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Measurement and verification of a municipal water pumping project

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Abstract
The processes that were followed to develop the baseline to Measure and Verify (M&V) a Municipal Demand Side Management (DSM) water pumping project that is being implemented is described in this paper. This paper is a follow-up on a previous paper presented at the ICUE 2004 (Measurement and Verification of a Municipal Water Pumping Project). The previous paper described the M&V process and the methodology that would be used to develop the baseline for the project. The project is currently in the implementation phase.

To develop the baseline, energy data was recorded for all the pumps as well as the total flow from the pump station. The baseline was developed by determining an average 30 minute weekday, Saturday and Sunday profile. The baseline also includes a relation between daily water pumped and electricity consumption. Therefore, the baseline can be adjusted if the total amount of water pumped daily is lower or higher than the average values used. This will ensure that the baseline takes possible load growth or possible load reduction into consideration. The baseline will be used to determine the impact of the project after implementation.

Keywords: measurement and verification, water pumping, load management, baseline development

1 Overview

This paper describes the development of a baseline for the Witbank municipal water pumping project. The baseline was developed for the pump station and for the pumps at the reservoir. The baseline will be used during the post-implementation phase to determine the actual savings of the project. The effect of load growth on the baseline is also discussed in this paper.

The DSM project aims to reduce the average demand between 18:00 and 20:00 during weekdays by 3.138 MW.

1.1 Site description

The pump station is situated after the sluices of the Witbank Dam, which is located east of Witbank, in the Mpumalanga Province. This is the main site where the DSM activities will occur. A basic layout is shown in Figure 1.

Point B is situated in the town of Witbank, and is the reservoir collection point for the pumped water before it goes to the purification works. This point is situated at Klipfontein, adjacent to the N4 highway, at the western end of Witbank. The systems that will be affected by the DSM-project activity consist of four pumps (1045 kW) at the pump station and three pumps (145 kW) at the reservoir (point B).

1.2 Audit of systems

Raw water is pumped directly from the Witbank Dam via three pipelines to two concrete reservoirs at point B. This is done with four 1045 kW pumps. From here, the water gravitates at a constant rate underneath the N4 highway through a culvert to the Witbank Water Purification Works (WWPW) in town. Raw water also gravitates to the Highveld Steel industry situated to the west of Witbank. On days when the WWPW demands a lower volume of water, excess water flows from the concrete reservoirs to an open quarry situated at point B.

On days of higher demand, water is pumped back from the quarry to the concrete reservoirs in order to supplement the demand for water gravitating to the WWPW and Highveld Steel. Since the level of the quarry is too low for water to gravitate to the WWPW and Highveld Steel, water has to be pumped from here to the two reservoirs. This is

