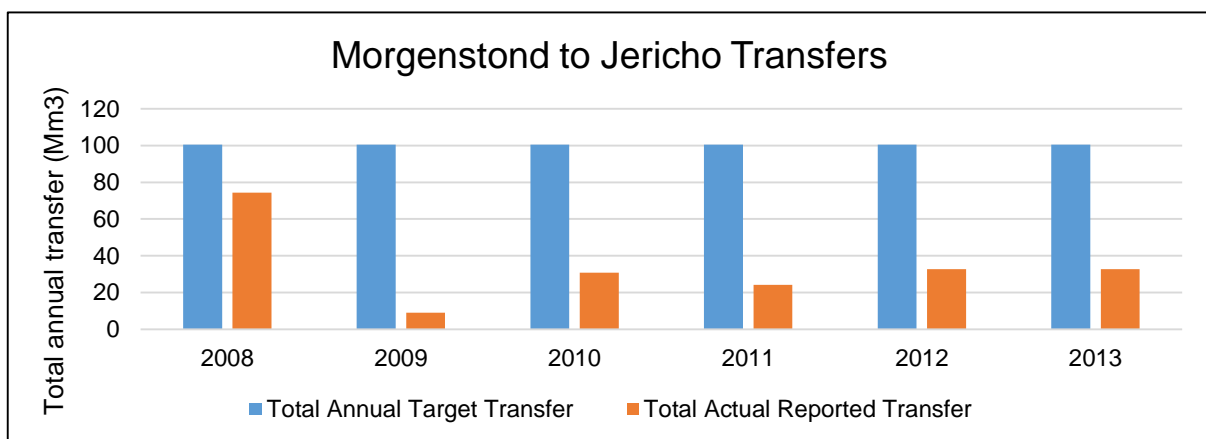
C-4: Annual targets and actual volumes for Usutu GWS – From Heyshope Dam to Grootdraai Dam.



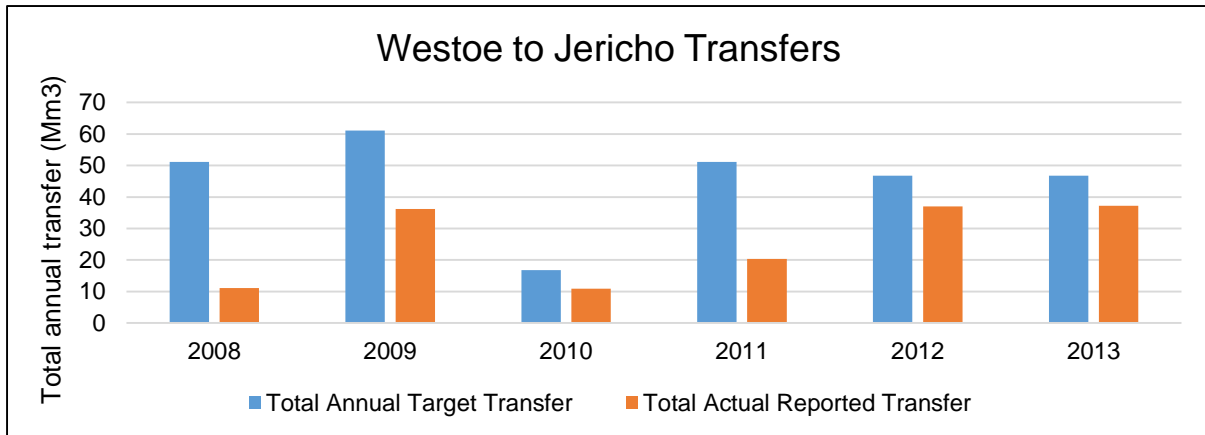
C-5: Annual targets and actual volumes for Usutu GWS – From Heyshope Dam to Morgenstond Dam.



