

**An integrated methodology to measure and verify
energy conservation under incentive-based
irrigation pumping programmes**

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EXECUTIVE SUMMARY

Water scarcity and droughts have become a looming threat in many counties worldwide. In South Africa, a water crisis is upon the country and estimations show a supply shortfall of 17% by 2030. When considering water consumption per sector, agriculture surpasses all other sectors by far with a global average surface water usage of 70%. Investigations in South Africa, and other countries in the world, have shown that inefficient irrigation water application, over-irrigation and waste are prominent and there is a tremendous potential for conservation. If water can be conserved through irrigation system optimization and efficient irrigation practices on South African farms by only 28%, it can hypothetically fill the 2030 supply shortfall. Alongside water, there is also significant energy conservation potential with investigations showing a near energy use reduction of 40% being achieved. Since there is such a usage improvement potential with both water and energy, conservation attempts are expected to be commonly found with significant impacts achieved. This is however not the case and in general conservation is hampered by a lack of necessary incentives and other obstacles. Incentive vehicles are required to encourage or persuade irrigators to invest in conservation technologies and adopt conservative irrigation practices. Here caution is advised since agriculture is very complex and interwoven, and a mechanism such as water tax can disturb a delicate economic balance which can have many negative interactive effects. A method is required to unlock the conservation potential of the agricultural sector without these risks. The problem is that even if there is some type of water incentive or reduced usage rebate for an irrigator, this is not adequate to fund and sustain efficiency conservation. However, if the benefit from other available incentives, like energy conservation and greenhouse gas mitigation, can be combined with that of water, the goal is much more achievable.

A very crucial requirement of incentive mechanisms is proper quantification of the real attained savings. Depending on the incentive mechanism, the savings quantified should adhere to strict regulation and high confidence levels with low error margins. The quantification process goes under many names but will be referred to in this study as Measurement and Verification (M&V). The practice of M&V on irrigation conservation can be very challenging and often discourages or prevents conservation projects even though there are incentives available. In addition, the largest conservation impact in the agricultural sector is distributed over thousands of small irrigation points which cannot justify conventional M&V methods. Another concerning observation is that the combined bottom-up results of electrical conservation projects and programmes, over all sectors, show a significant impact, however, this same impact is not observed higher on the electrical grid. This calls into question both the validity of the M&V results and the effectiveness of the conservation methods implemented.

The focus of this study is to overcome irrigation conservation M&V challenges by providing original, practical and cost-effective M&V approaches, methodologies and frameworks that create a novel turnkey solution which can quantify irrigation electrical energy conservation on a project level, programme level and regional level. Although water conservation is evidently of higher importance here, the greater focus is on electrical energy conservation since this, with related incentives, can be utilised to realise water conservation. Thus, the primary aim of this study is developing a novel integrated methodology to measure and verify irrigation pumping energy conservation under incentive-based projects and programmes. Greenhouse gas mitigation can also be directly connected to quantified energy conservation which again opens carbon market offset possibilities.

Project level M&V is defined as the full contractual life evaluation of a project making use of full-time metering of key project parameters. Exceptional evaluation difficulties were experienced and cumbersome M&V methodology challenges were encountered with demand-side management irrigation pumping projects part of this study. On these conventional baseline development methods were ineffective and unique M&V methods were devised, developed and implemented. The study also intends to give guidance to M&V entities, project investors and implementers on what is required for proper M&V. Through this, project stakeholders can pre-emptively ensure that the correct mechanisms

for a successful conservation project are in place. It also gives guidance to ensure that proper M&V is already implemented from the project planning phase. Project level M&V is generally for large projects that can justify high M&V costs associated with full project quantification. However, for programme type irrigation energy conservation rollouts this is not feasible and a programme level M&V method is necessary to quantify impacts. Programme level M&V is defined here as a method of quantification that does not use continuous metering, but incorporates a calibrated simulation model or a deemed savings approach to establish conservation impacts over the programme's contractual life. One such irrigation programme, the Eskom Standard Product Programme (SPP) in South Africa, is investigated. Unique methods are designed to effectively determine conservative but representative energy efficiency impacts without using continuous power demand profile measurements. The study also focusses on an original calibrated simulation M&V model to establish the available peak load for irrigation load shifting Energy Conservation Measures (ECMs). This approach can determine the available peak period load before any implementation attempts, show the available shiftable load and provide the post-implementation reduction impact that has been achieved.

In order to address the problem of bottom-up impacts not being visible on the electrical grid, the study presents a unique regional level M&V methodology that allows M&V assessments and impact validation at a higher level. This can be bound to a certain area, a region or an entire province or country. A regional level M&V methodology has the advantage of providing results quickly and allows for tracking sustainability of savings over time, long after project or programme level M&V has ceased. However, a regional level M&V approach can be very cumbersome and complicated requiring intuitive methods to be successfully implemented and executed. The study discusses an exceptional case study where the regional M&V approach was implemented. This case study did not only draw an M&V boundary around a region, but the entire Western Cape province of South Africa. The study also gives attention to the fundamental aspects that are used to perform M&V, i.e. M&V metering, meter data quality and proper meter sampling. It is regularly observed how the importance of these are underestimated and sometimes neglected. If these fundamentals are not appropriately executed and put into place early, it is found that the M&V of incentive-based projects and programmes encounter disastrous shortcomings with incentive requirements. Proper meter sampling methods are often a significant challenge. Large enough sample groups, improper sampling plans and the difficulties that come with sampling load profiles hinder M&V approaches in attaining high enough confidence levels and low error margins when required. Attention is also given to the design of a simplified sampling concept which reduces load profiles to key single value ratios.

After a proper foundation has been established and methods have been developed for project level, programme level and regional level M&V with M&V metering, the study is concluded with an integrated enveloping M&V methodology. Hereby the ultimate goal of realising water conservation in the agricultural sector is focussed on. Integration is done on the following levels: (1) integrating project, programme and regional level M&V to better quantify energy savings for incentive mechanisms such as the SPP; (2) defining water and greenhouse quantification at project, programme and regional level and showing how quantification will be done; (3) integrating this with energy conservation and combined reporting; (4) proposing early integration of M&V into projects, programmes and into policies through which water conservation can be ultimately realised; (5) evaluating the applicability of the South African energy efficiency section 12L tax rebate (Income Tax Act 58 of 1962) to agricultural irrigation ECMs; (6) proposing to enlarge the span and reach of section 12L for irrigation; and (7) providing a framework and conceptual design for a future study to realise this expansion through a unique Agri-M&V approach

Keywords and phrases: Water conservation, energy conservation, greenhouse gas mitigation, agricultural irrigation pumping, peak period load shifting, energy efficiency, incentive mechanisms, Eskom Integrated Demand Management, Eskom Standard Product Programme, section 12L tax rebate, measurement and verification: project level, programme level and regional level top-down.

