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Measurement and verification of irrigation pumping DSM projects: Application of novel methodology designs

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Abstract
In South Africa the agricultural sector is a significant energy user, with irrigation pumping being the single biggest electricity-demanding farming activity. The agricultural and commercial sectors contribute 6.5% to annual South African electricity sales. Since 2004, Eskom demand side management (DSM) programmes actively engaged farmers to reduce peak period power usage. Farmers with higher power usage were also assisted to move from Landrate tariff structure to Ruraflex in order to incentivise away from peak-period power use. As part of the DSM programme, a number of large evening peak-load-shifting irrigation projects were implemented. Independent measurement and verification (M&V) assessments were made to establish attained savings over the contracted project life. The M&V of DSM projects normally have problems that complicate project assessments, but even taking this into account, the M&V team experienced exceptional difficulties and cumbersome M&V methodology challenges with certain irrigation projects. Normal baseline development methods were ineffective and novel M&V methods needed to be devised and developed. This paper explains the normal M&V methodology used for typical DSM projects and how it is applied. It gives guidance on baseline metering equipment, sampling and metering point selection. Further it demonstrates project specific issues and service level adjustment (SLA) anomalies that render normal M&V methodologies ineffective. It shows novel and alternative baseline development and SLA methods that were incorporated on DSM projects to accurately quantify project impacts.

Keywords: load shifting, evening peak, meter sampling, baseline development, energy neutral, service level adjustment

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1. Introduction

In South Africa agriculture has the largest water demand of any sector (Du Plessis, 2009) and uses 62% of the 13.2 billion m^3 annual usable runoff rainwater yield, according to water accounts of South Africa (Statistics SA, 2000). This implies that the sector would be a large energy user for its irrigation activities. According to Eskom's integrated results (2016), the agricultural sector is a notable 4.7% of yearly total Eskom electricity sales. The single biggest electricity demand in farming activities is pumping irrigation water from canals, rivers, holding dams or boreholes.

Since 2004, Eskom's demand-side management (DSM) programmes actively engaged farmers to reduce peak period power usage. Farmers with higher power usage were also assisted to move from Landrate tariff structure to Ruraflex in order to encourage power use outside of peak periods. As part of DSM, a number of large irrigation DSM projects were implemented to specifically shift irrigation power use from the evening peak. These were normally focused on large farms making extensive use of irrigation or jointly implemented with a regional irrigation board. On these and other DSM projects, independent measurement and verification (M&V) assessments were made to establish the actual attained savings over the contracted project life (Den Heijer, 2010). The M&V activities on municipal water-pumping load-shifting are described by Bosman et al. (2006); Gouws, (2013) gives the M&V activities on load-shifting interventions for a refrigeration plant system. The North-West University M&V team was contracted by Eskom DSM to M&V 15 different irrigation-pumping DSM projects, totalling 650 irrigation pumps and a combined evening peak reduction target of 15 MW.

The M&V of DSM projects frequently experiences problems that complicate project assessments, and the M&V team has had exceptional difficulties and challenges with irrigation projects (Storm, 2008) in the form of practical DSM project issues or circumstances. As a result, the normal baseline development strategies proved to be ineffective and new methods needed to be devised and developed. This paper first discusses the normal M&V methodology used for irrigation pumping and some other DSM projects. This provides a background to an account of the effectiveness of the M&V methodology. The project's specific issues, and the uniqueness of baseline development methods to accurately quantify project impacts, are discussed.

2. Normal M&V methodology for load-shifting DSM projects

Figure 1 shows a typical farm irrigation setup, consisting of three river pumps moving water to crop circles, micro-irrigation blocks and a holding dam. Pump 1 (P1) delivers water to a storage dam, from where pump 2 (P2) pumps water to a crop circle. Pump 3 (P3) functions as a backup for pump 4 (P4)