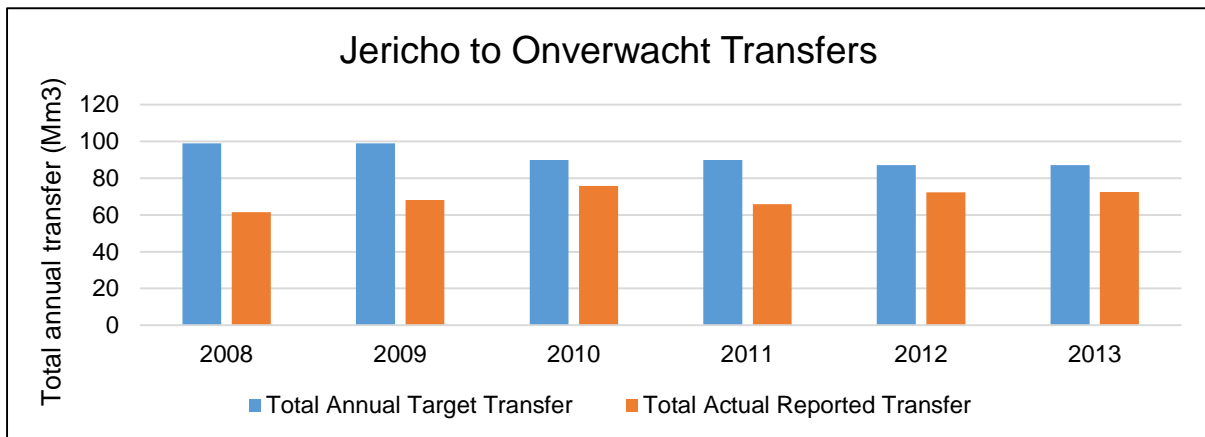
C-6: Annual targets and actual volumes for Usutu GWS – From Morgenstond Dam to Jericho Dam.



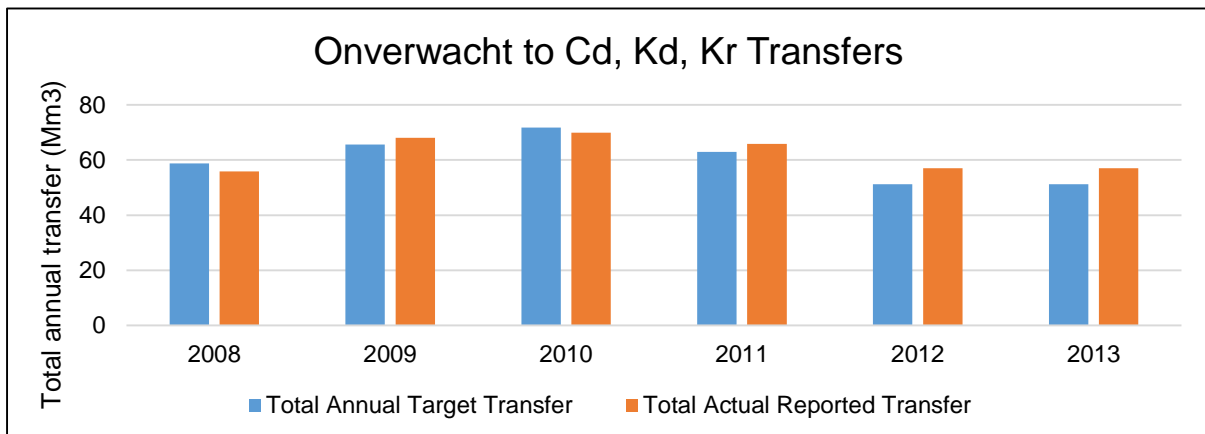
C-7: Annual targets and actual volumes for Usutu GWS – From Westoe Dam to Jericho Dam.



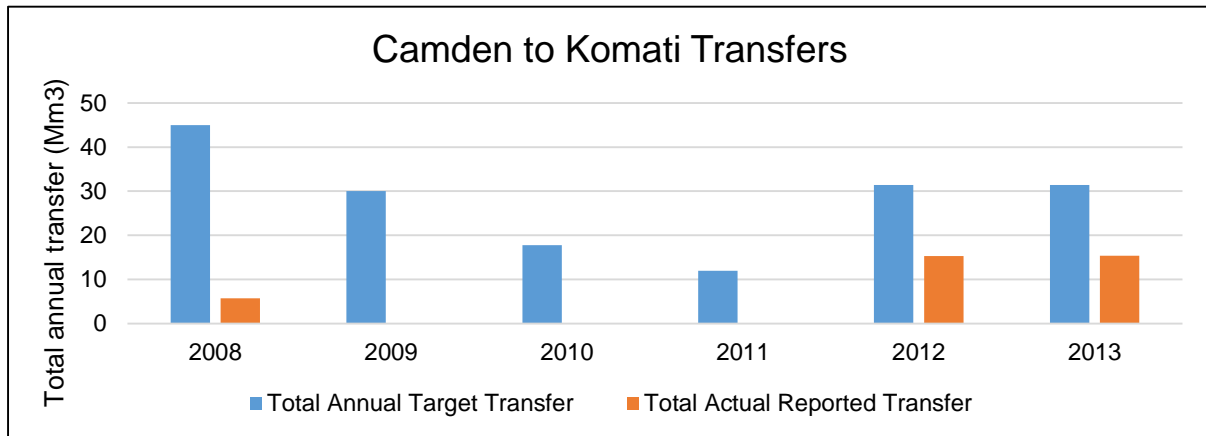
C-8: Annual targets and actual volumes for Usutu GWS – From Jericho Dam to Onverwacht reservoir.