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NOMENCLATURE

A	Amp – Unit of electrical current flow
AC	Alternating Current
AMR	Automatic Meter Reading
ASHRAE	American Society of Heating, Ventilating, and Air Conditioning Engineers
BBC	British Broadcasting Corporation
BMS	Building Management System
CALMAC	California Measurement Advisory Council
CDM	Clean Development Mechanism
CER	Certified Emission Reduction
CIMIS	California Irrigation Management Information Services
CFL	Compact Fluorescent Lamp
CO ₂	Carbon dioxide
CT	Current Transformers
DB	Distribution Board
DC	Direct Current
DEA	Data Envelopment Analysis
DIY	Do It Yourself
DMP	Demand Market Participation
DMU	Decision Making Unit
DOE	Department of Energy
DSM	Demand-Side Management
E	Evaporation
ECM	Energy Conservation Measure
EE	Energy Efficiency
EEDSM	Energy Efficiency and Demand-Side Management (Eskom)
EMP	Electromagnetic Pulse
EMV	Evaluation, Measurement and Verification
ESCO	Energy Services Company
ESM	Energy Savings Measure
ET	Evapotranspiration
ETL	Extract Transform and Load
EVO	Efficiency Valuation Organization
FAO	Food and Agriculture Organization of the United Nations
FAS	Farming Advice Service
FEMP	Federal Energy Management Program
GHG	Greenhouse Gas
GIS	Geographic Information Systems
GMT	Greenwich Mean Time
GPRS	General Packet Radio Service
GSM	Global System for Mobile communication
GW	Gigawatt
HVAC	Heating, Ventilation and Air Conditioning
ICUC	Irrigation Consumptive Use Coefficient
IDM	Integrated Demand Management
IEPD	Industrial Efficiency Policy Database

IML	Integrated Multi-Logger
IPCC	Intergovernmental Panel on Climate Change
IPMVP	International Performance Measurement and Verification Protocol
ISO	International Organization for Standardization
kV	kilovolt
kW	kilowatt
kWh	kilowatt hour
KZN	KwaZulu-Natal
LCD	Liquid Crystal Display
mA	milliamp
MRV	Measurement, Reporting and Verification
MVA	Mega Volt Ampere
MVCSA	Measurement and Verification Council for South Africa
MW	Megawatt
MWh	Megawatt hour
M&V	Measurement and Verification
NC	Normally Closed
NEMP	North American Energy M&V Protocol
NERSA	National Energy Regulator of South Africa
NO	Normally Open
NRCS	Natural Resources Conservation Service
NTC	Negative Temperature Coefficient
PA	Performance Assessment
PCB	Printed Circuit Board
PDD	Project Design Document
PoA	Programme of Activities
PRD	Partial Root Drying
PT	Positive Temperature (for PT100 or P1000)
QCP	Quality Control Path
QMP	Quality Management Plan
RF	Radio Frequency
RLM	Residential Load Management
SA	South Africa
SABS	South African Bureau of Standards
SANAS	South African National Accreditation System
SANEDI	South African National Energy Development Institute
SANS	South African National Standard
SARS	South African Revenue Services
SCADA	Supervisory Control And Data Acquisition
SI	Sustainable Intensification
SIM	Subscriber Identity Module
SLA	Service Level Adjustment
SMS	Short Message Service
SOP	Standard Offer Programme
SPP	Standard Product Programme
SQL	Structured Query Language
SWH	Solar Water Heating

T	Transpiration
ToU	Time of Use
TWh	Terawatt hour
UK	United Kingdom
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America
V	Volt
VER	Verified Emission Reduction
VSD	Variable Speed Drive
VT	Voltage Transformer
V-NAMA	Vertically Integrated National Appropriate Mitigation
W	Watt
WAS	Water Administration Systems
ZAR	South African Rand
12L	Section 12L of the South African Income Tax Act

Chapter 1

Introduction, problem statement and scope of study

1.1 INTRODUCTION

Water scarcity has become prominent in many countries worldwide with droughts threatening water availability. Droughts are a part of South Africa's history, however, the regularity and lengths of droughts have increased during the last couple of decades. The most significant effects of a drought are undoubtedly felt worse by the agricultural sector, before its effect ricochets to the rest of the industries. According to Gadanakis *et al.* (2015) studies on the effects of extreme weather conditions connected to climate change conclude that water availability for agriculture is threatened in general (Daccache *et al.*, 2011; DEFRA, 2009; Environment Agency, 2008; Jenkins *et al.*, 2009).

The dreaded result of water scarcity was experienced by South Africans very recently, especially in the Western and Eastern Cape provinces. Exceptionally high water restrictions were put on agriculture and the population. For instance, in the legislative capital of South Africa, Cape Town, a daily 50 litre per person usage limit needed to be enforced (City of Cape Town, 2018) for certain periods.

The water shortage problem in South Africa was already ranked as the third highest risk when doing business in South Africa by the World Economic Forum (WEF) in 2017 (GreenCape, 2018; WEF, 2017). Although water demand is significant in other sectors, agricultural irrigation globally accounts for 70% of freshwater consumption (Orum, 2010; Calzadilla *et al.*, 2008) while in barren and semi-arid regions the value reaches 90% (Tarjuelo *et al.*, 2015; Molden, 2007). As a result, irrigators are experiencing pressure from other competing sectors to reduce water usage (Speelman *et al.*, 2008; Malano *et al.*, 2004).

According to the Department of Water and Sanitation's (DWS) 2013–2015 annual strategic overviews of the water sector in South Africa, 62% of South Africa's yearly rainfall water yield was used for agricultural purposes (DWS, 2013; DWS, 2015). The usable mean annual rainwater runoff is 13.2 billion m³ (Du Plessis, 2014; Statistics South Africa, 2000). Estimations show that by 2030 South Africa will experience a 17% supply-demand gap (GreenCape, 2018; WEF, 2017).

This study investigates and confirms the prevalence of significant over-irrigation, inefficient application and water wastage in the South African agricultural sector. If the irrigation water usage efficiency can be improved by 28% through optimised irrigation, which seems idealistic but attainable according to study findings, it is conceivable to realise more than a 17% water usage reduction on the National water resources. This can fill the expected 2030 water shortage gap. It is hard to comprehend any other investment that can cost-effectively increase water resources by 17%. Rainfall cannot be increased; building more dams and water supply pipelines are exorbitantly expensive; sea water desalination is becoming technically feasible, but still comes at a very high cost.

On the energy side, population growth worldwide has led to increased energy demand which has resulted in energy shortfalls and excessive strain on electrical networks. The escalating energy shortages, combined with climate change concerns that are prominent worldwide, are the driving forces for programmes and initiatives to curb excessive demand, utilization and waste. Associated with the

high water usage, the agricultural sector is also a considerable consumer of energy in South Africa. According to Eskom's integrated results (Eskom IDM, 2016), the agricultural sector contributes a notable 4.7% of yearly total to Eskom's electricity sales. The single biggest electricity demand in farming activities is pumping irrigation water from canals, rivers, holding dams or boreholes for irrigation.

This study will show that common irrigation practices and technologies in South Africa are not only wasting water, but also prone to energy inefficiency and waste. Here the improvement potential is tremendous and the study will show through investigations that an average irrigation energy efficiency improvement of near 40% is realised. This is attained through optimising the pumping system through a Variable Speed Drive (VSD). These savings may even be increased to 50% by improving irrigation practices and focusing on water usage and pumping system efficiency.

With the droughts and pressure on the agricultural sector, and the electrical shortfalls mentioned, it is to be expected then, that water and electricity conservation initiatives to improve irrigation performance should be common practice and should have a significant impact, especially since agricultural irrigation uses more than two thirds of freshwater globally. However, this not the case, even though there is a large conservation potential. It was found that water conservation attempts have difficulty being initiated and are hampered by a lack of incentive, and management thereof.

There can be a contrast between social and business aims; a farmer's goal might be to achieve the maximum production and profit per water unit, while an environmental conservation goal might be to use the minimum water for the value of production (Gadanakis *et al.*, 2105; Knox *et al.*, 2012).