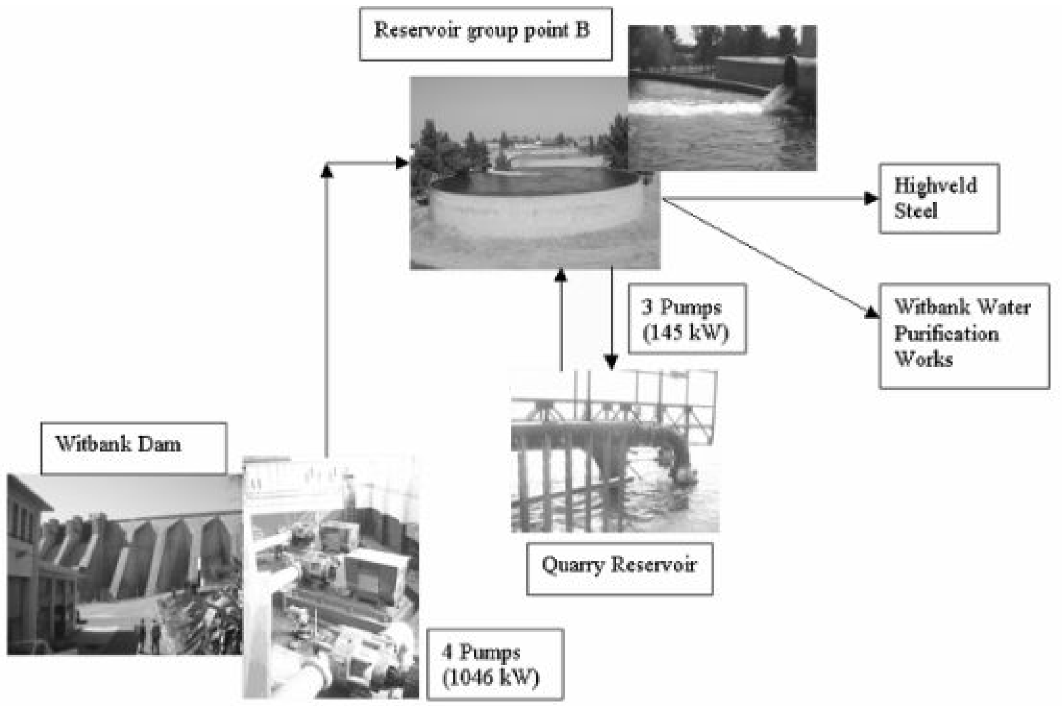

Figure 1: Schematic layout of the project

done with three pumps, each driven by a 145 kW motor. The total storage capacity of 263 Mega litres (ML) has been shown to be sufficient for a 48-hour storage backup for the expected summer peak consumption until 2005.

1.3 Current operation

Currently, the pumps at the Witbank Dam pumping station are running 24 hours per day. The quarry is used during the week to help the pump station match the water demand. Three pumps operate during the week at the pump station.

During the weekends, the fourth pump of the pumping station provides the extra delivering capacity to math the water demand and that required to fill the quarry. Because of this, there are no backup pumps available.

1.4 Demand-side management activities

1.4.1 Description

The project consists of the following: A new pump station was build at the Witbank Dam on a higher flood line, and will be able to accommodate extensions as well as improved drainage facilities. Two additional 1045kW pumps will be installed in the new pump station. The four existing pumps will be moved to the new pump station providing six pumps. Five pumps will be operating outside the peak demand periods of Eskom, with the sixth pump on standby only.

Figures 2 and 3 show the current and proposed operating strategies during a weekday and a day on the weekend. It can be seen that the maximum

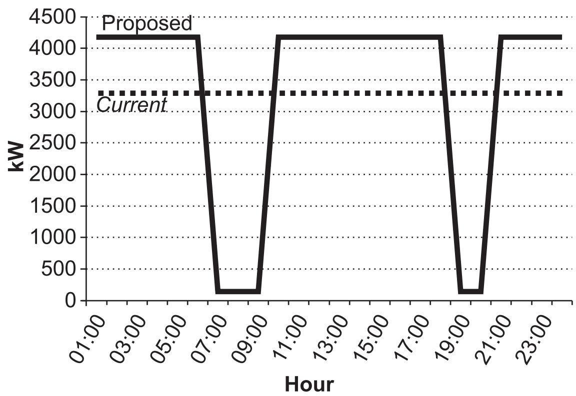

Figure 2: Current and proposed operation during the week

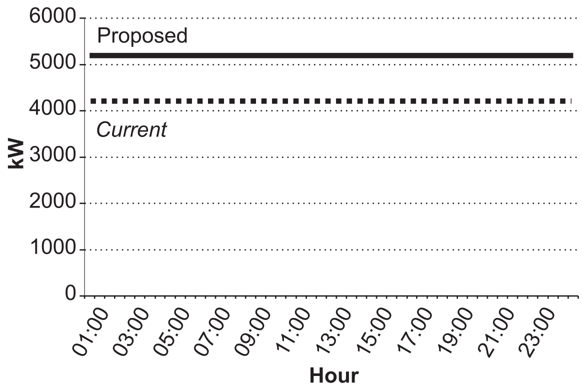

Figure 3: Current and proposed operation during the weekends

demand will increase with the proposed pump system, but during peak periods, there will be a demand of only 145kW. During the weekends, the proposed operation is five pumps operating in order to fill the quarry for days of higher water demand as described in paragraphs 1.2 and 1.3.

1.4.2 Assumptions

The following assumptions have been made by the Energy Service Company (ESCO) during their calculations:

- A standard growth in water demand of 1.5% per year.
- The planned development of 10 000 housing stands in the next 5 years are also included in the water demand.
- Eskom 2003 MegaFlex tariffs are used in calculations.

2 Baseline characterization process

2.1 Baseline strategy

In order to determine the baseline for the electrical consumption of the pumps, the following variables need to be taken into consideration:

- Amount of water pumped,
- Liquid flow rate,
- Size of the pipeline,
- Length of the pipeline,
- Geometry of the pipeline,
- Static Head,
- Amount of pumps operating,
- Efficiency of the pumps,
- Size of the pumps, and
- Medium that is pumped.