C-9: Annual targets and actual volumes for Usutu GWS – From Onverwacht reservoir to Camden, Kendal and Kriel power stations.



C-10: Annual targets and actual volumes for Usutu GWS – *From Camden reservoir to the Inkomati scheme.*



APPENDIX D

D-1: Section-A Case study results – Actual- and Approximated DSM Savings

Date	Weekday	Actual DSM Saving(kW)	Approx. DSM Saving(kW)	% Difference
2014-07-01	2	4.25	5.04	18.43%
2014-07-02	3	4.83	5.31	9.81%
2014-07-03	4	5.55	5.58	0.55%
2014-07-04	5	5.62	5.92	5.33%
2014-07-07	1	4.91	5.45	10.96%
2014-07-08	2	4.98	5.20	4.31%
2014-07-09	3	4.91	4.83	-1.72%
2014-07-10	4	6.41	5.89	-7.99%
2014-07-11	5	4.28	5.23	22.19%
2014-07-14	1	4.44	4.67	5.04%
2014-07-15	2	5.81	5.53	-4.86%
2014-07-16	3	5.03	5.05	0.45%
2014-07-17	4	6.53	5.97	-8.52%
2014-07-18	5	4.84	5.18	6.96%
2014-07-21	1	4.09	5.41	32.26%
2014-07-22	2	5.33	5.57	4.64%
2014-07-23	3	5.53	5.86	5.90%
2014-07-24	4	5.10	5.61	9.98%
2014-07-25	5	4.08	4.92	20.49%
2014-07-28	1	4.32	5.03	16.57%
2014-07-29	2	5.48	5.64	2.99%
2014-07-30	3	4.56	5.25	15.28%
2014-07-31	4	2.22	6.27	182.48%
2014-08-01	5	8.15	7.26	-10.99%
2014-08-04	1	4.63	5.20	12.34%
2014-08-05	2	5.81	5.78	-0.59%
2014-08-06	3	6.27	6.28	0.04%
2014-08-07	4	6.45	6.34	-1.74%
2014-08-08	5	8.16	6.85	-16.03%
2014-08-11	1	3.93	4.80	22.11%
2014-08-12	2	5.92	5.84	-1.37%
2014-08-13	3	5.84	6.04	3.37%
2014-08-14	4	5.64	5.93	5.16%
2014-08-15	5	4.76	6.19	30.07%
2014-08-18	1	4.86	5.38	10.72%
2014-08-19	2	7.33	6.38	-12.95%
2014-08-20	3	6.98	6.36	-8.91%
2014-08-21	4	5.34	5.76	7.83%

2014-08-22	5	4.49	5.22	16.14%
2014-08-25	1	5.78	6.01	3.92%
2014-08-26	2	4.06	4.84	19.28%
2014-08-27	3	6.64	5.61	-15.56%
2014-08-28	4	3.58	4.24	18.45%
2014-08-29	5	6.79	6.22	-8.36%
2014-09-01	1	3.34	4.19	25.61%
2014-09-02	2	6.96	7.07	1.59%
2014-09-03	3	7.65	6.62	-13.38%
2014-09-04	4	6.40	6.35	-0.77%
2014-09-05	5	5.13	6.03	17.71%
2014-09-08	1	7.64	6.70	-12.32%
2014-09-09	2	5.54	5.86	5.77%
2014-09-10	3	4.37	4.88	11.56%
2014-09-11	4	5.94	6.06	2.00%
2014-09-12	5	7.46	6.72	-9.92%
2014-09-15	1	3.86	6.94	79.93%
2014-09-16	2	4.83	5.37	11.24%
2014-09-17	3	5.47	5.99	9.41%
2014-09-18	4	5.18	5.66	9.21%
2014-09-19	5	5.06	5.58	10.22%
2014-09-22	1	9.52	7.35	-22.78%
2014-09-23	2	6.90	6.21	-10.05%
2014-09-24	3	4.91	5.48	11.64%
2014-09-25	4	4.29	5.03	17.22%
2014-09-26	5	7.18	6.83	-4.88%
2014-09-29	1	5.04	5.57	10.63%
2014-09-30	2	5.10	5.60	9.96%
Total average (MW)		5.49	5.74	4.62%