Thus, without incentive vehicles, it is difficult to convince farmers to invest in conservation technologies and practices. An incentive vehicle is broadly defined here as a mechanism that, when implemented, will motivate, enable, force or guide an irrigator to adopt conservation practices. Such a mechanism may be water, energy or greenhouse gas reduction rebates, taxes, restrictions, penalties, curtailment, cap and trade or other mechanisms. The complication is that one incentive is generally not enough to overcome the barriers and encourage farmers to take up conservation technologies and practices.

However, if other incentive mechanisms can be combined with that of water, this could have a greater impact and bring along the necessary change. A variety of mechanisms to encourage conservation exist worldwide, see Figure 1-1. These range from water and greenhouse gas incentives, left of Figure 1-1, to cleaner production drives, energy conservation and with this, the associated advantages and benefits of irrigation efficiency. The availability and viability of incentive or charging mechanisms are greatly dependent on a country's conditions and politics though.

In order to cope with energy shortfalls, governments and electrical utilities react by implementing incentivized demand-side management programmes (Boslaugh, 2013; Gellings *et al.*, 1993). There has also been a global drive for greenhouse gas emission reduction and cleaner production (Theilmann, 2013; Chen *et al.*, 2017; Zivkovic *et al.*, 2018) with several incentive mechanisms introduced. Among other drives, the European Union's Common Agricultural Policy aims to improve the environmental footprint and profile of agriculture (Union, 2014; Vlontos, 2017). Depending on the country, there may be more than one incentive mechanism available for reduction in water usage, energy use and greenhouse gas emission, through which irrigation efficiency can be made more worthwhile. However, a key aspect of incentive mechanisms is the requirement of quantifying reductions.

Depending on the incentive mechanism and specialization field, the quantification method goes under names like the following: Measurement and Verification (M&V); Measurement, Reporting and Verification (MRV); Evaluation, Measurement and Verification (EMV); water accounting and others. With each there are also different standards and protocols which should be followed. The International Performance Measurement and Verification Protocol (IPMVP) states that M&V is the process of using

measurement to reliably determine actual savings achieved within a project by conservation initiatives. Furthermore, the IPMVP (2012) states that savings cannot be directly measured since savings represent the absence of usage (IPMVP, 2012). Instead, savings are established by comparing usage measured before and after implementation and introducing appropriate adjustments corresponding to changes in conditions.



Figure 1-1: Incentive mechanisms to overcome barriers to taking up conservation technologies and practices.

M&V in general can be challenging sometimes, however, M&V of irrigation conservation has shown to be especially difficult. The complexity and cost of irrigation conservation M&V frequently discourages projects or programmes although there are incentives available. With water, proper water accounting and defining actual water usage reduction in perspective of the water basin, are complex and key to any water conservation initiatives.

The aim of the present study is to overcome irrigation conservation M&V challenges by providing novel, practical and cost-effective M&V approaches and methodologies as well as an integrated framework. This creates a turnkey solution that can quantify irrigation electrical energy conservation under any typology. Although water conservation is of greater value here, the focus is on electrical energy conservation since this, with related incentives, can be utilised to realise water conservation.

In addition, greenhouse gas emission reductions can be directly connected to quantified energy conservation, which in turn opens up carbon market incentives and rebate possibilities. Energy conservation is advantageous in the following two ways: energy efficiency due to a reduction in use and peak period demand reduction which is critical for power supply utilities. If the correct policies with proper and effective M&V that comply with the requirements and regulations of the available incentive mechanisms are in place, then incentives can be combined to realise water conservation uptake amongst farmers.

1.2 PROBLEM STATEMENT

Water scarcity is an imminent threat to South Africa and other countries, and a way has to be found to reduce water consumption. Since the agricultural sector is the largest consumer of water and prone to inefficient use and waste, it would seem straightforward to simply optimise farming irrigation practices to conserve water or enforce reduced usage. However, this is a very complex problem and when combining incentives to encourage water conservation, it brings about even more complications. This

section provides the study problem statement and Figure 1-2 gives a flow chart outlining the problem statement. The following sections describe each part of this flow chart.

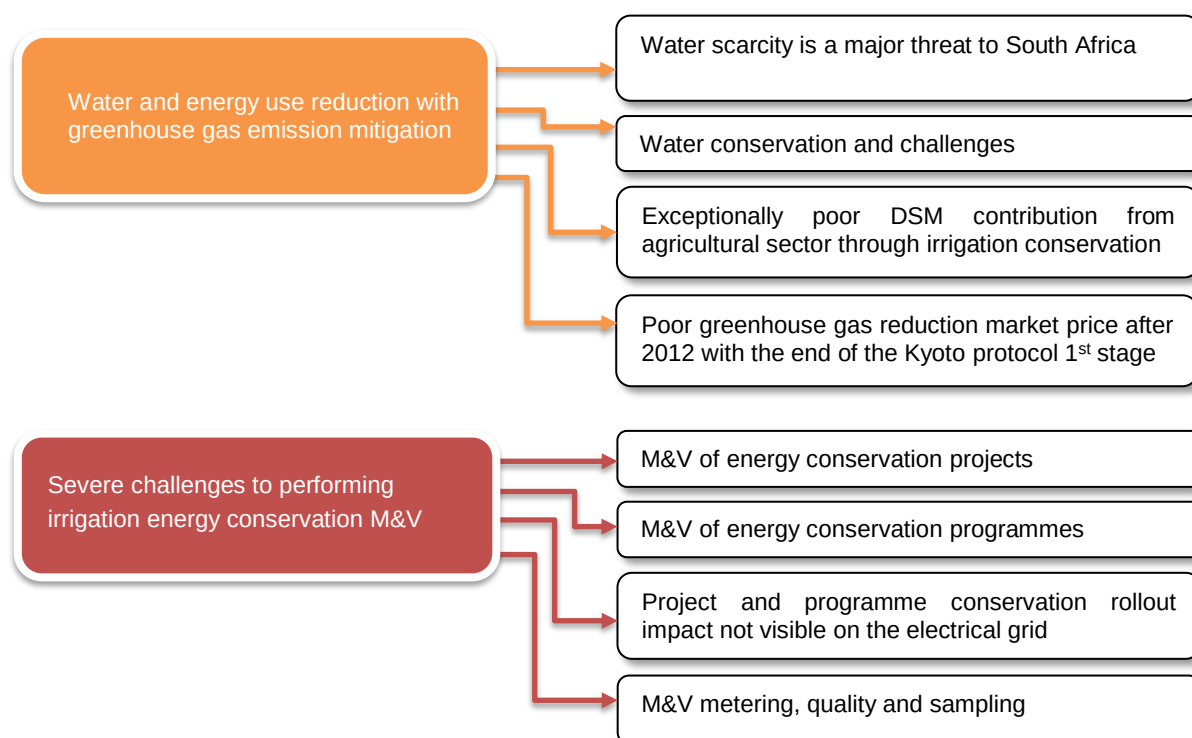


Figure 1-2: Flow chart outlining the study problem statement.

1.2.1 Water and energy use reduction with greenhouse gas emission mitigation

The first part of the problem statement, as seen in Figure 1-2, evaluates the water situation in South Africa and the potential for water conservation in the agricultural sector. It also looks at the worldwide situation regarding water conservation attempts and the associated challenges. From here the study considers how energy conservation can be utilised as an incentive and what has been accomplished thus far in South Africa. Lastly, the current poor greenhouse gas reduction market price is discussed. The boxes on the top right of Figure 1-2 are touched on individually in the following sections.

1.2.1.1 Water scarcity is an imminent threat to South Africa

As discussed in the introduction, South Africa has a history of droughts and indications show that these conditions may continue and are expected to get even worse, resulting in the mentioned 2030 supply gap (GreenCape, 2018). The agricultural sector is usually the first to experience the devastating effects of a drought with other sectors feeling the effects shortly thereafter. Water conservation is a very urgent matter.

