Effects of load shifting on water quality in a large potable water network

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ABSTRACT

Title: Effects of Load Shifting on water quality in a large potable water network

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Mathematical analyses indicated that significant possibilities exist for load shifting projects on a Large Potable Water Utility (LPWU) in South Africa. A primary concern remained, i.e. whether the load variation would have an effect on the water quality. Extensive simulation and testing were initiated in order to prove that the load shift will not affect the water quality.

In South Africa, the highest standard for drinking water is the Blue Drop award. The LPWU has received this award multiple times and strives to maintain it. An investigation was launched to determine if this load shifting project would have an effect on the quality standards to which the utility holds (SANS 241 (2011)).

The LPWU has over 3000 km of pipelines to supply potable water to the industrial heartland of the country as well as millions of domestic users. The LPWU network is the longest pumping network in the world and is still expanding.

The investigation included a simulation of a pumping simulation package to determine how the system would react to the changes. In this simulation, the load reduction in terms of Mega litre per day (Ml/day) was established. Results were compared to the normal operating parameters of the Water Treatment Works (WTW).

The mathematical analysis in this investigation concluded that an evening peak load shift of 24.5 MW is achievable. This dissertation will emphasise the necessity of a detailed investigation. The investigations and simulation will determine that the volume of water is well within the operating parameters of the WTW. Studies were done on each area of the plant. In-depth conversations with WTW personnel revealed that the reduction of the volume of water in question will not have an effect on the water quality.

Further, it was established that it would be possible to use the sumps of the water treatment works to achieve the desired load shift. By using the sumps of the WTW, a load shift can be done without stopping any process in the WTW with the exception of disinfection at the Booster Pump Stations (BPS), where the balancing reservoirs were used as buffer capacity.

The investigation shifted to establish whether stagnant water and a change in dosage would have an effect on the water quality in regard to the reduction and recovery load. As expected, the water never became stagnant at any moment due to the fact that only a small portion of the load was reduced.

The water quality and dosage report of the water utility was used and compared to normal operations. The planned load shift had no effect on any aspects of the water quality. The project is feasible and will reach the set targets without affecting the water quality,

Keywords: water quality, load shifting, potable water network, water distribution network, Blue Drop, water treatment

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Thank you to all the personnel of the water utility, especially Dries Strydom. Thank you to my colleague, Mr Wynand Breytenbach, who assisted me with the implementation of the strategies which were developed.

It is my hope that this dissertation provides a starting point and a stepping stone towards efficient operations in the water industry. Should anyone wish to continue research in this field, or take the implementation of the strategies further, my best wishes accompany them.

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ABBREVIATIONS

Abbreviation	Description
AMD	Acid Mine Drainage
BPS	Booster Pump Station
BWD	Bulk Water Distribution
DSM	Demand Side Management
DWC	Drink Water Compliance
ER	Engine Room
ESCo	Energy Services Company
kW	Kilowatt
kWh	Kilowatt-hour
LPWU	Large Potable Water Utility
Ml/day	Mega litre per day
mm	Millimetre
MW	Megawatt
MYPD	Multi-Year Pricing Determination
NERSA	National Energy Regulator of South Africa
NMD	Notified Maximum Demand
PS	Pump Set
SANS	South African National Standards
SBPS	Secondary Booster Pump Station
SCADA	Supervisory Control And Data Acquisition
TOU	Time Of Use
VSD	Variable Speed Drive
WSA	Water Services Authorities
WTW	Water Treatment Works

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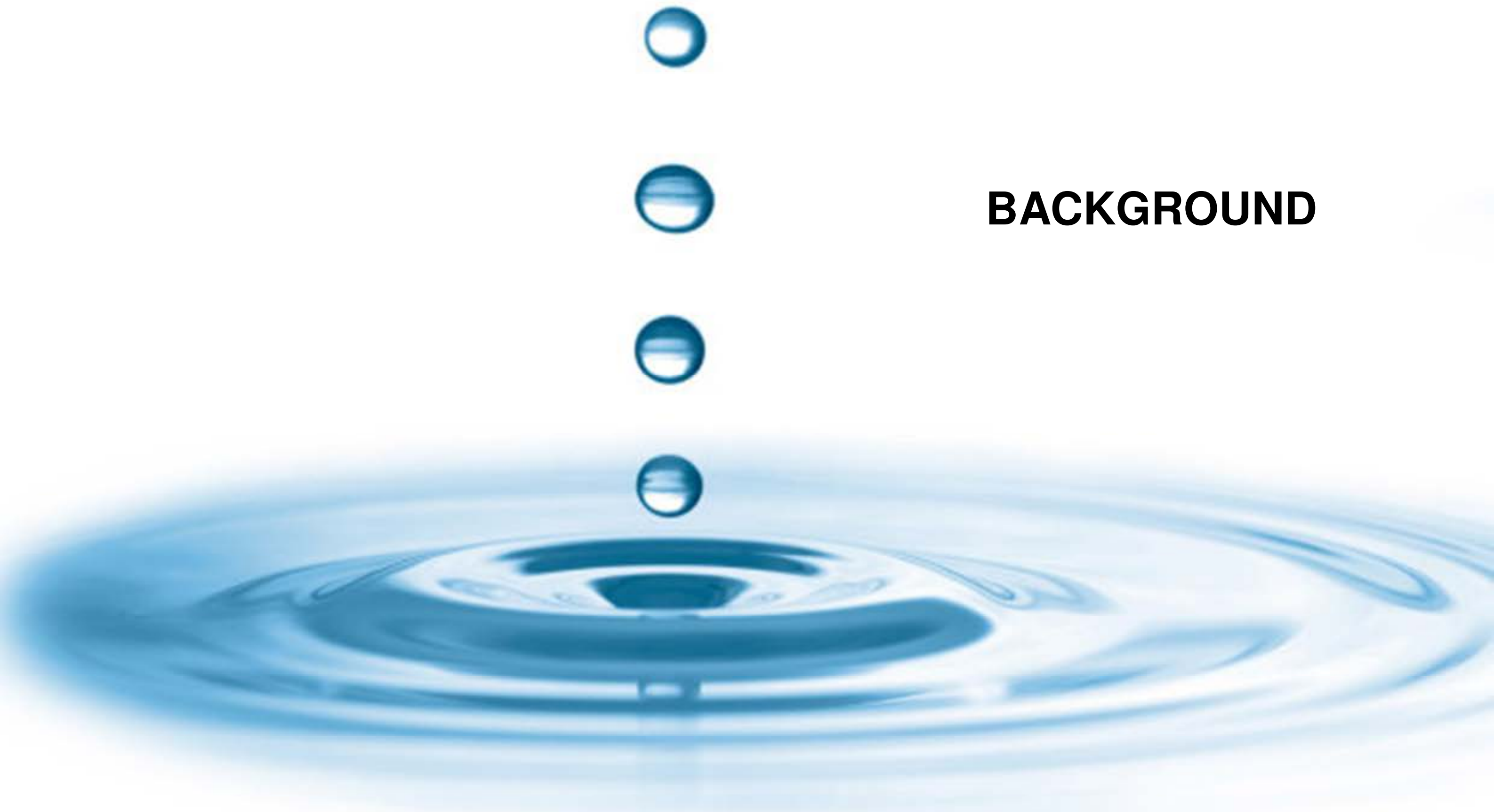
BACKGROUND



Chapter 1: On an LPWU network, there may exist large-scale cost savings by adjusting the pumping schedule. Large quantities of water are pumped on a daily basis from the Vaal dam in South Africa to large parts of Gauteng and even areas in North- West and Limpopo.

CHAPTER 1: BACKGROUND

1.1 Introduction

A Large Potable Water Utility (LPWU) in South Africa provides on average 3 600 megalitre per day (Ml/day) of potable water to 58 strategically placed reservoirs. The utility has 3 056 km of pipeline to accomplish this feat [1]. The LPWU supplies potable water to three metropolitan councils, 45 mines, 711 industrial users and 15 municipalities [2]. The utility has a vast area of supply as seen in Figure 1 below.

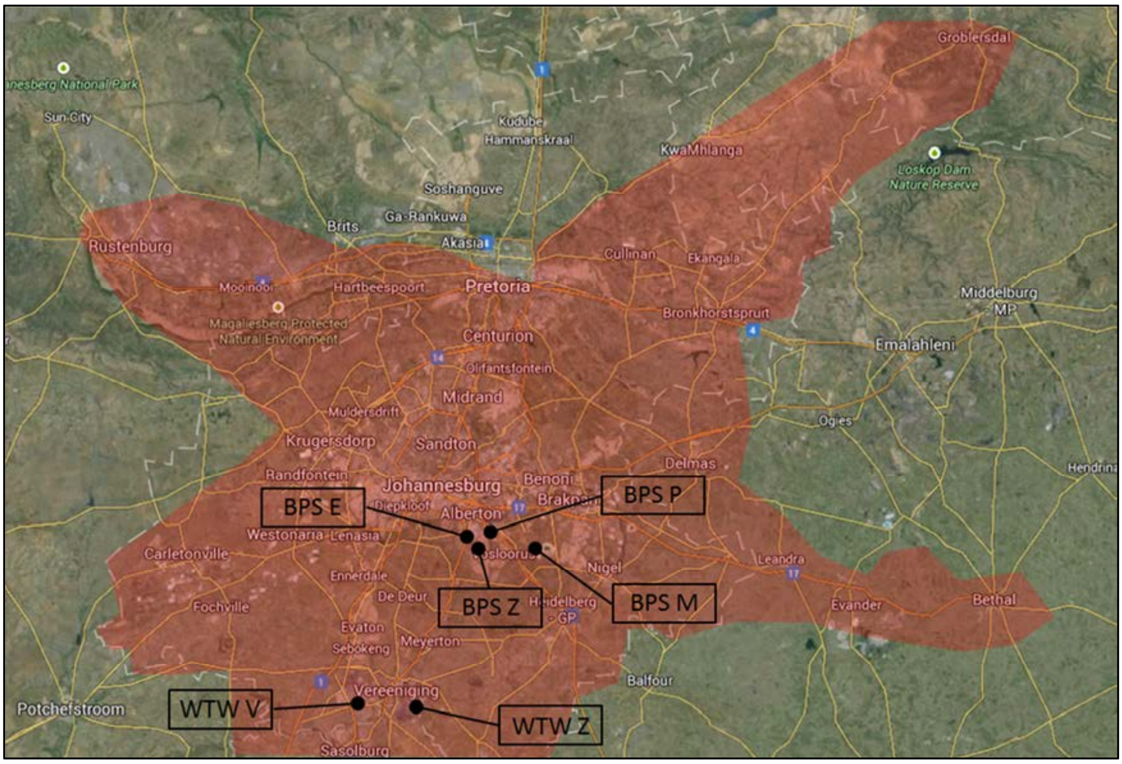


Figure 1: LPWU approximate area of supply (adapted from [3])

The LPWU network has two Water Treatment Works (WTW), namely WTW V and WTW Z. Each of the WTW has pump stations on site to distribute the water to the Booster Pump Stations (BPS) downstream. There are four major BPS, namely, BPS Z, BPS E, BPS P and BPS M. Further down the network multiple Secondary Booster Pump Stations (SBPS) transfer water to reservoirs.

The potable water supplier's pump stations are large compared to those in other industries, making the utility a prime candidate for cost-saving interventions. The installed capacities of the pump stations are listed in Table 1 below.

Table 1: Installed capacities of pumps station in the network

Pump Station	Installed capacity (kW)	Installed pumping capacity (ML/day)
WTW Z	143 402	5440
WTW V	55 225	2105
BPS Z	64 022	1100
BPS E	73 848	2600
BPS P	74 340	2505
BPS M	86 098	1320

LPWU was officially established on 8 May 1903. On 15 May 1903 the first official board meeting took place. The government intended the Board's members to be representatives of the Witwatersrand region. The new water utility also had to have a singular sense of purpose. The Board expropriated some private undertakings, resulting in *£ 2 216 238* to be paid out to these private companies [4].

The Board also had to pay *£ 176 584* to the Johannesburg town council for the existing infrastructure of pipes and reservoirs. From 1905, the Board started with efficient operations. The LPWU formerly used boreholes to supply the demand. Table 2, below, shows the overall water supply of the LPWU in 1911. SBPS Z was the most reliable source of water [4].

Table 2: Water sources of the LPWU in 1911 (adapted from [4])

Source	Ml/day	Percentage
BPS Z	26	65.17
SBPS Z	13	32.03
SBPS D	0.5	1.29
SBPS S	0.2	0.41
SBPS B	0.5	1.11
Total	40	100

In 1911 the Board realised that these boreholes were on the decline and the Chief Engineer was instructed to investigate water catchment in an 80 km radius of Johannesburg. In 1916 building of a barrage in the Vaal River commenced, serving as a water catchment. The barrage was completed in October 1923. In 1933, the Government decided to start building a dam on Vaalbank, later known as the Vaal dam. The increased storage capacity would increase the supply capabilities of the LPWU Board from 90 to 315 Ml/day [4].

Up until the 1940s the WTW V and BPS Z were the heart of the potable water utility. The WTW Z scheme was approved in 1949 and construction began. After WTW Z ER1 was completed in 1954, the system could be officially recognised as a water distribution network [4].

Many upgrades, BPS P, BPS E and BPS M followed to keep up with the demand and economic growth of the Republic of South Africa. Upgrades are scheduled at WTW Z and BPS P within the next four years, while on all of the other sites, upgrades are scheduled for the next ten years.

1.2 Cost saving due to load shifting

Electricity prices are determined and regulated by NERSA (National Energy Regulator of South Africa). The concept of an energy regulator is relatively new to South Africa. NERSA was established in 1995 and commenced its responsibilities towards Eskom in 2000. Before 1994, Eskom and the government had an agreement in which the electricity price was set at 15% less than the real price. The increases continued to the year 2000. As the demand grew from the late 1990s, the demand surpassed Eskom's supply capacity early in the 21st century [5].

NERSA utilises a pricing scheme based on the multi-year pricing determination (MYPD). In April 2007 Eskom submitted a petition to NERSA to revaluate the MYPD. NERSA agreed to a 14.7% increase. Eskom requested NERSA to review the increase based on the following reasons [5]:

- The unstable fuel (gas, coal) prices;
- Energy demand uncertainty;
- Change in quality of fuels;
- Fuel prices vary across regions.

Eskom applied for a 35% increase per annum [5]. Eskom's prices are adjusted on 1 April every year. The average price adjustment for the last decade can be seen in Table 3 [6].

Table 3: Electricity price increase the past decade (adapted from [6])

Year	**Average Price adjustment**
2004/5	4.1%
2006/7	5.1%
2007/8	5.9%
2008/9	27.5%
2009/10	31.3%
2010/11	24.8%
2011/12	25.8%
2012/13	16.0%
2013/14	8.0%
2014/15	8.0%

The increase in the cost of electricity makes load shifting projects more feasible for large energy consumers. Different stations of LPWUs have different tariff structures. All the LPWU sites are on a Time of Use (TOU) tariff structure. The different structures can be seen in Table 4. Due to the different structures the savings will differ. The potential cost saving difference will influence the feasibility of doing a project from the client's point of view.

Table 4: LPWU tariff structures [7]

LPWU site	**Tariff structure**
WTW Z	Eskom Megaflex Key Cust, 11kV
WTW V	Emfuleni Special Bulk <= 6.6kVA
BPS M	City Power MV TOU 13/14
BPS Z	Eskom Megaflex 11kV, < 300km, > 1MVA
BPS P	Eskom Megaflex 11kV, < 300km, > 1MVA
BPS M	Eskom Megaflex 11kV, < 300km, > 1MVA

Megaflex is a TOU tariff structure. Figure 2 shows the times of the day when different tariffs apply. The Eskom morning peak is between 07h00 and 10h00 and the evening peak between 18h00 and 20h00. For this project, the focus shall be on the Eskom evening peak period.

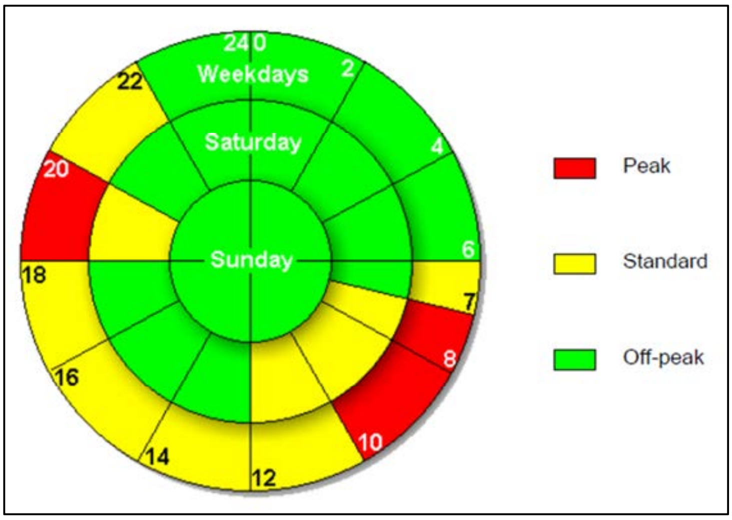


Figure 2: Megaflex structure [8]

As discussed, since 2007 the electrical energy price increased. The Megaflex tariffs for 2006/7 compared to 2013/14 can be seen in Table 3. As shown in Table 3 the rate increased dramatically since 2007. As shown in Table 5 the peak energy charge in the high demand season went from 59.53 c/kWh to 222.25 c/kWh. The price hike added up to a total of 273% in peak energy as seen in Figure 3 [9].

Table 5: Megaflex tariff increase (adapted from [8])

Megaflex tariff structure	Rate 2006/7	Rate 2013/14	Growth percentage
High-demand season (June-August)			
Peak	52.22c+ VAT = 59.53c/kWh	194.96c+ VAT = 222.25c/kWh	273%
Standard	13.81c+ VAT = 15.74c/kWh	59.06c+ VAT = 67.33c/kWh	327%
Off peak	7.51c+ VAT = 8.56c/kWh	32.07c+ VAT = 36.56c/kWh	327%
Low demand season (September-May)			
Peak	14.82c+ VAT = 16.89c/kWh	63.60c+ VAT = 72.50c/kWh	329%
Standard	9.20c+ VAT = 10.49c/kWh	43.77c+ VAT = 49.90c/kWh	375%
Off peak	6.52c+ VAT = 7.43c/kWh	27.77c+ VAT = 31.66c/kWh	326%

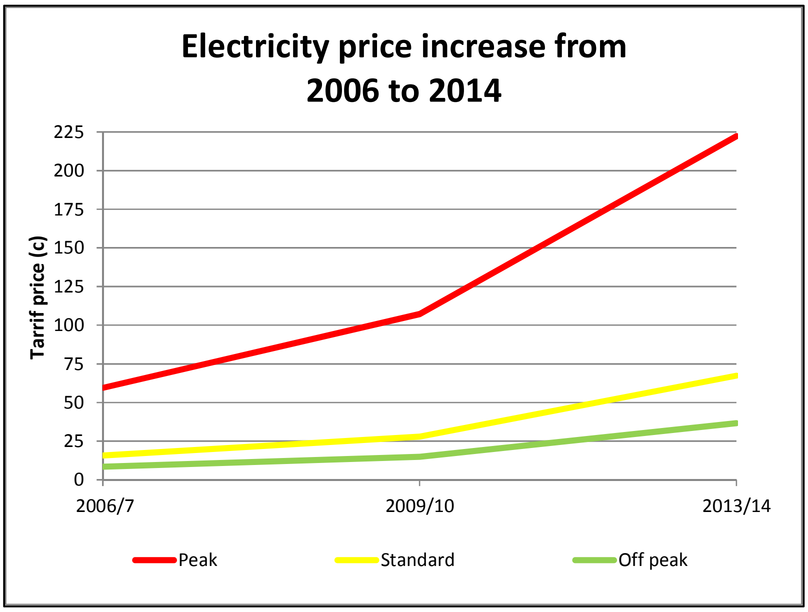


Figure 3: Price increase from 2006/7 to 2013/14 (adapted from [8] and [10])

Load shifting projects reduce electricity costs by shifting electricity usage from the expensive Eskom peak periods to the less expensive periods. It is essential to note the average consumption does not change [11]. In the case of LPWU, the same amount of water needs to be pumped on a daily basis.

A simplified power profile explaining load shifting can be seen in Figure 4. The load is shifted from the Eskom evening peak period to less expensive periods during the night. During the day, pumping must be maintained to supply the consumer's demand.

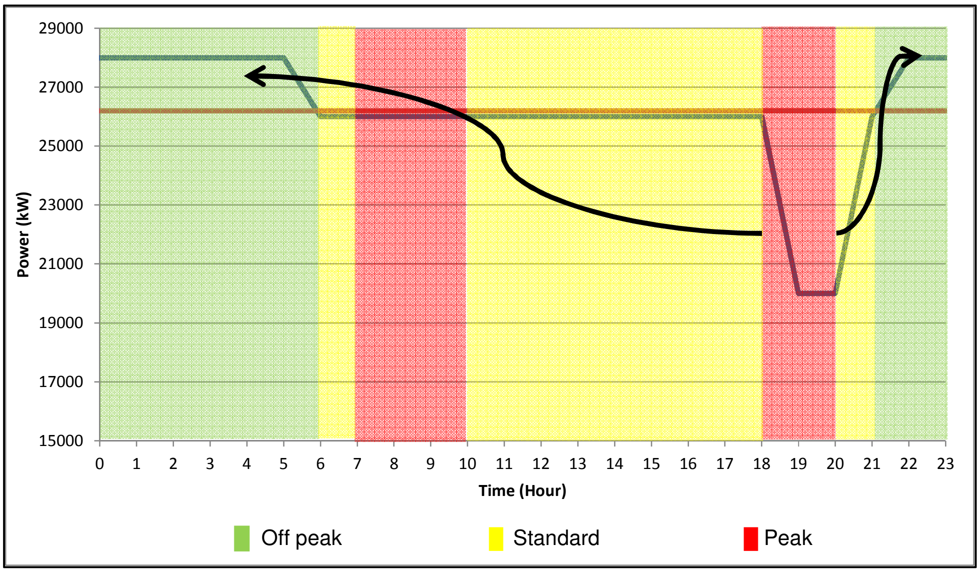


Figure 4: Example of load shifting with TOU (adapted from [11])

1.3 Potable water quality regulations in South Africa

Having safe drinking water is a rudimentary human right. The SANS 241: 2005 drinking water specifications do not pose notable risks for people of all ages [12]. Drinking water has multiple positive effects on a country's population. All Water Services Authorities (WSAs) must comply with these standards; research has shown water quality is poor in some non-metropolitan areas [12].

The South African Minister of Water Affairs announced a reward-based regulation in the water sector on 11 September in 2008 at the National Municipal Indaba in Johannesburg. The notion included two programmes: [13]

- Blue Drop Certification Programme for Drinking Water Quality Management.
- Green Drop Certification Programme for Waste Water Quality Management.

The Blue Drop Certification Programme for Drinking Water Quality Management measures and compares the performance of the (WSA) [12].

Secondly, to achieve blue drop status, the utility needs to adhere to the following requirements and is rewarded with points on each of the requirements [13]:

1. Water Safety Plan Process & Incident Response Management (15%);
2. Process Control, Maintenance and Management Skill (15%);
3. Drink Water Quality Monitoring Programme (15%);
4. Drink Water Sample Analysis Credibility (5%);
5. Submission of Drinking Water Quality Results (5%);
6. Drinking Quality Compliance (30%);
7. Publication of Drinking Water Quality Management Performance (5%);
8. Drinking Water Asset Management (15%).

The aim of the project is to do load shifting on LPWU without influencing drinking water compliance, making up 30% of the requirements for the Blue Drop award. Drinking Water Compliance (DWC) is based on the SANS 241 standards, attached as Appendix A [12].

The project does not affect any of the other requirements, except the DWC. The potable water utility measures the water quality on an hourly basis at the WTW and every two hours at the BPS. A typical water quality report of the WTW is shown in Figure 5.

DAILY WATER QUALITY REPORT
DATE: 24 HOURS: FROM 00:00 - 24:00 Of05/24/2012

pH (Specification: 7.600 - 8.800)

	B1	B2	B4	B6	B7	B8	B10	B12	B15	
Min	7.04	6.92	7.06	6.78	6.67	7.65	7.59	7.90	7.95	
Max	8.21	8.20	8.32	8.29	8.29	7.66	8.20	8.52	8.71	
24 hr Average	8.15	8.14	8.05	8.13	8.12	7.65	7.87	8.26	8.39	2.30
Standard Deviation	0.07	0.09	0.13	0.12	0.12	0.00	0.13	0.12	0.15	0.03
%Compliance (7.6 - 8.8)	100	99	99	99	99	100	99	100	100	99.65
%Non Compliance > 8.8	0	0	0	0	0	0	0	0	0	
%Non Compliance < 7.6	0	1	1	1	1	0	1	0	0	
Total Sapmles (7.6 - 8.8)	2871	2864	2845	2855	2860	2881	2852	2881	2881	
Total Samples > 8.8	0	0	0	0	0	0	0	0	0	
Total Samples < 7.6	10	17	36	26	21	0	29	0	0	
Total Samples	2881	2881	2881	2881	2881	2881	2881	2881	2881	
Volume in Ml	191	180	189	191	0	601	522	1167	104	3145

TURBIDITY (Specification: < 00.5 NTU)

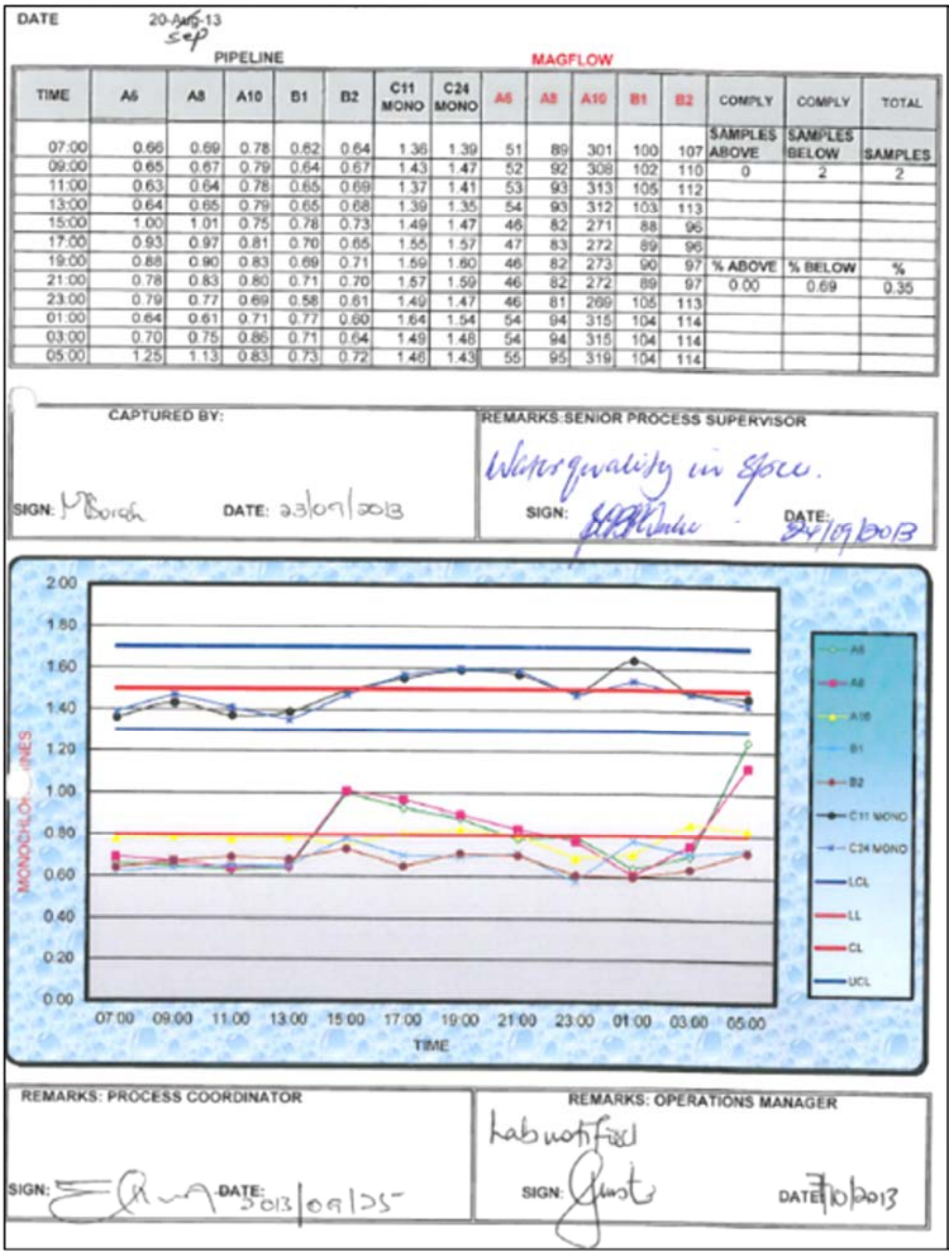
	B1	B2	B4	B6	B7	B8	B10	B12	B15	
Min	0.19	0.17	0.08	0.09	0.08	0.09	0.13	0.11	0.12	
Max	0.49	0.45	0.16	0.13	0.30	0.13	0.31	0.26	0.27	
24 hr Average	0.26	0.24	0.09	0.11	0.12	0.10	0.17	0.14	0.16	0.04
Standard Deviation	0.06	0.06	0.01	0.01	0.02	0.01	0.05	0.00	0.00	0.01
%Compliance (00 - 00.5)	100	100	100	100	100	100	100	100	100	100.00
%Non Compliance > 00.5	0	0	0	0	0	0	0	0	0	
%Non Compliance < 00	0	0	0	0	0	0	0	0	0	
Total Sapmles (00 - 00.5)	2881	2881	2881	2881	2881	2881	2881	2881	2881	
Total Samples > 00.5	0	0	0	0	0	0	0	0	0	
Total Samples < 00	0	0	0	0	0	0	0	0	0	
Total Samples	2881	2881	2881	2881	2881	2881	2881	2881	2881	
Volume in Ml	191	180	189	191	0	601	522	1167	104	3145

RESIDUAL CHLORINE (Specification: 00.800 - 4.0000 mg/l as free chlorine)

	B1	B2	B4	B6	B7	B8	B10	B12	B15	
Min	1.94	1.93	1.40	1.57	1.80	-1.25	-1.25	-1.25	-1.25	
Max	2.14	2.12	2.79	2.78	2.28	-1.25	-1.25	-1.25	-1.25	
24 hr Average	2.03	2.00	1.95	1.98	2.06	-1.25	-1.25	-1.25	-1.25	0.32
Standard Deviation	0.04	0.02	0.17	0.12	0.09	0.00	0.00	0.00	0.00	0.01
%Compliance (00.8 - 4.00)	100	100	100	100	100	0	0	0	0	23.93
%Non Compliance > 4.00	0	0	0	0	0	0	0	0	0	
%Non Compliance < 00.8	0	0	0	0	0	100	100	100	100	
Total Sapmles (00.8 - 4.00)	2881	2881	2881	2881	2881	2	2	2	2	
Total Samples > 4.00	0	0	0	0	0	0	0	0	0	
Total Samples < 00.8	0	0	0	0	0	2879	2879	2879	2879	
Total Samples	2881	2881	2881	2881	2881	2881	2881	2881	2881	
Volume in Ml	191	180	189	191	0	601	522	1167	104	3145

Figure 5: Typical WTW daily water quality report

The WTW focuses on three parameters, turbidity, pH and residual chlorine. All the case studies on the WTW will concentrate on these three parameters, since the reports were readily available on a daily basis. By complying with the three mentioned parameters, the SANS 241 will be met. These parameters will be discussed in chapter 2. A typical daily water quality report for the BPS is shown below in Figure 6.