D-3: Section-A Case study results – Actual- and Approximated electricity consumptions

Date	Weekday	Actual Energy (MWh)	Approx. Energy (MWh)	% Difference
2014-07-01	2	101.83	104.61	2.73%
2014-07-02	3	115.64	116.45	0.70%
2014-07-03	4	132.74	129.64	-2.33%
2014-07-04	5	134.50	147.71	9.82%
2014-07-07	1	117.47	123.15	4.84%
2014-07-08	2	119.23	111.46	-6.51%
2014-07-09	3	117.55	96.07	-18.28%
2014-07-10	4	153.32	146.34	-4.55%
2014-07-11	5	125.03	112.96	-9.65%
2014-07-14	1	106.31	90.05	-15.29%
2014-07-15	2	139.05	127.17	-8.54%
2014-07-16	3	120.39	105.21	-12.61%
2014-07-17	4	156.28	150.68	-3.58%

2014-07-18	5	115.87	110.65	-4.51%
2014-07-21	1	120.53	121.50	0.80%
2014-07-22	2	127.45	129.43	1.56%
2014-07-23	3	132.45	144.53	9.12%
2014-07-24	4	122.16	131.53	7.67%
2014-07-25	5	97.71	99.69	2.03%
2014-07-28	1	103.33	104.37	1.00%
2014-07-29	2	131.15	133.08	1.47%
2014-07-30	3	109.08	114.06	4.57%
2014-07-31	4	153.14	167.15	9.15%
2014-08-01	5	222.67	230.08	3.33%
2014-08-04	1	110.79	111.65	0.77%
2014-08-05	2	139.04	139.96	0.66%
2014-08-06	3	150.17	167.65	11.64%
2014-08-07	4	154.42	171.22	10.88%
2014-08-08	5	195.19	201.42	3.19%
2014-08-11	1	94.07	95.02	1.01%
2014-08-12	2	141.59	143.14	1.09%
2014-08-13	3	139.81	154.25	10.33%
2014-08-14	4	135.03	148.45	9.94%
2014-08-15	5	146.19	162.89	11.42%
2014-08-18	1	116.40	120.18	3.25%
2014-08-19	2	175.44	173.61	-1.04%
2014-08-20	3	167.09	172.37	3.16%
2014-08-21	4	127.78	138.99	8.78%
2014-08-22	5	107.53	112.43	4.56%
2014-08-25	1	138.41	152.70	10.32%
2014-08-26	2	97.14	96.62	-0.54%
2014-08-27	3	158.90	131.16	-17.46%
2014-08-28	4	85.71	76.03	-11.29%
2014-08-29	5	162.55	164.63	1.28%
2014-09-01	1	79.82	74.45	-6.73%
2014-09-02	2	211.87	215.90	1.90%
2014-09-03	3	183.00	187.74	2.59%
2014-09-04	4	153.19	171.93	12.23%
2014-09-05	5	139.70	153.99	10.23%
2014-09-08	1	182.79	192.13	5.11%
2014-09-09	2	132.62	144.56	9.00%
2014-09-10	3	104.63	98.01	-6.32%
2014-09-11	4	142.24	155.56	9.37%
2014-09-12	5	189.94	193.76	2.01%
2014-09-15	1	198.96	207.44	4.26%
2014-09-16	2	115.64	119.71	3.52%
2014-09-17	3	142.31	151.54	6.49%
2014-09-18	4	124.05	133.95	7.98%
2014-09-19	5	121.17	129.82	7.14%
2014-09-22	1	227.92	238.83	4.79%
2014-09-23	2	165.11	163.60	-0.91%