Therefore, the equation is as follows:

$$IP_{kW} = f(X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, X_9) \quad (1)$$

Where:

IP_{kW} = electric power
X_1 = liquid flow rate
X_2 = size of the pipeline
X_3 = length of the pipeline
X_4 = geometry of the pipeline
X_5 = static head
X_6 = amount of pumps operating
X_7 = efficiency of the pumps
X_8 = size of the pumps
X_9 = medium that is pumped

To develop the baseline, how the system would have been without any DSM intervention, only the variables that change before and after implementation need to be examined. The following variables will stay the same before an after implementation:

- Size of the pipeline,
- Length of the pipeline,
- Geometry of the pipeline,
- Static Head,
- Efficiency of the pumps,
- Size of the pumps, and
- Medium that is pumped.

Therefore, the equation is simplified to:

$$IP_{kW} = f(X_1, X_2,) \quad (2)$$

Where:

IP_{kW} = electrical power
X_1 = amount of pumps operating
X_2 = liquid flow rate

This equation is used to determine the average demand profile (kW) for a typical day and can be seen in Figures 4, 6 and 8. In order to determine the daily energy consumption (kWh), Equation 2 needs to be integrated over time.

$$E_{kWh} = \int_{i=1}^{24} IP_{kW\,i} \quad (3)$$

Now the question arises: how sensitive is the energy consumption to the number of pumps operating? An analysis was done and the resulting graphs can be seen in Figures 5, 7 and 9. The procedure of the analysis is described in paragraph 2.2 to paragraph 3.7.

Figures 5, 7 and 9 show the relation between the daily energy consumption (kWh) and the daily amount of water pumped. From these figures, it can be determined that the influence of the number of pumps operating is minimal. The energy consumption equation can be simplified to a function of only the water flow rate. Therefore Equation 3 is simplified to:

$$E_{kWh} = f(X_1) \quad (4)$$

Where: X_1 = Water flow rate.

2.2 Determining the baseline

The energy data of the 4 pumps at the pump station and the 3 pumps at the reservoir pumps (Point B) has been recorded since October 2003, and is still being recorded at present. The flow from the pump station was recorded since February 2004. This means that the following data is available:

- Averaged 30-minute amp meter readings of each pump affected.
- Daily water pumped at the pump station.

The above values have been used to do the following:

- Determine the kW in 30-minute periods with some assumptions.
- Determine from the metered data an average Weekday profile, consisting of 48 actual metered values.
- Determine from the metered data an average Saturday profile, consisting of 48 actual metered

values.

- Determine from the metered data an average Sunday profile, consisting of 48 actual metered values.
- Determine the maximum operating capacity (kW) during the metered period for Weekdays, Saturdays and Sundays.
- Determine the pre-DSM utilisation factors for Weekdays, Saturdays and Sundays in the time of use (TOU) periods. This is a factor indicating the average utilisation of equipment in the TOU periods with the respect to the total installed capacity of affected equipment.
- Determine the daily kWh electricity consumption for the metered period for Weekdays, Saturdays and Sundays.
- Determine a relation between the daily water pumped and the daily electricity consumption for Weekdays, Saturdays and Sundays.
- Determine the reference value (daily water pumped and electricity consumption) for which the baseline was developed.

2.3 Baseline data gathering, assumptions and calculations

2.3.1 Boundaries of the baseline

Energy was metered at all the affected pumps in the pump stations. The energy loggers were synchronised before installation. All the data was then added so that a total energy reading for all the affected motors was obtained.

Data were logged at 5-minute intervals, averaged to 30-minute intervals.

2.3.2 Assumptions

Only the current of one phase of all the motors was metered. To convert the current to kW, a number of assumptions were made. The assumptions are:

- All the phases of the motors are balanced.
- The voltage of the pumps at the pump station is 2 200 Volts.
- The voltage of the pumps at the reservoir group is 380 Volts.
- All the motors of the pump station have a pre-implementation power factor of 0.9.
- All the motors of the reservoir group have a pre-implementation power factor of 0.9.

2.3.3 Calculations needed for the baseline

– kW Calculations

Using the assumptions stated in the previous paragraph, the kW for the pumps was calculated using the following equation:

$$kW = \frac{\sqrt{3} \times power\_factor \times Volts \times Amps}{1000} \quad (5)$$

To verify both the accuracy of the assumptions and the actual calculation, the calculated values were compared to actual meter readings. There was only a small (less than 2%) variation between the two values.