DATE 20-Aug-13 Sep

PIPELINE MAGFLOW

TIME	A6	A8	A10	B1	B2	C11 MONO	C24 MONO	A6	A8	A10	B1	B2	COMPLY	COMPLY	TOTAL
07:00	0.66	0.69	0.78	0.62	0.64	1.36	1.39	51	89	301	100	107	SAMPLES ABOVE	SAMPLES BELOW	SAMPLES
09:00	0.65	0.67	0.79	0.64	0.67	1.43	1.47	52	92	308	102	110	0	2	2
11:00	0.63	0.64	0.78	0.65	0.69	1.37	1.41	53	93	313	105	112			
13:00	0.64	0.65	0.79	0.65	0.68	1.39	1.35	54	93	312	103	113			
15:00	1.00	1.01	0.75	0.78	0.73	1.49	1.47	46	82	271	88	96			
17:00	0.93	0.97	0.81	0.70	0.65	1.55	1.57	47	83	272	89	96			
19:00	0.88	0.90	0.83	0.69	0.71	1.59	1.60	46	82	273	90	97	% ABOVE	% BELOW	%
21:00	0.78	0.83	0.80	0.71	0.70	1.57	1.59	46	82	272	89	97	0.00	0.69	0.35
23:00	0.79	0.77	0.69	0.58	0.61	1.49	1.47	46	81	269	105	113			
01:00	0.64	0.61	0.71	0.77	0.60	1.64	1.54	54	94	315	104	114			
03:00	0.70	0.75	0.86	0.71	0.64	1.49	1.48	54	94	315	104	114			
05:00	1.25	1.13	0.83	0.73	0.72	1.46	1.43	55	95	319	104	114			

CAPTURED BY:

SIGN: DATE: 23/09/2013

REMARKS:SENIOR PROCESS SUPERVISOR

Water quality in spec.

SIGN: DATE: 24/09/2013

REMARKS: PROCESS COORDINATOR

SIGN: DATE: 2013/09/25

REMARKS: OPERATIONS MANAGER

Lab notified

SIGN: DATE: 7/10/2013

Figure 6: Typical BPS water quality report

The potable water utility uses the parameter to keep their water within the highest standards. The aim of this dissertation will be to realise the load shifting without influencing the water quality stated above.

1.4 Water utilisation in South Africa

The volume of water on the earth is constant. Water is unevenly distributed all over the world and consequently, also in South Africa. The world receives an average rainfall of 985 mm per year and South Africa only receives 492 mm. South Africa is by definition a water stressed country as it receives approximately half the amount of rainfall than the rest of the world [14] [15]. The eastern half of South Africa receives more rain than the western half due to climate conditions as seen in Figure 7 [14].

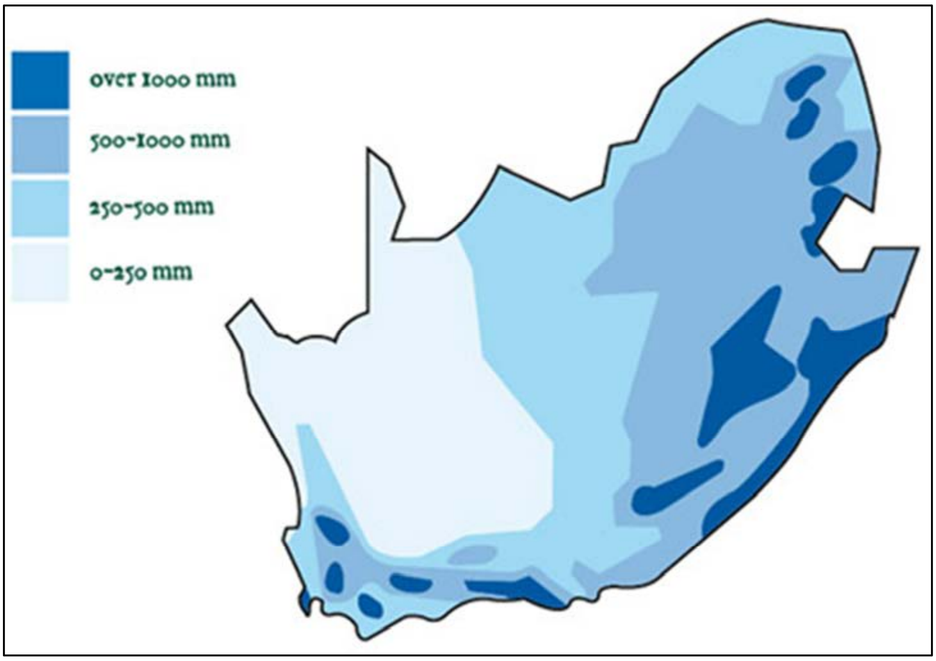


Figure 7: Rainfall distribution in South Africa [14]

Currently, South Africa has dams to store water. Numerous water schemes transfer water from wetter regions to the drier parts. Water is in high demand in the industrial heartland of South Africa [14] [15]. More than 99% the water pumped by this network is potable. Most of the water used in South Africa is not for human consumption as seen in Figure 8. In homes with gardens up to 46% of the monthly consumption is used for gardens [14].

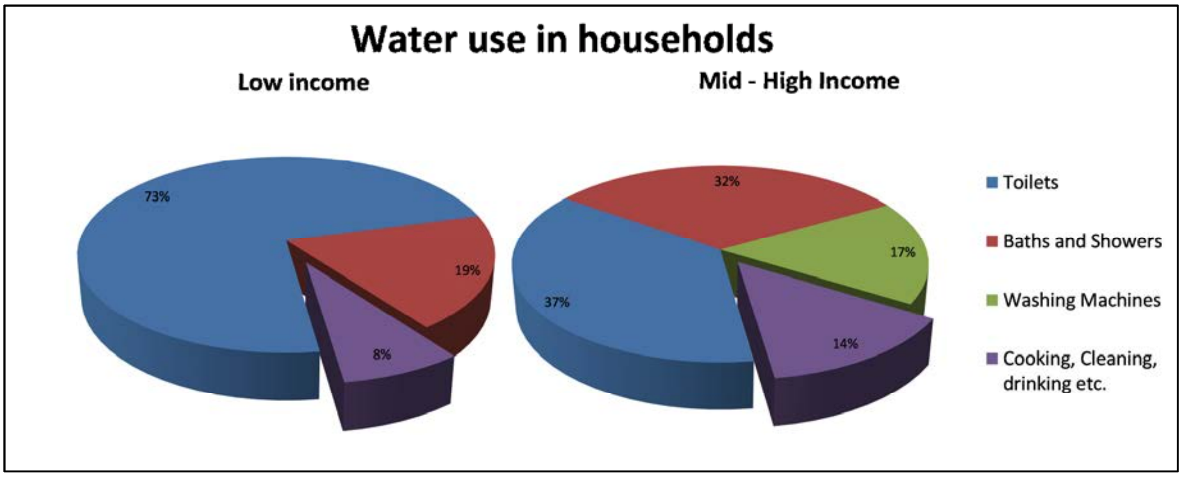


Figure 8: Breakdown of water usage in households (adapted from [14])

As seen in Figure 8, the purple wedges represent potable water consumed by humans. The potable water utility supplies on average 4000 Ml/day. From the displayed information, a mere 560 Ml/day is used for human consumption. Possible investigations to use *grey water* in South Africa can be done.

1.5 Distribution equipment

The LPWU has several different types of pumps and water storage facilities. Due to the immense scale on which this water utility operates, storage is crucial. The utility pumps water to selected reservoirs located in areas at a higher altitude than their surroundings. To pump to these heights, LPWU utilises multistage pumps. Each one of the BPS has different types of pumps. The four main BPS pump to more than two separate destinations.

All the pumps at the LPWU are serviced bi-annually. The running hours of the pumps are recorded and efficiency tests are conducted every 8 000 hours. Implementing a project to record and display the power, pressures and flow, the efficiency can be calculated in real time. Maintenance can be improved if the efficiencies are visible in real time. The formula that shall be used is shown below [16].

$$P_h = \frac{q\rho g h}{(3.6 \times 10^6)}$$

Where:

P_h = hydraulic power (kW)

q = flow rate (m^3/h)

ρ = density of the fluid (kg/m^3)

g = gravity constant (9.81 m/s^2)

h = difference in head (m)

$$P_s = \frac{P_h}{\eta}$$

Where

P_s = Pump power (kW)

η = efficiency coefficient [16]

The efficiency factor is not the extract efficiency of the pumps. The formula shown above can be used to track the efficiency of the pumps and plan for maintenance in future.

Using the stated formula, the different stages of the pump sets, and overall weak links in the system, can easily be established.

1.5.1 Double stage double suction horizontal centrifugal pumps

The most common pump set found on LPWU is double stage double suction horizontal centrifugal pump sets. Double stage pump sets operate at high pressures to overcome the head required [17]. The size of these pumps can be seen in Figure 9 below. The pump sets shown above typically pump 100 Ml/day to 200 Ml/day.

Figure 9: Double stage double suction horizontal centrifugal pump set (photo by author)

1.5.2 Single stage double suction horizontal centrifugal pumps

Single stage pumps are used in areas where the horizontal head is flat. These pumps have the capacity of getting a high volume of water to low areas. These pumps are typically used to supply water to smaller reservoirs. The smaller reservoirs typically have a lower demand. Secondary booster pump stations use single stage pumps as well.

Figure 10: Single stage double suction horizontal centrifugal pumps (photo by author)

Although the single stage pumps operate at lower pressures, the size of the pumps is still notable, as seen in Figure 10. The single stage pumps typically only pump 30 Ml/day to 100 Ml/day with the exception of the pumps being used at the pump station supplying water to WTW V pumping over 400 Ml/day.

1.5.3 Pipelines

The LPWU has an elaborate network of pipes underlying Gauteng. These pipelines range between 600 mm and 4500 mm in diameter. The pipelines cause some restriction due to the age of the potable water utility's aging network. A full schematic depiction of all the pipelines would be difficult to produce since the sheer number of pipes is too high. Figure 11 shows a simplified presentation of the pipe network.

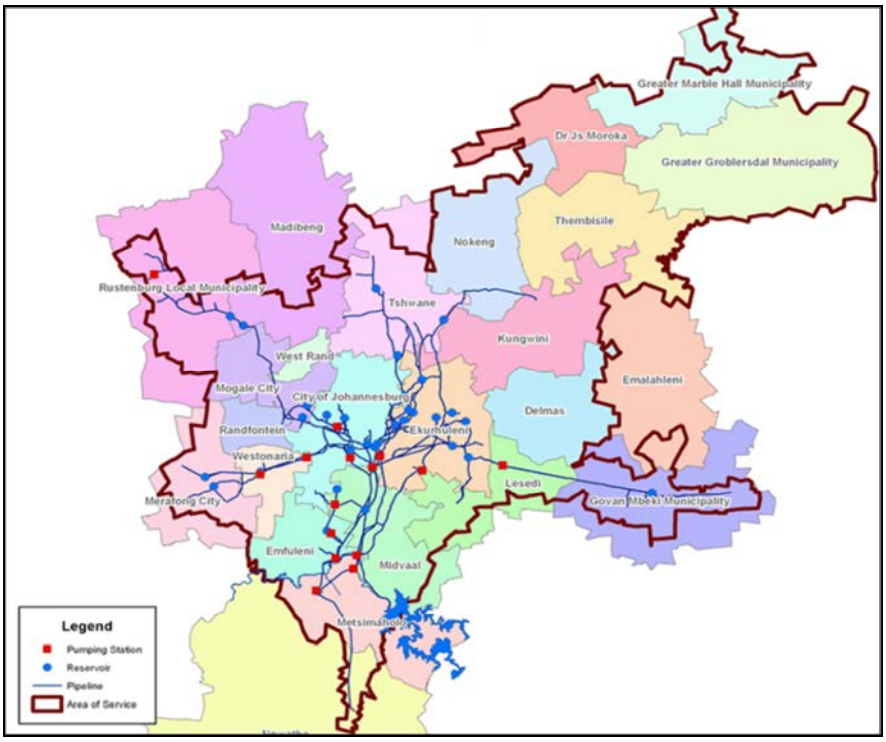


Figure 11: LPWU simplified pipe network (adapted from [1])

As seen in Figure 11 the pipes stretch over five provinces. Figure 12 shows the pipeline between WTW Z and BPS Z being installed in the 1940s. The size of the pipelines is considerable. On the premises of BPS Z, is a pipe plant where the pipes for the LPWU are manufactured.

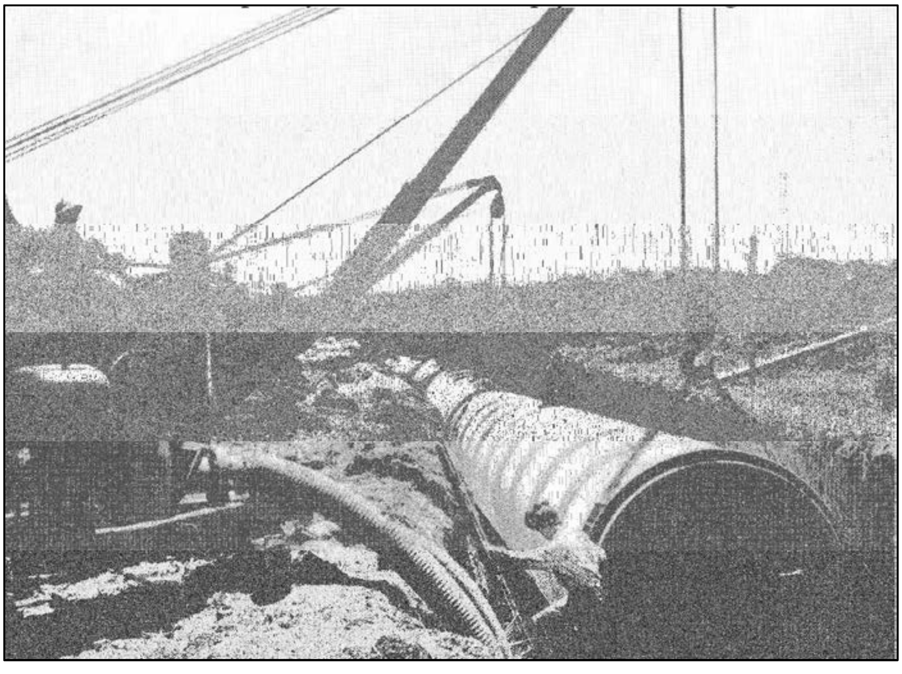


Figure 12: 2100mm pipeline being installed

1.5.4 Storage systems

LPWU used several different storage systems. The first and greatest is the Vaal Dam. The Vaal Dam has a volume of 2 060 000 m³ [18]. WTW Z extracts from the Vaal dam via an aqueduct. WTW V's water is pumped out of the Vaal River by a pump station located on the banks of the Vaal River near Vanderbijlpark.

WTW Z has a 500 Ml forebay to which water is sent from the Vaal Dam before the station utilizes the water. The pump stations at WTW Z have sumps varying in size. ER 4, for example, has two sumps; one 40 Ml and the other 20 Ml [19]. WTW V has smaller onsite storage capacities. The sedimentation bays are used as buffer capacity.

At the BPS Z, the DS reservoir is used as the balancing reservoir. The DS reservoir has a small pump station supplying water to the surroundings. The BPS E, BPS P and BPS M have balancing reservoirs onsite to cope with the excess flow. The balancing reservoirs serve as a buffer, should a trip occur at the WTW, but only for typically an hour. Shown in Figure 13 is the aerial view of balancing reservoirs on the site.

Figure 13: Aerial view of balancing reservoirs [20]

Experts are in agreement on the construction principles of reservoirs. A primary objective is to inhibit the growth of algae and water-based organisms. The reservoirs should be made as deep as possible, preferably deeper than 7 – 9m [21]. The municipal supply reservoirs range in sizes from 25 Ml to 650 Ml. BPS P provides water to the two largest reservoirs in the southern hemisphere (576 Ml and 650 Ml, typically holding 900 Ml for consumers) as shown in Figure 14.

Figure 14: Aerial view of downstream reservoirs [22]

Most of the downstream reservoirs are built into a hill with multiple support beams. The reservoirs are enclosed and kept below 18°C to prevent algae growth. The chlorine and ammonia dosage prolongs the water shelf-life within the reservoirs and inhibits algae and micro-organism growth. [23]

1.6 Objectives of this dissertation

During the investigation phase of the cost saving intervention project, the client had the concern that the loadshift should affect the potable water quality. A study and secondary investigations were required.

This dissertation will prove that the cost saving intervention will not affect the potable water quality of the LPWU. All the sections of the WTW and disinfection stations at the BPS will be examined and tested. The effects of the change in flow on dosage and the plant equipment will be investigated and compared to typical operating conditions. Ultimately the dissertation aims to prove that a planned load shift would not affect the potable water quality.

1.7 Overview of this dissertation

Chapter 1 gives background on the reason for this project. The chapter will explain why it is feasible to do a load shifting project on the largest water utility in South Africa. A discussion of the drinking water standards is crucial to this chapter.

The chapter will examine the uses of water in South Africa and how each sector uses the water. Not all drinking water is used for human consumption. Furthermore, Chapter 1 gives background on the equipment used for water storage and distribution.

Chapter 2 is an in-depth discussion of each section of the WTW and parameters of each. The focus will be primarily on whether the change in water volume can be absorbed and adjusted. Chapter 2 provides proof that a small change in flow (approximately 200 Ml/day) is well within the limits of the equipment used in the WTW. Secondly, the author will give the background on disinfection of potable water with chlorine.

Research done on load shifting will be discussed. In the past, no research was done on the effects of load shifting on a potable water quality in a network of this magnitude. This dissertation emphasises that load shifting is possible in similar industries and will be possible on large water networks.

Chapter 3 focuses on the methodology that the author followed in conducting this investigation. The author states the methodology and applies the mentioned methods to the LPWU network. The system is modelled and simulated on a real-time simulation package. The real-time simulation assisted the author to establish the MW to ML/day ratio of each site. The simulations showed in which areas a load shift would be more likely.

The simulation was programmed to mimic the system within the normal process constraints. The data acquired from this simulation is compared to actual results obtained from extensive testing done on site by the author. The data used is collected by a third party to validate the tests.

Chapter 4 describes three (3) case studies. Case Study 1 focused on existing historical data where a trip occurred at Engine room 4. A reduced flow of 300 Ml/day for 31.5 hours had no effects on the water quality.

Case Study 2 focused on the total reduction of flow at ER 4 for 12 hours. When the WTW got back online and returned to 1800 Ml/day, there were no effects on the water quality. Case Study 1 and Case Study 2 confirm that the equipment at the WTW can handle a sudden increase and/or decrease in the flow.

Case study 3 focused on the effects on BPS. At BPS Z, BPSE and BPSP the load was reduced during the Eskom evening peak period. Flow was returned to normal operations after the test. The effects of the tests on water quality were comparable to standard operations.

The quality reports remarked no change in water quality and this test definitively proved that it would be possible to do a load shifting project on the BPS without interfering with the WTW. No pumps were switched off at the WTW. The data gathered from these case studies can be applied to other BPS and other water utilities.

Chapter 5 recommends further studies to the system and potential electricity cost savings. The conclusion is clear that by reducing the load in the Eskom evening peak period will have no effect on the water quality of the network. The chapter gives recommendations of potential further investigation opportunities that can be done to save more money and power.

2

WATER PURIFYING AND WATER DISTRIBUTION EQUIPMENT

'We are in the midst of a water crisis that has many faces…the overriding problem is one of water quality and management…'

UN World Water Development Report, 2003

Chapter 2: An overview of a typical Water treatment plant. An in-depth discussion of each element of the treatment process. Discussions of load shifting on other industries and the lack of similar projects in water distribution networks will be discussed.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Reducing the water flowrate for two hours during the Eskom evening peak period may have an effect on the water quality of the LPWU. This chapter will focus on each of the sections within the purification plant as well as a downstream disinfection.

The water purification process starts at the WTW. From the forebay, the water is pumped by raw water pumps to the flocculator. Figure 15 is a representation of WTW Z works area 4. At the other works areas and WTW V the water is allowed to gravitate towards the flocculator.

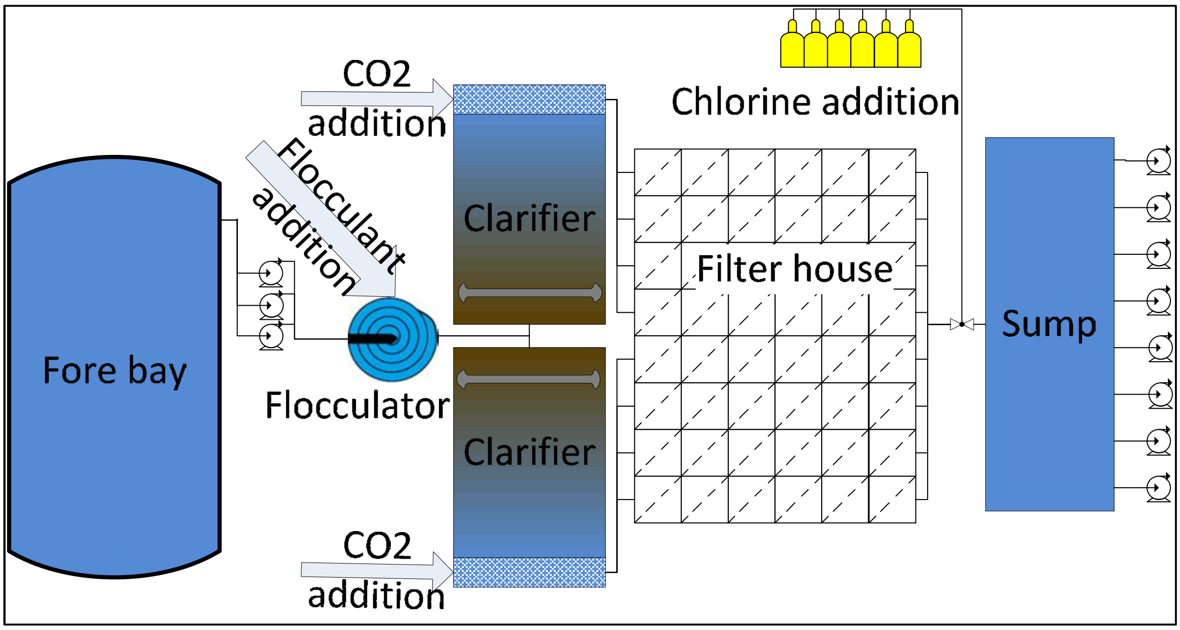


Figure 15: Typical water purification plant layout

Inside the flocculator a flocculant is added, in this case, sodium silica is used as a flocculant (see section 2.2). The water gravitates within the spiral flocculator towards the clarifier. In the clarifier, the flocculator gets the needed contact time to let the solid particles within the water settle. As seen in the aerial photograph (Figure 16) the water turns from murky to transparent.

Figure 16: Aerial view of a clarifier [24]

The water flows from the clarifier into the stabilisation's bays. Inside these bays, situated at the end of the clarifier, the water is agitated with carbon monoxide to restore the pH to the desired value. When the water is agitated it becomes less dense and flows smoothly towards the sand filter beds. Inside the filter house, the last solids are removed from the water.

From the filterhouse, the water flows to the sump before it is pumped away to the downstream reservoirs and BPS. Chlorine is added to sterilise the water between the filterhouse and sump. Each of the sections of the WTW will be discussed in the flowing sections.

2.2 Screening

At the river water is passed through coarse screens where large debris and living organisms are trapped. The water is thereafter passed through finer screens, removing most of the algae before it continues to the WTW [25]. In Figure 17 below is an example of a metal screen.

Figure 17: Metal screen [26]

2.3 Coagulation and flocculation

Coagulation is the first step in the treatment at the LPWU. Coagulation and flocculation are the addition of coagulants to produce flocks and remove suspended particles. Adding a coagulant accelerates the natural settling time of particles [27]. Suspended particles may be mineral or organic. Existing as a colloidal suspension, the suspension in the water is stable and has a slow rate of particle flocculation [28].

The reasons for the stability may be [28]:

- Electrostatic interactions;
- Hydrophilic effects;
- Steric effects.

Coagulation works on the principle of chemical mechanisms involving several steps. The rapid mixing in the flocculator allows the particles to collide with one another. Three types of mechanisms can occur [28]:

- Charge neutralisation;
- Polymer bridging;
- Electrostatic patch.

Charge Neutralisation is explained in Figure 18 below, where it can be seen that the particles have a negative charge. Some coagulants have a positive charge. This difference in charge draws the particles to the coagulant, resulting in larger and heavier flocks. The heavier flocks settle faster [29].

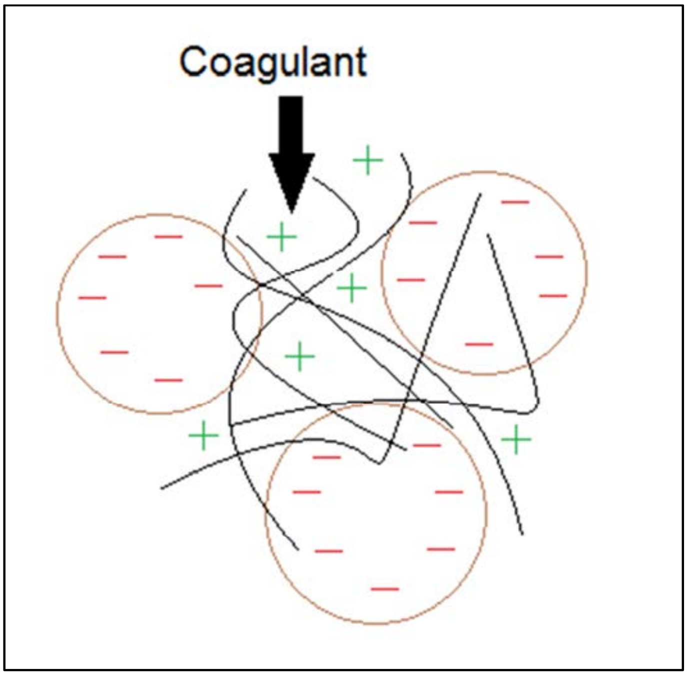


Figure 18: Charge neutralisation (adapted from [29])

Firstly, Lime is introduced to the water as a coagulant inside a flocculator (See Figure 19). Minutes after this, an organic polymer of Sodium Silica is added [26]. The addition of organic polymers is known to aid in the coagulation process. This reduces the amount of coagulant required [30].

Figure 19: Spiral flocculator [26]

For homogeneous mixing the coagulants and the raw water need to be mixed rapidly, followed by slow mixing [27]. A spiral flocculator is an excellent example. In the centre of the spiral, the solution is mixed rapidly and progresses slower to the outer rings of the spiral. The flocks then have the opportunity to develop inside this gradually-widening spiral where the pace decreases vividly [31].

Applicable to the WTW, flocculant is added per water volume, by lowering the flow rate the addition of flocculent will need to be adjusted. Currently, the flocculant is added by automated valves that need to be adjusted by the operator. When the flow rate is varied, the operator will have to adjust the flocculant addition accordingly [32].

2.4 Sedimentation and carbonation

Sedimentation is the method to deposit solid material from liquids from a state of suspension [33]. Clarifiers are utilised in conventional purification plants [34]. The flocks that are created by coagulation and flocculation are allowed to settle before the water is filtered. The clarifiers have a low flow velocity. The residence time inside the clarifiers is approximately 2 hours [19]. The clear water overflows into trenches as seen in Figure 20.