2014-09-24	3	117.45	124.75	6.22%
2014-09-25	4	102.59	104.03	1.40%
2014-09-26	5	192.79	200.30	3.89%
2014-09-29	1	120.55	129.43	7.37%
2014-09-30	2	121.95	130.98	7.41%
Total sum (MWh)		9,088.39	9,304.32	2.03%

D-3: Section-A Case study results – Actual- and Approximated electricity costs

Date	Weekday	Actual Cost (R)	Approx Cost (R)	% Difference
2014-07-01	2	70,730.13	76,421.81	8.05%
2014-07-02	3	93,809.84	86,930.96	-7.33%
2014-07-03	4	86,335.47	98,628.50	14.24%
2014-07-04	5	107,549.39	114,660.19	6.61%
2014-07-07	1	85,187.02	92,872.93	9.02%
2014-07-08	2	96,060.95	82,503.60	-14.11%
2014-07-09	3	92,664.58	68,848.70	-25.70%
2014-07-10	4	125,204.39	113,448.49	-9.39%
2014-07-11	5	103,176.07	83,831.81	-18.75%
2014-07-14	1	85,827.09	63,512.57	-26.00%
2014-07-15	2	104,999.26	96,438.12	-8.15%
2014-07-16	3	93,540.31	76,957.75	-17.73%
2014-07-17	4	120,624.02	117,293.30	-2.76%
2014-07-18	5	87,534.51	81,781.24	-6.57%
2014-07-21	1	88,796.65	91,404.92	2.94%
2014-07-22	2	75,946.54	98,442.08	29.62%
2014-07-23	3	109,121.05	111,840.66	2.49%
2014-07-24	4	97,289.70	100,306.23	3.10%
2014-07-25	5	67,963.26	72,064.36	6.03%
2014-07-28	1	72,365.74	76,212.09	5.32%
2014-07-29	2	87,605.04	101,681.04	16.07%
2014-07-30	3	79,538.67	84,810.48	6.63%
2014-07-31	4	125,901.26	131,903.57	4.77%
2014-08-01	5	187,047.28	187,734.87	0.37%
2014-08-04	1	76,824.23	82,666.71	7.60%
2014-08-05	2	108,514.94	107,786.13	-0.67%
2014-08-06	3	116,116.74	132,346.31	13.98%
2014-08-07	4	117,962.14	135,515.36	14.88%
2014-08-08	5	152,790.71	162,312.52	6.23%
2014-08-11	1	71,419.78	67,916.63	-4.91%
2014-08-12	2	118,974.49	110,605.66	-7.03%
2014-08-13	3	109,152.77	120,462.35	10.36%
2014-08-14	4	106,717.46	115,312.64	8.05%
2014-08-15	5	117,584.02	128,128.67	8.97%

2014-08-18	1	77,212.09	90,239.82	16.87%
2014-08-19	2	137,870.02	137,635.84	-0.17%
2014-08-20	3	133,605.07	136,540.65	2.20%
2014-08-21	4	102,784.95	106,923.96	4.03%
2014-08-22	5	59,533.99	83,365.77	40.03%
2014-08-25	1	108,213.68	119,087.54	10.05%
2014-08-26	2	68,619.05	69,338.04	1.05%
2014-08-27	3	113,421.23	99,980.00	-11.85%
2014-08-28	4	54,415.08	51,069.37	-6.15%
2014-08-29	5	134,123.68	129,666.59	-3.32%
2014-09-01	1	61,110.87	49,671.26	-18.72%
2014-09-02	2	180,841.57	175,151.85	-3.15%
2014-09-03	3	146,335.52	150,172.24	2.62%
2014-09-04	4	118,147.66	136,144.52	15.23%
2014-09-05	5	113,230.36	120,229.33	6.18%
2014-09-08	1	144,157.38	154,063.66	6.87%
2014-09-09	2	104,321.05	111,863.96	7.23%
2014-09-10	3	65,627.56	70,573.04	7.54%
2014-09-11	4	109,609.28	121,627.45	10.96%
2014-09-12	5	149,067.46	155,508.37	4.32%
2014-09-15	1	169,307.94	167,648.65	-0.98%
2014-09-16	2	82,605.77	89,820.39	8.73%
2014-09-17	3	112,286.35	118,062.26	5.14%
2014-09-18	4	86,174.59	102,450.00	18.89%
2014-09-19	5	93,634.70	98,791.61	5.51%
2014-09-22	1	180,980.03	195,494.39	8.02%
2014-09-23	2	134,237.09	128,757.82	-4.08%
2014-09-24	3	100,026.74	94,294.35	-5.73%
2014-09-25	4	57,025.88	75,909.17	33.11%
2014-09-26	5	153,568.13	161,310.54	5.04%
2014-09-29	1	103,338.15	98,442.08	-4.74%
2014-09-30	2	100,934.38	99,816.89	-1.11%
Total sum (R)		6,997,242.80	7,173,234.66	2.97%