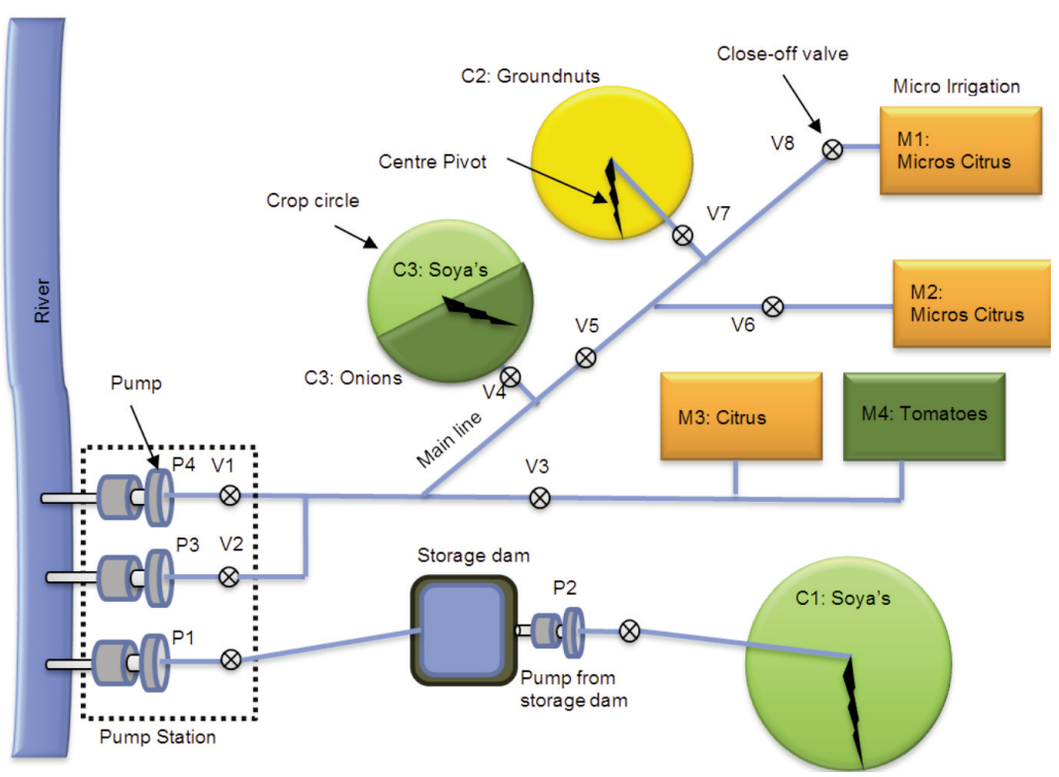

Figure 1: Typical irrigation farm pumping setup (SP programme supplementary M&V guideline, 2013).

and is used when maintenance is done on pump 4. The crop circles and micro blocks have different crops and irrigation schedules.

On this irrigation setup, a DSM project aims to shift all pumping loads from the Eskom peak periods, specifically the weekday evening peak of 18:00-20:00. This is achieved by retrofitting the irrigation pump with timers and equipment to allow automatic shutdown and start-up. The M&V entity would be required to assess the actual impacts attained through this intervention and the assessment is preceded by developing a baseline and baseline model. Load-shifting projects normally follow an energy-neutral baseline model since the DSM intervention does not affect the system efficiency, operational hours or process activities. It is accepted that, for irrigation, the amount of energy required to move water before and after intervention is the same (Storm, 2008). The aim of the irrigation DSM projects was not to reduce pumping activities, but solely to shift pumping activities from the evening peak. Section 3 describes the metering and process involved in developing a project baseline. It further describes how a baseline is adjusted, after DSM implementation, to reflect the old operational conditions. This is done through service level adjustment (SLA). Section 4 describes the SLA anomalies that make an energy-neutral baseline model ineffective.

3. Baseline development

The DSM project impact can be quantified by comparing the before and after intervention conditions. This is done by measuring and assessing the before and after pumping power demand profiles. Power demand profiles normally consists of daily 30 minute integrated demand values. Since it is not possible to simultaneously measure the power demand profile before and after the intervention, a baseline needs to be developed. The baseline represents what the power demand profile would have been without the DSM project intervention. Figure 2 shows a flow chart of the baseline development process described in the following sections.

3.1 Boundaries of the baseline model

A typical DSM irrigation project consists of load-shifting interventions on the irrigation pumps of one or several farms. Since the project scope is restricted to the pump station, the baseline boundary only includes the power demand and use (demand profiles) of the pump stations. In Figure 1, the boundary is drawn around the river pump station and around the pump at the storage dam.

3.2 Baseline data required and metering

The characteristics of irrigation pumping require the usage of continuous demand metering, unlike many other types of DSM projects. The latter projects frequently involve constant loads where demand spot measurements can be taken, and thereafter only operational hours captured for the baseline. Irrigation pumps are unique, since the irrigation pump may be used to irrigate several different crops, each having its own set pressure and operational demand. There may also be multiple crop types during the year (SP programme supplementary M&V guideline, 2013).

Project pump stations are hard to reach, via rough and obscure farm dirt roads or Jeep tracks, especially with larger DSM projects done with Irrigation Boards, and those in remote locations have other metering issues too (Storm *et al.*, 2008a), so it would be difficult and too expensive to measure all pumps included in the project. Also, pump station conditions are not always suitable to house costly M&V metering. A pump station is, in some cases, merely a rusty metal plate shading sus-