– Pre-DSM utilisation factors

For the pre-DSM utilisation factors, the following information and data was needed:

- Total installed capacity of the affected motors (4615 kW).
- The average kW demand in the TOU periods for a Weekday (2679 kW), Saturday (2712 kW) and Sunday (2537 kW).

To determine the pre-DSM utilisation factor, the following equation was used:

$$DSM\_Util = \frac{TOU\_kW\_Demand}{Installed\_Capacity} \quad (6)$$

2.3.4 Days used

Data recording started in October 2003. Not all data recorded was used. The primary reasons are the following:

- One or more of the loggers had a battery failure. This means that the energy consumption of not all the motors was recorded.
- Days where data was incomplete and not used.
- Days when the pumps were not running at typical operation.

In total, 43 days were used of which 28 were weekdays, 8 were Saturdays and 7 were Sundays.

2.3.5 Data integrity and validation

The logged data was put through a data integrity test module in order to eliminate invalid data such as the following:

- Motors operating at an extremely small load. Typically, a motor of 1045kW operating at only 5kW.
- Motors operating at far more than the rated capacity. No events were filtered due to this.

2.3.6 Baseline determination

After the data has been selected, the actual baseline can be determined. The baseline was developed by determining an average 30 minute Weekday profile, an average 30 minute Saturday profile and an average 30 minute Sunday profile. The baseline is presented later.

3 Baseline for Witbank Dam water pumping

3.1 Components of the baseline

The M&V baseline for the Witbank Water Pumping Project consists of the following components:

- Average Weekday, Saturday and Sunday demand profiles.
- Weekday, Saturday, and Sunday daily electricity consumption and daily water pumped scatter plots.

- The average pre-DSM utilisation factors in the time of use (TOU) periods for Weekdays, Saturdays and Sundays.

3.2 Baseline reference values

Essentially the baseline was developed assuming an average daily water flow rate. The values are indicated in Table 1 as well as on the graphs that follow (Figures 4, 6 and 8).

Table 1: Daily average water and electricity values of baseline determination period

	Daily average for the metered period		
	Weekday	*Saturday*	*Sunday*
Megalitre water	102.55	105.90	97.97
KWh consumption	63 895	66 834	60 900

3.3 Baseline and load changes experienced by Witbank water pumping

Variations in the daily average values indicated in will result in the baseline being adjusted using a to-be determined adding factor. If the water pumped (load) drops significantly, the baseline needs to be lowered. If the water pumped increases, the baseline needs to be lifted.

The method is as follows:

1. The total water pumped in mega litres (ML) daily will be known at the end of the month.
2. Using the equation from the electricity consumption vs. total water flow scatter plot, calculate what the baseline electricity consumption (kWh) would have been.
3. The baseline is then adjusted either upwards or downwards so that the total electricity consumption predicted by the baseline (area under the demand profile) is equal to the electricity consumption read off in step 2.

The adjustment will not be made by using a scalar (multiply all values with a factor). Instead, a constant value will be added or subtracted from all 48 points. In other words, the whole baseline will be shifted upwards or downwards. The baseline will thus differ from day to day, related to the total quantity of water pumped.

3.4 Information on the baseline demand profiles

Each of the baseline demand profiles contain the following information:

- The installed capacity using a solid line.
- The maximum operating capacity during the data recording phase of the specific day type using a dashed line.
- The baseline with 48 dots to indicate the values.

3.5 Weekday baseline

The baseline for weekdays is shown in this paragraph (Figures 4 and 5 and Table 2).

3.6 Saturday baseline

The baseline for Saturdays is shown in this paragraph (Figures 6 and 7 and Table 3).

3.7 Sunday baseline

The baseline for Sundays is shown in this paragraph (Figures 8 and 9 and Table 4).

Table 3: Saturday pre-DSM utilization factors

	Standard	*Off peak*
Installed capacity (kW)4 615	4 615	
Contractual value (kW)	3 138	3 138
Average (kW)	2736	2702
Utilisation factor (installed capacity)	59.3%	58.5%
Utilisation factor (contractual value)	87.2%	86.1%

Table 4: Sunday pre-DSM utilization factors

	Off peak
Installed capacity (kW)	4 615
Contractual value (kW)	3 138
Average (kW)	2537
Utilisation factor (installed capacity)	55.0%
Utilisation factor (contractual value)	80.9%

4 Conclusion

A relationship has been found between the energy consumption and the water flow rate. This was used to develop the baseline consisting of average Weekday, Saturday, and Sunday profiles. The baseline can be adjusted if the daily water pumped is lower or higher than the average values used. This will ensure that the baseline takes possible load growth or possible load reduction into consideration.