D-4: Section-B Case study results – Actual- and Approximated DSM Savings

Date	Weekday	Actual DSM Saving(kW)	Approx. DSM Saving(kW)	% Difference
2014-07-01	2	0.72	0.80	11.70%
2014-07-02	3	0.64	0.71	11.98%
2014-07-03	4	1.35	1.52	11.92%
2014-07-04	5	0.46	0.86	87.11%
2014-07-07	1	0.52	0.92	78.90%
2014-07-08	2	0.35	0.74	111.46%
2014-07-09	3	0.75	0.83	11.64%
2014-07-10	4	0.72	0.80	11.70%

2014-07-11	5	(1.26)	1.39	-210.71%
2014-07-14	1	0.83	0.92	11.50%
2014-07-15	2	1.00	1.11	11.45%
2014-07-16	3	1.22	1.36	11.71%
2014-07-17	4	1.02	1.14	11.47%
2014-07-18	5	1.19	1.24	4.11%
2014-07-21	1	1.69	1.73	2.32%
2014-07-22	2	1.05	1.17	11.49%
2014-07-23	3	1.35	1.52	11.92%
2014-07-24	4	0.86	0.96	11.47%
2014-07-25	5	0.47	0.53	12.86%
2014-07-28	1	0.94	1.05	11.44%
2014-07-29	2	0.77	0.86	11.58%
2014-07-30	3	0.72	0.80	11.70%
2014-07-31	4	(0.37)	2.34	-730.98%
2014-08-01	5	1.32	1.83	38.70%
2014-08-04	1	1.05	1.17	11.49%
2014-08-05	2	1.24	1.39	11.75%
2014-08-06	3	0.88	1.33	51.48%
2014-08-07	4	1.77	1.98	11.96%
2014-08-08	5	1.76	2.29	30.09%
2014-08-11	1	0.88	0.99	11.45%
2014-08-12	2	1.33	1.48	11.88%
2014-08-13	3	1.30	1.45	11.84%
2014-08-14	4	1.30	1.45	11.84%
2014-08-15	5	0.76	1.55	104.35%
2014-08-18	1	1.33	1.48	11.88%
2014-08-19	2	1.49	1.67	12.09%
2014-08-20	3	0.86	0.96	11.47%
2014-08-21	4	0.86	0.96	11.47%
2014-08-22	5	0.64	0.71	11.98%
2014-08-25	1	0.86	0.96	11.47%
2014-08-26	2	0.88	0.99	11.45%
2014-08-27	3	0.55	0.56	1.41%
2014-08-28	4	0.94	1.05	11.44%
2014-08-29	5	0.58	0.65	12.22%
2014-09-01	1	(0.29)	1.42	-589.07%
2014-09-02	2	1.55	1.74	12.12%
2014-09-03	3	1.27	1.42	11.79%
2014-09-04	4	1.35	1.52	11.92%
2014-09-05	5	1.38	1.55	11.96%
2014-09-08	1	1.69	1.89	12.09%
2014-09-09	2	0.97	1.08	11.44%
2014-09-10	3	0.66	0.74	11.87%
2014-09-11	4	1.63	1.83	12.12%
2014-09-12	5	1.19	1.33	11.66%
2014-09-15	1	0.74	1.17	58.70%
2014-09-16	2	0.66	0.74	11.87%

2014-09-17	3	0.83	0.92	11.50%
2014-09-18	4	0.72	0.80	11.70%
2014-09-19	5	0.69	0.77	11.78%
2014-09-22	1	1.71	1.92	12.05%
2014-09-23	2	0.83	0.92	11.50%
2014-09-24	3	0.80	0.89	11.53%
2014-09-25	4	0.99	1.45	47.25%
2014-09-26	5	1.63	1.83	12.12%
2014-09-29	1	1.02	1.14	11.47%
2014-09-30	2	0.86	0.96	11.47%
Total average (MW)		0.95	1.22	28.52%