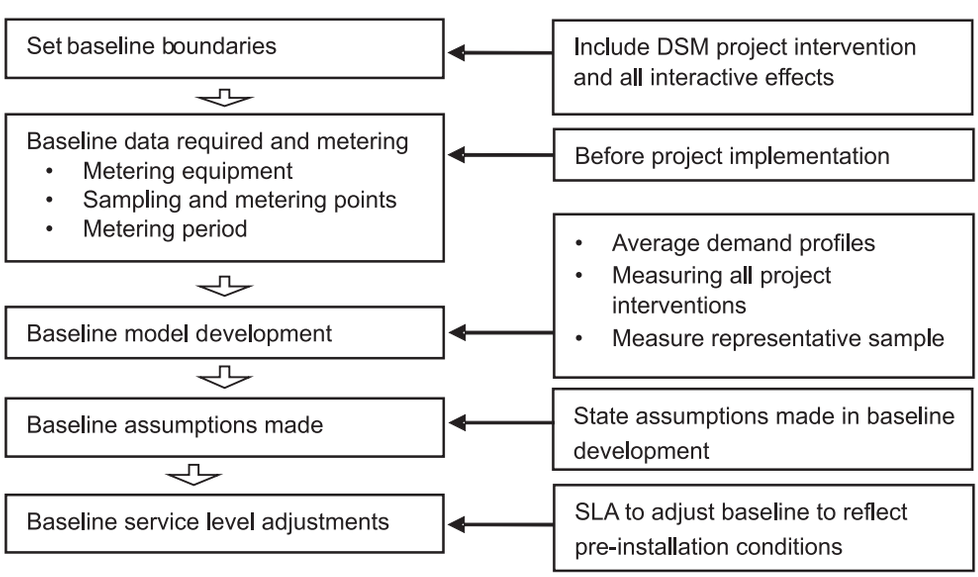

Figure 2: Flow chart of baseline process

pended with metal poles in the open veld (Storm et al., 2008a).Effective sampling of pump stations to be measured is crucial, however. A thorough sampling approach is required for representative measurements with a considerable confidence level (International Performance Measurement and Verification Protocol Committee, 2012; Carstens et al., 2014; CDM Sampling guidelines, 2009). A larger sample increases accuracy and confidence level but also significantly increases metering costs. Here, a proper cost versus accuracy model can assist sample size determination of irrigation pump stations. Since M&V only report on conservative savings, even a 50% confidence level may be acceptable, depending on the overall reporting objectives and the value of the savings involved (Steyn, 2014).

Statistical sampling is required so that a simultaneously random and even typographically spread (covering different farms) of measured pumps is achieved. The sampling has to be subjected to stratification, since only pump stations meeting the following criteria may be used:

- A large variety of pump sizes is found, ranging from 1.2 kW to 300 kW, meaning it may be required to allocate pumps to certain sizing groups.
- A large variety of crop types are found, which should be taken into account.
- In order to reduce data collection cost, meters must be remotely downloadable and this requires good GPRS reception in the pump station.
- Since power meters and GPRS communication devices are expensive, the pump station should provide protection against environmental conditions.
- River pump stations selected must be elevated above the flood line, since flooding, which happens often, could destroy metering.
- Theft of pumping equipment and cables for copper happens frequently in certain regions. It is preferable to install the pump station in a safe area, e.g. nearby the farmer's house.

Pump stations on different tariff structures may have different pumping demand profiles. Landrate customers have no incentive not to pump over the peak periods while Ruraflex customers may already avoid peak-period pumping and there may be less load available to shift from the evening peak. Larger pump stations are normally on Ruraflex, and historical data for baseline development can be retrieved via the Eskom MV90 system. If this data is accessible, no baseline metering needs to be installed, which can greatly reduce metering cost.

In the case where sample measured data need to be extrapolated to represent other pump stations, it is better to measure on pump level instead of the whole pump station. Some pump stations can house more than 10 pumps with different sizes and irrigate different crops. Unfortunately meter data on MV90 are that of a total pump station.

3.2.1 Baseline metering period

A proper baseline profile takes into account all operational conditions and seasonal variations. The baseline measuring period must be chosen so that measurements are representative of the average operations. The baseline measuring period for some DSM projects can be a few days or even months. It was observed, however, that for some irrigation projects more than a year of data may be required. Historical data from Eskom MV90 pump station measuring points revealed that pump stations show significant variation in yearly load factors.

3.3 Baseline model development

After the baseline metering period is completed and data gathered, 30 minute demand (kW) profiles can be collated for the measured pump stations or pumps. From these, average demand profiles need to be calculated. Here it should be decided what type of average profiles will suffice:

- average day type – average Monday, Tuesday etc;
- average week (all day types); or
- average weekday (Monday to Friday), Saturday and Sunday profiles.

The last mentioned is commonly used for irrigation projects since weekday pumping operations do not differ for agricultural purposes. Figure 3 shows a typical average weekday, Saturday and Sunday baseline. Over weekends, pumping activity normally differs significantly from weekdays. The actual day type electricity consumption is shown below the graphs.

Using average weekday, Saturday and Sunday profiles also allows effective reporting on the Eskom time of use (TOU) periods, as shown in Figure 4. The TOU periods differ for weekdays, Saturdays and Sundays. Figure 4 is applicable to the Eskom Megaflex, Miniflex and Ruraflex tariff structures (Eskom Tariff and Charges booklet, 2014). The energy cost significantly differs between the Peak, Standard and Off-peak periods.