Table 2: Weekday pre-DSM utilization factors

	Morning peak	*Standard*	*Evening peak*	*Off peak*
Installed capacity (kW)	4 615	4 615	4 615	4 615
Contractual value (kW)	3 138	3 138	3 138	3 138
Average (kW)	2 683	2 652	2727	2701
Utilisation factor (installed capacity)	57.1%	57.5%	59.1%	58.5%
Utilisation factor (contractual value)	85.5%	84.5%	86.9%	86.1%

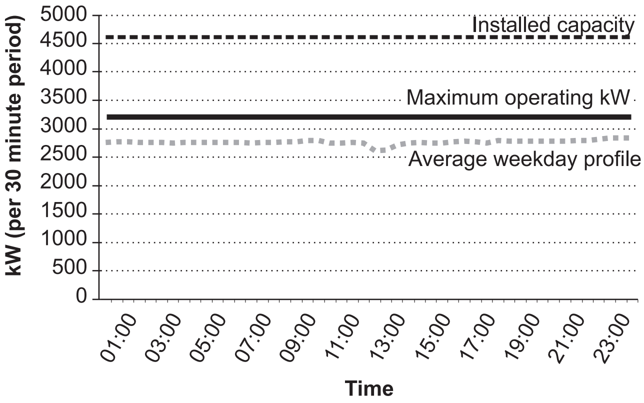

Figure 4: Average weekday demand profile: Weekday baseline

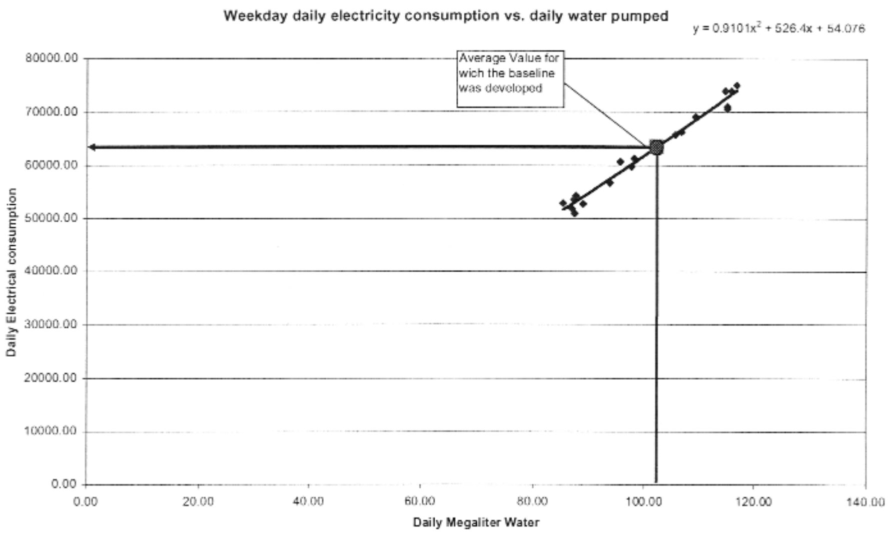

Figure 5: Daily water pumped and electricity consumption scatter plot

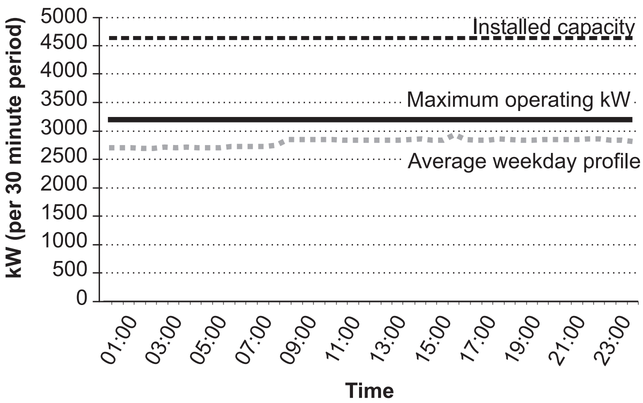

Figure 6: Average Saturday demand profile: Saturday baseline