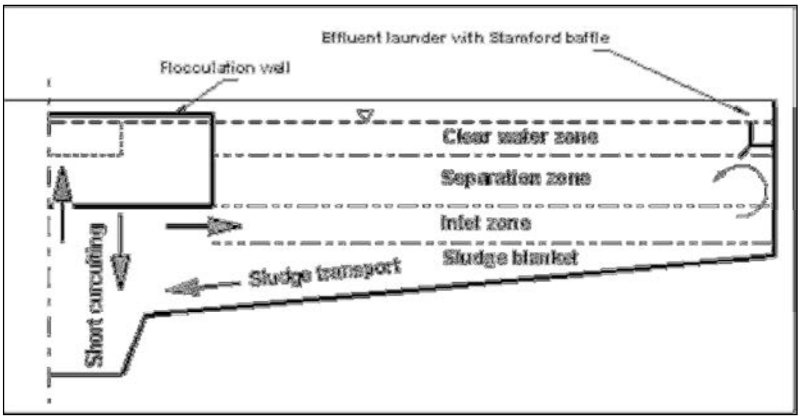


Figure 20: Basic clarifier [35]

The clear water is sent to the next step in the purification process. The sludge settles to the bottom of the clarifier and is removed by rakes as seen in Figure 21. The sludge that is collected from the bottom of the clarifier is pumped to an off-site facility. The facility dewaters the sludge. The sludge is sold for agricultural purposes [36].

Figure 21: Clarifier and flocculator at a WTW [19].

In relation to this investigation, clarification is a steady state, continued process. The lower the flow rate; the lower the overflow shall be. Reduced flow rate will not have an adverse effect on water quality or performance of the clarifier [37].

Carbonation occurs when carbon dioxide (CO_2) neutralises the pH of the water. The water is treated with lime for improved flocculation. The lime brings the pH to around 11.8 [19]. The lime softening reaction is shown in the equation below [38].

$$Ca(HCO_3)_2 + Ca(OH)_2 \leftrightarrows 2CaCO_3 \downarrow\ + 2H_2O$$
$$Mg(HCO_3)_2 + 2Ca(OH)_2 \leftrightarrows Mg(OH)_2 + CaCO_3 \downarrow\ + 2H_2O \quad [38]$$

The multivalent ions ($Ca^{2+}Mg^{2+}$) that precipitated is removed by the proceses and the water needs to be recorbonated to reduce scaling of the pipelines. Recarbonation lowers the pH to 8.4. Recarbonation can be used to remove arsenic, dissolved solids and radionuclides as well as improving the color [39]. The recarbonation reaction is shown in the equation below [38].

$$CaCO_3 + CO_2 + H_2O \leftrightarrows Ca(HCO_3)_2$$
$$Mg(OH)_2 + CO_2 \leftrightarrows Mg\ CO_3 + H_2O \quad [38]$$

The CO_2 is added to the carbonation bay in a gaseous form. The CO_2 is stored in liquid form and is vapourised before it is introduced to the process [38]. As seen in Figure 22 the overflow from the sedimentation tanks is agitated with the CO_2 and by mechanical impellers.

Figure 22: Carbonation bay (adapted from [19])

2.5 Sand filters

After most of the solids are removed from the water (by flocculation, sedimentation and precipitation), filtration is the final process to remove most of the finer particles and the last step in cleaning the water [27]. The main purpose of the filter is to capture matter in suspension and pathogenic germs [21].

Rapid gravity filtration is used in both WTW V and WTW Z. For rapid gravity filtration, pre-treatment is required such as flocculation and sedimentation. Rapid sand filters use graded sand as filter media. The penetration of the rapid filters is deeper than the slow filter. The filter is cleaned by backwashing [40]. Figure 23 is a representation of a typical rapid sand filter.

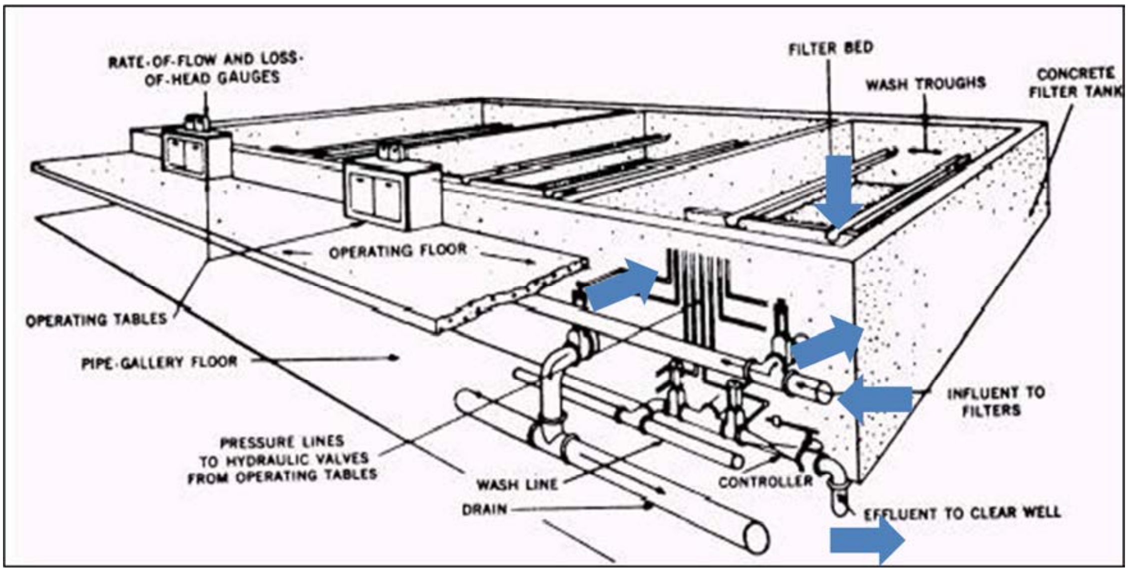


Figure 23: Rapid gravity sand filter [41]

The water flows vertically through the filter to a clear well as marked by the blue arrow. The entire process is continuous. Thus, the flow rate does not have a significant effect on the filter with the exception of high flow that negatively impacts the filters. At WTW Z, the purification plant can treat more than 4000Ml/day.

2.6 Chlorination

Disinfection is the last stage at the WTW before the water is pumped to the BPS. Chlorine is commonly used for disinfection. The lethal effect on bacteria is due to the obliteration of enzymes vital to the survival of pathogens. The chlorine reacts with the water as shown below [42].

$$Cl_2 + H_2O \leftrightarrows HClO + HCl$$

The reaction is supplemented by a second reaction [42]:

$$HClO \leftrightarrows ClO^- + H^+$$

The chlorine concentration is one of the parameters the LPWU uses to establish the water quality. It is crucial to disinfect the water as it may still contain traces of pathogens such as tuberculosis, cholera Hepatitis A and E coli [43]. Chlorine is added per volume of water with an automated control valve before the water enters the sump [44].

2.7 Measurements and standards

The LPWU focuses on individual parameters and doses chemicals accordingly. In the first steps of the purification process, the turbidity of the water is altered by flocculation and sedimentation. Turbidity can be defined as the lack of clarity of water. Turbidity should not be confused with the colour of the water. Turbidity is not a straight measurement of the suspended particles in the water. Turbidity is an optical measurement grounded on the interference of light passing through water [45].

The second aspect is the pH of the water. During flocculation the pH is changed to approximately 11.5 due to the addition of lime. Carbonation is applied to bring the pH down to 8 [19]. Before the water is pumped to the BPS the water is chlorinated to sterilize the water, the chlorine amount with which the water is dosed is critical. Too much chlorine may be harmful [26]. At the BPS water is dosed with chlorine once more, and ammonia is added, to extend the life of the water.

2.8 Completed research

No literature is available on cost saving intervention done on this scale in the water services industry in the world. Studies regarding load shifting and influences of load shifting have been done. The purpose of this section will be to review similar projects in other industries. The similarities between the reviewed studies and this dissertation will be drawn. Their objectives and results will be revised and compared.

2.8.1 Study 1: Load shifting on a potable water network

2.8.1.1 Objective

The goal of the study was to establish if it was possible to realise energy cost savings through load shifting. The study was done on the Vaal Gamagara Water Scheme. The author, MP Slade, focused on the Demand Site Management (DSM) initiative of Eskom.

Slade identified that the water distribution sector consumes a considerable amount of electricity, making these schemes suitable candidates for the DSM initiative. Slade focused on the re-scheduling of the pumps at the pump station. The load was shifted from the peak period to the off-peak periods [46].

2.8.1.2 Results

Slade used Real-time Energy Management Simulation (REMS) software, similar to what the author used, to simulate and later control the pump station, in order to test the simulation capabilities of the REMS software. The implementation of the REMS onsite was postponed and Slade conducted a manual test to demonstrate the simulation and his concept [46].

Slade did a manual test on an Engine Room (ER) with a 25 Ml/day capacity. Although the simulation which Slade had built was originally for a 22 Ml/day scenario, he adapted the scenario with high success. In Table 6, below, the simulation schedule, adapted schedule and realised schedule, are shown [46].

Table 6: Slade results (adapted from [46]

Hour	Simulation schedule (# pumps)	Adapted schedule (# pumps)	Realised schedule (# pumps)
0	6	6	6
1	6	6	6
2	6	6	6
3	6	6	6
4	6	6	6
5	6	6	6
6	6	6	6
7	0	0	0
8	0	0	0
9	0	0	0
10	3	6	6
11	3	6	6
12	3	6	6
13	3	6	6
14	3	6	6
15	3	6	6
16	3	6	6
17	3	6	6
18	0	0	0
19	0	0	0
20	6	3	3
21	6	3	3
22	6	6	6
23	6	6	6

As seen in Figure 24 the results of the intervention were 3.6 MW in the morning peak and 3 MW in the evening peak [46].

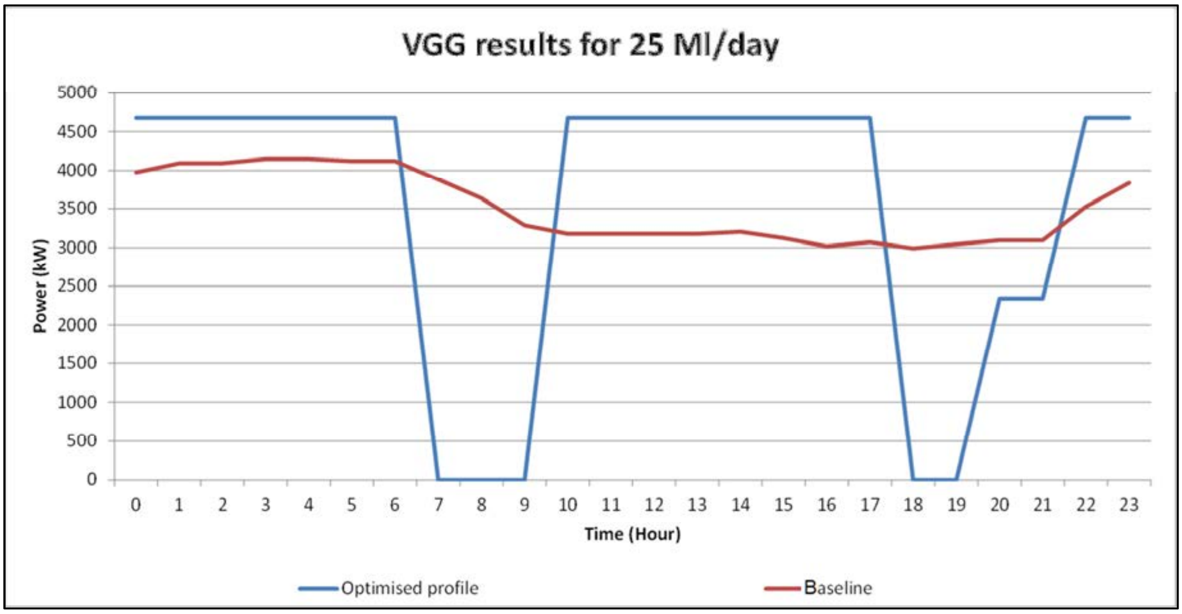


Figure 24: VGG manual load shift results (adapted from [46])

During the tests, problems were experienced on the SCADA and the reservoir levels could not be logged. The operator mentioned that no problems arose. Slade concluded that the intervention had no adverse effect on the downstream reservoir and that the upstream reservoir could handle the excess flow. A cost saving of *R30 300* could be realised per month in the summer if the intervention could be maintained [46].

Slade noted that the saving could not be maintained throughout the year due to water demand changes. In 2005, it was estimated that only a 2.6 MW load shift could be achieved. In March 2007 the potential dropped to 1.7 MW due to seasonal effects. In December 2007 during the peak demand period for water, 3 MW was achieved. The target was only 2.6 MW. Slade suggested that the long-term effects of the savings on the water distribution sector should be investigated [46].

2.8.1.3 Similarities to dissertation

Slade proved that a cost saving intervention was possible on a smaller pump station by shifting the load out of the Eskom peak periods. Slade confirmed that the intervention could be realised by using the reservoir instead of switching pumps off at the source or interrupting the other stations. Although the pump station is almost ten times smaller than the average station on the LPWU, a lot can be learned.

It cannot, however, be extrapolated to establish the load shift potential. Slade did not focus on the water quality of the system. By using this study, it is proved that a loadshift is possible on a small pump station. What will make this dissertation different is the immense scale and focus on potable water quality.

2.8.2 Study 2: Load shifting on a national pumping network

2.8.2.1 Objective

A study was done by A Nortje to implement a Demand Site Management (DSM) strategy on a national pumping network. The national system included five pump stations with a combined installed capacity of 36.5 MW [47].

2.8.2.2 Results

The total simulated load shifting capacity was established as 13.5 MW. REMS was used to simulate the system. After the implementation of the REMS control package, a load of

12.6 MW was shifted out of the peak period. Table 7 shows the simulated vs the actual results of the project [47].

Table 7: Simulated vs actual results (adapted from [47])

Pump station	Simulated results (MW)	Actual results (MW)
1	5.0	3.65
2	3.5	3.09
3	5.0	5.86

Nortje noted that the reason pump station 1 and pump station 2, did not meet the simulated target was due to maintenance done on the inlet canal. Even though the targets were not fully met, the cost saving was still considerable. On pump station 1 an estimate of *R 1.598 million* will be saved per year. For pump station 2 the saving will be *R 1.141 million*. Pump station 3 is estimated to save *R 2.6 million*. The total saving for the entire pumping network will amount to *R 4.765 million* per year [47].

2.8.2.3 Similarities to dissertation

The study successfully proved that a cost saving intervention is possible in a pumping network. The study demonstrated the validity of REMS, both in a simulation capacity as well as a control system. The potential to load shift on an entire pumping network will have a direct impact on the dissertation [47].

This dissertation will focus on the effect of load shifting on the quality of the potable water in a network. The cost saving will not be regarded, although it is essential to the feasibility of the project. Nortje established that the cost savings of a 3 MW load shift is large enough to make the project feasible [47]. The lessons learned by Nortje are valuable, as it proved that the cost savings intervention was possible. The methodology followed by Nortje will be adapted for this study.

2.8.3 Study 3: Effects of load shifting on water quality in a mine

2.8.3.1 Objective

The study was done by A Hasan to determine if a load shift would have any environmental effect. Hasan simulated a load shift on a mining system to determine the maximum savings achievable, disregarding the impact on the water quality [48].

After the maximum load shift was achieved. Hasan further investigated the environmental impact. In this case, the effect is directly equivalent to the iron content of the water. Hasan used the REMS simulation package to determine the savings achieved. Three different case studies were considered [48].

2.8.3.2 Results

Hasan simulated three different systems, a small single pump station, a large single pump station and an extensive pumping system. In Table 8, below, the specifications of the three case studies are shown [48].

Table 8: Hasan case studies (adapted from [48])

	Case Study 1	Case Study 2	Case Study 3
Installed capacity	11.72 MW	20.4 MW	13.75 MW and 23.1MW
Average pumping	20 Ml/day	80 Ml/day	24.8 Ml/day and 31.8 Ml/day
Load shift disregarding environmental impact	Morning Peak - 2.31 MW Evening Peak - 2.70 MW	Evening peak- 9.55 MW	Morning Peak - 2.55 MW Evening Peak - 5.52 MW
Environmental impact	Risk of surface dam overflow and acid water spillage	Increased iron content during the evening peak period. Risk of underground dam overflow	Plug valve is a critical component regarding water quality and cavity level
Initial cost-saving	R 544 950	R 780 600	R 610 200
Mitigation to minimise the environmental impact	Load shift only in the evening peak	Reduce the load shift	Change the control philosophy of the plug valve
Loadshift with environmental impact considered	Evening peak- 2.70 MW	Evening peak - 6.10 MW	Morning Peak - 2.55 MW Evening Peak - 7.90 MW

Due to the low pH the water is classified as AMD (Acid Mine Drainage) and requires underground treatment. The water is treated with lime to neutralise the acidity. The environmental department of the mine standards for the pH are between 8 and 10 [48].

Hasan first implemented a morning and evening load shift. He noted that by not regarding the environmental effect, a load shift was possible on each of the sites as seen in Table 8. It was further noted that the surface dams may overflow. The dangerously high level would cause the water to be spilled into the environment. With the mitigation, the cost saving was reduced but the environment was considered [48].

The second case study was done on a larger pump station. The water has a high iron content and high sulphate concentration that reduces the pH to a value below 4. The station is located 800 m below the surface and pumps water up to the treatment plant. Lime is used to reduce the iron content and increase the pH of the water. The iron content needs to be less than 1 ppm as required by the Department of Water Affairs and Forestry (DWAF) [48].

As seen in Table 8 the load shifting expectation was very high. After the 9.50 MW saving had been implemented, the water quality results had shown some serious concerns. The results can be seen in Figure 25.

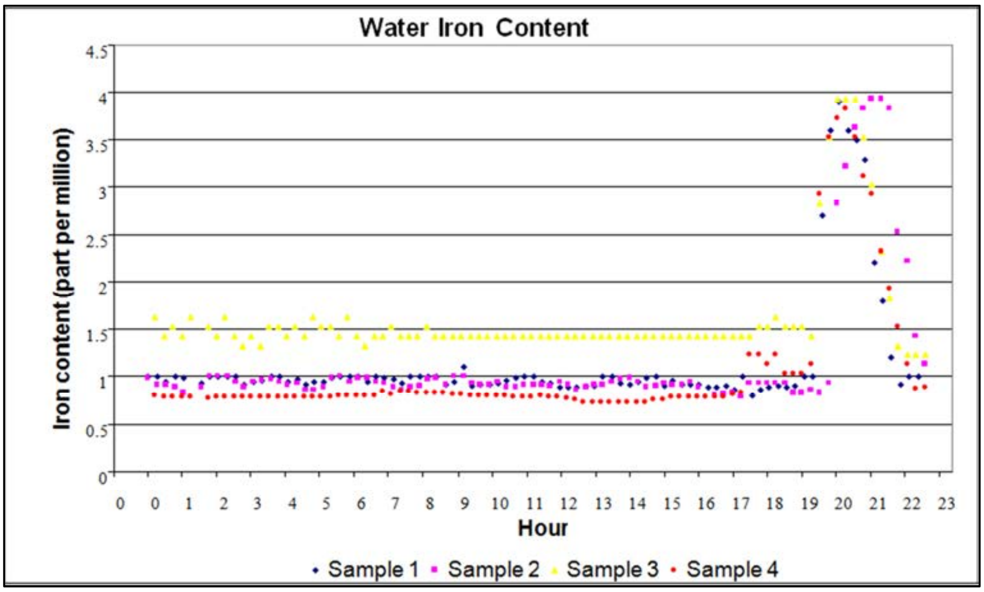


Figure 25: Water quality after the load shift (adapted from [48])

As seen in Figure 25 the iron content increased to nearly 4 ppm. The required iron content needs to be below 1 ppm. Hasan made the conclusion that not all the pumps could be switched off in the evening peak period. To lower the iron content, more lime needed to be added. To compensate for the peak period, an overdose of lime should have been added. The overdose would increase the cost of lime that the mine uses, drastically [48].

It was decided that the amount of pumping in the evening peak period need to be doubled. The pumps had to be left running, reducing the evening load shift to 7.80 MW. Hasan noted that the underground cavity's level fluctuated. The inflow to the cavity is not constant and in some cases, the cavity reached its top level. If the cavity overflows, the mine is in danger of flooding. On days when the cavity level was too high, the load shifting capacity dropped to 6.1 MW [48].

In the last case study two pump stations were linked. After a simulation was done and tests were done disregarding the environmental effect, a morning peak load shift of 2.55 MW and evening load shift of 5.52 MW were possible. It was found that the valve opening before the first pump station was crucial. The mine's environmental department had previously established that the optimal level of the cavity needed to be between 18m and 19m. The valve opening at this level needed to be at 24% [48].

If the cavity is 18m and above 19m, it results in turbulent flow inside the pipelines. The turbulent flow suspends the settled sediments in the water. The sediment will result in damage to the pumps and impact negatively on the surroundings. By adjusting the cavity valve, the problems were overcome. By adjusting the valve, the load shifting capabilities increased to a 7.9 MW evening load shift [48].

2.8.3.3 Similarities to dissertation

Hasan proved the validation of REMS software and showed that a load shift is possible in a series of pump stations. The study demonstrated that taking the entire load out of both periods will have an effect on the water quality. The mitigating strategies showed great insight into the different systems. The mitigating strategies can be applied to the LWPU.

Taking the cost of the chemicals used in the water purification process into account and compromising the load shifting capabilities, the client would still save money. Lastly, the study proves that load shifting is possible without negatively influencing the water quality. If the water quality is influenced negatively, numerous mitigation strategies can be applied to realise a cost saving.

2.8.4 Study 5: Load shifting on a water treatment plant

2.8.4.1 Objective

LA Els did a study on DSM initiatives on a municipal water treatment plant. Els noted that the pumps used in the water distribution sector used large amounts of power. The pumps distribute water at high pressures and significant flow rates [49].

Els investigated the potential of load shifting on a water treatment works. For load management on a WTW, the water quality may not be influenced negatively. Els developed a unique control strategy for the WTW. He also used the REMS software to simulate and implement the project [49]

2.8.4.2 Results

The WTW used for this study had three separate treatment plants. Water is pumped from a fresh water source to the WTW. After the water is treated, the water is distributed to three different reservoirs. From WTW 1 potable water is pumped to storage capacities after WTW 2 and WTW 3. The layout of the WTW can be seen in Figure 26 [49].

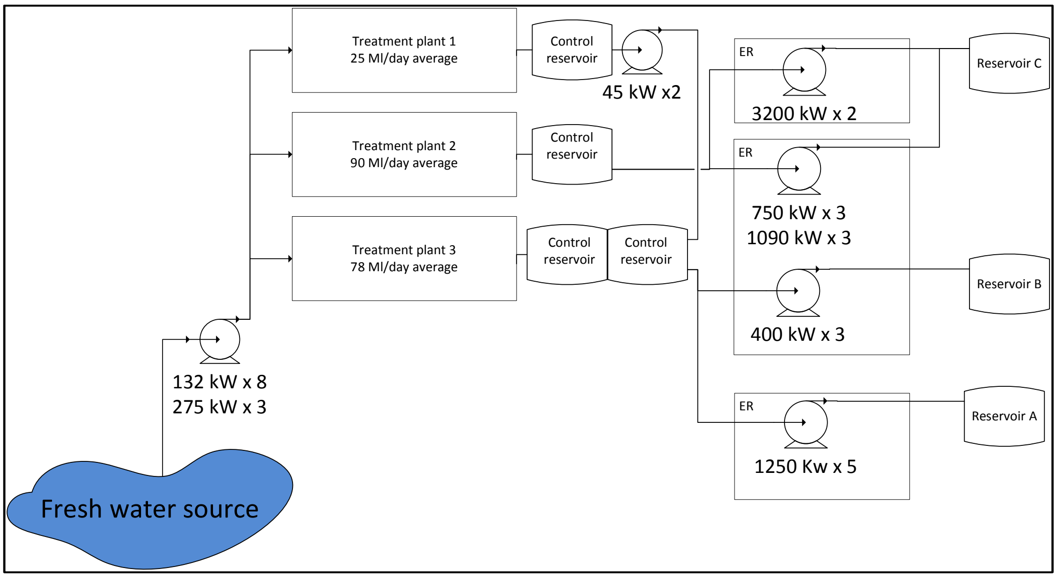


Figure 26: Municipal WTW layout (adapted from [49])

The WTW utilises the following strategies to purify the water [49]:

- Pre-chlorination;
- Polymer flocculation;
- Dissolved air flotation;
- Filtration (WTW 2& 3) and ozone treatment (WTW 1);
- Post chlorination.

The WTW supplies water to three reservoirs (155 Ml/day) from where the water is distributed downstream to multiple users. Els noted that the peak water usage periods are 08h00 - 10h00 and 18h00 – 20h00. After the investigation, Els proposed a load shift potential of 2.17 MW. He proposed that only one pump (1 000 kW) be operated in the evening peak period. The 8 hour off-peak period would be used to recuperate the lost load [49].

The network was simulated in REMS and the control strategy regarded the following [49]:

1. Installed capacities of the pumps;
2. Number of pumps at can be operated in parallel;
3. Minimum levels of the reservoirs;
4. Maximum levels of the reservoirs;
5. Columns available in the WTW.

The result of the simulation indicated a potential load shift of 2.35 MW. All the reservoir levels were within the set limits [49].

A series of tests was conducted to establish the validity of the simulation and investigation. During the five consecutive days, an average load shift of 2.13 MW was realised. As mentioned, the expected result of the study was 2.17 MW and the simulation predicted 2.35 MW. All the mentioned values are within 10% of each other, verifying the simulation and investigation [49].

The savings were sustained throughout performance assessment resulting in an average impact of 2.21 MW. Els noted that the main reason the savings declined was due to human error. He concluded that water treatment plants are prime candidates for DSM initiatives. The storage capacities were able to accommodate the variation in load. Algae bloom clogged the filters that reduced the savings. The savings could have been increased if the client agreed to implement the REMS system to control the plant automatically [49].

2.8.4.3 Similarities to dissertation

The study focussed on load shifting on a WTW. Similar to this dissertation many of the challenges experienced in Els's research, were present. The water that is distributed daily is considerably less than the LPWU. The author will use the principle of using the control reservoirs. Els proved that a load shift is possible on a water distribution system. The cost saving intervention was conducted within the constraints of the treatment plant. In this dissertation, the author will prove that a cost saving intervention is possible on a larger scale.

2.9 Conclusion

All the equipment used in the WTW is able to handle a reduced and increased flow of 200 Ml/day. This was established by the research above as well as interviews the author conducted with site personnel. The residence time and size of the sedimentation basis will be able to absorb the change in flow for the two hours during the Eskom evening peak period.
As mentioned in Chapter 1 the sumps before the ER are also sufficient to absorb the excess and reduced flow. The sand filter functions better at reduced flow. If the flow is increased within the parameters of the filter, it will be no problem. It is important to note that a reduction of 200 Ml/day is a mere 16 Ml in two hours. When compared to the normal operations of 3 150 Ml/day it is negligible. As mentioned the chlorine and CO_2 are added per volume of water. If the flow is varied, the dosage will be adjusted.

From the similar studies investigated it can be concluded that load shifting is possible on potable pumping systems. The REMS software is reliable and can be used for this study. It is important to note that this investigation is the first of its kind done in a potable and pumping network of this immense scale.

3

METHODOLOGY

Chapter 3

This chapter will give a perspective on how to do an energy cost saving investigation on an extensive water network while modelling the system and simulating the entire network. Discussion of the model and simulation results conclude this chapter.

CHAPTER 3: METHODOLOGY

3.1 Introduction

The opportunity exists for cost-efficient pumping on a large potable water network. An explicit method needs to be followed to do an investigation of this immense scale. Proper research and site audits will make the process easier. After the author had done detailed site visits, a simulation was done to verify if the load shift is possible. The simulation would establish if the targets set for the load management project would be within the limits laid down by the WTW.

Each BPS distrubutes water to different altitudes. Due to the differences in the head, the power usage of each BPS differs. It can be established from this simulation what the water load reduction potential will be on each BPS. This reduction in water volume will be compared to the capabilities of the WTW. The initial investigation was purely mathematical. This chapter will emphasize and explain how to do a full investigation.

3.2 Methodology

Various steps need to be followed to do a load shifting project. To prove that a loadshift will not affect the water quality, firstly, it needs to be established if the load shift is possible. The investigation needs to be done within the parameters set by the WTW. Section 3.2 will discuss the steps necessary to successfully conduct an investigation on a potable water network. Section 3.3 and 3.4 will show how the author applied these steps in the research to prove the findings of the dissertation.

The following steps need to be taken to conduct the investigation:

- Collection of data to compile a baseline;
- Do a calculation to establish if the possibility exists to do a load shifting project;
- Conduct site visits;
- Do a study on the WTW and determine the operational parameters;
- Do a case study on historical values;
- A detailed simulation;
- Data obtained from the simulation must be compared to real life situations;
- Do practical tests on-site.

Power profiles can be obtained in various ways. Most common would be to get the power reading of the client from the Supervisory Control and Data Acquisition (SCADA) department. Obtaining the Eskom bills will help the investigator establish the possible cost saving. For this investigation, the data was obtained from an independent company. The company had installed power meters at the incomers of each of the stations. The data collected by the company could be accessed, with authorisation, via the internet.