3.4 Baseline assumptions made

Variables or circumstances that may influence the project performance cannot all be measured or monitored with DSM projects, so certain assumptions must be made and agreed between stakeholders. Any later change of circumstances requires appropriate baseline adjustments. Typical assumptions made during irrigation pumping baseline development include:

- baseline measuring period is representative of the typical project irrigation pumping;
- sample pumps that were measured reflect

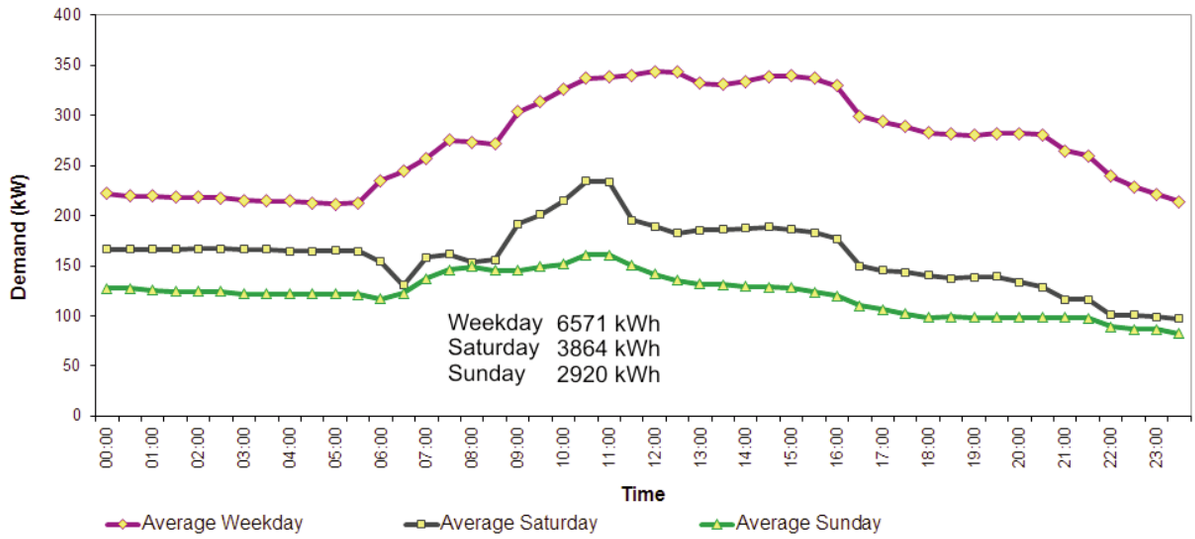

Figure 3: Baseline development process.

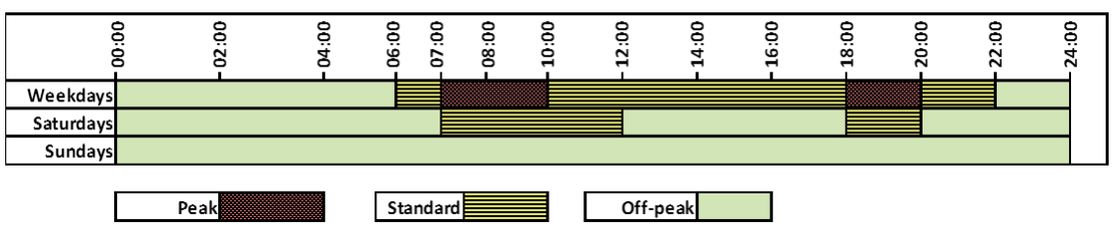

Figure 4: Eskom time of use periods (Eskom tariff and charges booklet, 2014).

the whole group's operations; and

- system pumping resistance or system efficiency is not affected by the DSM project.

3.5 Baseline service level adjustment and performance assessments

The impact of the project needs to be assessed at the completion of DSM project interventions. Data from the same measuring points as used for baseline development have to be collected, while project performance assessments and reporting can be done on any interval a client requires. It is normal practice to have monthly or quarterly project performance assessments.

The actual demand profile allows the baseline demand profiles to be scaled up or down according to a 24-hour energy-neutral SLA_{factor}. Thus, the daily baseline kWh becomes equal to the actual demand profile daily kWh, i.e., $kWh_{baseline} = kWh_{actual}$. The actual measured profiles of the assessment period can then be subtracted from the adjusted baseline to calculate the attained savings.

4. Service level adjustment anomalies

Certain anomalies found on irrigation projects make the 24-hour SLA ineffective, although in general it is a very good method. The following section describes several of the anomalies found and SLA alterations made to effectively capture the impact of the project.

4.1 Night load reduction

It was observed that the planned evening peak DSM targets were not met during the performance assessment (PA) period of an irrigation DSM project. The project underperformed at an average of 50% despite the required switching occurring as planned. This underperformance was investigated and all the possible causes evaluated, as discussed in the next sections.