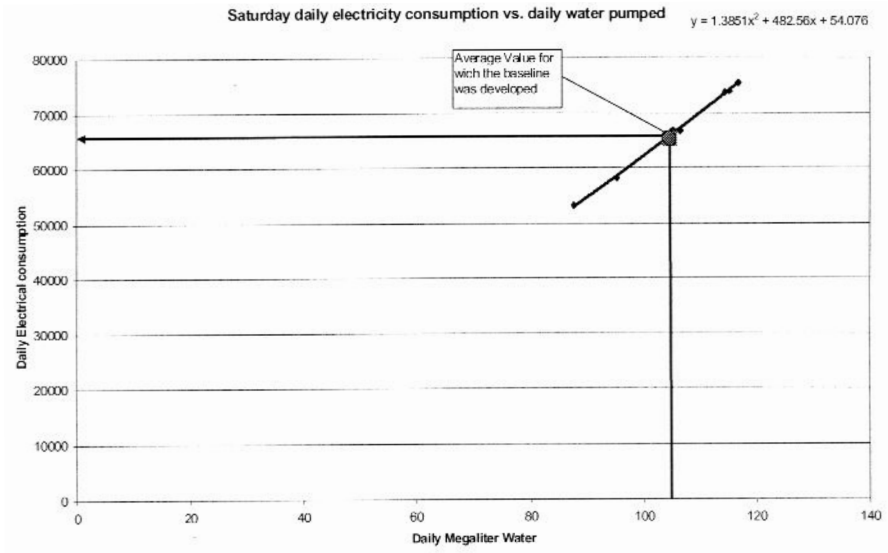

Figure 7: Daily water pumped and electricity consumption scatter plot

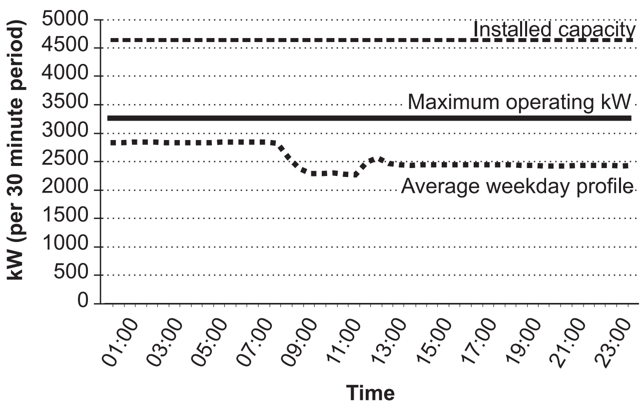

Figure 8: Average Sunday demand profile: Sunday baseline

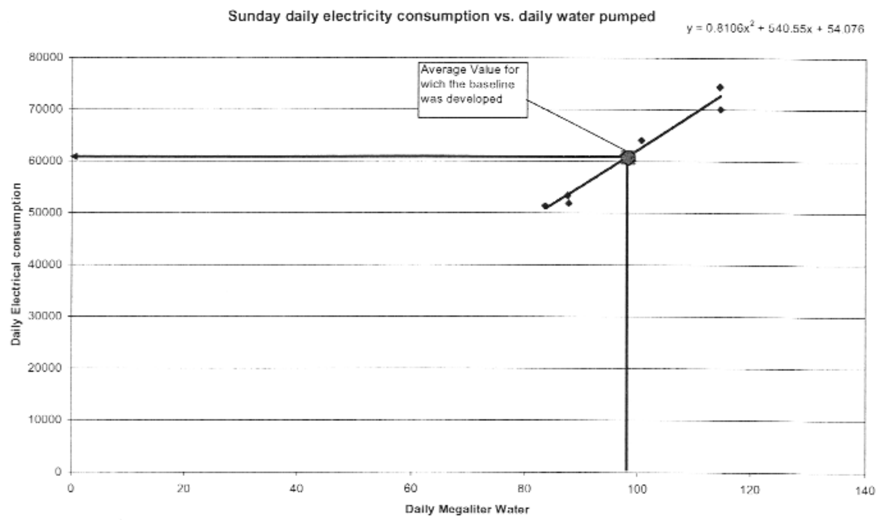

Figure 9: Daily water pumped and electricity consumption plot

If all the pumps are switched of during Eskom's evening peak hours, then an average of 2.8 MW will be dropped. Therefore, 90% of the ESCO's intended target will be realised. This is still within Eskom's requirements and the project can be classified as successful.

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