The power data was used to calculate the current pump scheduling and to determine the amount of pumps operated by the client. The power data was used to calculate the current pump scheduling and to determine the amount of pumps operated by the customer. Figure 27 shows how the pump station generally operates. By scheduling the pump sets differently, a load shift can be done.

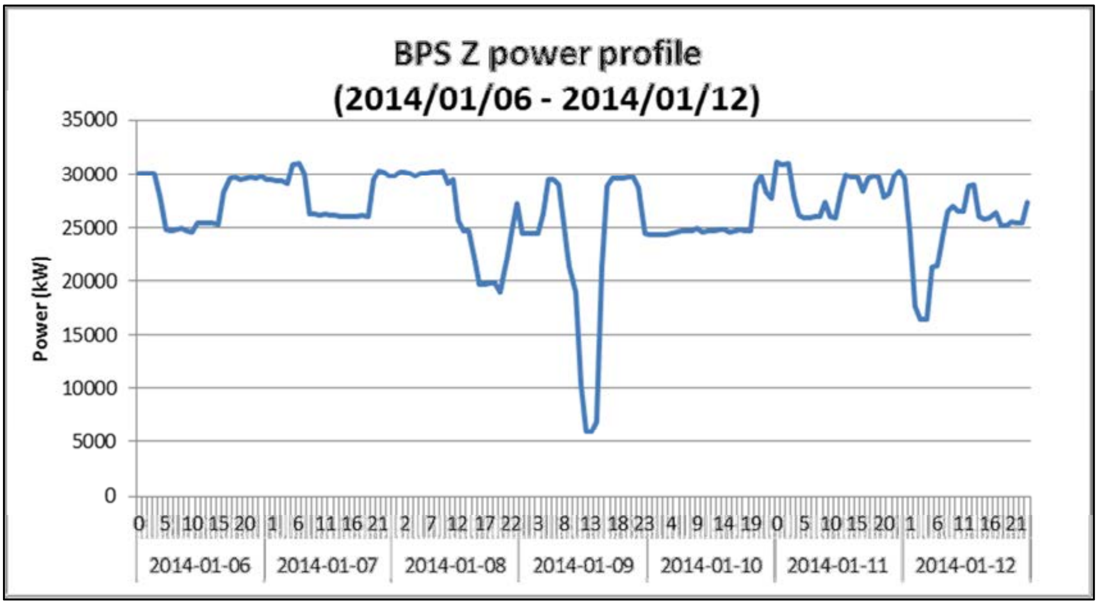


Figure 27: Typical power profile for a week

From the power profile, an estimate load shift can be calculated, although this is not the case for all the pump stations. Conducting site visits to establish the process constraints is necessary. Conducting an in-depth site visit is fundamental for a successful investigation. The following aspects of the pump stations are crucial:

- Installed and spare capacity;
- Notified maximum demand (NMD);
- Storage capacity;
- Number of pumps and pump sizes;

- Secondary disinfection constraints;
- Pipe restrictions;
- General operations limits;
- Site specific restrictions.

To gather the mentioned information, the author found it best to have a meeting with relevant personnel (operations co-ordinator, shift foreman and pump operators). The staff members who had been working at the facility for an extended period, typically, know some of the finer detail.

The installed and spare capacity is the main limiting factors. If the pump station is running at full capacity - no opportunities for a load shifting project exists. All the LPWU sites must have 25% spare capacity at all times. Thus, if the station has four pumps and three of these pumps run 24 hours a day, load shifting would not be possible.

The NMD will restrict the pump station to operate a certain amount of pumps. For example, BPS E has an installed capacity of 2 505 Ml/day but is limited to 1 300 Ml/day due the NMD. The NMD may not be reached or exceeded during the project and is thus an important process constraint. If the NMD is reached at any time during the month, the client will pay fines for three months and this will make the cost saving obsolete.

The storage capacity and pump sizes will determine the number of pumps that can be switched off to minimise the impact the load shift has on the system. The secondary disinfection system will determine how much the flow can vary without switching affecting the water quality. Although the chlorine addition is added per volume of water if the change is too drastic, the disinfection will not adapt fast enough.

Pipe restriction needs to be noted. At WTW V, for example, the pipeline to BPS E can only manage 750 Ml/day. The flow cannot be increased to 800 Ml/day even if the installed capacity and NMD allow it. Pumping more water into the pipeline will lead to pumping inefficiencies and damage to infrastructure. A burst pipe will discharge approximately 5 000 l/s of water if three 200 Ml/day was running into that particular pipeline as shown in Figure 28.

Figure 28: Example of a large pipeline burst [50].

General and site specific restrictions can be gathered by speaking to site personnel as mentioned previously. At BPS Z, for example, the installed capacity is 1 100 Ml/day. Due to transformer constraints only 700 Ml/day can be pumped. Individual pump sets cannot be run simultaneously due to the start-up current for these pumps. In Figure 29 an example of a start-up current is shown.

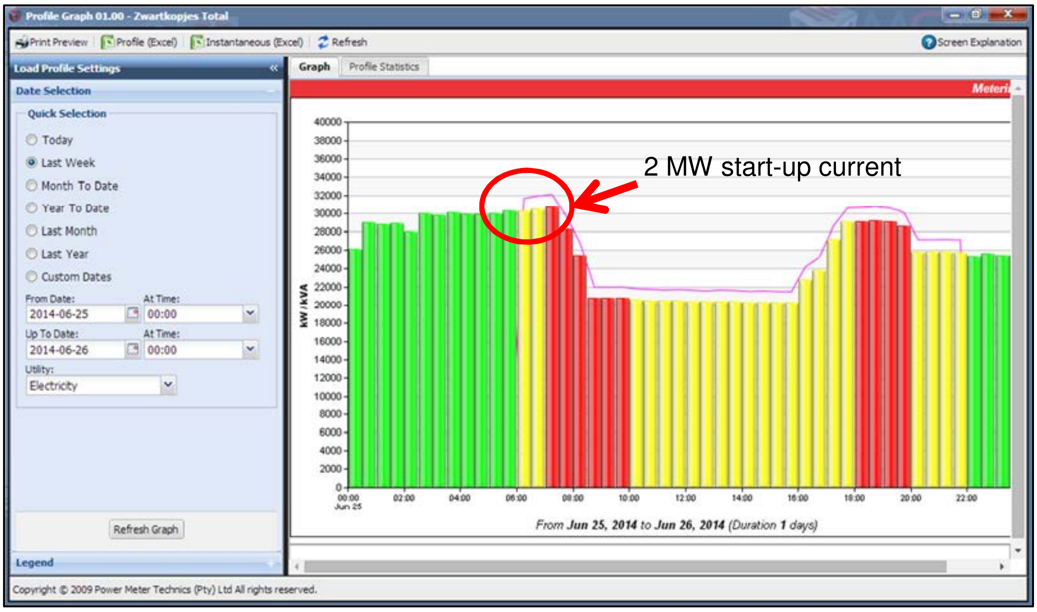


Figure 29: Example of start-up current [7]

A study on the WTW will determine what effect the load shift will have on the water quality. The author scheduled a meeting with a water quality technician. A complete audit of the

WTW had to be be conducted. The technician and the author went through the entire WTW and discussed the effects on each of the sections. The impact of the lower flow and increased flow must be noted. Lower flow is beneficial to the water quality.

The author used historical data where unscheduled maintenance occurred, to establish the impact on the WTW. In sections 4.2 and 4.3, the author used two different days where one pump set tripped and the entire engine room stopped. The water quality department keeps all the water quality reports for auditing purposes.

All the mentioned parameters above can be taken into account when programming the simulation. Various simulation packages exist. For this investigation, a simulation package was chosen on the following aspects:

- The simulation needs to have the mathematical capacity to accommodate a network of this scale;
- The pump control must be programmable;
- All data should be logged in predefined intervals.

The REMS software had the capacity to simulate the network and was readily available to the author. Thus, the REMS software was chosen to simulate the network. The simulation procedure is discussed in section 3.4. A thorough investigation will give a good estimation of the load shift achievable. After results are obtained from the simulation, the values must be correlated with real data obtained from the LPWU to validate the simulation. The validation of the simulation is discussed in section 3.5.

After the savings achievable is proven by the simulation, a testing procedure can be discussed with the pump station personnel. The pump station or area with the smallest risk must be tested first. The result of a test on a BPS is discussed in section 4.3. After the test, all water quality reports must be examined to ensure the load shift had no effect on the water quality. Any deviations from the set limits are unacceptable.

The LPWU has a system according to which they currently pump. The daily call must be met. The daily call is calculated by the Bulk Water Distribution Department (BWD). The implementation of a proper SCADA and a prediction model may render this system obsolete.

3.3 Modelling of the potable water network

The LPWU has a vast network as shown in Figure 30. Water is extracted from the Vaal dam and Vaal River, purified and distributed to municipalities, the agricultural sector and industry. The network is divided into six systems.

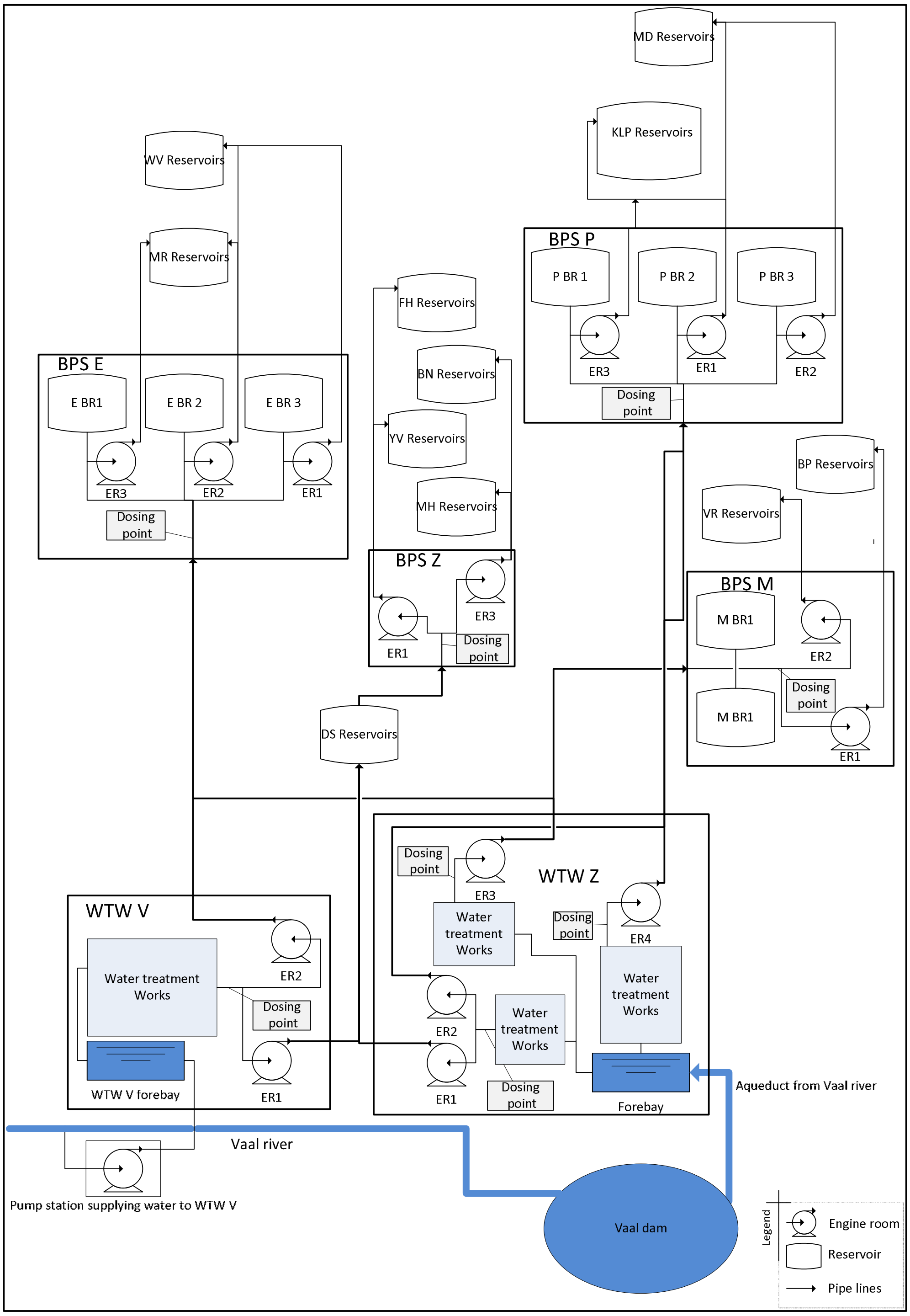


Figure 30: LPWU pumping network

3.3.1 Water treatment works Z

The WTW Z system draws water from the Vaal Dam by means of an aqueduct. The water is stored in the forebay at WTW Z. WTW Z has a combination of outdated and new infrastructure. The station was built and upgraded through the years. Currently ER 5 is being planned. After the addition of ER5, WTW Z will be the largest pump station in the world.

WTW Z has four works areas. Works area 1 and works area 2 have only one WTW and two pump stations, ER 1 and ER 2. ER 1 has six 100 Ml/day double stage pump sets supplying water to the BPS Z. Typically only four pump sets run every day. ER 2 has seven 100 Ml/day pump sets supplying water to BPSP. Five of these pumps run during a typical day.

Works area 3 has a WTW and ER. The ER has eight pump sets. Water is supplied to the BPS E and BPS M. Works area 3 has two massive 300 Ml/day pump sets, four 200 Ml/day pump sets and two 100 Ml/day pumps sets. Typically only one 300 Ml/day pump set and two 200 Ml/day pump sets run. The output capacity is restricted by the WTW limited flow and the inflow aqueduct. From the investigation, the author can predict the possibility of load shifting at the following areas shown in Table 9.

Table 9: Possible loadshift on WTW Z

Engine room	Possible load shift
ER 1	0 MW
ER 2	3.5 MW
ER 3	3.5 MW
ER 4	5.5 MW

3.3.2 Water treatment works V

WTW V supplies water to the surrounding area, BPS Z and BPS E. WTW V has one WTW area and two pump stations. It is a timeworn station and is registered as a heritage site. The station is situated in Vereeniging. Water is supplied to WTW V from a pump station located on the bank of the Vaal River.

ER 1 has three double stage vertically mounted pump sets; pump set 1 and 2 have an installed capacity of 200 Ml/day and pump set 3 an installed capacity of 100 Ml/day. Only one 200 Ml/day pump set and one 100 Ml/day pump set can be run at a time due to efficiency issues. This ER supplies water to the BPS Z.

ER 2 has 13 pump sets. The station is divided into three areas, namely the Iscor pumps, the low-lift pumps and high-lift pumps. The Iscor areas have three water single stage 30 Ml/day pumps that run inconsistently. The Iscor pumps are the only raw water pumps in the network. Personnel from Iscor phone staff at the pump station to start the pumps when they require water.

The low-lift area has five single stage 100 Ml/day pumps and supplies water to a SBPS. Three pumps run continuously to keep up with the demand and one is down for maintenance. Two of the pump sets have Variable Speed Drives (VSD) that is outdated and unreliable.

The high-lift area has five double stage 200 Ml/day pump sets. The high-lift area supplies water to the BPS E. Three of these pump sets run daily to keep up with the demand. The pipeline is restricted into which the pump sets pump. The pipeline can only manage 750 Ml/day as previously mentioned. Thus, it is not possible to run four pump sets.

WTW V is old and outdated. If the load is shifted at this station, the load cannot be recovered. WTW V's water is supplied from a pump station located on the bank of the Vaal River. The flow at the pump station is restricted to ± 1 000 Ml/day.

WTW V has small sumps; consequently, no water can be stored onsite during the Eskom evening peak period. The inflow from the pump station supplying water to WTW V can be lowered but the station would not be able to recover the load after the Eskom evening peak period. Shown in Table 10, the author predicts no saving is possible. From the author's experience a lack of storage capacity will make a load shift and load recovery nearly impossible.

Table 10: Possible load shift on WTW V

Engine room	Possible load shift
ER 1	0 MW
ER 2	0 MW

3.3.3 Booster pump station Z

BPS Z supplies water to the Johannesburg and East Rand region. The BPS has eleven 100 Ml/day pump sets. ER 1 has four double stage pump sets supplying water to the FH and YV reservoirs. Typically one pump set will run throughout the day to each of the reservoirs.

ER 3 has seven three-stage pump sets. Two of these pump sets supply water to the Forest Hill reservoir and the other is divided into the BN and MH reservoirs. On the entire BPS Z, five to six pumps will be running on a typical day. All the pump sets can pump to any of the downstream reservoirs by selecting the appropriate valves. The secondary disinfection plant of the station is well equipped and can easily accommodate a 300 Ml/day reduction in flow for two hours.

BPS Z does not have balancing reservoirs on the site. The DS reservoirs act as the balancing reservoirs for the system. SBPS DS is located on the premises of the reservoirs. Water is drawn off before DS reservoir by industrial users like Group Five and the Heineken brewery. SBPS DS water is pumped to the ED and OF reservoirs. Typically around 150 Ml/day is drawn off every day by all the mentioned users. From the data gathered on the site, the author predicts a load shift will be possible as seen in Table 11.

Table 11: Possible load shift on BPS Z

Engine room	Possible load shift
ER 1	5.8 MW
ER 3	5.8 MW

3.3.4 Booster pump station E

The BPS E supplies water to the West Rand and Rustenburg. The BPS has an installed capacity of 2 000 Ml/day but is limited by the NMD to 1 300 Ml/day as previously mentioned. ER 1 has eight 100 Ml/day double stage pump sets. ER 1 pumps water to the MR and WV reservoirs. Pump sets 1, 3, 5 and 7 are dedicated to the MR reservoir while pump sets 2, 4, 6, 8 are devoted to the WV reservoir. The reason for this is to ensure all the pumps have the same running hours for maintenance.

ER 2 has five 200 Ml/day double stage pump sets. The ER is dedicated to the WV reservoir. During a typical day, two pump sets will be running. ER 3 has four 200 Ml/day double stage pump sets dedicated to the MR reservoir. Two pump sets are running on average at all times. Typically the entire BPS E pumps approximately 1 200 Ml/day.

BPS E has three 20 Ml balancing reservoirs. The reservoirs can be used to absorb the excess water flow to BPS for two hours. The secondary disinfection plant of this station is well equipped. A sudden change in flow would not have an effect on the secondary disinfection. The station is designed to accommodate a much greater flow. From the data gathered on the site, the author predicts a load shift will be possible as seen in Table 12.

Table 12: Possible load shift on BPS E

Engine room	Possible load shift
ER 1	0 MW
ER 2	0 MW
ER 3	6 MW

3.3.5 Booster pump station P

The BPS P supplies water to the Johannesburg and parts of Pretoria. The BPS can supply 1 660 Ml/day. Due to a boom in the development of the BPS P system the BPS pumps at its maximum capacity of 1 660 Ml/day for most of the year. The station has three ER.

ER 1 has seven 90 Ml/day double stage pump sets. Three has been ongoing maintenance for the better part of the last two years. When the station is running at 1 660 Ml/day, three pumps typically run in ER 1. The ER supplies water to the KLB reservoirs.

ER 2 has four 180 Ml/day double stage pump sets and five 30 Ml/day single-stage pumps. The five 30 Ml/day pumps are dedicated to the MD reservoir. The average demand of this reservoir is approximately 50 Ml/day.

The four 180 Ml/day pump sets are dedicated to the KLB reservoirs. One pump set must be off at all times for spare capacity as mentioned in section 3.2. Three pump sets run continuously to keep up with the demand. ER 3 has four 200 Ml/day double stage pump sets and is dedicated to the KLB reservoirs. Future upgrades include ER 3b that will have four 200 Ml/day double stage pump sets and a fourth balancing reservoir.

The station is well equipped with a secondary disinfection plant and a variation in flow will not have an effect on the water quality at BPS P. The high demand is concerning. BPS P has three 23 Ml balancing reservoirs that can be used to absorb the excess water flow to BPS for two hours. From the data gathered on the site, the author predicts that a load shift will be possible as seen in Table 13.

Table 13: Possible load shift on BPS P

Engine room	Possible load shift
ER 1	2.5 MW
ER 2	0 MW
ER 3	0 MW

3.3.6 Booster pump station M

BPS M supplies water to the East Rand and the northern parts of Pretoria. The BPS has two ERs. ER 1 has four 200 Ml/day double stage pump sets and four 100 Ml/day single-stage pumps. The ER supplies water to the BP and VF reservoirs. Typically three 200 Ml/day pump sets and a 100 Ml/day pump run every day.

ER 2 has three 30 Ml/day single-stage pumps. The ER supplies water to the VR reservoir. The pumps are solely run depending on the demand. Typically one pump will be running every day. The station's secondary disinfection plant is well equipped. A variation in flow can be adapted too, with ease. The disinfection equipment on the site is automatic. A concern at BPS M is frequent trips.

The frequent trips are due to insufficient maintenance on the transformers and cable theft. BPS M has two 20 Ml balancing reservoirs that can be used to absorb the excess water flow to BPS for two hours. The author predicts the following savings shown in Table 14.

Table 14: Possible load shift on BPS M

Engine room	Possible load shift
ER 1	3.5 MW
ER 2	0 MW

3.4 Simulation

3.4.1 Pump controller

The simulation was done in a Real-time Energy Management simulation package, powerful enough to simulate the LPWU. Due to the immense scale of the network the simulation had to be done on different pages and had to be connected to one another. The programming of the simulation is seen in Figure 31. During the Eskom evening periods, the simulation was allowed to switch pumps off if the reservoir was above a predetermined level.

The program allowed for increase pumping during the off-peak periods. Depending on the size of the pump station and downstream capacity the number of pumps that can be switched off is varied. The initial level of the downstream reservoir was retrieved from real data. The simulation is a reflection of how the LPWU operated during average conditions. Average conditions were used due to data unavailability from the client.

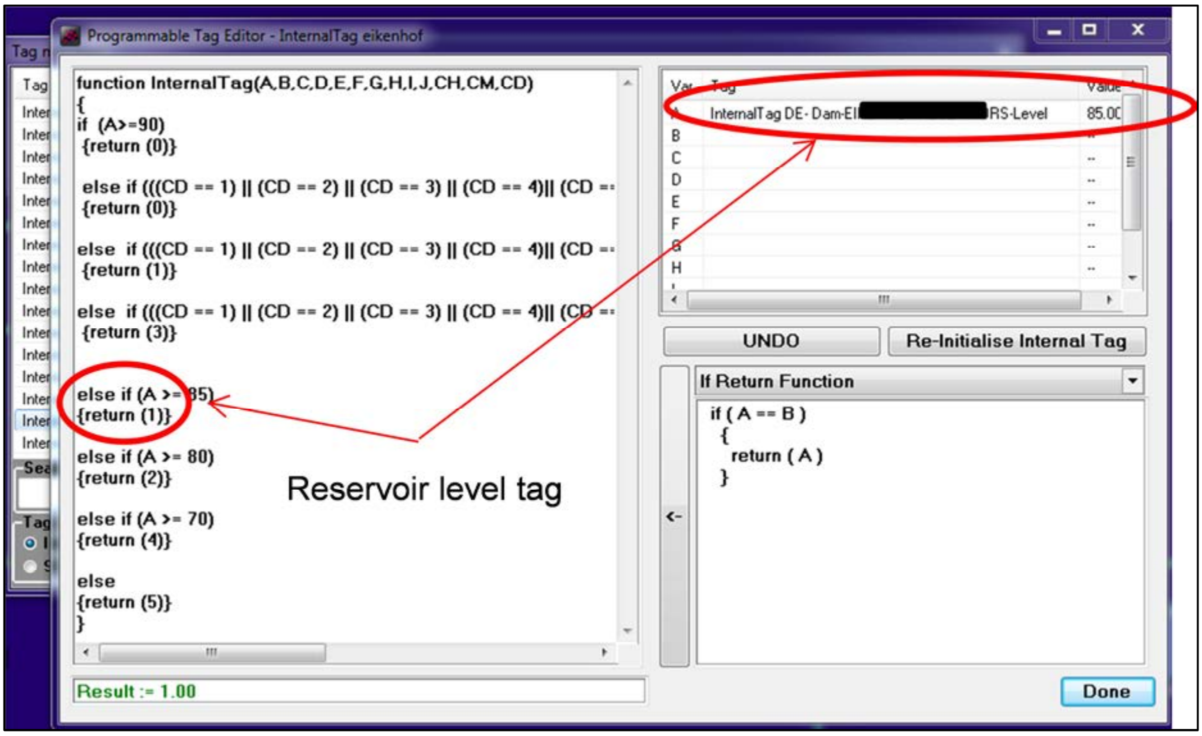


Figure 31: Basic programming of the simulation

All of the pump controllers were programmed similarly. The pump stations at the WTW were programmed according to the balancing reservoirs onsite at the BPS. The limits of the BPS balancing reservoirs are not as strict as the downstream reservoirs. If the load shift is synchronised, there was no visible effect on the balancing reservoirs.

3.4.2 WTW simulation

Figure 32 shows the page of the pumping station at the WTW Z. The WTW cannot be simulated by this package. The constraints were based on the limits of the WTW. Thus, if the load shift were possible in the simulation, there would be no effect on the water quality.

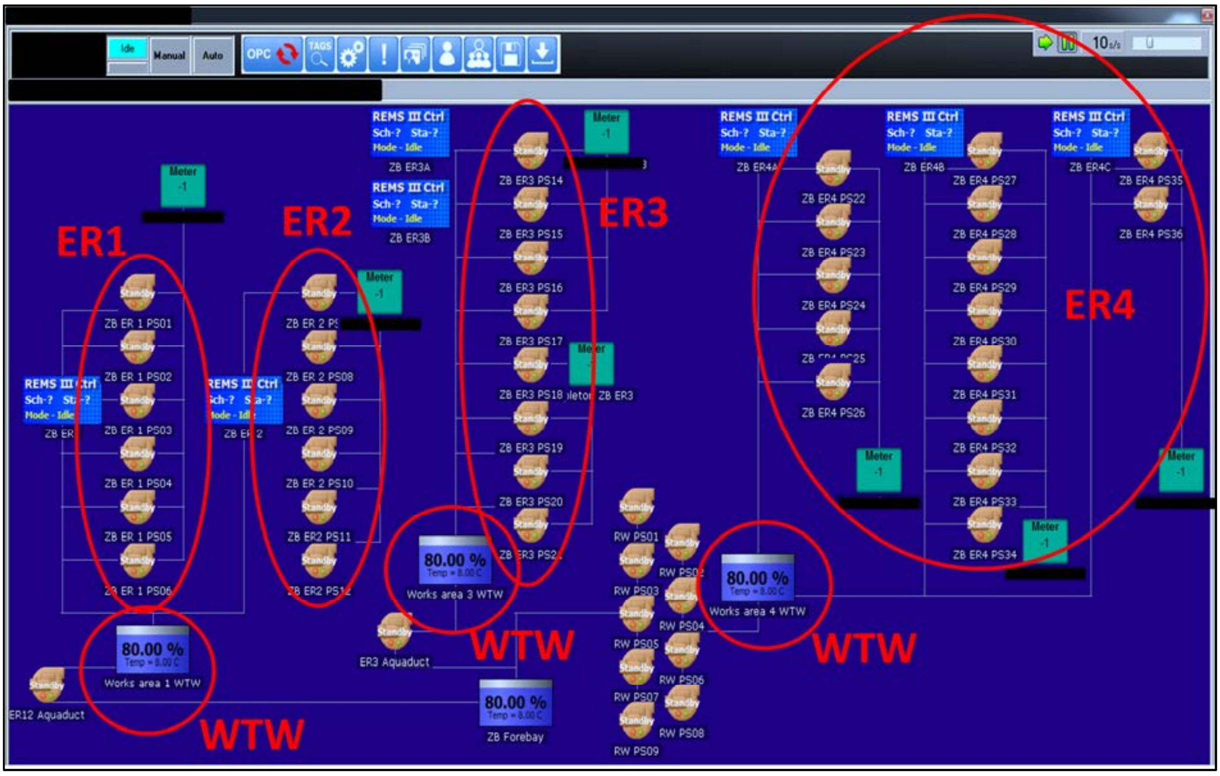


Figure 32: WTW Z simulation

The WTW Z simulation was based on the demand of the balancing reservoirs at the BPS. In ER 1, the simulation allowed for one pump set to be switched off. A reduction of one pump set was well within the limits of the demand and WTW. At ER 2, a maximum of two pumps could be switched off during the Eskom evening peak. ER 4 has the greatest possibility to do a load shift. The sump prior to the ER has a capacity of 60 Ml. The large capacity available will prevent a load shift from affecting the WTW.

WTW V is shown in Figure 33. At the WTW V, it would be challenging at times when demand is at its lowest. Due to the increase in demand in recent years and outdated infrastructure, the station is pumping at maximum capacity to keep up. If the flow is reduced even for an hour, the station would not be able to recover the load.