1.2.1.2 Water conservation and challenges

Water usage efficiency can be enhanced by improving irrigation practices, thus achieving an economic advantage while simultaneously decreasing environmental burdens (Levidow *et al.*, 2014). There is much literature available on irrigation pump setup and distribution system optimization with improvements varying from inexpressive leak repairing to costly equipment replacements. Unfortunately, improved irrigation methods and other conservation initiatives do not inherently result in true water usage reduction. In contrast, FAO (2017) shows with a recent worldwide study that in most

cases water savings are not achieved but water usage actually increases. For incentive mechanisms it is important to determine what exactly happens to water in order to define and quantify the actual water conservation savings or recovery. The literature survey in Chapter 2 will elaborate on consumptive and non-consumptive uses relating to this topic.

Conservation incentive mechanisms may be introduced and applied in many ways. Even better regulation can sometimes result in reduced pumping activities. This study also shows that farmers' pumping activities significantly altered since South African Water Board flow meters were installed on river water extraction points. Water pricing mechanisms may include volumetric, area, input or output pricing, quotas and water markets (Orum *et al.*, 2010, Johansson *et al.*, 2002; Tsur and Dinar, 1997). Orum *et al.* (2010) notes the following:

- If the farmer controls the delivered water supply, volumetric pricing will be better since it gives an incentive for efficient irrigation, strategies and irrigation systems, citing Bos *et al.* (1990); and
- Although water taxes may result in efficient irrigation, increasing water prices raises concerns regarding the political reaction and the risk of increased food prices, as well as competition with international markets and the changing nature of stable food prices, citing Molle (2002). Water taxes may have an adverse result regarding land use, citing Berbel *et al.* (1999). Farmers might invest in different crops or stop irrigating, instead of adopting new technologies and strategies to save water.

Care should be taken with water taxes or other restrictive measures; in South Africa especially, farmers already face high crop input costs and difficult farming conditions. Water restrictions and taxes would increase the current burden on farmers and further reduce already low profit margins. Government investment in irrigation technology improvements can often result in higher water prices, but without the full potential benefits being achieved through water efficiency (Levido *et al.*, 2014). Governments can also have cleaner and improved production programmes with the aim of reducing irrigation farm water usage by concentrating on irrigation system improvements.

According to Orum *et al.* (2010) and Huffaker, (2008), overall these investments have benefited the farmers, although not all the objectives of the conservation of water have been met. This can easily occur if proper water accounting and impact quantification methods are not incorporated to track conservation and keep incentive beneficiaries accountable. This highlights the importance of incorporating appropriate M&V to assess water saving impacts.

Considering the above, the better approach in South Africa would be to avoid water taxes and rather focus on energy and related incentive mechanisms through which farmers can be motivated and assisted to invest in conservation technologies and practices. The question at hand is what successes have been achieved through irrigation Energy Conservation Measure (ECM) incentives in South Africa thus far.

1.2.1.3 Exceptionally poor demand-side contribution from the agricultural sector

Since 2004, South Africa's focus regarding energy has been towards the threat of energy shortages. Initiatives such as the Eskom Integrated Demand Management (IDM) programme, from South Africa's only power utility, have had a significant impact on the energy demand of the country, so far as to have achieved a 'negawatt' capacity equivalent to that of an average power station (Eskom IDM, 2013). The major focus during the past decade of these programmes and projects has been on the residential, industrial, mining and commercial sectors due to the energy intensity of these, especially relating to peak hour demand reduction rather than sustainable energy efficiency.

The agricultural sector in South Africa contributes between 4% and 4.7% to the annual electricity demand and consumption (Eskom IDM, 2013; Eskom IDM, 2016). Figure 1-3 shows the summer and winter power demand profiles of the entire South Africa. Typical summer day peaks are above 32 Gigawatt (GW) while typical winter profiles surpass 36 GW.

Only using 4%, the winter agricultural peak load is 1.44 GW and in summer the peak load is 1.28 GW. According to Eskom IDM (2013), the annual electrical sales to the agricultural sector is 8.64 Terawatt hours (TWh). Considering these values, the agricultural sector is a considerable electrical energy user.

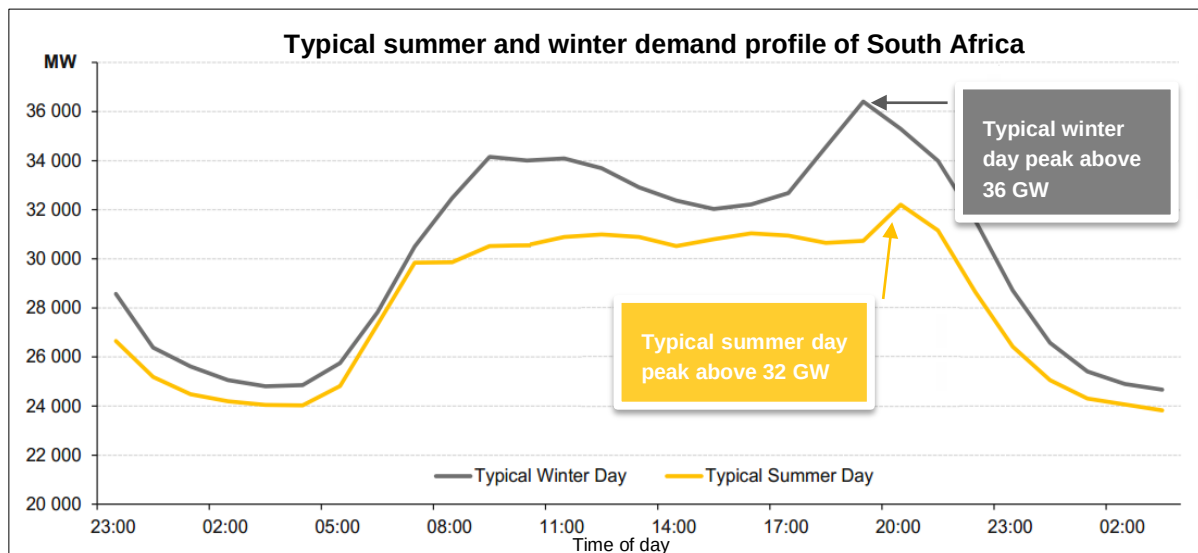


Figure 1-3: South African summer and winter power demand profiles (Adapted from Eskom IDM, 2013).

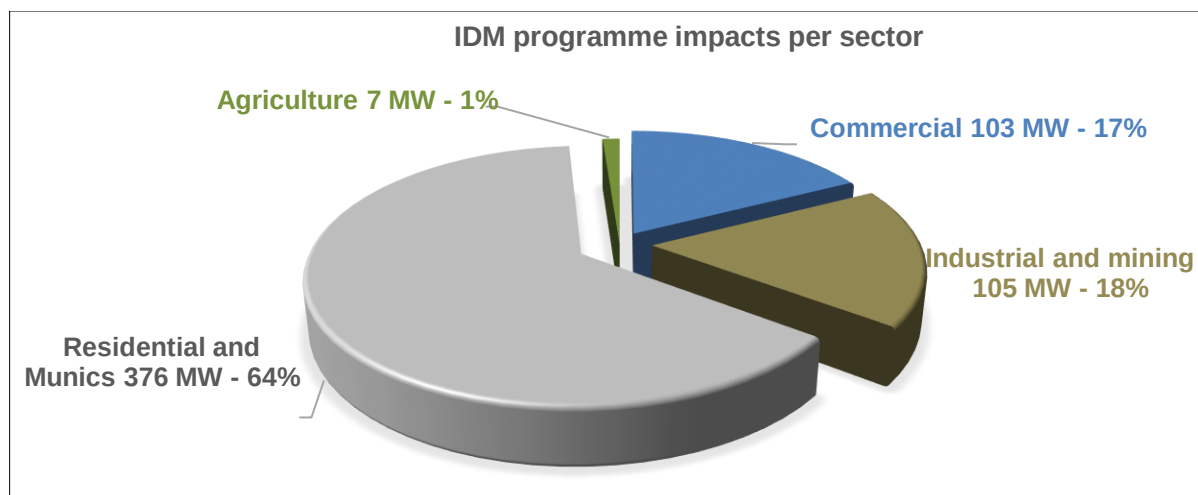


Figure 1-4: Eskom IDM Programme – sector impacts (Adapted from Eskom IDM, 2013).