D-5: Section-B Case study results – Actual- and Approximated electricity consumptions

Date	Weekday	Actual Energy (MWh)	Approx. Energy (MWh)	% Difference
2014-07-01	2	16.25	16.27	0.11%
2014-07-02	3	14.38	14.14	-1.63%
2014-07-03	4	30.63	32.57	6.35%
2014-07-04	5	17.50	17.69	1.06%
2014-07-07	1	18.75	19.10	1.88%
2014-07-08	2	15.00	14.85	-1.00%
2014-07-09	3	16.88	16.98	0.60%
2014-07-10	4	16.25	16.27	0.11%
2014-07-11	5	28.13	29.73	5.72%
2014-07-14	1	18.75	19.10	1.88%
2014-07-15	2	22.50	23.36	3.80%
2014-07-16	3	27.50	29.03	5.55%
2014-07-17	4	23.13	24.06	4.06%
2014-07-18	5	26.88	26.28	-2.20%
2014-07-21	1	38.13	37.30	-2.17%
2014-07-22	2	23.75	24.77	4.31%
2014-07-23	3	30.63	32.57	6.35%
2014-07-24	4	19.38	19.81	2.25%
2014-07-25	5	10.63	9.89	-6.93%
2014-07-28	1	21.25	21.94	3.24%
2014-07-29	2	17.50	17.69	1.06%
2014-07-30	3	16.25	16.27	0.11%
2014-07-31	4	48.13	52.41	8.91%
2014-08-01	5	36.88	39.66	7.54%
2014-08-04	1	23.75	24.77	4.31%
2014-08-05	2	28.13	29.73	5.72%
2014-08-06	3	26.88	28.32	5.36%
2014-08-07	4	40.00	43.20	8.00%
2014-08-08	5	46.88	51.00	8.79%
2014-08-11	1	20.00	20.52	2.60%

2014-08-12	2	30.00	31.86	6.20%
2014-08-13	3	29.38	31.15	6.05%
2014-08-14	4	29.38	31.15	6.05%
2014-08-15	5	31.25	33.28	6.49%
2014-08-18	1	30.00	31.86	6.20%
2014-08-19	2	33.75	36.11	7.00%
2014-08-20	3	19.38	19.81	2.25%
2014-08-21	4	19.38	19.81	2.25%
2014-08-22	5	14.38	14.14	-1.63%
2014-08-25	1	19.38	19.81	2.25%
2014-08-26	2	20.00	20.52	2.60%
2014-08-27	3	12.50	10.60	-15.22%
2014-08-28	4	21.25	21.94	3.24%
2014-08-29	5	13.13	12.72	-3.06%
2014-09-01	1	28.75	30.44	5.89%
2014-09-02	2	35.00	37.53	7.23%
2014-09-03	3	28.75	30.44	5.89%
2014-09-04	4	30.63	32.57	6.35%
2014-09-05	5	31.25	33.28	6.49%
2014-09-08	1	38.13	41.07	7.74%
2014-09-09	2	21.88	22.65	3.53%
2014-09-10	3	15.00	14.85	-1.00%
2014-09-11	4	36.88	39.66	7.54%
2014-09-12	5	26.88	28.32	5.36%
2014-09-15	1	23.75	24.77	4.31%
2014-09-16	2	15.00	14.85	-1.00%
2014-09-17	3	18.75	19.10	1.88%
2014-09-18	4	16.25	16.27	0.11%
2014-09-19	5	15.63	15.56	-0.42%
2014-09-22	1	38.75	41.78	7.83%
2014-09-23	2	18.75	19.10	1.88%
2014-09-24	3	18.13	18.39	1.48%
2014-09-25	4	29.38	31.15	6.05%
2014-09-26	5	36.88	39.66	7.54%
2014-09-29	1	23.13	24.06	4.06%
2014-09-30	2	19.38	19.81	2.25%
Total sum (MWh)		1,630.63	1,699.35	4.21%