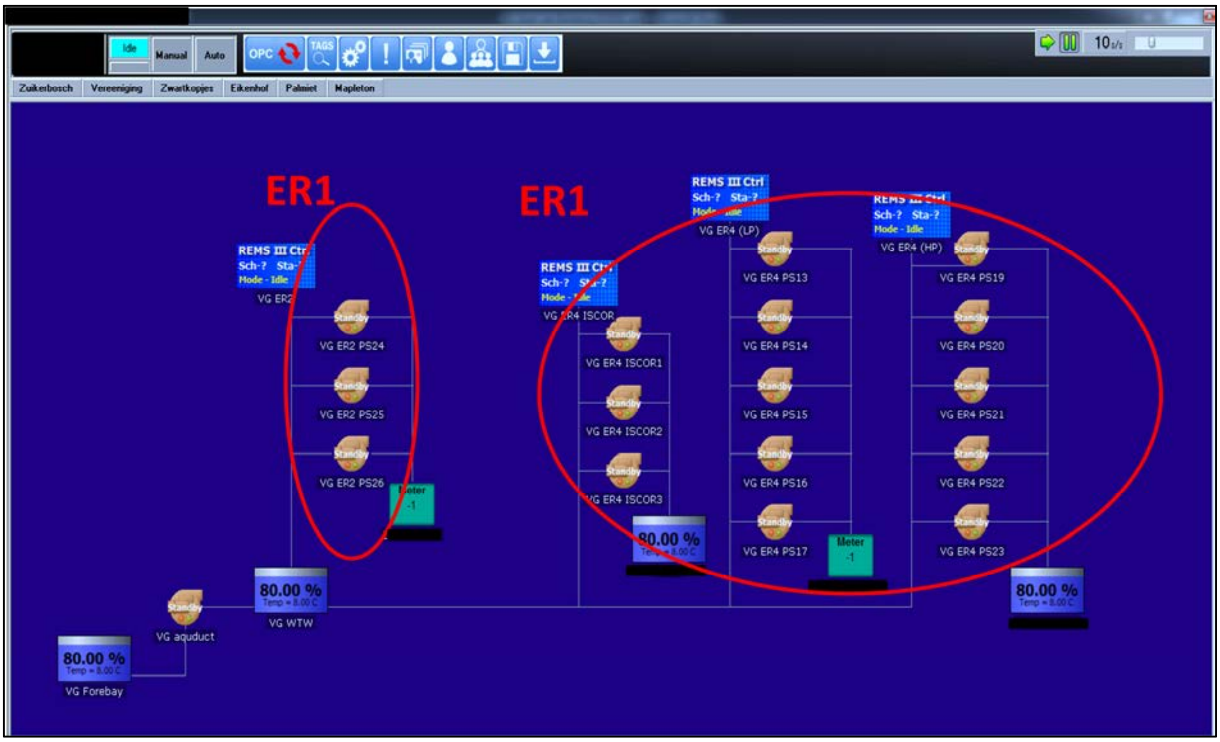


Figure 33: WTW V simulation

As previously mentioned the storage capacity onsite is smaller than 4 Ml. With the small storage capacity, the entire plant needs to be interrupted. The most concerning reason that a load shift is not possible, is that the pump station supplying water to the WTW has four 400 Ml/day pumps. If a load shift was scheduled, the smallest amount of load that can be reduced is 400 Ml/day. The simulation confirmed what the author suspected.

3.4.3 BPS simulation

From the pumping stations at the WTW, water is sent to the four BPS as shown in Figure 34, Figure 35, Figure 36 and Figure 37. The BPS is programmed to keep the downstream reservoirs within limits that were set by the client. The outflow of the downstream reservoirs was determined by taking the average of the water that is pumped on a daily basis to the reservoirs over a year. The levels of the reservoirs were not available. The author had to make the assumption that the water that the reservoirs receive on a daily basis is the average consumption.

BPS Z is shown in Figure 34. The demand per day for the BPS Z could be determined more accurately. BPS Z documents the water pumped daily to each reservoir. SBPS D has three

90 Ml/day pump sets. The station was programmed to pump according to the tariff structure from 2014. In the simulation, the programming used by the LPWU was mimicked.

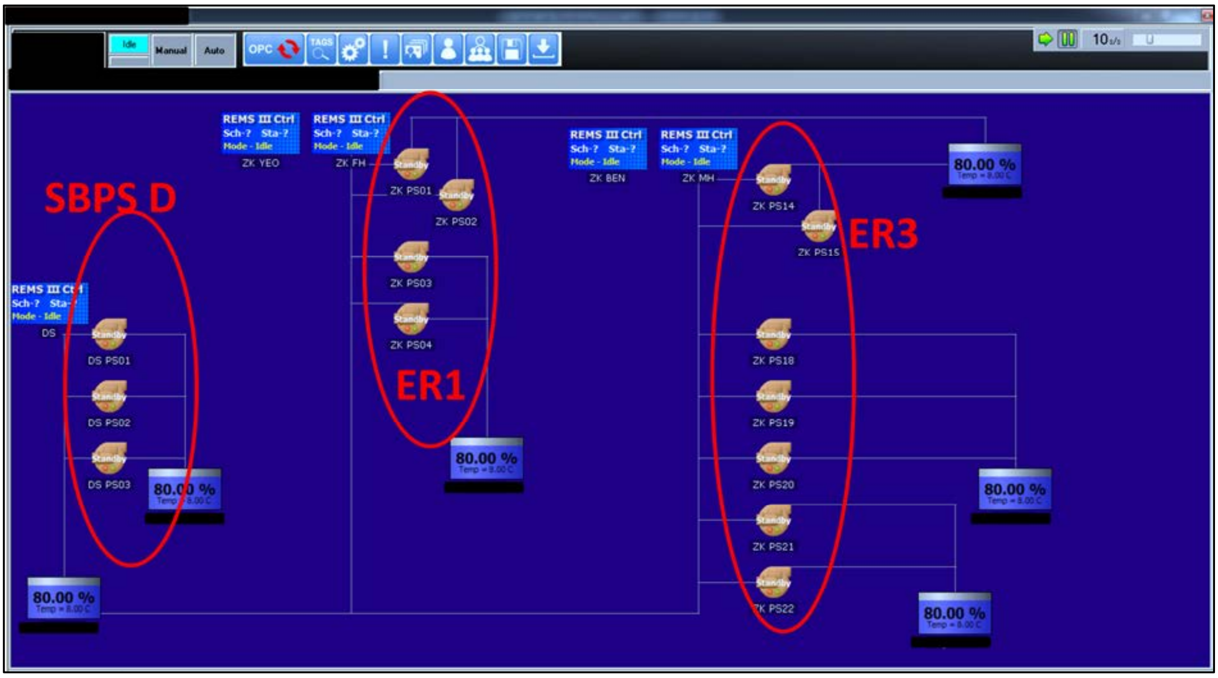


Figure 34: BPS Z simulation

BPS Z is programmed to switch off a maximum of three pump sets. As mentioned, BPS Z only supplies water to a settled residential area. The consumption of the downstream reservoirs is consistent and a large load shift can be realised throughout the year. The consumption of the downstream reservoirs has remained consistent over the past decade making BPS Z a prime candidate for sustained energy cost savings.

BPS E shown in Figure 35 was programmed to switch a pump off in each ER (circled in red). The flow of the entire station was documented every day and was used to calculate the demand of the downstream reservoirs. The simulation was programmed to switch off pump sets at any ER. The focus was on ER 3.

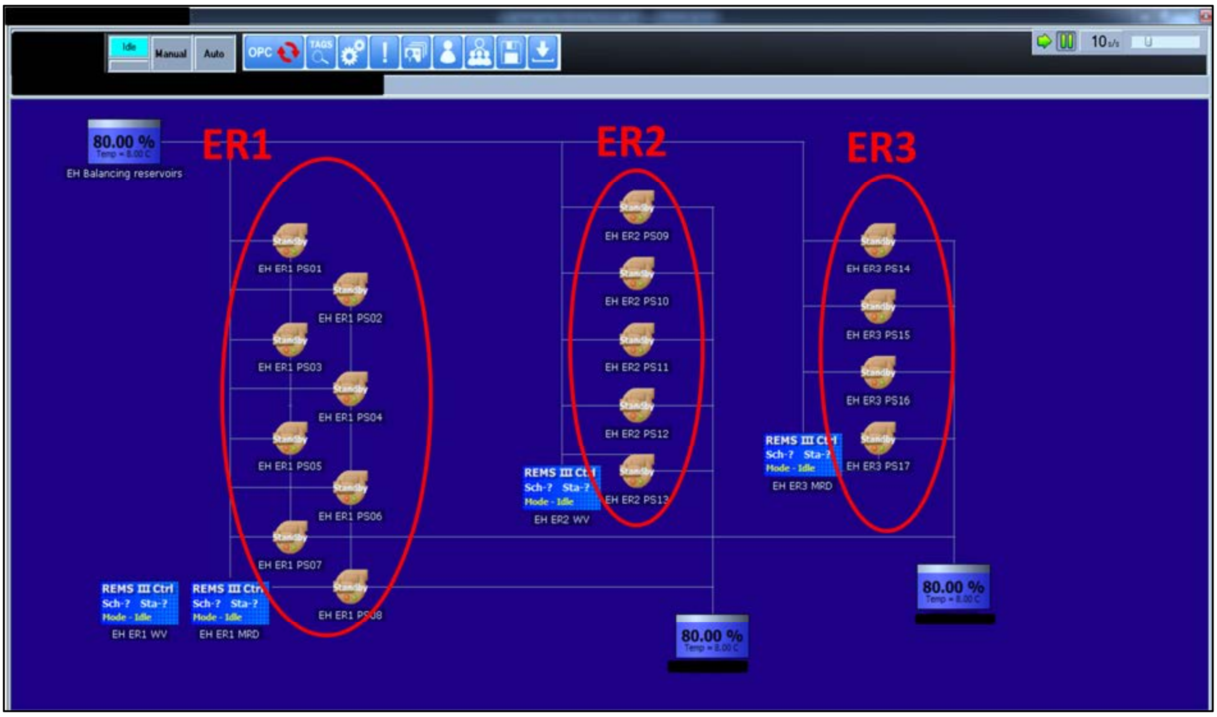


Figure 35: BPS E simulation

The downstream reservoirs have similar storage capacities. The downstream reservoir level parameters were between 65% and 80%. The balancing reservoir level was reduced during the off-peak period to accommodate the excess flow during the Eskom evening peak period. The consumption of the BPS is dependent on the weather.

The higher the outside temperature, the higher the consumption. BPS E is pumping under its installed capacity. The station was initially built to accommodate the increase in the mining sector. In the past years the mining industry declined. The decline in demand makes significant savings possible in the winter.

BPS P shown in Figure 36 is pumping at maximum capacity most days. The simulation allowed for one pump in ER 3 to be switched off if the reservoir KB allowed it. The main saving will be at ER 1 (circled in red). It was found that the 90 Ml/day pump sets are very inefficient and would have the smallest impact on the system.

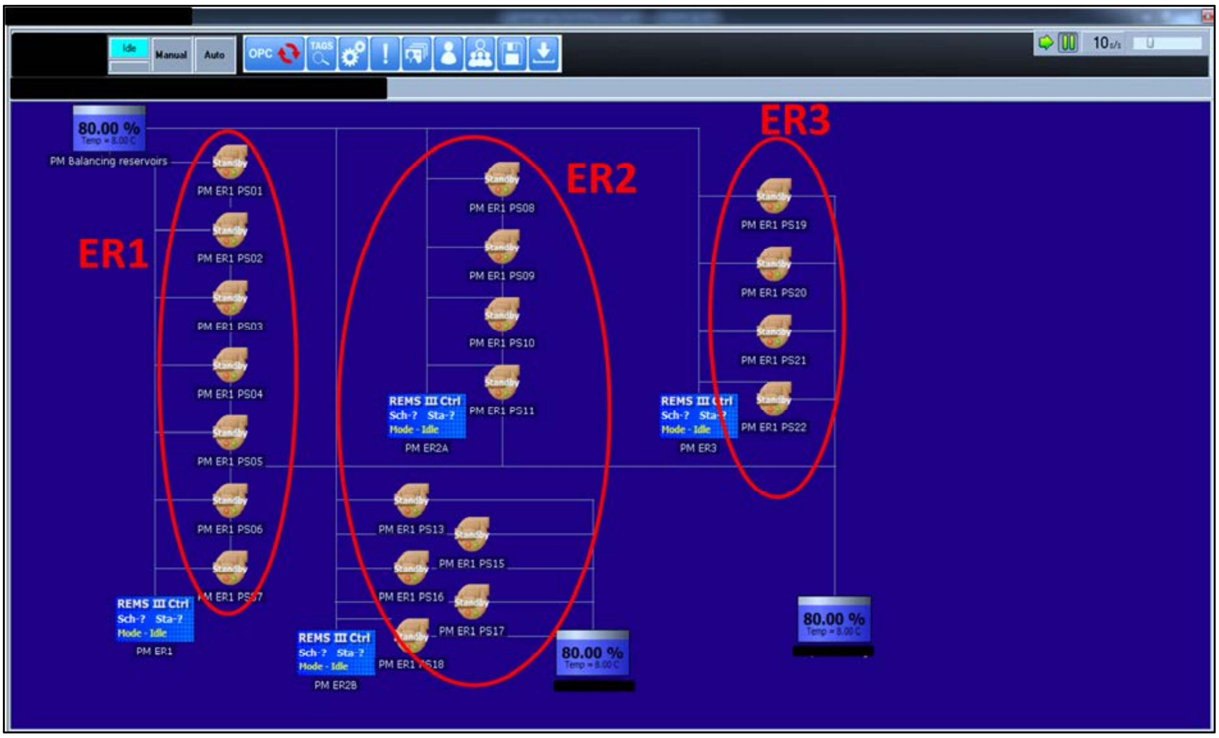


Figure 36: BPS P simulation

The 90 Ml/day pump sets were programmed to switch off every night except if the downstream reservoir was below 65%. Due to the increase in demand BPS P can only accommodate a load shift in times when the demand is lower than average (1 660 Ml/day).

BPS M, shown in Figure 37, was programmed to switch off pumps in only ER 1. The VR pumps have a small capacity and do not run continuously. If the downstream reservoir's level was above 85%, a 200 Ml/day pump set was switched off. If the BP reservoirs were between 84% and 70%, a 100 Ml/day pump was switched off.

The downstream reservoir the ER 1 supplies to, is unpredictable and the level is constantly on the decline. A load shift would be very challenging at BPS M. BPS M has two balancing reservoirs, making the onsite storage capacity 30% less than the other BPS. High demand and smaller onsite storage capacity are compelling reasons why a load reduction is not possible in the moderate to high demand season.

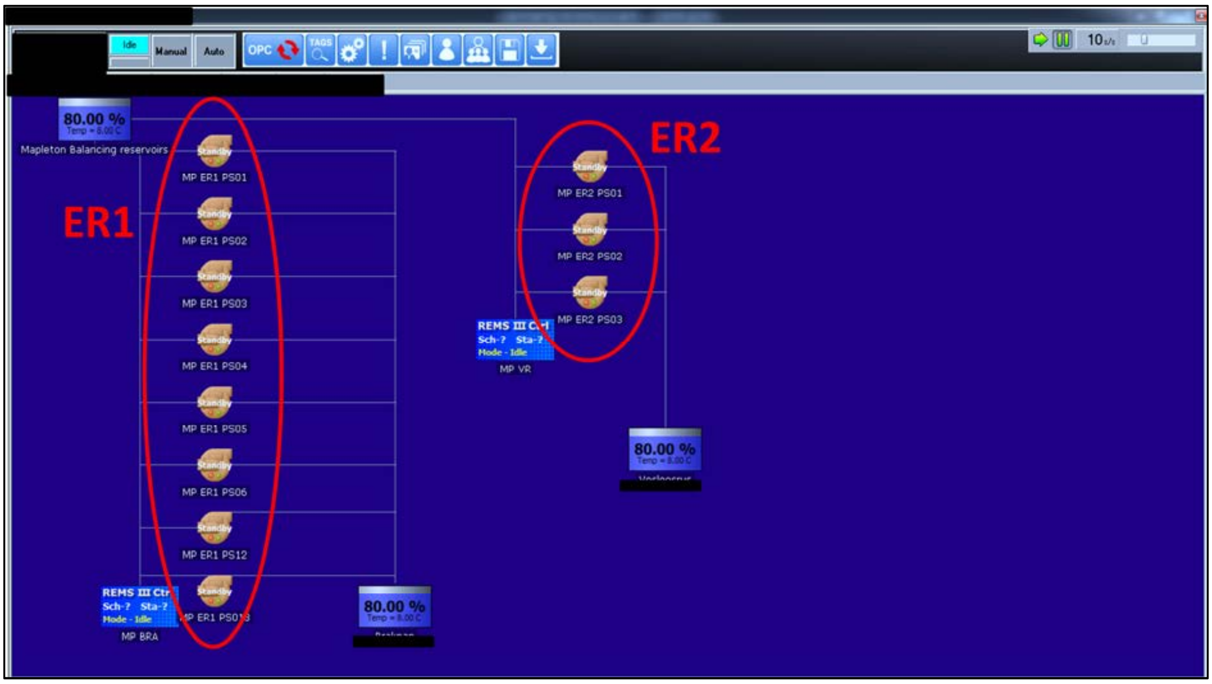


Figure 37: BPS M simulation

The simulation was simulated at a rate of 60s/s. The slow rate was due to the immense scale of this network. If the simulation was sped up, it would crash or have excessive lag. The simulation was left to run for five days to gather an adequate amount of data. The results are shown in section 3.5.

3.5 Verification of simulation

3.5.1 Simulation results

The results of the load shift from the simulation can be seen in Table 15. The overall accuracy was 3%, with the largest differences being WTW Z and BPS P. The reason for the discrepancies is that the installed motor rated power was stated by the author. The simulation was simulated for one month and the results depicted the average of the month. Even with the differences seen in Table 15, the overall accuracy is still >95% of the simulation results.

Table 15: Load shift results from simulation

Station	Simulation results (MW)	Investigation results (MW)	Difference
WTW Z	12.1	12.5	3%
WTW V	0	0	0%
BPS E	5.8	6	3%
BPS Z	11.2	11.6	3%
BPS P	2.3	2.5	8%
BPS M	3.7	3.5	6%
Total	35.1	36.1	3%

LPWU is close to its maximum operation capacity. The balancing reservoirs allowed a safe load shift. From the simulation, it is seen that the reduction on the WTW would be negligible. The author decided to do further investigations if these savings were possible before doing actual tests. The author will use the knowledge gained from the simulation to conduct an enhanced study.

3.5.2 Investigation and verification of the simulation

WTW Z has the potential to do a load shift at Works area 3 and Works Area 4. Works area 4 has a sufficient size sump to load shift safely. By scheduling the load shift in accordance with the sump level, a load shift will not influence the WTW.

The station has a 500 Ml forebay that will allow for a load shift if the WTW needs to be interrupted. From 2012 to 2014 the demand for WTW Z increased significantly. The increase caused the station to run at maximum capacity for most parts of the year. At Works area 1 and 2, the possibility of load shifting exists. Due to site approval processes, no tests could be done on WTW Z.

WTW V had no potential for a load shift from the simulation. The author arranged meetings with the operations personnel and conducted an in-depth investigation. It was found that the WTW V station had various physical constraints. The station was running at maximum capacity. At ER 1, for instance, there are three pump sets, two 200 Ml/day pumps and one 100 Ml/day pump set. Typically during the day a 100 Ml/day and a 200 Ml/day will be running to keep up with the demand.

The pipeline restricts running two 200 Ml/day pump sets due to its small size. When two 200 Ml/day pump sets ran simultaneously, the efficiency of the pumps was extremely low, To such an extent that it is better to run a 200 Ml/day and a 100 Ml/day pump set. Further investigation showed that the storage capacity was relatively small. ER 1 only had a 4 Ml sump. 4 Ml is equivalent to a 100 Ml/day pump being off for one hour. The small storage capacity suggests that the WTW will have to be interrupted to do a cost saving intervention.

It was found that this would not be possible since the WTW is old and lacks instrumentation. The WTW will also not be able to recuperate the lost load. The WTW is running at full capacity. AT ER 4 the situation is much worse. The ER is scheduled for an upgrade within the next five years. At the current operating conditions, it would not be impossible to recover the load, once lost.

The pumps supplying to the BPS E are running at 600 Ml/day. The pipeline is restricted to 750 Ml/day as mentioned. Thus, by starting one more 200 Ml/day pump set, the pipeline would not be able to accommodate the excess flow. The restrictions make it impossible to recuperate the lost load. WTW V is not on a time-based tariff structure. A load shift would be pointless from a financial point of view. With all the constraints and relatively no cost savings, it is not recommended to do an electricity cost saving intervention at WTW V. As the author predicted, no load shift will be possible on WTW V.

Chlorine disinfection would not be interrupted at any of the WTW. The chlorine dosage is operated by a “semi-automatic” valve. The parameter of this valve has to be set every two hours by an operator. The change in flow will be detected by the operator and adjusted accordingly. A planned reduction can be adjusted with very little trouble.

BPS E has the potential to switch off one 200 Ml/day pump during the Eskom evening peak. The station has the necessary equipment. Downstream chlorine disinfection is automatic and easily adjustable. The BPS Z has the potential to do a 12 MW load shift due to the size of the DS reservoir. Before the DS reservoir, reservoir water is drawn off to various factories. The DS reservoirs have a smaller BPS as well.

Typically, of the 600 Ml/day that are pumped to the DS reservoirs only 490 Ml/day reach the BPS Z. The volume of water entering the BPS makes it possible to do a load shift. The chlorine disinfection is done automatically. A 12 MW load shift computes to a 200 Ml/day reduction in flow during the Eskom evening peak period. The 200 Ml/day reduction is well within the limits of the disinfection plant.

As mentioned in section 3.3, the BPS P is running at its full capacity for most parts of the year. The simulation established that a pump set in ER 1 can be switched off for two hours during the Eskom evening peak period. Switching off this pump set will amount to a load variation of 90 Ml/day - 70 Ml/day. A variation of 90Ml/day - 70 Ml/day is well within the limits of the secondary disinfection plant.

At the BPS M, a 100 Ml/day can be safely reduced even with the smaller storage capacity. The 100 Ml/day variation is well within the limits of the disinfection plant. Doing a load shift on ER 2 is not feasible because the pumps are small and run inconsistently.

3.5.3 Test results

Tests were conducted on all four the BPS. The BPS Z and BPS E yielded the best results. The results of the tests are shown in Table 16. If the client was more open to the idea, the proposed savings could have been realised. During the course of the project, the saving would increase as the personnel would get more familiar with the load shifting procedure. The differences were purely due to human intervention.

Table 16: Load shift test results

Station	Simulation results (MW)	Investigation results (MW)	Actual Results (MW)
WTW Z	12.1	12.5	0
WTW V	0	0	0
BPS E	5.8	6	5.9
BPS Z	11.2	11.6	11.1
BPS P	2.3	2.5	2.0
BPS M	3.7	3.5	0

The results of the tests will be discussed in detail in Chapter 4. The simulation could not estimate the reservoir levels correctly, only the decline during the Eskom evening peak period. The reason for the inaccuracy can be attributed to the fact that the demand could only be obtained per day and not per hour.

As the author expected from the investigation, a load shift would be possible on the LPWU. If some of the problems are fixed and the upgrades are complete, the loadshift can be much greater. The main reason that no savings were shown on WTW Z and BPS M was due to the unwillingness of the client to perform any tests on the site. The sites that were tested are correlated with the results which are shown in Table 17.

Table 17: Comparison between expected results and actual results

Station	Simulation results (MW)	Investigation results (MW)	Actual results (MW)
BPS E	5.8	6	5.9
BPS Z	11.2	11.6	11.1
BPS P	2.3	2.5	2
Total	19.3	20.1	19

The accuracy of the investigation that was done and the simulation can be seen in Table 17. When the unsuccessful results are removed, the investigated results are within >90% accuracy of the actual results. The simulation results are accurate with >95%. The close relation proves the validity of the simulation and investigation. The actual results verify both the investigation and simulation done within the constraints of the water purification plant.

3.6 Conclusion

By following the methodology stated, an investigation can be done on any similar site. The most important aspect is the detailed site visit and meetings with site personnel. The modelling proved that every situation is different. If the methodology is followed, any system, however complex, can be modelled.

By hard coding the WTW parameters into the simulation, a load shift can be simulated without affecting the water quality. Chapter 4 will focus on the effects of a tested loadshift on the water quality. The simulation is accurate enough to simulate the network in a steady state. Due to outflow changing every moment of the day, the reservoir levels cannot be estimated with >80% accuracy. The investigation proved the results of the simulation.

4

CASE STUDIES

Chapter 4
Verification of the cost-efficient control strategies implemented on the actual pumping network at LPWU.

CHAPTER 4: CASE STUDIES

4.1 Introduction

It was determined that the load shift will not have a significant effect on the water quality by the investigation and simulations in Chapter 3. That definitively proves the concept; case studies were done to see the real effect on the system. Case study 1 will show that a 300ML/day reduction will not have an impact on the water quality. Case study 2 will prove that a total reduction of the entire pumping station will have no effect on water quality. Case study 3 will look at a day when load shifting tests are done on the BPS.

4.2 Case study 1

On the 15th of July 2012 pumps of WTW ZER 4, were switched off for 31.5 hours as seen in Figure 38 due to unforeseen maintenance. This case study will focus on the water quality after a reduction in flow transpired.

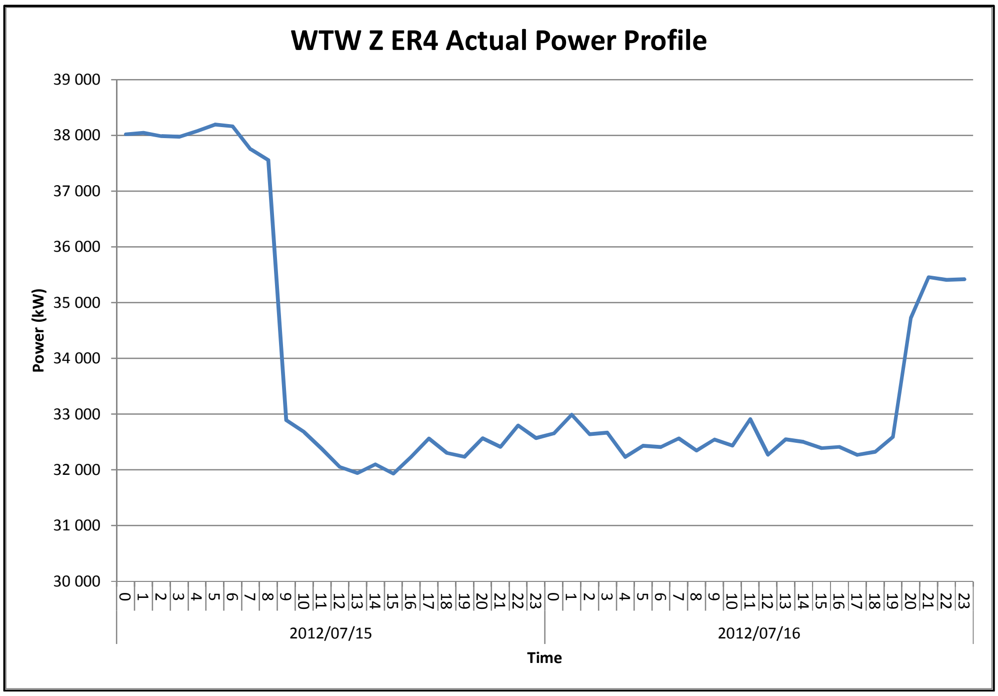


Figure 38: WTW Z power profile on 15 July 2012 to 16 July 2012.

As seen in Figure 38 a trip occurred in ER 4. From Figure 39 it can be seen that a flow reduction of 300 Ml/day arose. The reduction in flow will be similar to what will be done during load shifting. The amount of 300 Ml/day reduction is 30% more than the planned load shift.

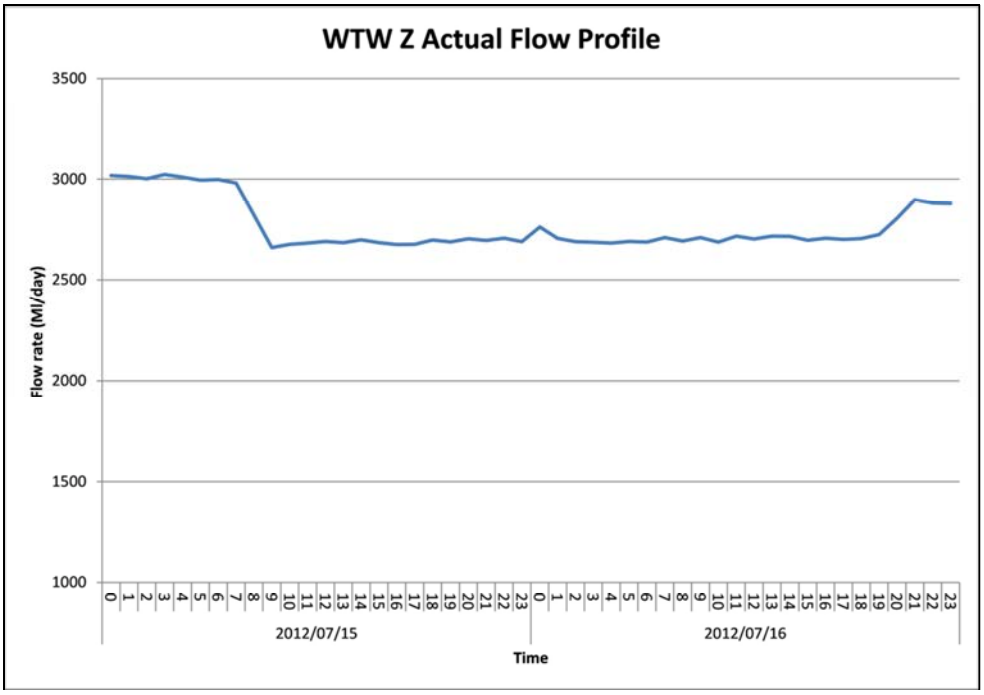


Figure 39: WTW Z water flow rate of outgoing pipelines on 15 July 2012 to16 July 2012

The effect on the water quality for this period can be seen in Figure 40 and Figure 41. The measurements were taken in each of the outgoing pipelines (B 8, B 10, B 12 and B 15) each leading to different BPS.