4.1.1 Baseline and performance assessment profiles

Figure 5 shows a graph comparing the DSM project developed average weekday baseline profile with the actual average weekday profiles of the PA months. The baseline profile is the top bold line, while the PA profiles are all the bottom lines. During the morning hours from 0:00–6:00 it was noticed that the pumping load significantly reduced throughout the PA months when compared with the baseline period. The same occurrence could be seen late in the evenings (20:00–0:00) after the Eskom evening peak. From 7:30 in the morning and onwards the pumping load increased drastically, as the farmers started to irrigate crops. Between

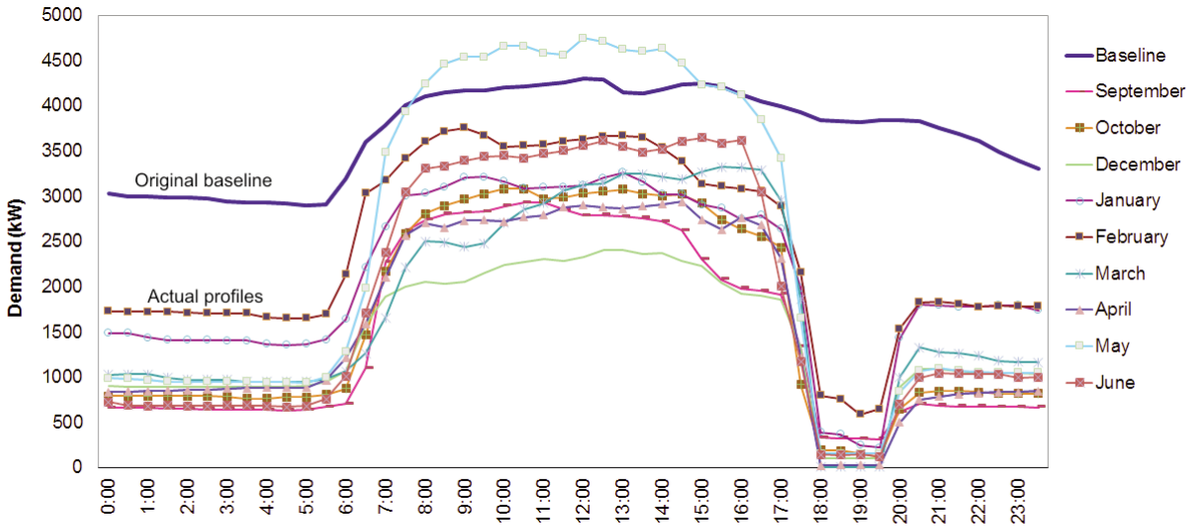

Figure 5: Average weekday baseline compared with actual average weekday PA profiles (Storm et al., 2008b).

18:00 and 20:00 the pumps were switched off again automatically for the evening peak period.

4.1.2 Effects of pumping load reduction on DSM project impacts

The actual profiles in Figure 6 suggest that the evening peak switching made a large evening DSM impact. However, the shows that the 24-hour energy neutral SLA adjustment described in section 3.5 lowered the SLA baseline profile from the original baseline profile (thick dark line on top) to the service level adjusted baseline (lighter line in the middle – same shape). This significantly reduced the available DSM evening peak impact, despite evidence of large switching from the switch-off drop in the actual profile.

4.1.3 Causes of load reduction

Two prominent possible causes responsible for the late evening and early morning additional load reduction were investigated. These were:

- higher rainfall during PA period than during the baseline period – this would cause the farmers to reduce their pumping activities; and
- a change in operation conditions and pumping schedules as side-effects of the DSM project implementation.

The rainfall data of the region was obtained for both the baseline and PA periods. An analysis of this data showed that no distinct higher or lower rainfall scenario could be found. Since the project was spread over a large area, the rainfall differed significantly between the individual rainfall measuring points.

The actual cause of the load reduction was found to be an unforeseen side effect of the DSM project itself. There were also water flow meters installed along with the DSM switching gear and valves needed to automate the pumps for the evening peak switching. These water meters were then utilised by the regions' irrigation board to track

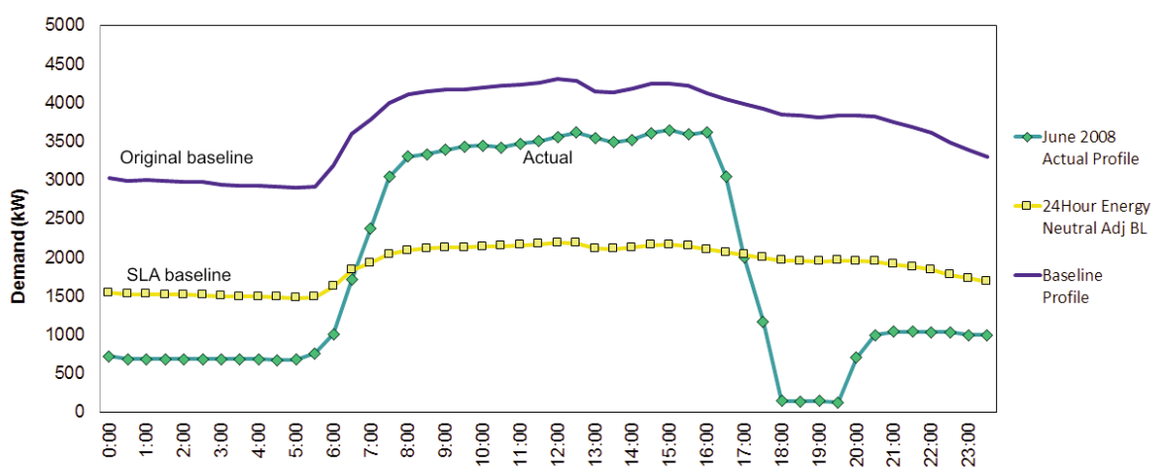

Figure 6: Average weekday developed baseline profile, actual PA profile and 24-hour SLA baseline profile.

each farmer's water usage, since every farmer had a certain water allocation. Before the DSM project implementation, the irrigation board could not track the water usage and check if the farmers stayed within their allocations. This resulted in farmers leaving the pumps running through the night, as seen from the baseline profile in Figure 6. Afterwards, during the PA period, the farmers had to comply with the water allocations and therefore adjusted their pumping schedules to occur during the day time.