Figure 1-4 gives a pie chart of the 2013 Eskom financial year IDM peak period demand reduction achieved per sector (Eskom IDM, 2013). Through peak load shifting projects, only 1% (7MW) of the demand reduction accomplished was in the agricultural sector. Compared to the other sectors and considering its contribution to the total South African demand, this is exceptionally low.

In addition, the sustainability of the demand reduction achieved through irrigation projects was poor with underperformance prominent to the end of the three-year DSM contract, as was seen from M&V

performance assessment reports. After the performance period contract ended, the savings further declined. This shows that with the attempts made thus far, very little ECM impacts were achieved in the agricultural sector. Reasons for this include, among others:

- The cost and difficulty of implementing irrigation ECMs;
- Project impacts are overestimated initially;
- Irrigation farms are scattered with ECM project sites often far from each other and difficult to reach;
- Difficulty and cost of proper M&V; and
- Although there are many large project sites, the biggest hurdle is that the major impact is spread over thousands of smaller irrigation projects. In South Africa there are around 60 000 centre pivot irrigation systems alone, without considering other irrigation methods such as sprinklers and micros, but the typical pump size is around only 30 kW (Scheepers et al, 2013). A programme approach would be required here instead.

1.2.1.4 Poor greenhouse gas reduction market price

After the 2012 end of the Kyoto protocol first stage, the price of Certified Emission Reductions (CERs) and Verified Emission Reductions (VERs) plummeted. Clean Development Mechanism (CDM) projects under the United Nations Framework Convention on Climate Change (UNFCCC) already had challenges due to costs, the additionality prerequisite and strict methodology monitoring requirements. Now, with the low CER price, CDM projects are rarely worthwhile.

1.2.2 Severe challenges to performing irrigation ECM M&V

Referring to Figure 1-2, this section discusses the severe challenges and difficulties with the M&V of irrigation ECM projects and ECM programmes. It also shows that the combined bottom-up assessed impacts of these types of initiatives, over all sectors, are not visible higher up on the electrical grid. The section ends with a discussion on challenges surrounding M&V metering and sampling

1.2.2.1 M&V of ECM Projects

The M&V of ECM projects in any sector normally have problems that complicate project assessments, but even taking this into account, exceptional evaluation difficulties have been experienced and cumbersome M&V methodology challenges have been encountered with agricultural irrigation pumping. Here an ECM project can be one pump, several pumps or a project consisting of hundreds of pumps where the impacts of these are confined under one boundary.

Such a project requires full contractual life M&V evaluation and normal or conventional M&V methods are commonly used, which involve physical metering of all or key project parameters over the whole contractual period of the project. In this context, a project requires full metering of all pumps (demand profile metering) or appropriately sampled pumps. Challenges were experienced with conceptual easy load shifting ECMs and normal energy neutral baseline methods were found to be ineffective. These projects did not even include energy efficiency or situations where load shifting and energy efficiency are combined. Here proper designed alternative M&V methodologies are required to enable proper quantification.

There are well-developed M&V guidelines and standards like the IPMVP and the South African National Standards SANS 50010 and SANS 50015 / ISO 50015:2014 (IPMVP, 2012; SABS, 2018; SABS, 2015). However, there is no real information or guidance available to M&V practitioners on the specific

evaluation of irrigation ECM projects, what M&V and metering strategies to follow and how to approach baseline development with appropriate service level adjustment methods.

This, with other challenges, results in project performance not being effectively quantified from the beginning and the M&V approach later needing to be changed. This change often comes at significant cost and possible saving losses in the period already evaluated.

It is also observed that ECM implementers, more commonly known as Energy Services Companies (ESCOs), overestimate the attainable targets of irrigation load shifting projects resulting in project under performance. Also, the correct or full extent of the data and information on which proper M&V analysis can be done are not gathered.

In general, stakeholders (power utility and project investors) are not aware of the pitfalls and challenges with irrigation ECM projects and the M&V thereof. Frequently project underperformance or project issues are only discovered after the project has already been implemented. Here proper guidance is required to assist with the M&V of irrigation ECM projects.

1.2.2.2 M&V of irrigation ECM programmes

Only large projects with significant ECM impacts can justify the high M&V cost associated with full project M&V described in the preceding section. However, the largest agricultural irrigation energy conservation potential is on smaller irrigation points. These are often scattered and cannot justify project type M&V. Similar to the industrial, commercial and mining sectors, smaller fixed type ECM technology rollouts or retrofits can be done through large incentive-based programmes over hundreds of irrigation pumps. A project M&V approach requires extensive baseline and metering for the whole life of the project). Metering and data gathering costs can be cumbersome and also very expensive.

In addition to this, independent M&V specialists are required to track the ongoing savings throughout the project life. M&V for programmes fundamentally differs in the following aspects from project M&V:

- No profile metered baseline period and no reference energy drivers,
- No ongoing metering is performed on the ECM after implementation,
- No profile baseline development, and
- The incentive is paid to participating parties at the beginning of the project, on a projection of the savings over a set period; thus
- There is no ongoing tracking of the project performance.

Considering these differences, and the very unique and unpredictable nature of the agricultural sector, conventional project M&V approaches are inapplicable and alternative methods are required to assess irrigation ECM programme impacts. However, impacts should be determined in such a manner to still have acceptable confidence levels and error margins as required by an incentive mechanism. In addition, there should be functional methods and techniques which can be used for validation and verification of programme savings.

One incentive mechanism that was explored as part of the study is the Eskom Standard Product Programme (SPP). Under the SPP, an energy saving rebate is paid to participating parties upon the implementation of a standard and proven energy efficiency technology to replace a standard old inefficient technology (Van der Merwe, 2011). The initial technologies allowed under the SPP included energy efficient lighting, heat pumps, efficient lighting shower heads and solar water heating (Van der Merwe, 2011).

An Eskom IDM energy advisor team (Scheepers et al., 2013) also set out to establish an Eskom SPP for irrigation demand reduction and energy efficiency, thus, M&V assessment was required. As

discussed in the previous section, conventional M&V of irrigation projects are exceptionally challenging. The special conditions and requirements of programme M&V and those of the Eskom SPP, required a new and unique M&V methodology to quantify ECM impacts under the SPP.

1.2.2.3 Project and programme impact not visible on the grid

When large-scale irrigation energy conservation projects and programmes are implemented, it is very important to see the actual effects of these on a higher level. Often, the combined results of project and programme M&V might show considerable savings, however, the regional power grid does not experience the impact reported by this bottom-up approach.