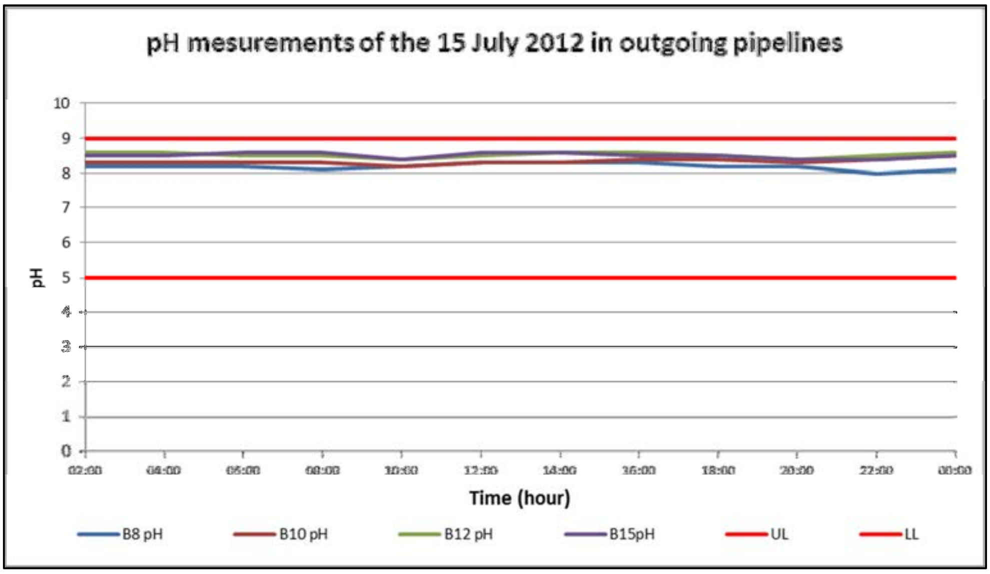


Figure 40: WTW Z pH measurements on 15 July 2012

The pH is required to be between 9 and 5. The desired pH level is 8.5. As seen in Figure 40 nearly no change can be seen after the flow was reduced by 300 Ml/day. The second parameter is the turbidity of the water. The turbidity is required to be below 0.5 NTU. The LPWU strives to keep the turbidity below 0.2 NTU. In Figure 41 it can be seen that the turbidity on the outgoing pipeline is constant and within the specifications set by the LPWU.

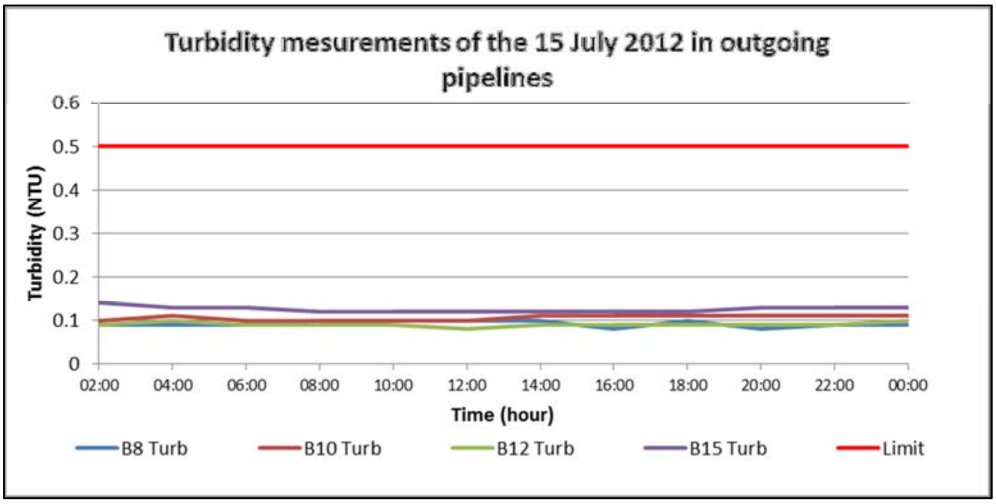


Figure 41: WTW Z turbidity measurements on 15 July 2012

There was no moment that the water did not comply with the standards. If a 300 Ml/day reduction in flow has no effect on the water quality and the operations of the WTW, it can be safely concluded that a 200 Ml/day reduction and increase will not have an impact on the water quality. The reports can be seen in Appendix C.

4.3 Case study 2

In this case study, the entire ER 4 was completely down. On the 22 and 23 May 2012, all pumps of WTW ZER 4 were switched off for 12 hours as seen in Figure 42 due to unforeseen maintenance. In Figure 42 the power profile for the two days can be seen. This correlates well with the flow profile as seen in Figure 43.

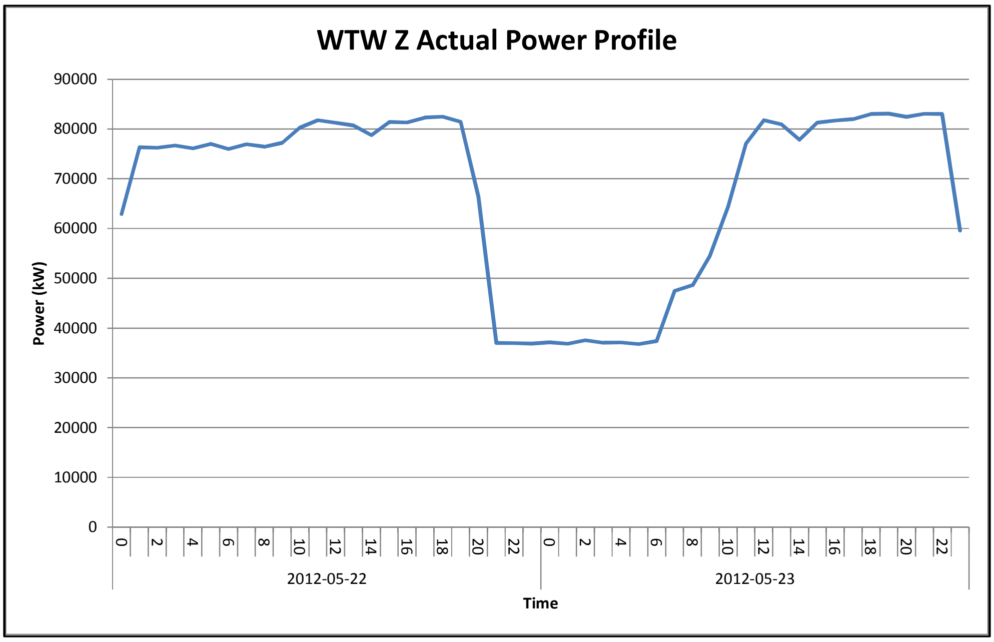


Figure 42: WTW Z power profile from 22 May 2012 to 23 May 2012.

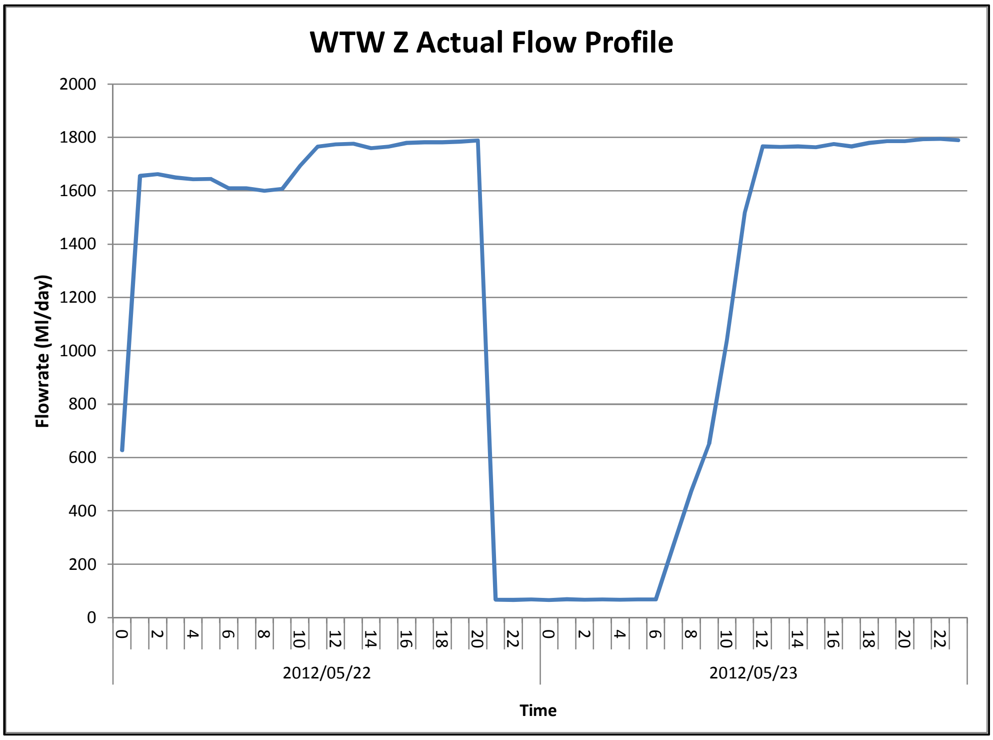


Figure 43: WTW Z Water flow rate from 22 May 2012 to 24 May 2012

In Figure 43 it can be seen that a flow reduction of 1 800 Ml/day occurred. The reduction in flow is nine times larger than what will be done during load shifting. As seen in Figure 43 the flow rates dropped during 22 May 2013. The station recovered the flow on 23 May 2012 from 06h00 to 14h00. During these hours, the station went from a low flowrate back to normal operations. The sudden decrease in flow had no effect on the outgoing water quality as seen in Figure 44 and Figure 45.

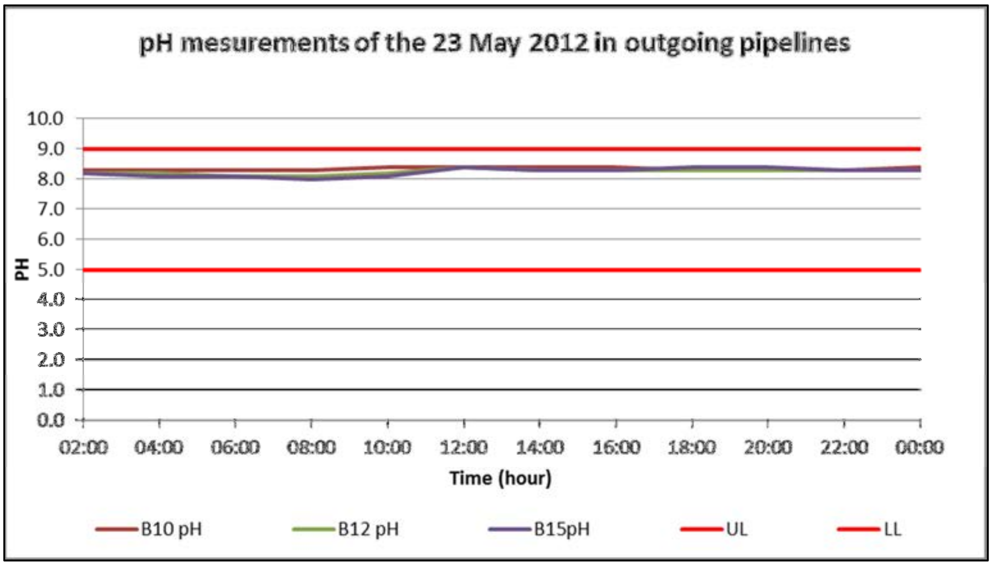
1


Figure 44: WTW Z pH measurements on 23 May 2012

The pH is required to be between 9 and 5. The desired pH level is 8.5. As seen in Figure 44 nearly no change can be seen after the flow was reduced by 1 800 Ml/day. The second parameter is the turbidity of the water. The turbidity is required to be below 0.5 NTU. The LPWU strives to keep the turbidity below 0.2 NTU. In Figure 45 it can be seen that the turbidity on the outgoing pipeline is constant and within the specifications set by the LPWU.

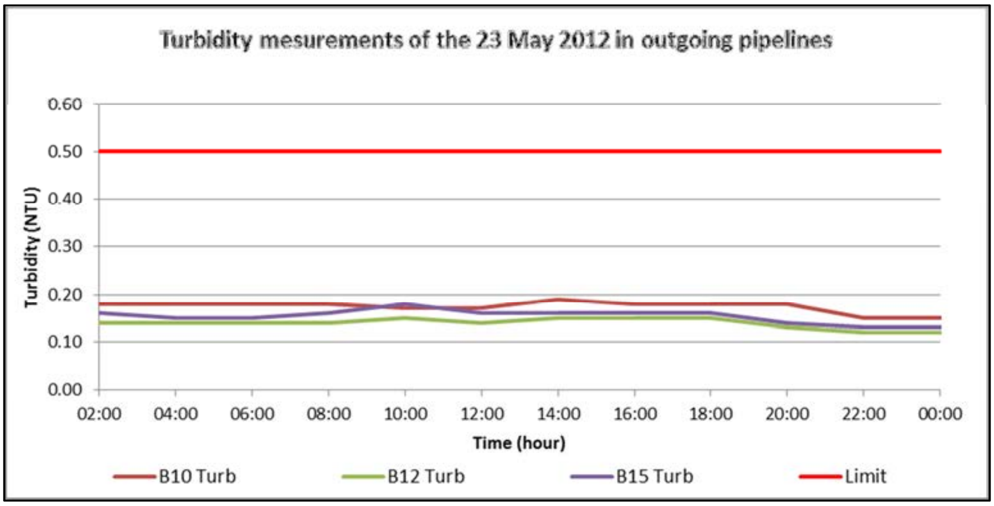


Figure 45: WTW Z turbidity measurements on 23 May 2012

The water quality was investigated for the following 48 hours after the significant decrease in flow (Appendix C). There was no moment that the water did not comply with the standards. If a near total reduction in flow has no effect on the water quality and the operations of the WTW, it can be safely concluded that a 200 Ml/day reduction and increase will not have an impact on the water quality.

4.4 Case study 3

4.4.1 BPS Z methodology

On 20 September 2013 a test was conducted on ZWK. A 100ML/day pump set in ER 3 as well as in ER 1 was switched off at 17h55 before the Eskom evening peak period. The installed capacities of the pump sets are 5650 kW and 6163 kW. After the Eskom evening peak period, the pump operator was instructed to continue operations as usual.

4.4.1.1 Load shift results

The pumps were switched off from 17h55 to 20h30 which can be seen in Figure 46. The baseline is adjusted energy neutral, indicated by the red line. The average evening peak saving achieved was approximately 11.1 MW. The results can be seen in Appendix B.

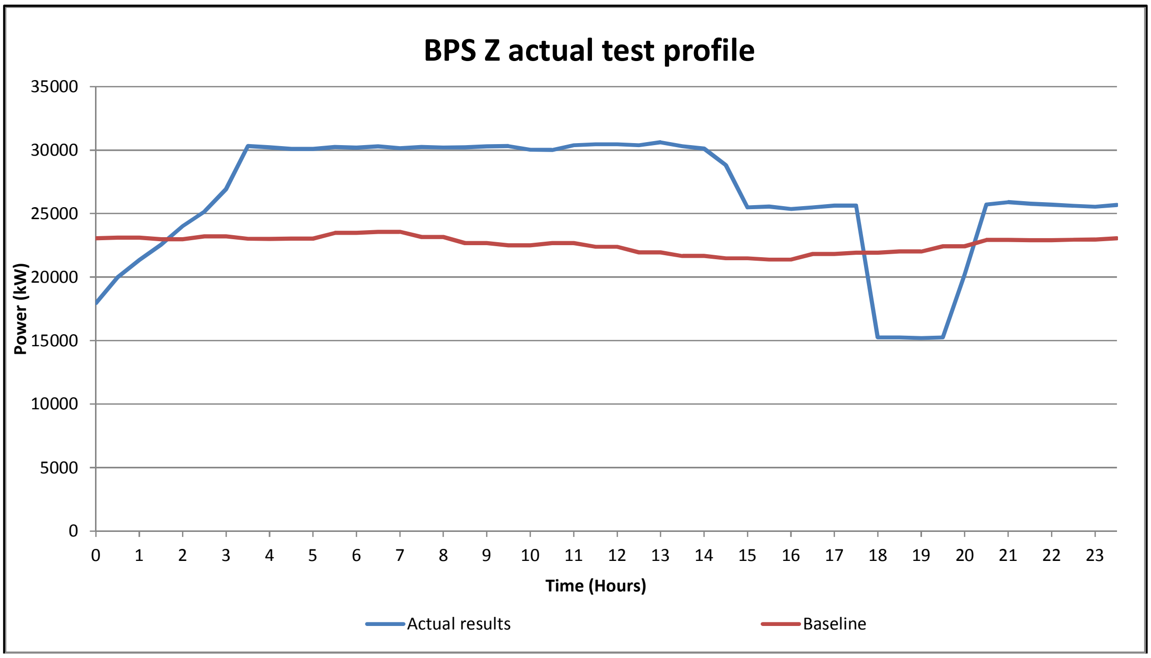


Figure 46: Power profile for BPS Z on 20 September 2013

Increased pumping from 06h00 to 14h30 can be attributed to the reduced pumping between 00h00 and 04h00. This resulted in lower than expected cost savings.

4.4.1.2 Water Quality

Incoming potable water is dosed with monochlorine. The dosage amount is determined by the incoming water's monochlorine concentrations. The dosage is directly related to water quality. Figure 47 shows the monochlorine concentrations measured on the outgoing pipelines.

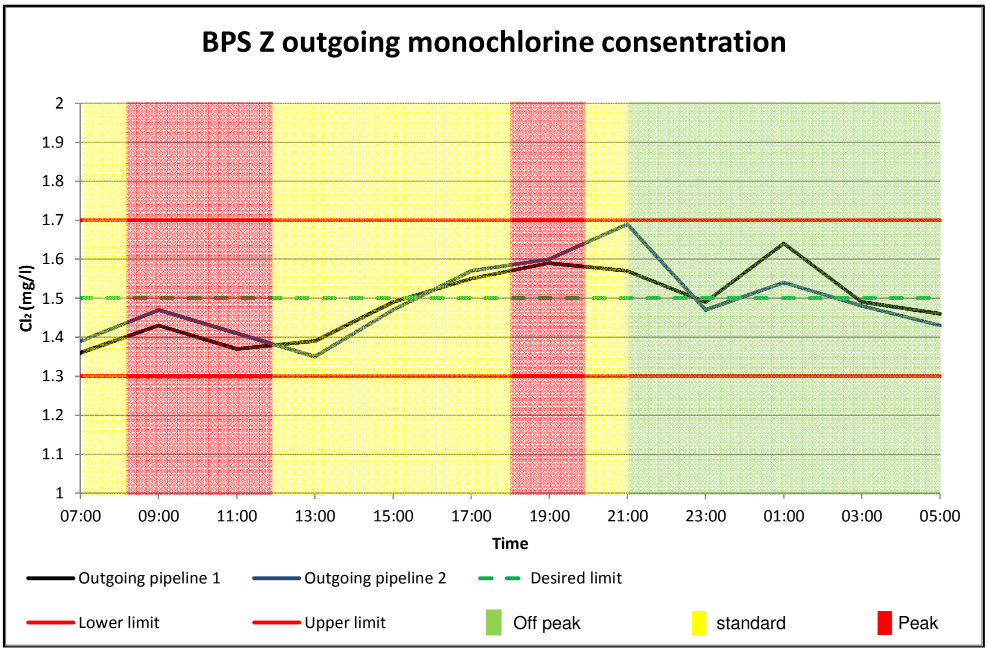


Figure 47: BPS Z water quality on 20 September 2013

On 20 September 2013, during the load shift test, the water quality was 99.31% compliant. See Appendix C for daily water quality reports. According to the standards set by LPWU the outgoing lines monochlorine levels must be between 1.3 mg/l and 1.7 mg/l. Although outgoing pipeline 2 measured a reading close to the maximum, it was still within the limits and not caused by the load shift. As seen in Figure 46, no come-back load was present that could influence the water quality

4.4.2 BPS E methodology

On 4, November 2013 a test was conducted on BPS E. It was decided to switch off the pump set 10 in ER 2. The installed capacity of this pump set is 6800 kW. The pump was switched off at 17:45 before the Eskom evening peak period. After the Eskom evening peak period, the pump operator was instructed to continue operations as usual.

4.4.2.1 Load shift results

The pump set was switched off from 18h00 to 20h30 shown in Figure 48. The baseline is adjusted energy neutral, indicated by the red line. The evening peak average saving achieved was 5.5 MW. The results can be seen in Appendix B.

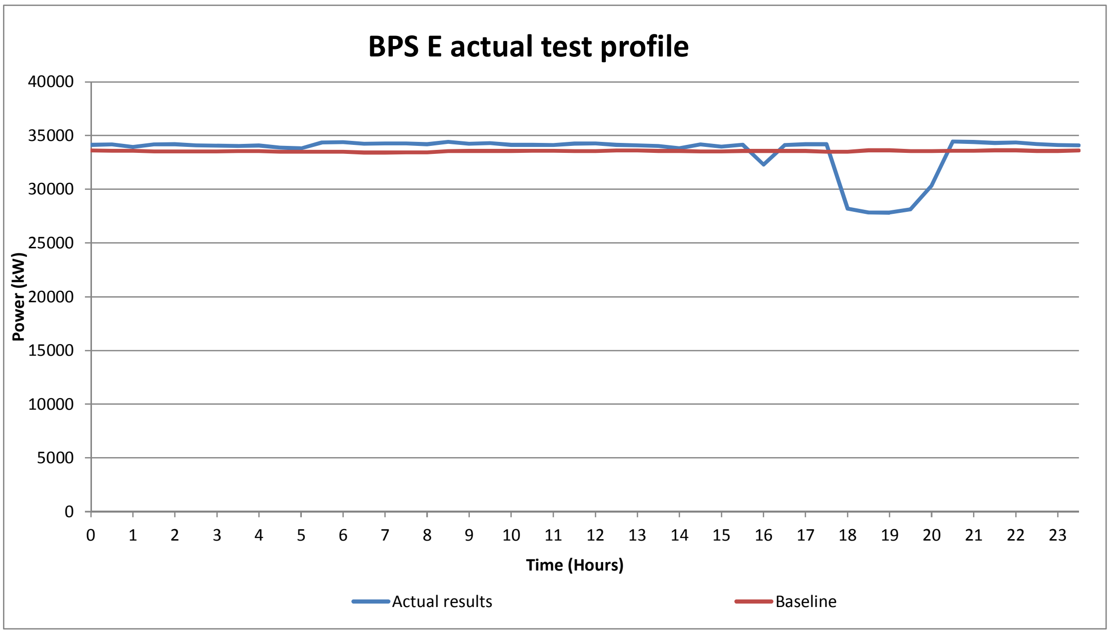


Figure 48: Power profile for BPS E on 4 December 2013.

4.4.2.2 Water quality

The dosage amount given to the incoming potable water is determined by the incoming water's monochlorine concentrations, which are directly related to water quality. Shown in Figure 49, the monochlorine concentrations measured on the incoming and outgoing pipelines are depicted.

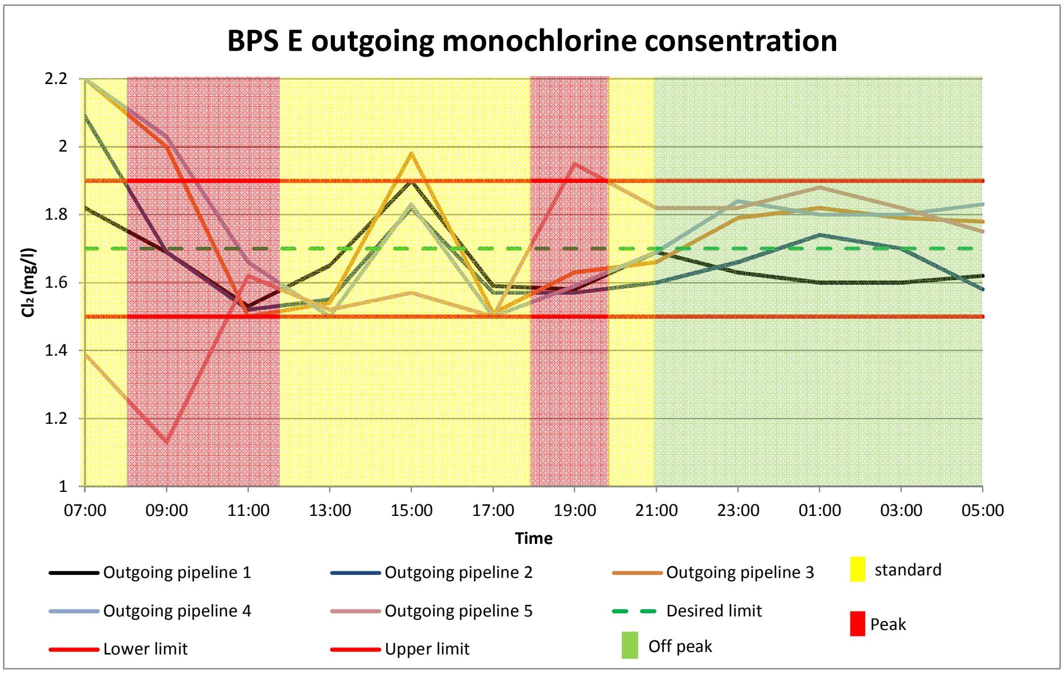


Figure 49: BPS E water quality on 4 December 2013

On 4 December 2013, during the load shift test, the water quality was 100% compliant. See Appendix C for daily water quality reports. According to the standards set by the LPWU the outgoing lines' monochlorine levels must be between 1.5 mg/l and 1.9 mg/l. The readings before 11h00 were as a result of difficulties experienced at the WTW and were not influenced by the load shift

4.4.3 BPS P methodology

On 29 October 2013 a test was conducted on BPS P. It was decided to switch off Pump set 7 (2500 kW) in ER 1. The pump set is dedicated to the KB reservoir. The pump was switched off at 17:55 before the Eskom evening peak period. After the Eskom evening peak period, the pump operator was instructed to continue operations as usual.

4.4.3.1 Load shift results

A pump set was switched off from 17h55 to 20h00 which can be seen in Figure 50. The baseline is adjusted energy neutral, indicated by the red line. The evening peak average saving achieved was approximately 2 MW. The results can be seen in Appendix B.

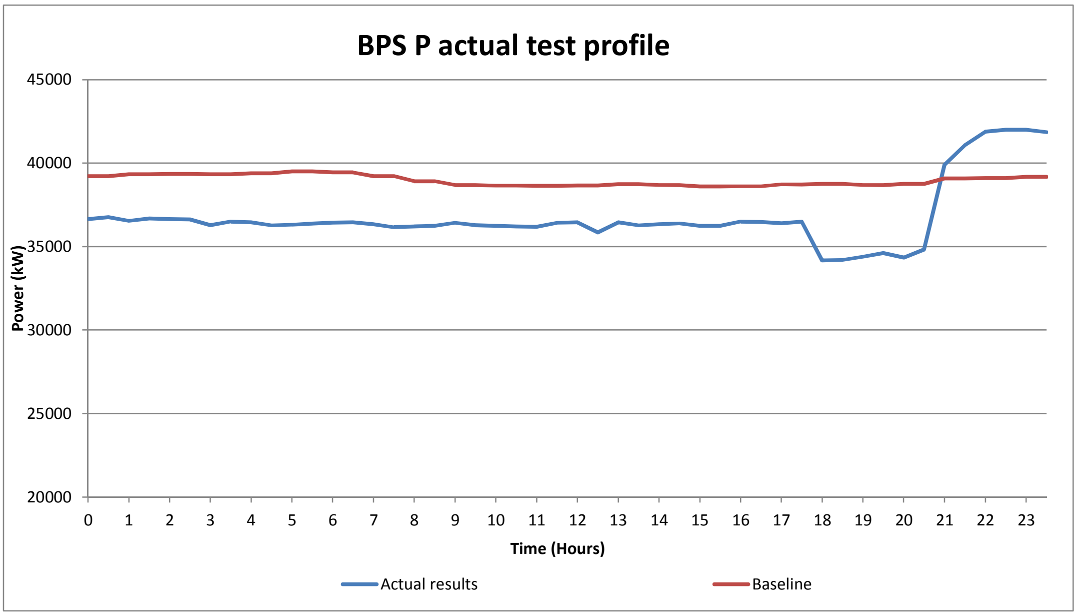


Figure 50: kW profile for BPS P ER 1 on 29 October 2013

4.4.3.2 Water quality

Incoming potable water is dosed with monochlorine. The dosage amount is determined by the incoming water's monochlorine concentrations. This is directly related to water quality. Shown in Figure 51, are the monochlorine concentrations measured on the outgoing pipelines.