4.1.4 The SLA alteration

The desired pump switching and evening peak load reduction occurred as planned for the DSM project. The unforeseen early morning and late evening load reduction had, however, a negative effect on the calculated DSM impacts. The implication was that the 24-hour SLA methodology did not accurately incorporate the operational conditions that prevailed during the PA period. An alternative approach to more accurately quantify the impact of DSM was to use a day operational-hour SLA. Here, only that part of the day during normal pump operations was used to determine the SLA factor.

Figure 8 shows that between 8:30 and 16:30 the pump operation was the same as during the baseline period. The maximum operation load differed because of variations in seasonal water requirements. The operational time of the day could, therefore, be used as the kWh neutral time period.

The SLA factor calculation procedure of Section 3.5 is now applicable, as given by Equation 1.

$$SLA_{Factor} = \frac{kWh\ ACT_{Operational}}{kWh\ BL_{Operational}} \quad (1)$$

The kWh of the actual PA profile was divided by the kWh of the baseline profile between 8:30 and 16:30 to obtain the operational-hour SLA factor. The SLA factor was, finally, applied over the 24-hour baseline profile, multiplying with each 30 minute baseline profile point. The new service level-adjusted baseline was, consequently, achieved.

Figure 8 shows the original baseline profile, an actual PA month profile, the old 24-hour SLA baseline, and the new operational-hour SLA baseline. The new SLA baseline was not lowered drastically

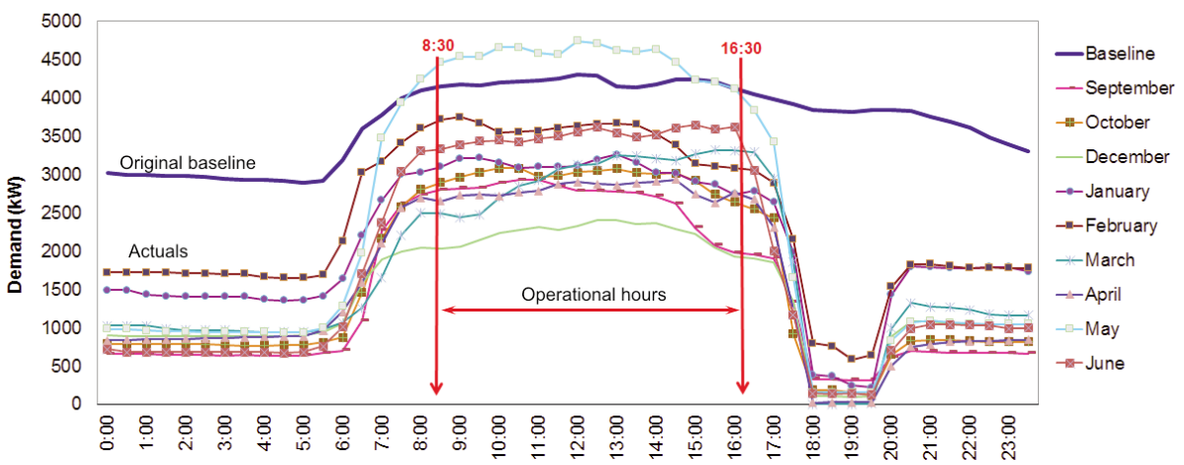

Figure 7: Operational kWh neutral SLA period (Storm et al., 2008b).