This scenario was especially seen with the Eskom IDM DSM programme that was introduced over all the sectors (not only irrigation) in South Africa. An M&V method, on an area or regional level, is required to perform an evaluation that is able to quantify and validate the savings reported by irrigation projects and programmes.

Also, it is time consuming and intensive to gather the information to calculate bottom-up results of projects and programmes in an area. This leads to assessment results being delivered weeks after the end of the assessment period. Often, these types of results are required much sooner, especially in times when an electrical grid is under strain and accelerated actions are required.

1.2.2.4 M&V metering, quality and sampling

Well-designed methodologies with M&V projects and programmes in general receive the required attention during ECM projects. Unfortunately, it frequently happens that the fundamental aspects which are used to perform M&V are underestimated, neglected or not suitably implemented. M&V metering, meter data quality and appropriate meter sampling form the basis of any proper M&V approach.

It was observed with M&V practitioners, ESCOs and other stakeholders that there is often a severe gap in knowledge on M&V metering. In many cases M&V practitioners or ESCOs use and install temporary metering to gather baseline data themselves. If installations are not done properly and there is not a clear understanding of what is being measured, it can compromise the usefulness, correctness and accuracy of the data collected. With sites that already have metering installed, M&V practitioners and ESCOs should have the adequate knowledge to assess the correctness of such installations.

Here it is important to note that the installation and implementation of metering and Automatic Meter Reading (AMR) systems can be challenging. Even more so, metering on irrigation ECMs are especially challenging and problematic and it was found that it often hinders or even prevents successful M&V.

The IPMVP guideline and the SANS 50015 and SANS 50010 standards, for example, provide very good guidance on M&V, data transparency, integrity and correctness of project metering data (IPMVP, 2012; SANS 50015:2015; SANS 50010:2018). Other standards like the SANS 474 and NRS 057 provide a code of good practice for the installation of electrical metering (SANS 474:2009 & NRS 057:2009). Specific standards, data sheets and installation specifications also exist for water flow meters and other M&V metering. However, these documents and standards do not necessarily provide guidance and solutions to the practical aspects and challenges experienced with the metering in the field. In addition, the usefulness of these documents to a non-technical person, or the availability thereof can be a problem. In some cases, it was found that project stakeholders and even M&V practitioners were not aware of the existence of such documents.

Aside from the significant increase in cost of metering when an AMR system is incorporated, there is another set of complications. An AMR system is often experienced as a black box where meter data enters and then something can be viewed via an AMR online system. It is not entirely clear to the M&V

practitioner if what is measured in the field, is actually what is displayed and provided by this system. It may occur that as data passes through this black box, it is introduced to multiplication factors, averaging and other changes without the knowledge of the M&V practitioner. This creates a serious gap and compromises a clear, transparent and auditable data trail.

Alongside metering, proper meter sampling methods are sometimes a significant obstacle. Large enough sample groups, improper sampling plans and the difficulties that come with sampling load profiles hinder M&V approaches in attaining high enough confidence levels and low error margins, if required. Simplified sampling concepts are required that can reduce load profiles to key single value ratios.

1.3 SCOPE OF STUDY - THESIS OVERVIEW

A method is required to unlock the energy conservation potential in the agricultural sector through which water conservation can be realised. This study considers the irrigation conservation potential and the possible incentive mechanisms and aspects, but focuses on the critical area of the quantification of conservation. The aim here is to develop and apply a functional but cost-effective turnkey M&V solution.

The study content with original contribution and chapter breakdown is provided in the following sections. Figure 1-5 gives a flow chart that provides an overview of the scope of the study with the chapter breakdown also indicated.

1.3.1 Literature survey

The introductory chapter is followed by a literature survey and evaluation on possible irrigation conservation interventions, implementation associated issues and specific M&V challenges and quantification requirements. This is shown on top of Figure 1-5 in the literature survey block. Alongside this, the study investigates examples of incentive mechanisms and discusses the related M&V specifications and standards; see the middle of Figure 1-5.

The critical requirement of any incentive mechanism is the quantification of conservation impacts. Here proper background on the field of M&V, the function thereof as well as qualitative measures are provided. The combined effect of these incentive mechanisms would enable farmers to invest in efficient technologies and adopt improved irrigation practices.

This is used as leverage to attain reduced water consumption with the associated reduced electrical usage, reduced electric demand and cleaner production. Several other aspects related to the study, providing the relevant background for the above, are also discussed in the literature survey chapter.

For example, critical pillars to ensure the success of any conservation initiative are proper governing policies, accounting and set limits as shown in the middle left of the literature survey block in Figure 1-5. Without these, the practical implementation and sustainability of any incentive mechanism ECM impact would be fruitless.

1.3.2 Novel integrated M&V approach

Below the literature survey block in Figure 1-5, a novel integrated M&V approach is presented which envelopes project level, programme level and regional M&V solutions. These are each separately discussed in chapters. Project level, Chapter 3, is for large projects on a farm, or over several farms, and uses conventional full M&V to quantify conservation achieved.