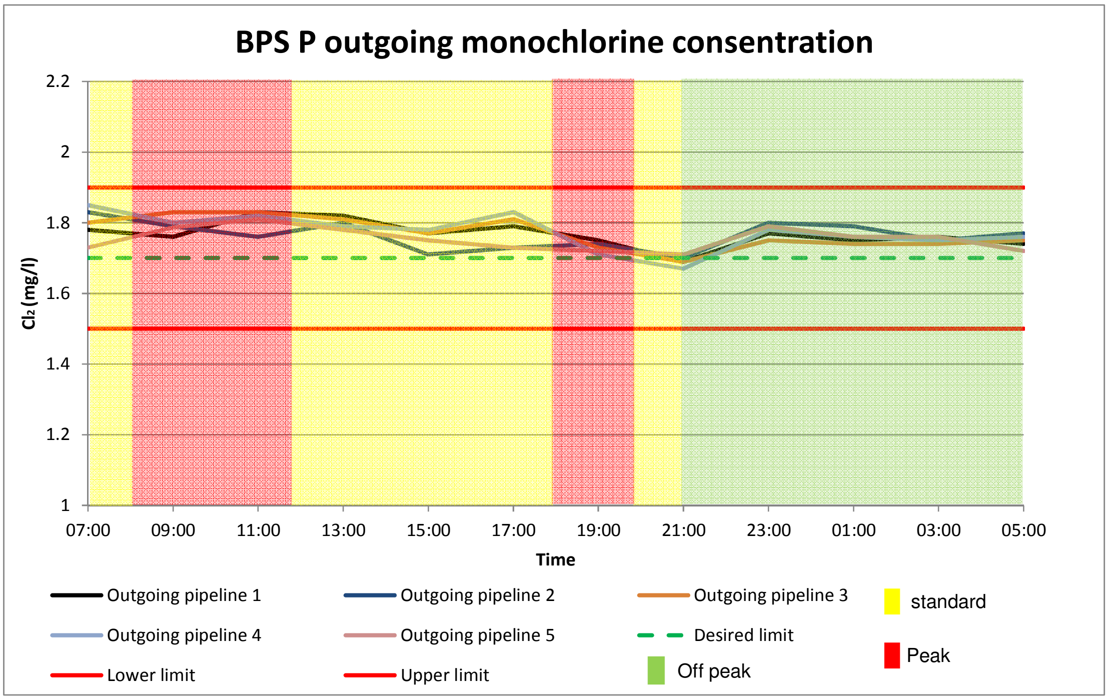


Figure 51: BPS P water quality on 29 October 2013

On 29 October 2013, during the load shift test, the water quality was 100% compliant. See Appendix C for daily water quality reports. According to the standards set by LPWU the incoming lines monochlorine levels must be between 1.5 mg/l and 1.9 mg/l.

4.5 Applying this research to other pump stations

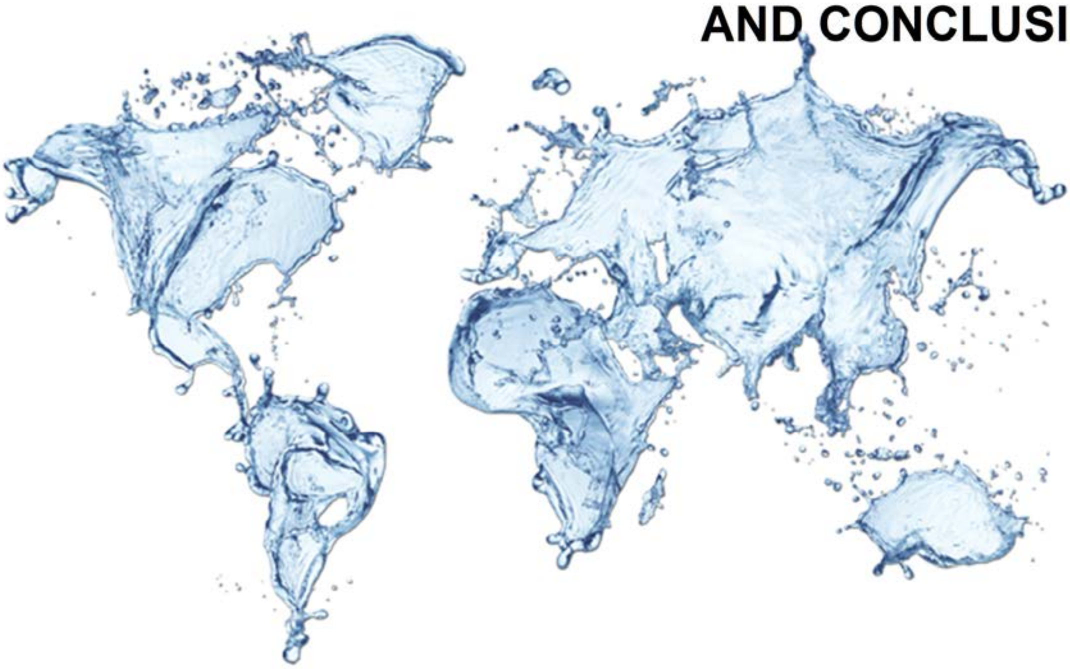
From the case studies, it is shown that the load shift had no effect on the water quality. Thus, a load shift can be done in the WTW ER as well. Due to company approval processes the tests could not be done on WTW Z or WTW V. If the capacity of WTW Z is upgraded, a project can safely be done. A test was done on BPS M but is not included in the case studies since a station trip occurred before the test was completed.

4.6 Conclusion

The effect of variable flow due to load shifting for two hours will not have any effect as indicated by historical occurrences. There will not be enough time for the water to be stagnant to an extent that it will influence the quality of the water. Load shifting on the water treatment works will limit the amount of water pumped from the booster pump stations. All filters and settling tanks will be able to handle the low flow.

5

RECOMMENDATIONS AND CONCLUSION



Chapter 5: The overview and conclusions of the chapters are discussed in this chapter. A clear conclusion will be made. Recommendation for future work is discussed.

CHAPTER 5: RECOMMENDATIONS AND CONCLUSION

5.1 Overview

Chapter 1 gave a brief introduction to the LPWU. The scale of the operations was emphasised. The LPWU supplies water to 4 provinces and millions of users. The reason for the viability of this project, is the increases in the electricity price. In the last decade, the price of electricity on the Megaflex tariff increased by 270% during the Eskom evening peak period.

A load shifting project would still ensure that the amount of water the LPWU needs to supply, is sustained daily. The period during which the majority of the water will be pumped, will be moved out of the peak period to the off-peak and standard periods. With the major increase in the electricity price and the high cost during the Eskom evening peak period, savings that will make the project feasible are ensured.

If the load is shifted from the Eskom evening peak period to other times of the day, the reduction and recovery of the load may not affect the water quality. The Blue Drop award is the highest award for water quality in South Africa. The LPWU holds the award to a high honor. 30% of the Blue Drop award is based on the quality of the water that is pumped to consumers daily. These standards will be the focus of the investigation.

The water situation in South Africa is dire. With below average rainfall and arid areas, water needs to be pumped over hundreds of kilometers to the consumers in drier regions. It was established that only 15% of the potable water that is supplied by the LPWU, was used for human consumption. Households with gardens use up to 46% of potable water for gardening. Savings among consumers could relieve the water situation.

The LPWU uses several different types of pumps to distribute the potable water to its consumers. Maintenance of the pumps are on international standards but can be improved. The improvements will be implemented with the load shifting project. Double stage double suction horizontal centrifugal pump sets are used to overcome the head required where the BPS pump to reservoirs are located at high altitudes.

Where the head is insignificant, the stations use single stage pumps. In some cases, the smaller single stage pumps are used in an area with a low demand. The LPWU utilises pipelines ranging from 600mm to 4500mm. The system has 58 strategically placed reservoirs that form part of the responsibility of the LPWU. The size of the reservoirs varies between 650 Ml and 30 Ml. The BPS each has onsite balancing reservoirs except BPS Z, which uses the DS reservoir as storage capacity.

The objective of the dissertation was to prove that a load shift would not have an effect on the water quality. The primary concern was that the change in flow would affect the WTW and the dosing at the BPS. One of the personnel had a concern that the water would become stagnant during the load shift.

Chapter 2 gave an insight into the water treatment process. From where raw water enters the plant to where it meets the consumer, WTW Z can absorb the load shift. The amount of flow reduced is negligible to the daily capacity. The sumps before the pump stations at WTW Z ER4 are 80 Ml. The sumps will be able to absorb the reduced pumping during the Eskom evening peak period.

In South Africa, no project or research has been done on load shifting in a potable water distribution networks of this magnitude. The author investigated similar studies with smaller pump stations and installed capacities. First, it was investigated if a load shifting project is possible on a small potable water network. It was concluded that a cost savings intervention was possible without interrupting the supply to the WTW by using on-site storage.

Load shifting done on a pumping network was investigated. The study established a load shift is possible on the network. The feasibility of the study done on the network aided to establish if a load shifting project would be financially feasible. The effects of load shifting on a pumping network in a mine were investigated.

Although the size of the system and constraints were different, it could be established that if the entire station was switched off it would influence the water quality negatively. In the last study, it was proved that load shifting is possible in a municipal water treatment plant with similar treatment processes.

It was concluded that the simulation software used is a reliable estimation and can be used for this dissertation. The study concluded that the WTW would be able to absorb the change in the flow. The dosage at the BPS would not be influenced since it is added per volume of water.

Chapter 3 stated the methodology on how an investigation should be conducted on a large potable water distrubution network. The main areas of focus should be in doing an in-depth site investigation. The smaller details and site specific constraints need to be noted. Having meetings and interviews with personnel on-site is crucial to the success of a site investigation.

After the investigations were done, a simulation with the mentioned parameters could be done. By hard coding the parameters and small details into the simulation, it was possible to establish the load shifting capacity accurately without influencing the water quality. The investigation results and the simulation results had >95% overall accuracy.

The author investigated the results of the simulations by conducting a second investigation. The simulation results were deemed accurate. It was concluded that a 35.1 MW load shifting would be possible on the LPWU. The tests were conducted on the BPS and the savings were verified. Tests could not be conducted on the WTW due to the unwillingness of the client. It was established that 19 MW was possible on the sites where the tests were allowed.

Chapter 4 had three case studies to determine if the cost saving intervention would have an effect on the water quality. Historical data was used to establish if a variation in load would have an effect on the water quality and the overall operations of the WTW. Case Study 1 focused on a reduction of 300 Ml/day. The water quality reports of the client showed no discrepancies in the water quality during the day.

Case study 2 was done on WTW Z ER4, where the entire ER was down. The flow rate varied between 1800 Ml/day and 0 Ml/day. During the reduction, no change was observed in the water quality reports. After the operations had been returned to normal, again no discrepancies were noticed in the water quality report for the following two days. Concluding that a variation in load that is planned would have no effect on the potable water quality.

Case study 3 indicated that load shifting would be possible on the BPS without influencing the WTW. A test was arranged on each of the BPS. BPS Z realised an 11.1 MW load shift by reducing the flow by 200 Ml/day without influencing the water quality. Throughout the day, the quality was 99.31% compliant which is well within the limits of the LPWU. The test on BPS E realised a 5.5 MW saving by reducing the flow by 200 Ml/day and the water quality was 100% compliant.

On BPS P, it was decided to reduce the load by 90 Ml/day which resulted in a 2 MW load shifting during the Eskom evening peak period. The station has a daily and maximum output of 1 660 Ml/day. The influence of the 90 Ml/day could not be noticed in the water quality report and the quality was 100% compliant.

It was concluded that the test would be possible on BPS M as well. If permission could be obtained from the operations department to conduct a test at WTW Z, it would have had no effect on the water quality. A load shift would not be possible on WTW V due to small sumps and outdated infrastructure.

5.2 Conclusion

A load shifting project would be possible on the LPWU without influencing the potable water quality. A variation in flow at WTW Z would have no effect on the water quality. The normal operations of the LPWU are more erratic than a planned load shift for two hours. A loadshift is not possible on WTW V due to capacity constraints and old infrastructure.

The demand from the consumers does not stop at any point in time. Thus, no water will become stagnant in the downstream reservoirs. The pumping will only be reduced by a small portion and not shut off. This small reduction has a negligible effect on the flow of the water. At BPS a load shift is possible without influencing the WTW. The control valves of the chlorine and ammonia dosage would be able to absorb the excess flow. The results of the test are shown in Table 18.

Table 18: Summary of results

Station	Simulation results (MW)	Investigation results (MW)	Actual Results (MW)	Water Quality compliance
WTW Z	12.1	12.5	0 (6 MW historical data)	100%
WTW V	0	0	0	-
BPS E	5.8	6	5.9	99.31%
BPS Z	11.2	11.6	11.1	100%
BPS P	2.3	2.5	2.0	100%
BPS M	3.7	3.5	0	-
Total	35.1	36.1	29.4	99.83%

The savings achieved, investigated values and simulated values, are within >95% accuracy of one another. The water quality was within the set limits, which provided proof that the simulation and investigation were done within the parameters of the water treatment plant and equipment. Thus, a load shift will have no effect on the potable water quality.

5.3 Recommendations for further work

Throughout the study limiting factors was identified to increase the load shifting capabilities with regards to the water quality. For future studies, the maintenance of the LPWU can be synchronised with the tariff structures to increase savings without having an effect on the operations and water quality. The further investigation of load shifting on the WTW equipment may yield good results. Changing the schedule of the backwash pumps in the filter house and sludge pumps, should be investigated as well.

In potable water networks, the demand is seasonal. The effect of seasons should be investigated. In the high demand months, the load shift may place unnecessary pressure on the purification equipment and compromise water quality. Low temperatures in winter can have an effect on the chemical reactions in the WTW. The low temperatures can affect the coagulation, flocculation, carbonation and sterilisation. If the process is slower due to the low temperatures, the load shift savings may be influenced.

The study proved that a load shift within the parameters will not have an effect on the water quality. Further study may be done to optimise the entire network from the raw water source to the consumer. If the system is viewed holistically, greater savings can be achieved with no adverse effect on the water quality. Future investigation into the usage of grey water in the industrial sector should be done.

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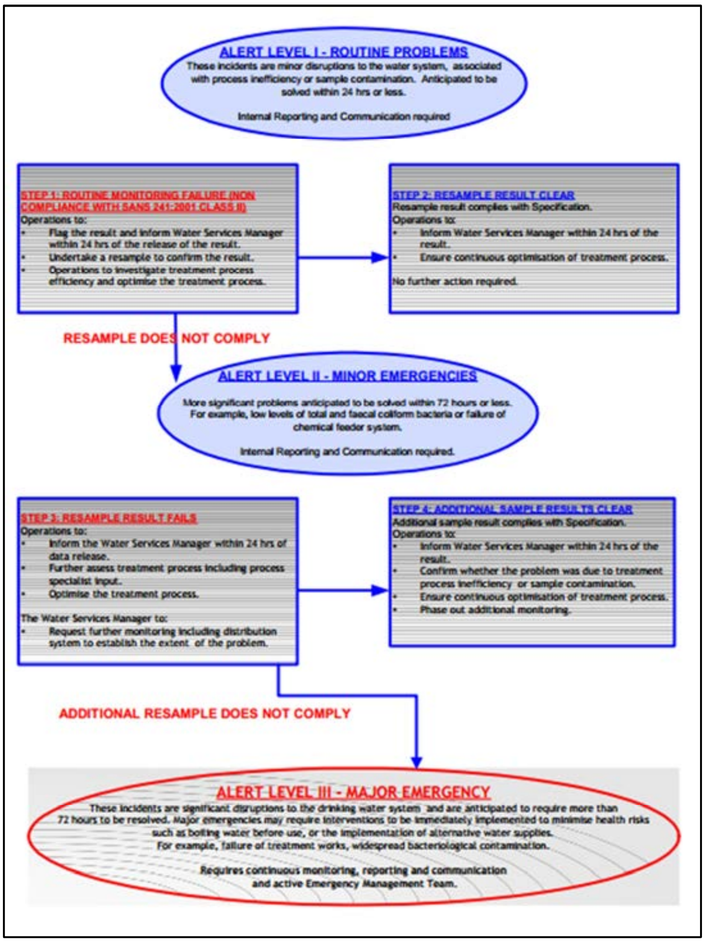
APPENDIX A

Table 19: Microbiological safety requirements [13]

1	2	3	4	5
Determinand	**Unit**	**Allowable compliance contribution**[a]		
		95% of samples, min.	**4% of samples, max.**	**1% of samples, max.**
		Upper limits		
E. coli[b] or	count/100 mL	Not detected	Not detected	1
Thermotolerant (faecal) coliform bacteria[c]	count/100 mL	Not detected	1	10

[a] The allowable compliance contribution shall be at least 95 % to the limits indicated in column 3, with a maximum of 4 % and 1 %, respectively, to the limits indicated in column 4 and column 5. The objective of disinfection should, nevertheless, be to attain 100 % compliance to the limits indicated in column 3.
[b] Definitive, preferred indicator of faecal pollution.
[c] Indicator of unacceptable microbial water quality, could be tested instead of *E. coli* but is not the preferred indicator of faecal pollution. Also provides information on treatment efficiency and aftergrowth in distribution networks.

Figure 52: Acute drinking water quality failure model – response actions



APPENDIX B

Table 20: BPS Z test results

Profile Download for BPS Z Total

Group Utility : Electricity **Document Date:** 2009-06-09
Applicable Tariff : Eskom Megaflex 11kV, < 300km, > 1MVA 14/15

Period From : 2013-09-20 00:00 To 2013-09-21 00:00

Reading Date	Reading Time	h	Hour	kWh+	kW	Baseline	kVA
2013-09-20	00:00	0	0	8982.5	17965	23041.64	19139.61
2013-09-20	00:30	0		9990.51	19981.02	23096.83	21271.87
2013-09-20	01:00	1	1	10681.49	21362.98	23096.83	22714.75
2013-09-20	01:30	1		11279.53	22559.06	22978.86	23993.59
2013-09-20	02:00	2	2	12003.21	24006.42	22978.86	25500.59
2013-09-20	02:30	2		12583.67	25167.34	23207.33	26651.23
2013-09-20	03:00	3	3	13470.5	26941	23207.33	28562.64
2013-09-20	03:30	3		15151.89	30303.78	23013.92	32148.96
2013-09-20	04:00	4	4	15115.5	30231	23013.92	32041.99
2013-09-20	04:30	4		15051.15	30102.3	23024.37	31912.73
2013-09-20	05:00	5	5	15045.01	30090.02	23024.37	31869.24
2013-09-20	05:30	5		15119.85	30239.7	23470.39	32062.55
2013-09-20	06:00	6	6	15093.85	30187.7	23470.39	31962.21
2013-09-20	06:30	6		15146.63	30293.26	23562.48	32086.28
2013-09-20	07:00	7	7	15071.9	30143.8	23562.48	31897.12
2013-09-20	07:30	7		15124.05	30248.1	23164.33	32008.63
2013-09-20	08:00	8	8	15104.3	30208.6	23164.33	31975.57
2013-09-20	08:30	8		15113.61	30227.22	22680.1	31974.85
2013-09-20	09:00	9	9	15151.42	30302.84	22680.1	32085.88
2013-09-20	09:30	9		15152.68	30305.36	22506.08	32040.63
2013-09-20	10:00	10	10	15014.03	30028.06	22506.08	31747.8
2013-09-20	10:30	10		15008.03	30016.06	22680.55	31622.95
2013-09-20	11:00	11	11	15187.94	30375.88	22680.55	31965.6
2013-09-20	11:30	11		15226.52	30453.04	22393.98	32062.35
2013-09-20	12:00	12	12	15228.43	30456.86	22393.98	32114.42
2013-09-20	12:30	12		15192.4	30384.8	21943.35	32009.19
2013-09-20	13:00	13	13	15305.61	30611.22	21943.35	32271.81
2013-09-20	13:30	13		15152.05	30304.1	21664.68	31952.2
2013-09-20	14:00	14	14	15060.9	30121.8	21664.68	31773.88
2013-09-20	14:30	14		14404.28	28808.56	21485.1	30398.37
2013-09-20	15:00	15	15	12748.17	25496.34	21485.1	26913.24
2013-09-20	15:30	15		12780.15	25560.3	21372.29	26952.96
2013-09-20	16:00	16	16	12681.49	25362.98	21372.29	26730.29
2013-09-20	16:30	16		12745.18	25490.36	21825.7	26881.3
2013-09-20	17:00	17	17	12817.42	25634.84	21825.7	27023.6
2013-09-20	17:30	17		12811.23	25622.46	21931.45	27022.31
2013-09-20	18:00	18	18	7625.2	15250.4	21931.45	16194.25
2013-09-20	18:30	18		7627.58	15255.16	22012.58	16196.55
2013-09-20	19:00	19	19	7602.84	15205.68	22012.58	16145.25
2013-09-20	19:30	19		7626.59	15253.18	22427.3	16188.8
2013-09-20	20:00	20	20	10102.08	20204.16	22427.3	21460.85
2013-09-20	20:30	20		12862.59	25725.18	22927.8	27124.77
2013-09-20	21:00	21	21	12948.39	25896.78	22927.8	27290.33
2013-09-20	21:30	21		12888.07	25776.14	22910.43	27165.3
2013-09-20	22:00	22	22	12855.48	25710.96	22910.43	27103.98
2013-09-20	22:30	22		12803.53	25607.06	22946.43	27034.22
2013-09-20	23:00	23	23	12768.85	25537.7	22958.31	26960.05
2013-09-21	23:30	23		12845.82	25691.64	23041.64	27089.61

Table 21: BPS E test results

Profile Download for BPS E Total

Group Utility : Electricity **Document Date:** 2009-06-09

Applicable Tariff : City Power MV TOU 14/15

Period From : 2013-12-4 00:00 To 2013-12-5 00:00

Reading Date	Reading Time	h	Hour	kWh+	kW	Baseline	kVA
2013-12-04	00:00	0	0	17071.96	34143.92	33606.28	19139.61
2013-12-04	00:30	0		17083.77	34167.54	33592.01	21271.87
2013-12-04	01:00	1	1	16968.26	33936.52	33592.01	22714.75
2013-12-04	01:30	1		17086.75	34173.5	33523.33	23993.59
2013-12-04	02:00	2	2	17101.35	34202.7	33523.33	25500.59
2013-12-04	02:30	2		17048.73	34097.46	33517.07	26651.23
2013-12-04	03:00	3	3	17026.69	34053.38	33517.07	28562.64
2013-12-04	03:30	3		17013.63	34027.26	33541.74	32148.96
2013-12-04	04:00	4	4	17033.52	34067.04	33541.74	32041.99
2013-12-04	04:30	4		16944.67	33889.34	33510.29	31912.73
2013-12-04	05:00	5	5	16900.9	33801.8	33510.29	31869.24
2013-12-04	05:30	5		17179.95	34359.9	33494.35	32062.55
2013-12-04	06:00	6	6	17187.88	34375.76	33494.35	31962.21
2013-12-04	06:30	6		17121.8	34243.6	33431.2	32086.28
2013-12-04	07:00	7	7	17140.5	34281	33431.2	31897.12
2013-12-04	07:30	7		17135.7	34271.4	33447.91	32008.63
2013-12-04	08:00	8	8	17102.47	34204.94	33447.91	31975.57
2013-12-04	08:30	8		17206.15	34412.3	33573.47	31974.85
2013-12-04	09:00	9	9	17117.65	34235.3	33573.47	32085.88
2013-12-04	09:30	9		17150.85	34301.7	33564.08	32040.63
2013-12-04	10:00	10	10	17067.3	34134.6	33564.08	31747.8
2013-12-04	10:30	10		17068.76	34137.52	33576.06	31622.95
2013-12-04	11:00	11	11	17055.95	34111.9	33576.06	31965.6
2013-12-04	11:30	11		17130.25	34260.5	33535.49	32062.35
2013-12-04	12:00	12	12	17138.31	34276.62	33535.49	32114.42
2013-12-04	12:30	12		17071.31	34142.62	33596.8	32009.19
2013-12-04	13:00	13	13	17045.9	34091.8	33596.8	32271.81
2013-12-04	13:30	13		17020.9	34041.8	33572.13	31952.2
2013-12-04	14:00	14	14	16912.3	33824.6	33572.13	31773.88
2013-12-04	14:30	14		17090.97	34181.94	33529.94	30398.37
2013-12-04	15:00	15	15	16987.64	33975.28	33529.94	26913.24
2013-12-04	15:30	15		17075.91	34151.82	33555.64	26952.96
2013-12-04	16:00	16	16	16149.6	32299.2	33555.64	26730.29
2013-12-04	16:30	16		17057.17	34114.34	33569.34	26881.3
2013-12-04	17:00	17	17	17100.41	34200.82	33569.34	27023.6
2013-12-04	17:30	17		17097.19	34194.38	33502.49	27022.31
2013-12-04	18:00	18	18	14099.11	28198.22	33502.49	16194.25
2013-12-04	18:30	18		13921.82	27843.64	33616.09	16196.55
2013-12-04	19:00	19	19	13911.52	27823.04	33616.09	16145.25
2013-12-04	19:30	19		14067.76	28135.52	33549.49	16188.8
2013-12-04	20:00	20	20	15175.08	30350.16	33549.49	21460.85
2013-12-04	20:30	20		17219.1	34438.2	33576.4	27124.77
2013-12-04	21:00	21	21	17196.3	34392.6	33576.4	27290.33
2013-12-04	21:30	21		17158.76	34317.52	33615.45	27165.3
2013-12-04	22:00	22	22	17174.38	34348.76	33615.45	27103.98
2013-12-04	22:30	22		17112.55	34225.1	33561.66	27034.22
2013-12-04	23:00	23	23	17057.96	34115.92	33561.66	26960.05
2013-12-05	23:30	23		17044.74	34089.48	33606.28	27089.61

Table 22:BPS P test results

Profile Download for BPS P Total

Group Utility : Electricity **Document Date:** 2009-06-09

Applicable Tariff : Eskom Megaflex <300km >500,66kV Key Rand Water 14/

Period From : 2013-10-29 00:00 To 2013-10-30 00:00

Reading Date	Reading Time	h	Hour	kWh+	kW	Baseline	kVA
2013-10-29	00:00	0	0	18318.45	36636.9	39216.16	19139.61
2013-10-29	00:30	0		18380.2	36760.4	39216.16	21271.87
2013-10-29	01:00	1	1	18269.8	36539.6	39331.41	22714.75
2013-10-29	01:30	1		18349.1	36698.2	39331.41	23993.59
2013-10-29	02:00	2	2	18325.15	36650.3	39355.62	25500.59
2013-10-29	02:30	2		18314.05	36628.1	39355.62	26651.23
2013-10-29	03:00	3	3	18142.75	36285.5	39318.85	28562.64
2013-10-29	03:30	3		18254.35	36508.7	39318.85	32148.96
2013-10-29	04:00	4	4	18227.8	36455.6	39390.41	32041.99
2013-10-29	04:30	4		18137.8	36275.6	39390.41	31912.73
2013-10-29	05:00	5	5	18154.7	36309.4	39500.93	31869.24
2013-10-29	05:30	5		18186.05	36372.1	39500.93	32062.55
2013-10-29	06:00	6	6	18222.3	36444.6	39437.75	31962.21
2013-10-29	06:30	6		18225.6	36451.2	39437.75	32086.28
2013-10-29	07:00	7	7	18167.2	36334.4	39219.73	31897.12
2013-10-29	07:30	7		18081.65	36163.3	39219.73	32008.63
2013-10-29	08:00	8	8	18098.4	36196.8	38916.98	31975.57
2013-10-29	08:30	8		18127.15	36254.3	38916.98	31974.85
2013-10-29	09:00	9	9	18214.3	36428.6	38685.81	32085.88
2013-10-29	09:30	9		18142.95	36285.9	38685.81	32040.63
2013-10-29	10:00	10	10	18121.35	36242.7	38654.39	31747.8
2013-10-29	10:30	10		18096.8	36193.6	38654.39	31622.95
2013-10-29	11:00	11	11	18095.4	36190.8	38640.08	31965.6
2013-10-29	11:30	11		18214.1	36428.2	38640.08	32062.35
2013-10-29	12:00	12	12	18224.95	36449.9	38664.54	32114.42
2013-10-29	12:30	12		17929.6	35859.2	38664.54	32009.19
2013-10-29	13:00	13	13	18228.15	36456.3	38743.83	32271.81
2013-10-29	13:30	13		18137.45	36274.9	38743.83	31952.2
2013-10-29	14:00	14	14	18169	36338	38689.86	31773.88
2013-10-29	14:30	14		18190.85	36381.7	38689.86	30398.37
2013-10-29	15:00	15	15	18121.35	36242.7	38603.55	26913.24
2013-10-29	15:30	15		18122.95	36245.9	38603.55	26952.96
2013-10-29	16:00	16	16	18252.75	36505.5	38607.95	26730.29
2013-10-29	16:30	16		18237.2	36474.4	38607.95	26881.3
2013-10-29	17:00	17	17	18201.05	36402.1	38723.92	27023.6
2013-10-29	17:30	17		18247.3	36494.6	38723.92	27022.31
2013-10-29	18:00	18	18	17088.35	34176.7	38771.4	16194.25
2013-10-29	18:30	18		17100.1	34200.2	38771.4	16196.55
2013-10-29	19:00	19	19	17196.05	34392.1	38687.2	16145.25
2013-10-29	19:30	19		17305.35	34610.7	38687.2	16188.8
2013-10-29	20:00	20	20	17172.6	34345.2	38747.09	21460.85
2013-10-29	20:30	20		17412.95	34825.9	38747.09	27124.77
2013-10-29	21:00	21	21	19947	39894	39081.57	27290.33
2013-10-29	21:30	21		20538.85	41077.7	39081.57	27165.3
2013-10-29	22:00	22	22	20940.15	41880.3	39103.77	27103.98
2013-10-29	22:30	22		20998.15	41996.3	39103.77	27034.22
2013-10-29	23:00	23	23	21001.95	42003.9	39169.83	26960.05
2013-10-30	23:30	23		20925.45	41850.9	39169.83	27089.61