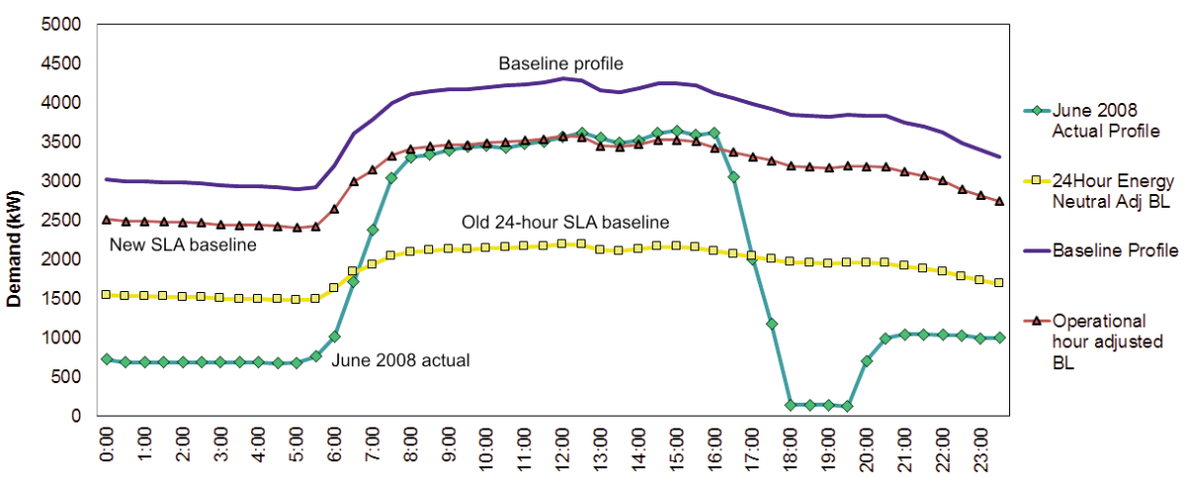

Figure 8: Average weekday developed baseline, Actual, 24-hour SLA baseline and the new operational-hour SLA baseline (Storm et al., 2008b)

anymore and made a larger available DSM impact. This method more accurately portrayed the DSM switching impacts and was not influenced by the morning and evening load reduction.

4.2 The morning peak period reduction

With certain DSM projects the farmers were encouraged or in some cases assisted to move from the Landrate tariff structure to Ruraflex, subsequently becoming an additional incentive not to pump over the evening peak on top of the DSM project.

4.2.1 Baseline and performance assessment profiles

Figure 9 shows the project baseline profile, 24-hour neutral SLA baseline profile and actual PA period profile. The baseline profile represents a typical irrigation profile with higher day pumping demand. Similarly to the situation described in Section 4.1, the SLA baseline was drastically reduced and did not capture the actual DSM switching that occurred. The culprit here was morning peak switching. The farmers took the advantage of Ruraflex and moved their irrigation practices from the morning peak.

4.2.2 The SLA alteration

The SLA alteration that would not be affected by the additional morning peak switching was required. It was preferable to remove the morning peak from the baseline, since the aim of M&V was to evaluate the DSM intervention evening peak impact only. Baseline setting was, therefore, made equal to the actual setting. The SLA excluded the morning peak period and the baseline was energy-neutral from 0:00–6:00 and 10:00–23:59. Figure 10 shows the new SLA baseline with the original baseline and the PA actual. The SLA baseline was higher and accurately quantified the DSM evening peak impact.

4.3 Other SLA anomalies and baseline challenges

The M&V Team also came across the following SLA anomalies and baseline challenges:

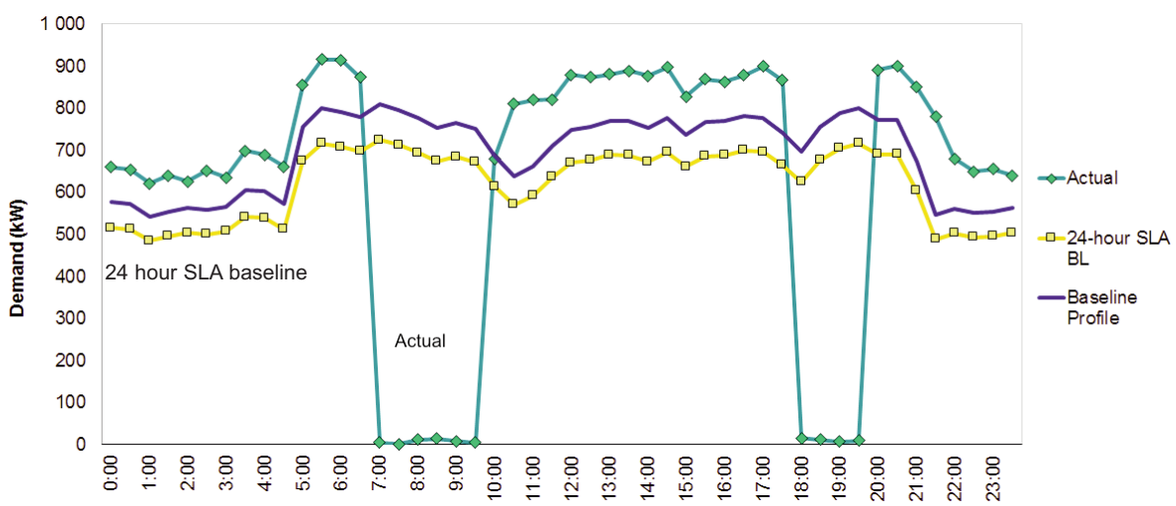

Figure 9: Average weekday developed baseline, actual, 24-hour SLA baseline and the new operational-hour SLA baseline (Storm et al., 2008b).