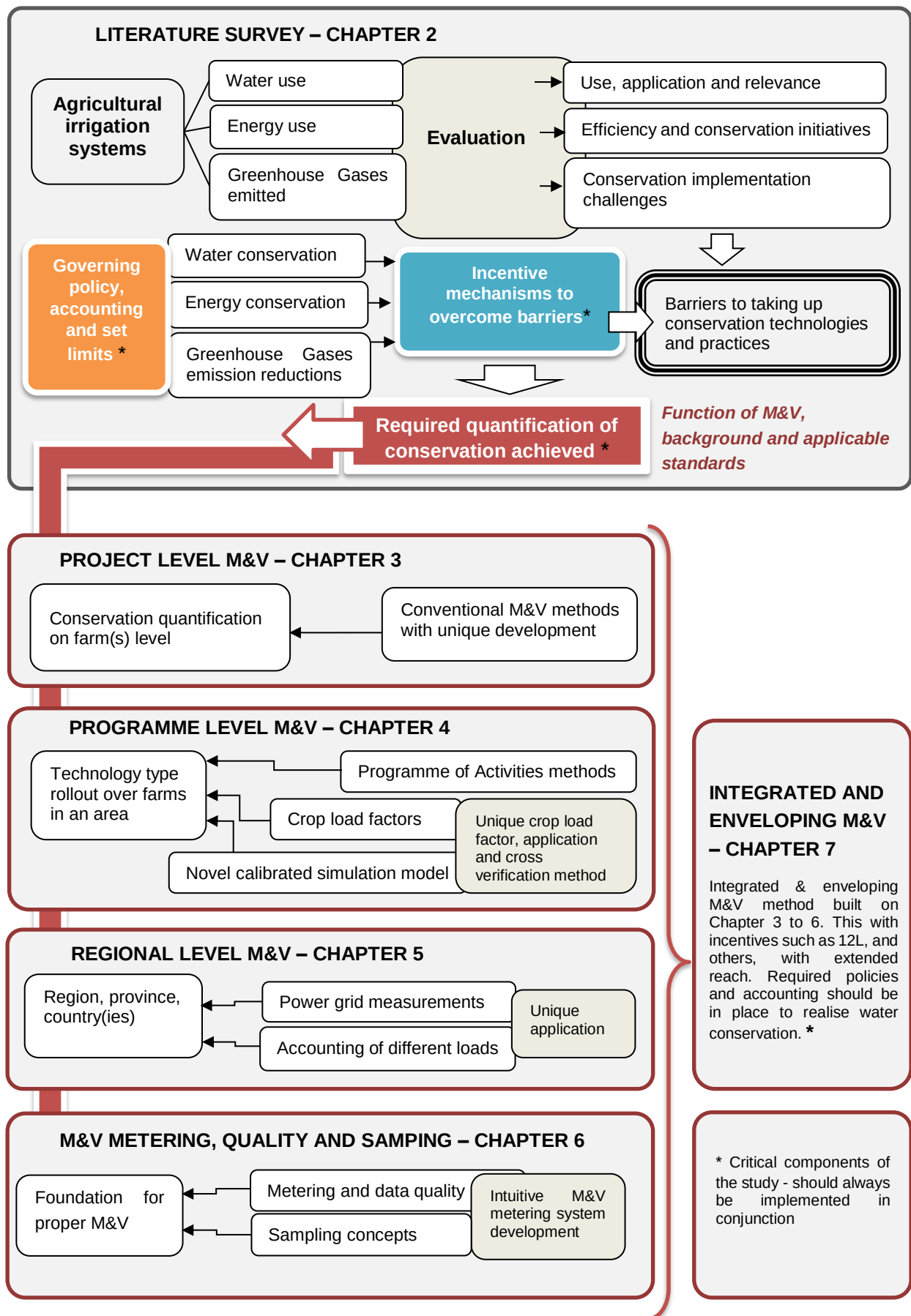


Figure 1-5: Flow chart of the integrated M&V methodology.

Following this is Chapter 4 with programme level M&V, which is for programmes that allow a specific conservation technology rollout over many farms in an area, but do not allow conventional project level M&V. Regional level discussed in Chapter 5 provides a top-down approach to evaluate conservation impacts on a higher area or regional level. The three levels of M&V, project, programme and regional are focussed on electrical energy quantification. Chapter 6 focusses on M&V metering, meter data quality and appropriate meter sampling.

The content of Chapter 2 to Chapter 6 sets the foundation for Chapter 7 which integrates these while including more designs. This provides a novel turnkey solution which is ultimately aimed at enabling water conservation. The following sections describe the content of each chapter as outlined in Figure 1-5, how the problem statement of Section 1.2 is addressed in each chapter, how each chapter contributes to the field and the novelty of each chapter.

1.3.2.1 Project level M&V

Normal baseline development methods were ineffective with irrigation ECM projects and unique M&V methods were devised, developed and implemented to enable effective impact quantification. Further development was done to provide a complete M&V solution for any type of irrigation DSM project or a combination of different types. These include:

- Load shifting,
- Energy efficiency with an energy driver (energy governing factor),
- Energy efficiency without an energy driver,
- Combination of load shifting and energy efficiency,
- Load prevention or clipping, and
- Combination of clipping and energy efficiency.

Considering each project type, this study looks at the different aspects of baseline development, from the baseline boundaries to saving calculations. Also, different pumping setups are discussed with proper baseline development methods designed and presented. Following this, Service Level Adjustment (SLA) anomalies found in actual projects with alternative baseline methods are provided. Baseline development challenges found in the field are also discussed.

With the unique methods developed, this study intends to give guidance for M&V entities, project investors, utilities, clients and ESCOs on what is required for proper M&V. Through this, project stakeholders can pre-emptively check that the correct M&V and associated requirements are in place, to ensure a successful DSM ECM project. It also gives guidance to ensure that proper M&V is actioned from the DSM project planning phase to avoid common pitfalls.

For this purpose, an example analysis is performed on the typical information an ESCO would provide for a proposed irrigation DSM project. Here the aim is to accomplish the following:

- Inform ESCOs and stakeholders how project information is handled and scrutinized by an M&V practitioner;
- Provide insight for project stakeholders (specifically the power utility and project investors) on the pitfalls which should be avoided with irrigation projects;
- Provide evaluation methods for new project decision makers to evaluate the feasibility of a proposed DSM project quickly at the very beginning, before implementation; and
- Provide guidance for M&V entities on what to look out for, what M&V strategy to follow and how to approach baseline development.

1.3.2.2 Programme level M&V

From the problem statement provided in Section 1.2.2.3, a novel M&V methodology is thus developed to quantify ECM impacts under the SPP. This involves designing methods to effectively determine conservative, but representative impacts without continuous power demand profile measurement. The design involves unique methods to quantify operational demand reduction, annual kWh and annual average demand reduction impacts. The design is also broadened to pumps irrigating multiple crop areas and different kinds of crops.

The methodologies and techniques developed are validated and verified through establishing independent cross check measures. Here a unique regional top-down M&V approach is introduced which can be incorporated to verify the actual total energy efficiency and load reduction impact on the electricity grid. This is discussed under regional level M&V in the next section.

The main focus of the SPP programme, and therefore also of the M&V evaluation method developed, is determining the annual kWh energy savings. The resulting limitation here is that the method cannot show when energy is consumed by the pump during the day. Therefore, it is not possible to determine if the demand reduction related to the SPP kWh saving occurs over the Eskom peak periods.

It would be valuable if there was a method that could accurately determine how much of the SPP reductions that was achieved, actually occurred over the Eskom peak period. Hereby the SPP could also show what contribution it made to peak reduction. It would be even more valuable if there was a method that could also show what irrigation peak pumping load would be available for possible load shifting projects.

In light of these needs, an original calibrated simulation M&V model is designed and developed. It presents a special variable confidence level approach which realises cost-effective implementation of different applications. These range from irrigation area load availability impact feasibility studies to SPP-like programmes (with load shifting) which have differing levels of accuracy. Although this focusses on the Eskom irrigation SPP, the processes followed can be used on any similar programme rollout incentive-based mechanisms.

1.3.2.3 Regional level M&V

The study presents a unique irrigation regional level M&V methodology which allows M&V assessments and impact validation at a higher level. Through this, the real contribution that irrigation projects and programmes, in an area or region, have on the electrical grid can be quantified. A regional or area level M&V approach also has the advantage of providing results much quicker when compared to a bottom-up approach.

Depending on data availability from the power grid AMR systems, this can allow project stakeholders to rapidly (the day after, or even the same day) monitor the impact of project or programme interventions and to be able to swiftly react if impacts are not reached. Through this, corrections or system adjustments can be made on the ECMs to ensure targets are met in future. This is in comparison to the vast amount of data and delay of normal power utility billing point AMR systems (end of the month billing); bottom up results are usually only available two to four weeks after the assessment period ends.

Thus, if a problem occurs at the beginning of the assessment period, it can take weeks or even months before the problem is discovered. With the above method, however, regional or area level M&V also allows cost-effective immediate and long-term sustainability tracking of project and programme impacts over time. This can continue even long after project or programme level M&V has ceased to evaluate the degradation of ECM savings.

However, a regional level M&V approach can be very challenging and complicated as will be described in the study. Here intuitive methods are required to successfully implement and execute regional level M&V. To reveal the challenges and how it can be overcome, an exceptional case is presented where a regional M&V approach is implemented. The case study does not only draw an M&V boundary around a region, but the entire Western Cape province of South Africa. The Western Cape is the fourth largest of the nine South African provinces (Statistics South Africa, 2009). In comparison, the Western Cape is slightly larger than the state Mississippi in the United States of America (USA), and just more than half the size of the United Kingdom. Thus, it is a very large M&V region that was under evaluation. Through this case study, the process involved with regional level M&V is demonstrated, the associated pitfalls and challenges are discussed and solutions are provided.