APPENDIX C

Table 23: WTW Z water quality report on 15 July 2013

					DATE: 15 July 2012				
Time	B1 pH	B2 pH	B4 pH	B6 pH	B7 pH	B8 pH	B10 pH	B12 pH	B15pH
02:00	8.2	8.1	7.9	8.0	off	8.2	8.3	8.6	8.5
04:00	8.1	8.1	7.9	8.0	off	8.2	8.3	8.6	8.5
06:00	8.1	8.0	7.8	8.0	off	8.2	8.3	8.5	8.6
08:00	8.1	8.1	7.9	8.0	off	8.1	8.3	8.5	8.6
10:00	8.3	8.2	7.9	8.0	off	8.2	8.2	8.4	8.4
12:00	8.3	8.2	7.9	8.0	off	8.3	8.3	8.5	8.6
14:00	8.3	8.3	7.9	8.0	off	8.3	8.3	8.6	8.6
16:00	8.2	8.2	7.9	8.0	off	8.3	8.4	8.6	8.5
18:00	8.2	8.1	7.9	8.0	off	8.2	8.4	8.5	8.5
20:00	8.2	8.1	7.9	8.0	off	8.2	8.3	8.4	8.4
22:00	8.2	8.1	8.0	8.0	off	8.0	8.4	8.5	8.4
00:00	8.2	8.2	7.9	8.1	off	8.1	8.5	8.6	8.5
Min	8.1	8.0	7.8	8.0	0.0	8.0	8.2	8.4	8.4
Max	8.3	8.3	8.0	8.1	0.0	8.3	8.5	8.6	8.6
Avg	8.2	8.1	7.9	8.0	#DIV/0!	8.2	8.3	8.5	8.5
Not compliant	0	0	0	0	0	0	0	0	0
Not compliant	0	0	0	0	0	0	0	0	0
# Samples	12	12	12	12	0	12	12	12	12
Time	B1 Turb	B2 Turb	B4 Turb	B6 Turb	B7 Turb	B8 Turb	B10 Turb	B12 Turb	B15 Turb
02:00	0.10	0.12	0.09	0.10	off	0.09	0.10	0.09	0.14
04:00	0.09	0.10	0.09	0.10	off	0.09	0.11	0.10	0.13
06:00	0.08	0.10	0.09	0.09	off	0.09	0.10	0.09	0.13
08:00	0.08	0.10	0.10	0.10	off	0.10	0.10	0.09	0.12
10:00	0.08	0.10	0.10	0.10	off	0.10	0.10	0.09	0.12
12:00	0.08	0.10	0.10	0.10	off	0.10	0.10	0.08	0.12
14:00	0.09	0.10	0.11	0.12	off	0.10	0.11	0.09	0.12
16:00	0.09	0.10	0.10	0.11	off	0.08	0.11	0.09	0.12
18:00	0.09	0.10	0.11	0.11	off	0.10	0.11	0.09	0.12
20:00	0.09	0.10	0.10	0.10	off	0.08	0.11	0.09	0.13
22:00	0.09	0.10	0.10	0.10	off	0.09	0.11	0.09	0.13
00:00	0.09	0.11	0.10	0.11	off	0.09	0.11	0.10	0.13
Min	0.08	0.10	0.09	0.09	0.00	0.08	0.10	0.08	0.12
Max	0.10	0.12	0.11	0.12	0.00	0.10	0.11	0.10	0.14
Avg	0.09	0.10	0.10	0.10	#DIV/0!	0.09	0.11	0.09	0.13
Not compliant	0	0	0	0	0	0	0	0	0
# Samples	12	12	12	12	0	12	12	12	12
Time	B1 CL_2	B2 CL_2	B4 Cl_2	B6 Cl_2	B7 CL_2	B8 CL_2	B10 CL_2	B12 CL_2	B15 CL_2
02:00	1.5	1.6	1.6	1.6	off	2.0	1.8	1.6	1.4
04:00	1.6	1.6	1.6	1.5	off	1.8	1.9	1.7	1.6
06:00	1.5	1.6	1.6	1.5	off	2.0	2.0	1.7	1.3
08:00	1.5	1.5	1.6	1.5	off	1.8	2.0	1.7	1.3
10:00	1.5	1.5	1.8	1.5	off	1.9	2.0	1.9	1.7
12:00	1.5	1.5	1.7	1.5	off	1.7	1.7	1.7	1.4
14:00	1.5	1.5	1.5	1.5	off	1.8	1.7	1.7	1.6
16:00	1.5	1.5	1.5	1.5	off	1.9	1.6	1.6	1.6
18:00	1.5	1.5	1.5	1.5	off	1.8	1.6	1.6	1.6
20:00	1.5	1.5	1.4	1.5	off	1.8	1.6	1.6	1.6
22:00	1.5	1.5	1.5	1.5	off	1.8	1.6	1.6	1.6
00:00	1.5	1.5	1.5	1.5	off	1.9	1.5	1.4	1.4
Min	1.5	1.5	1.4	1.5	0.0	1.7	1.5	1.4	1.3
Max	1.6	1.6	1.8	1.6	0.0	2.0	2.0	1.9	1.7
Avg	1.5	1.5	1.6	1.5	#DIV/0!	1.9	1.8	1.7	1.5
Not compliant	0	0	0	0	0	0	0	0	0
# Samples	12	12	12	12	0	12	12	12	12

Table 24: WTW Z water quality report on 23 May 2013

DAILY WATER QUALITY REPORT

DATE: 23 May 2013

pH (specification: 7.60 - 8.80)

	B1	B2	B4	B6	B7	B8	B10	B12	B15	
Min	8.3	8.3	7.9	8.1	7.9	8.3	8.3	8.1	8.0	
MAX	8.7	8.6	8.3	8.5	8.3	8.5	8.4	8.4	8.4	
Hourly average	8.5	8.4	8.1	8.3	8.1	8.4	8.3	8.3	8.2	pH: Ave Compliant
% compliance (7.6 - 8.8)	100	100	100	100	100	100	100	100	100	100
% non-compliance > 8.8	0	0	0	0	0	0	0	0	0	
% non-compliance < 7.6	0	0	0	0	0	0	0	0	0	
Tot samples: (7.6 - 8.8)	12	12	12	12	12	12	12	12	12	
Tot samples > 8.8	0	0	0	0	0	0	0	0	0	
Tot samples < 7.6	0	0	0	0	0	0	0	0	0	
Total samples	12	12	12	12	12	12	12	12	12	

TURBIDITY (specification: <0.5 NTU)

	B1	B2	B4	B6	B7	B8	B10	B12	B15	
MIN	0.20	0.18	0.19	0.17	0.20	0.27	0.15	0.12	0.13	
MAX	0.31	0.29	0.21	0.18	0.32	0.52	0.19	0.15	0.18	
Hourly average	0.24	0.23	0.20	0.18	0.24	0.39	0.17	0.14	0.15	Turb: Ave Compliant
%compliance	100	100	100	100	100	75	100	100	100	97
Tot compliant(<0.5)	12	12	12	12	12	9	12	12	12	
Total samples	12	12	12	12	12	12	12	12	12	

RESIDUAL CHLORINE (specification: 0.80-4.0 mg/l as free chlorine)

	B1	B2	B4	B6	B7	B8	B10	B12	B15	
MIN	1.5	1.5	1.7	1.3	1.5	1.6	1.0	1.5	1.3	
MAX	1.6	1.7	2.7	1.5	1.8	2.1	1.7	1.8	1.8	
Hourly average	1.5	1.6	2.4	1.4	1.6	1.8	1.6	1.7	1.6	Cl2: Ave Compliant
%compliance	100	100	100	100	100	100	100	100	100	100
Total compliant	12	12	12	12	12	12	12	12	12	
Total samples	12	12	12	12	12	12	12	12	12	

Table 25: WTW Z water quality report on 24 May 2012

DATE: 24 HOURS: FROM 00:00 - 24:00 OF05/24/2012

pH (Specification: 7.600 - 8.800)

	B1	B2	B4	B6	B7	B8	B10	B12	B15	
Min	7.04	6.92	7.06	6.78	6.67	7.65	7.59	7.90	7.95	
Max	8.21	8.20	8.32	8.29	8.29	7.66	8.20	8.52	8.71	
24 hr Average	8.15	8.14	8.05	8.13	8.12	7.65	7.87	8.26	8.39	2.30
Standard Deviation	0.07	0.09	0.13	0.12	0.12	0.00	0.13	0.12	0.15	0.03
%Compliance (7.6 - 8.8)	100	99	99	99	99	100	99	100	100	99.65
%Non Compliance > 8.8	0	0	0	0	0	0	0	0	0	
%Non Compliance < 7.6	0	1	1	1	1	0	1	0	0	
Total Sapmles (7.6 - 8.8)	2871	2864	2845	2855	2860	2881	2852	2881	2881	
Total Samples > 8.8	0	0	0	0	0	0	0	0	0	
Total Samples < 7.6	10	17	36	26	21	0	29	0	0	
Total Samples	2881	2881	2881	2881	2881	2881	2881	2881	2881	
Volume in Ml	191	180	189	191	0	601	522	1167	104	3145

TURBIDITY (Specification: < 00.5 NTU)

	B1	B2	B4	B6	B7	B8	B10	B12	B15	
Min	0.19	0.17	0.08	0.09	0.08	0.09	0.13	0.11	0.12	
Max	0.49	0.45	0.16	0.13	0.30	0.13	0.31	0.26	0.27	
24 hr Average	0.26	0.24	0.09	0.11	0.12	0.10	0.17	0.14	0.16	0.04
Standard Deviation	0.06	0.06	0.01	0.01	0.02	0.01	0.05	0.00	0.00	0.01
%Compliance (00 - 00.5)	100	100	100	100	100	100	100	100	100	100.00
%Non Compliance > 00.5	0	0	0	0	0	0	0	0	0	
%Non Compliance < 00	0	0	0	0	0	0	0	0	0	
Total Sapmles (00 - 00.5)	2881	2881	2881	2881	2881	2881	2881	2881	2881	
Total Samples > 00.5	0	0	0	0	0	0	0	0	0	
Total Samples < 00	0	0	0	0	0	0	0	0	0	
Total Samples	2881	2881	2881	2881	2881	2881	2881	2881	2881	
Volume in Ml	191	180	189	191	0	601	522	1167	104	3145

RESIDUAL CHLORINE (Specification: 00.800 - 4.0000 mg/l as free chlorine)

	B1	B2	B4	B6	B7	B8	B10	B12	B15	
Min	1.94	1.93	1.40	1.57	1.80	-1.25	-1.25	-1.25	-1.25	
Max	2.14	2.12	2.79	2.78	2.28	-1.25	-1.25	-1.25	-1.25	
24 hr Average	2.03	2.00	1.95	1.98	2.06	-1.25	-1.25	-1.25	-1.25	0.32
Standard Deviation	0.04	0.02	0.17	0.12	0.09	0.00	0.00	0.00	0.00	0.01
%Compliance (00.8 - 4.00)	100	100	100	100	100	0	0	0	0	23.93
%Non Compliance > 4.00	0	0	0	0	0	0	0	0	0	
%Non Compliance < 00.8	0	0	0	0	0	100	100	100	100	
Total Sapmles (00.8 - 4.00)	2881	2881	2881	2881	2881	2	2	2	2	
Total Samples > 4.00	0	0	0	0	0	0	0	0	0	
Total Samples < 00.8	0	0	0	0	0	2879	2879	2879	2879	
Total Samples	2881	2881	2881	2881	2881	2881	2881	2881	2881	
Volume in Ml	191	180	189	191	0	601	522	1167	104	3145

Table 26: WTW Z water quality report 25 May 2012

DAILY WATER QUALITY REPORT
DATE: 24 HOURS: FROM 00:00 - 24:00 OF05/25/2012

pH (Specification: 7.600 - 8.800)

	B1	B2	B4	B6	B7	B8	B10	B12	B15	
Min	6.86	6.92	6.98	7.05	6.83	5.31	6.35	6.81	6.91	
Max	8.34	8.21	8.44	8.33	8.55	8.74	8.32	8.53	8.67	
24 hr Average	8.07	8.05	8.02	7.99	8.28	8.39	8.00	8.31	8.44	#VALUE!
Standard Deviation	0.09	0.08	0.13	0.12	0.14	0.18	0.15	0.10	0.12	#VALUE!
%Compliance (7.6 - 8.8)	99	100	100	99	100	100	99	100	100	#VALUE!
%Non Compliance > 8.8	0	0	0	0	0	0	0	0	0	
%Non Compliance < 7.6	1	0	0	1	0	0	1	0	0	
Total Sapmles (7.6 - 8.8)	2863	2867	2867	2862	2870	2868	2862	2874	2874	
Total Samples > 8.8	0	0	0	0	0	0	0	0	0	
Total Samples < 7.6	18	14	14	19	11	13	19	7	7	
Total Samples	2881	2881	2881	2881	2881	2881	2881	2881	2881	
Volume in Ml	192	181	182	211	###	599	529	1169	105	#VALUE!

TURBIDITY (Specification: < 00.5 NTU)

	B1	B2	B4	B6	B7	B8	B10	B12	B15	
Min	0.17	0.17	0.08	0.07	0.10	0.09	0.11	0.10	0.12	
Max	0.30	0.27	0.10	0.18	0.15	0.26	0.23	0.47	0.91	
24 hr Average	0.20	0.19	0.09	0.09	0.11	0.11	0.12	0.11	0.13	#VALUE!
Standard Deviation	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.00	0.00	#VALUE!
%Compliance (00 - 00.5)	100	100	100	100	100	100	100	100	100	#VALUE!
%Non Compliance > 00.5	0	0	0	0	0	0	0	0	0	
%Non Compliance < 00	0	0	0	0	0	0	0	0	0	
Total Sapmles (00 - 00.5)	2881	2881	2881	2881	2881	2881	2881	2881	2872	
Total Samples > 00.5	0	0	0	0	0	0	0	0	9	
Total Samples < 00	0	0	0	0	0	0	0	0	0	
Total Samples	2881	2881	2881	2881	2881	2881	2881	2881	2881	
Volume in Ml	192	181	182	211	###	599	529	1169	105	#VALUE!

RESIDUAL CHLORINE (Specification: 00.800 - 4.0000 mg/l as free chlorine)

	B1	B2	B4	B6	B7	B8	B10	B12	B15	
Min	1.47	1.41	1.29	1.27	0.00	0.00	-1.25	-1.25	-1.25	
Max	1.76	1.71	2.15	1.75	0.03	0.03	-1.25	-1.25	-1.25	
24 hr Average	1.70	1.62	1.67	1.54	0.00	0.00	-1.25	-1.25	-1.25	#VALUE!
Standard Deviation	0.03	0.04	0.11	0.09	0.00	0.00	0.00	0.00	0.00	#VALUE!
%Compliance (00.8 - 4.00)	100	100	100	100	0	0	0	0	0	#VALUE!
%Non Compliance > 4.00	0	0	0	0	0	0	0	0	0	
%Non Compliance < 00.8	0	0	0	0	100	100	100	100	100	
Total Sapmles (00.8 - 4.00)	2881	2881	2881	2881	10	10	2	2	2	
Total Samples > 4.00	0	0	0	0	0	0	0	0	0	
Total Samples < 00.8	0	0	0	0	2871	2871	2879	2879	2879	
Total Samples	2881	2881	2881	2881	2881	2881	2881	2881	2881	
Volume in Ml	192	181	182	211	###	599	529	1169	105	#VALUE!

Table 27: BPS Z water quality report on 20 September 2013

DATE 20-~~Aug~~-13 Sep

	PIPELINE							MAGFLOW							
TIME	A6	A8	A10	B1	B2	C11 MONO	C24 MONO	A6	A8	A10	B1	B2	COMPLY	COMPLY	TOTAL
07:00	0.66	0.69	0.78	0.62	0.64	1.36	1.39	51	89	301	100	107	SAMPLES ABOVE	SAMPLES BELOW	SAMPLES
09:00	0.65	0.67	0.79	0.64	0.67	1.43	1.47	52	92	308	102	110	0	2	2
11:00	0.63	0.64	0.78	0.65	0.69	1.37	1.41	53	93	313	105	112			
13:00	0.64	0.65	0.79	0.65	0.68	1.39	1.35	54	93	312	103	113			
15:00	1.00	1.01	0.75	0.78	0.73	1.49	1.47	46	82	271	88	96			
17:00	0.93	0.97	0.81	0.70	0.65	1.55	1.57	47	83	272	89	96			
19:00	0.88	0.90	0.83	0.69	0.71	1.59	1.60	46	82	273	90	97	% ABOVE	% BELOW	%
21:00	0.78	0.83	0.80	0.71	0.70	1.57	1.59	46	82	272	89	97	0.00	0.69	0.35
23:00	0.79	0.77	0.69	0.58	0.61	1.49	1.47	46	81	269	105	113			
01:00	0.64	0.61	0.71	0.77	0.60	1.64	1.54	54	94	315	104	114			
03:00	0.70	0.75	0.86	0.71	0.64	1.49	1.48	54	94	315	104	114			
05:00	1.25	1.13	0.83	0.73	0.72	1.46	1.43	55	95	319	104	114			

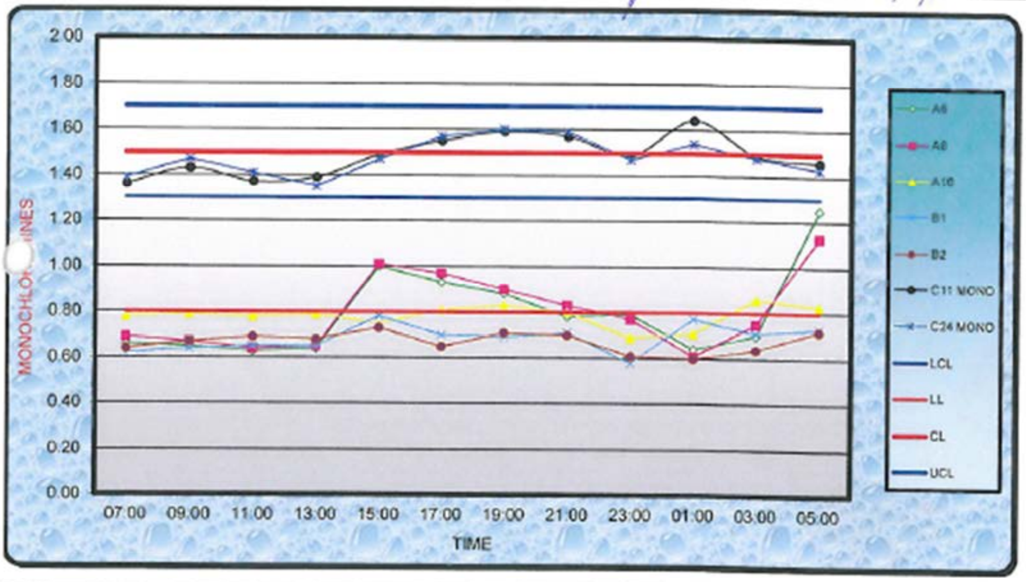
CAPTURED BY:

SIGN: DATE: 23/09/2013

REMARKS: SENIOR PROCESS SUPERVISOR

Water quality in spec.

SIGN: DATE: 24/09/2013



REMARKS: PROCESS COORDINATOR

SIGN: DATE: 2013/09/25

REMARKS: OPERATIONS MANAGER

Lab notified

SIGN: DATE: 7/10/2013

Table 28: BPS E water quality report on 5 November 2013

PIPELINE / RESERVOIR

TIME	A19	B7	B14	Q1 MONO	Q2 MONO	Q3 MONO	Q4 MONO	Q5 MON	R1	R2	R3
07:00	0.87	0.30	0.75	1.82	2.09	2.20	2.20	1.39	1.18	1.45	1.19
09:00	0.77	0.30	0.88	1.69	1.62	2	2.03	1.13	1.37	1.78	1
11:00	0.76	0.30	0.86	1.53	1.52	1.5	1.66	1.62	1.47	1.47	0.98
13:00	0.74	0.33	0.83	1.65	1.56	1.54	1.56	1.52	1.59	1.6	1.14
15:00	0.63	0.12	0.81	1.9	1.82	1.9	1.83	1.57	1.49	1.12	1.14
17:00	0.72	0.25	0.77	1.59	1.57	1.51	1.5	1.5	1.6	1.31	1.32
19:00	0.68	0.36	0.74	1.58	1.57	1.63	1.59	1.86	1.59	1.64	1.3
21:00	0.67	0.38	0.74	1.69	1.6	1.66	1.69	1.82	1.57	1.61	1.39
23:00	0.86	0.32	0.72	1.63	1.66	1.79	1.84	1.82	1.5	1.14	1.32
01:00	0.75	0.29	0.65	1.6	1.74	1.82	1.80	1.66	1.53	1.85	1.34
03:00	0.82	0.45	0.73	1.80	1.70	1.79	1.80	1.82	1.81	1.79	1.43
05:00	0.90	0.34	0.92	1.62	1.58	1.78	1.83	1.75	1.57	1.75	1.34

MAGFLOW

TIME	B7	B14	A19	Q1	Q2	Q3	Q4	Q5	COMPLY	COMPLY	TOTAL
07:00	244	694	77	120	151	97	68	604	SAMPLES ABOVE	SAMPLES BELOW	SAMPLES
09:00	247	695	85	111	161	106	59	606	0	0	0
11:00	365	315	462	160	119	137	30	616			
13:00	366	322	497	168	215	260	128	420			
15:00	313	450	406	160	208	255	116	406			
17:00	321	424	417	164	211	260	118	416			
19:00	367	220	498	158	219	302	78	209	% ABOVE	% BELOW	%
21:00	365	237	497	169	211	246	137	416	0.00	0.00	0.00
23:00	369	240	504	166	206	231	143	412			
01:00	372	282	507	167	204	227	148	409			
03:00	372	341	506	165	201	220	150	404			
05:00	366	339	498	468	208	237	414	412			

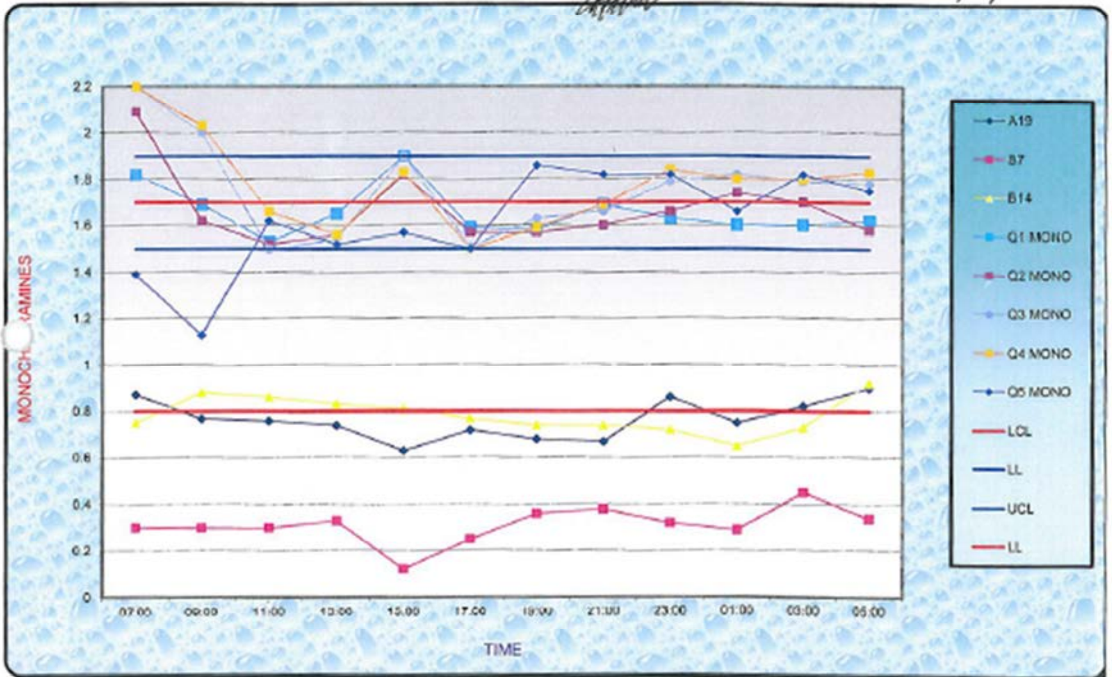
CAPTURED BY:

SIGN: [signature] DATE: 05.11.2013

REMARKS:SENIOR PROCESS SUPERVISOR

Vl1 lost 600 to EIK due to lithabo pump trips.

SIGN: [signature] DATE 06/11/2013.



REMARKS:PROCESS COORDINATOR

SIGN [signature] DATE 2013/11/05

REMARKS:OPERATIONS MANAGER

Lab notified

SIGN [signature] DATE 8/11/2013

Table 29: BPS P water quality report on 30 September 2013

DATE 29-Oct-13

RESERVOIR

TIME	B4	B6	B13	O1 MONO	O2 MONO	O3 MONO	O4 MONO	O5 MONO	R1	R2	R3
07:00	0.62	0.72	0.58	1.78	1.83	1.80	1.85	1.73	1.51	1.37	1.36
09:00	0.56	0.46	0.63	1.76	1.79	1.83	1.80	1.78	1.54	1.41	1.37
11:00	0.54	0.63	0.84	1.83	1.76	1.83	1.82	1.81	1.59	1.93	1.37
13:00	0.54	0.72	0.93	1.82	1.80	1.81	1.79	1.78	1.48	1.68	1.39
15:00	0.60	0.72	0.60	1.77	1.71	1.77	1.78	1.75	1.35	1.43	1.67
17:00	0.55	0.75	0.70	1.79	1.73	1.81	1.83	1.73	1.39	1.35	1.58
19:00	0.54	0.73	0.76	1.75	1.74	1.73	1.71	1.72	1.51	1.87	1.61
21:00	0.50	0.70	0.79	1.69	1.70	1.69	1.67	1.71	1.54	1.74	1.68
23:00	0.62	0.72	0.58	1.77	1.80	1.75	1.78	1.79	1.41	1.57	1.36
01:00	0.56	0.67	0.92	1.76	1.79	1.74	1.78	1.78	1.39	1.56	1.88
03:00	0.54	0.72	0.93	1.76	1.75	1.74	1.75	1.76	1.41	1.68	1.39
05:00	0.42	0.56	0.72	1.74	1.77	1.75	1.76	1.72	1.47	1.37	1.62
AVE	0.55	0.68	0.75								

MAGFLOW

TIME	B4	B6	B13	O1	O2	O3	O4	O5
07:00	325	348	648	152	271	266	46	601
09:00	331	353	657	154	279	286	47	608
11:00	325	349	651	149	270	260	46	596
13:00	328	349	652	148	285	255	46	599
15:00	328	351	643	147	284	260	46	602
17:00	325	361	645	143	289	261	46	598
19:00	324	348	643	107	269	234	47	609
21:00	395	426	732	122	264	237	46	615
23:00	388	425	723	172	248	296	48	787
01:00	392	425	715	172	257	288	62	806
03:00	391	425	669	162	254	272	58	774
05:00	396	426	667	163	255	274	58	774

COMPLY SAMPLES ABOVE	COMPLY SAMPLES BELOW	TOTAL SAMPLES
0	0	0
% ABOVE	% BELOW	%
0.00	0.00	0.00

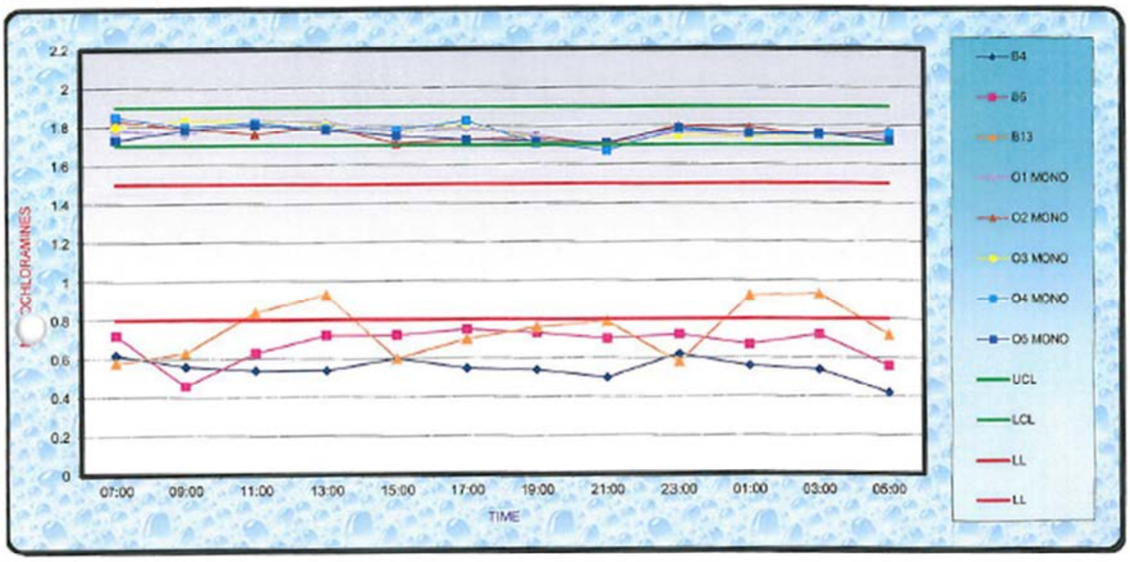
CAPTURED BY:

SIGN: [signature] DATE: 30.10.2013

REMARKS:SENIOR PROCESS SUPERVISOR

Water quality in spec

SIGN: [signature] DATE 30/10/13



REMARKS:PROCESS COORDINATOR

SIGN [signature] DATE 2013/10/30

REMARKS:OPERATIONS MANAGER

SIGN [signature] DATE 31/10/2013