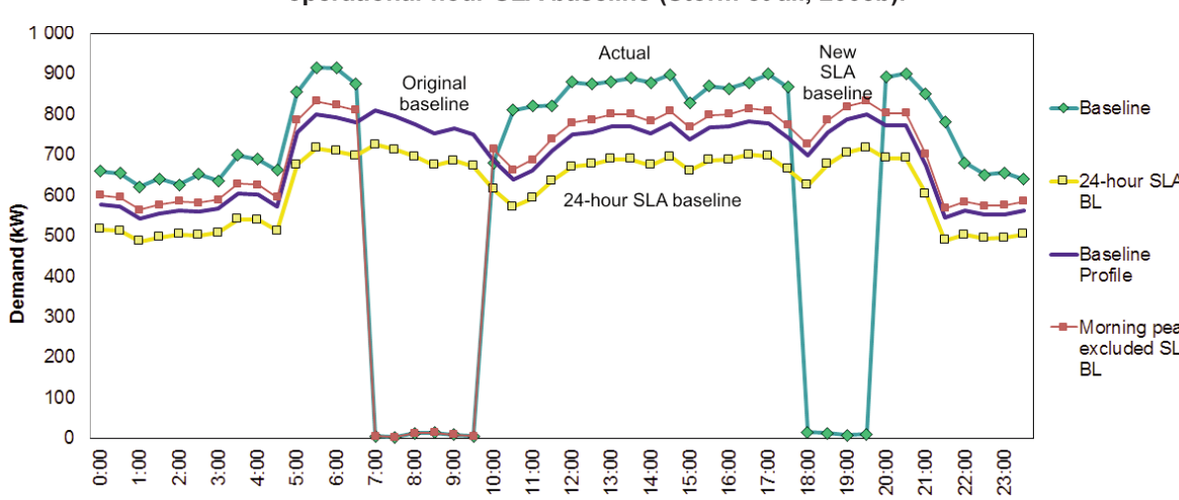

Figure 10: Original baseline, 24-hour neutral SLA baseline and new morning peak excluded SLA baseline and actual profile (Storm et al., 2008b).

- Weekend loads increased.
- Pumping schedules: Due to evening peak pump switch-off the farmer could not keep up to pumping schedules in the high pumping seasons. This resulted in the farmers also irrigating over weekends.
- Changing of tariff structure: Here pump stations moving from Landrate to Ruraflex was primarily the cause. The farmers took advantage of cheap weekend Ruraflex tariffs and moved some of irrigation activities from weekdays to weekends.
- Energy efficiency interventions with the DSM project: During the scoping phase of an irrigation DSM project it was observed that an energy efficiency intervention was accomplished by improving the pipeline efficiency. The SLA method was developed to also incorporate the efficiency demand reduction so that this did not negatively affect the evening peak DSM impact. This was done by considering the full operational load difference of before and after implementation.

5. Baseline challenges

Challenges with several DSM projects during the baseline development period prevented the planned baseline approach from being followed. Some of these included:

- Eskom awareness campaigns – On certain projects it was stated by stakeholders that Eskom awareness campaigns on pumping and pumping times changed the operational profiles observed during the baseline period. The baseline period needed to be moved to an earlier period to satisfy all project stakeholders.
- Irrigation attainable impacts – A study of hundreds of pumps included in DSM projects was performed by the North-West University's M&V team to evaluate the typical available evening peak switching load compared with installed capacities. The reason behind this was that project implementers did not perform effective project viability assessment metering beforehand. Only the motor installed capacities in the total estimated project evening peak demand reduction target were used. The study concluded that only 15–30% of the installed capacity is available for evening peak switching. With certain outliers a 40% available value was observed. The values subsequently assisted M&V teams and DSM managers to evaluate the possibility of a proposed project reaching the stated targets before project implementation.
- Load prevention instead of shifting – In the early stages of DSM, some project implementers confused load shifting with load prevention. They understood the DSM contract as only preventing evening peak instead of shifting an available load. This resulted in a major project under-performance.
- Metering challenges – These complicated the baseline development and data gathering during the PA phase, which required redundant metering and data gathering systems.

6. Discussion and conclusions

Load-shifting projects normally follow an energy-neutral baseline model, since the DSM intervention does not affect system efficiency, operational hours or process activities. For projects such as irrigation pumping, it is accepted that the amount of energy required moving water before and after intervention is the same. During the performance assessment of irrigation DSM projects, the evening peak switching seemed to make a large evening impact. However, the 24-hour energy-neutral SLA lowered the SLA baseline profile significantly and did not capture the actual DSM impact. This was due to different SLA anomalies that occurred after the baseline period, including effects such as night load reduction, morning peak period reduction, weekend load increased, and energy-efficiency interventions with the DSM project. This required a consideration for alternative SLA methods.

For projects that showed night load reduction, a day operational-hour SLA approach that enabled a more accurate quantification of the DSM impacts was used. An implication of this was that only that part of the day during which pumps were operating normally was used to determine the SLA factor. Alternative methods presented in this investigation can be used as an approach to solve similar projects to effectively capture DSM impacts.

Several DSM projects exposed the baseline challenges, such as Eskom awareness campaigns, limited irrigation attainable impacts, load-prevention instead of shifting and intensive metering; and methods to overcome these challenges were proposed. Limited irrigation attainable impacts resulted in 15–30% of the installed motor capacity available for evening peak switching. These results assisted in evaluating the possibility of a proposed project reaching the stated targets before implementation.

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