D-6: Section-B Case study results – Actual- and Approximated electricity costs

Date	Weekday	Actual Cost (R)	Approx Cost (R)	% Difference
2014-07-01	2	9,204.88	9,191.81	-0.14%
2014-07-02	3	12,550.19	7,350.67	-41.43%
2014-07-03	4	25,018.44	23,307.18	-6.84%
2014-07-04	5	10,624.13	10,419.23	-1.93%
2014-07-07	1	16,458.13	11,646.66	-29.23%
2014-07-08	2	17,582.63	7,964.39	-54.70%
2014-07-09	3	16,151.69	9,805.52	-39.29%
2014-07-10	4	15,350.13	9,191.81	-40.12%
2014-07-11	5	31,970.06	20,852.33	-34.78%
2014-07-14	1	13,385.50	11,646.66	-12.99%
2014-07-15	2	18,780.88	15,328.93	-18.38%
2014-07-16	3	24,260.25	20,238.62	-16.58%
2014-07-17	4	25,148.56	15,942.64	-36.61%
2014-07-18	5	20,576.81	17,863.82	-13.18%
2014-07-21	1	34,855.44	27,401.14	-21.39%
2014-07-22	2	22,693.63	16,556.35	-27.04%
2014-07-23	3	29,814.69	23,307.18	-21.83%
2014-07-24	4	14,003.19	12,260.37	-12.45%
2014-07-25	5	8,871.56	3,668.40	-58.65%
2014-07-28	1	13,151.38	14,101.50	7.22%
2014-07-29	2	14,078.25	10,419.23	-25.99%
2014-07-30	3	15,350.13	9,191.81	-40.12%
2014-07-31	4	49,077.56	40,491.11	-17.50%
2014-08-01	5	32,693.81	29,444.30	-9.94%
2014-08-04	1	22,898.13	16,556.35	-27.70%
2014-08-05	2	23,542.69	20,852.33	-11.43%
2014-08-06	3	20,399.81	19,624.91	-3.80%
2014-08-07	4	32,477.63	32,512.86	0.11%
2014-08-08	5	37,888.81	39,263.69	3.63%
2014-08-11	1	12,692.75	12,874.08	1.43%
2014-08-12	2	30,355.25	22,693.47	-25.24%
2014-08-13	3	29,935.19	22,079.76	-26.24%
2014-08-14	4	30,125.94	22,079.76	-26.71%
2014-08-15	5	33,688.88	23,920.89	-28.99%
2014-08-18	1	24,400.75	22,693.47	-7.00%
2014-08-19	2	31,152.00	26,375.74	-15.33%
2014-08-20	3	15,726.81	12,260.37	-22.04%
2014-08-21	4	18,990.19	12,260.37	-35.44%
2014-08-22	5	14,662.19	7,350.67	-49.87%
2014-08-25	1	18,220.31	12,260.37	-32.71%
2014-08-26	2	10,580.75	12,874.08	21.67%
2014-08-27	3	14,934.88	4,282.11	-71.33%
2014-08-28	4	10,657.88	14,101.50	32.31%

2014-08-29	5	12,861.44	6,123.25	-52.39%
2014-09-01	1	20,883.25	21,466.05	2.79%
2014-09-02	2	30,282.25	27,603.17	-8.85%
2014-09-03	3	20,113.38	21,466.05	6.73%
2014-09-04	4	23,097.19	23,307.18	0.91%
2014-09-05	5	19,688.50	23,920.89	21.50%
2014-09-08	1	32,573.31	30,671.72	-5.84%
2014-09-09	2	16,644.06	14,715.22	-11.59%
2014-09-10	3	15,470.63	7,964.39	-48.52%
2014-09-11	4	32,496.19	29,444.30	-9.39%
2014-09-12	5	27,682.69	19,624.91	-29.11%
2014-09-15	1	14,647.75	16,556.35	13.03%
2014-09-16	2	16,042.88	7,964.39	-50.36%
2014-09-17	3	18,958.50	11,646.66	-38.57%
2014-09-18	4	18,041.25	9,191.81	-49.05%
2014-09-19	5	18,002.69	8,578.10	-52.35%
2014-09-22	1	32,421.13	31,285.44	-3.50%
2014-09-23	2	10,503.63	11,646.66	10.88%
2014-09-24	3	14,498.31	11,032.94	-23.90%
2014-09-25	4	31,849.56	22,079.76	-30.67%
2014-09-26	5	31,351.69	29,444.30	-6.08%
2014-09-29	1	21,135.94	15,942.64	-24.57%
2014-09-30	2	14,956.94	12,260.37	-18.03%
Total sum (R)		1,419,185.81	1,148,444.98	-19.08%