1.3.2.4 M&V metering and sampling

Considering the challenges with M&V metering, especially with irrigation ECM, the study focusses on providing value and contributing to the M&V field in the following ways. This study will:

- Show the difficulties and challenges that are experienced specifically with irrigation ECM M&V metering (although these challenges are also largely applicable to ECMs in other sectors);
- Explain and demonstrate the basic concept of metering and AMR systems, showing how these function, which parts are critical and which areas give challenges;
- Identify the areas where a data audit trail can become unclear with metering and AMR systems;
- Provide background on what type of meters are frequently used with irrigation and related projects, showing how these function and which pitfalls to look out for; and
- Through this, provide M&V practitioners and other stakeholders with relevant background and information when sourcing metering and AMR systems suitable for M&V.

The above is done alongside the presentation and explanation of an innovative metering and AMR system that was designed and developed to specifically address M&V meter challenges as part of the study. The aim is to establish a redundant but cost-effective solution that fits M&V specific requirements and conditions. It is shown how intuitive design alleviates the challenges with M&V metering and quality.

The logger and communication device is designed in such a way that all components and sensors are sourced in South Africa. In addition, the full device manufacturing also occurs in South Africa making it a proudly South African product. The challenges to provide a cost-effective product were substantially increased by using only local components and a local workforce.

With M&V metering, it is very important to have a proper data Quality Management Plan (QMP) to track and evaluate data. Such a QMP can have a Quality Control Path (QCP) document or protocol which identifies the possible places which can influence data or compromise quality or delivery. A discussion is provided on the quality control of typical meter systems starting at metering installations and the interaction of installers with loggers and equipment during installations, to the online system where data can be viewed and analysed. The QCP identifies possible risk areas and provides key inputs for the QMP.

The QMP is based on an ISO9001 Quality Management System (QMS) that was used for M&V purposes. The QMP also aligns with the latest M&V standards surrounding metering and related subjects. The use of multiple metering points or intelligent multiple meter approaches, which replace the necessity for relying on operational level conditions and boundary limits, are also looked at. A discussion is provided in which the function of normal metering can be stretched through strategized application, by which it can increase the M&V capability and reach thereof.

The study further considers how a sampling approach of a first of its kind CDM project study can be applied to reduce the complexity of sampling irrigation load profiles. In addition, it provides the conceptual design of an irrigation ECM simplified sampling concept that reduces load profiles to key single value ratios. Attention is also given to the value of over sampling practices. Proper and thorough guidelines on sampling and the relevant statistics already exist. Thus, statistical analysis is not performed but focus is placed on providing concepts that can assist with setting up proper sampling plans for irrigation ECM projects and programmes.

1.3.2.5 Integrated M&V

With a proper foundation established in Chapters 2 to 6 and functional M&V methods developed, this chapter focusses on an integrated M&V methodology. Through this, the ultimate goal of realising water conservation in the agricultural sector is addressed. Here integration is done and concepts and frameworks are proposed on the following levels:

- Integrating project, programme and regional level M&V to better quantify energy savings for incentive mechanisms such as the SPP;
- Expanding this to options under the South African 12L tax rebate through a new proposal. Section 12L of the South African Income Tax Act 58 (of 1962 - with the 2013 section 12L latest replacement) was introduced to establish a special allowance for taxpayers through energy efficiency, which promotes energy security, while combating climate change through incentivising taxpayers to use energy more efficiently (Seligson, 2015).;
- Defining water and greenhouse quantification at project level, programme level and regional level and explaining how quantification will be done;
- Integrating this with energy conservation; and
- Integrating M&V into projects, programmes and policies early on through which water conservation can be ultimately realised.

Here it should be clearly stated that if conservation projects or programmes are not accompanied with a strict governing policy, accounting, set limits and project maintenance, conservation attempts will most probably be fruitless or not sustainable. This is especially the case with water. According to FAO (2017), the essential sequence of actions for an adequate and sustainable water resource is:

- 1) Establish a proper water accounting system providing quantitative water balance estimates;
- 2) Set well designed water allocation limits; and
- 3) Motivate and assist users to maximize the benefit of the water allocated. Here improved irrigation methods and conservation initiatives will be applicable.

If the reach of mechanisms like 12L can be increased to incorporate agricultural irrigation energy efficiency, it can have a major contribution towards the aim of conservation. Currently every South African Rand (ZAR) spent by the government to sustain the power supply infrastructure of South Africa does only that - sustains the power supply network. However, every Rand that will be spent on 12L tax incentives for irrigation projects will not only help sustain electrical power supply, but will also save tremendous amounts of water, reduce carbon emissions, allow growth of the economy and enable food security by assisting farmers. Some of the other benefits may include:

- **For the farmer** - Electricity expenses will be reduced; prevention of over-irrigation can lead to lower fertiliser use and increase in crop yields. Therefore, profit margins will increase.
- **For farm employees** - Reduced input costs will increase profit margins for the farmers, this in turn enables improved job security and increased remuneration for farm employees.

- **For technology suppliers** - Energy efficiency technology providers, like VSD suppliers, will benefit due to increased equipment sales. Thus, new jobs will be created to cater for installations, monitoring and routine maintenance.
- **For the economy** - Since crop input costs are reduced, this can have a knock-on effect on the rest of the economy and will contribute to containing food inflation.
- **For Eskom** - Relief on the strained electricity grid and strained power stations will be provided. Increasing energy efficiency in this manner will reduce the demand on the network at a fraction of the cost of upgrading the electrical infrastructure. A project of this nature will reduce strain on the distribution networks to farms and remote areas – precisely those networks that cost much development and maintenance but yield little return from a grid-cost recovery perspective.

1.4 ORIGINALITY AND CONTRIBUTION OF STUDY

This study considers an original approach to address an imminent water shortage threat not only in South Africa, but also in many other countries. The study contemplates and analyses existing methods and facts, and uses these to design new methods and approaches with mathematical equations. This enables both novel development and unique application. In addition, it combines both existing and newly developed methods, incorporating the effort of other researchers and established approaches with international accepted standards in these specialist fields. New insight is gained and applied through this which further realises new approaches and applications which can address the water crisis.

The study is executed by identifying, presenting and formulating a relevant and highly important original research topic with novel design and development. This is performed in the present chapter, Chapter 1, and is followed by an encompassing and comprehensive literature survey, Chapter 2, which outlines and highlights the necessity and novelty of the study. This is followed by Chapter 3 to 6 (project level, programme level, regional level M&V and M&V metering and sampling) which contributes in several ways, including application, design and development of new methods and approaches with guidance. Each chapter has a specific focus which investigates a problem, designs methods and carries out a numerical assessment, where applicable, to address that part of the research problem.

The methods and approaches are validated and verified as will be discussed in the following section. Each chapter assesses the results obtained and methods designed and draws conclusions to motivate its originality. Chapter 7, integrated M&V, incorporates the contribution of Chapters 3 to 6 to provide an integrated and enveloping solution to the research problem. This is followed by Chapter 8 which summarises the conclusions of Chapters 3 to 7, and critically assesses the study's results for shortcomings or potential risks, as well as providing recommendations for future improvements.

1.5 KEY RESEARCH QUESTIONS

The below key research questions are addressed in this study. All of these are relevant in order to provide a complete integrated irrigation M&V solution as depicted in Figure 1-5.

- How severe is the water scarcity situation in South Africa and other countries, and what sector is the major water user?
- What are the water and energy conservation possibilities in agricultural irrigation and what is the success rate of these? Here it is important to determine what is required to increase the success rate.
- Are there incentive mechanisms available for agricultural irrigation and how can these be applied to assist with water conservation?

- What are the impact quantification requirements and standards and how should these be applied? The multi-level quantification method can be developed from this.
- Are there challenges with project level M&V? More specifically:
 - What are the components of a baseline and how is proper baseline development done?
 - What are the pitfalls and solutions required for different type of irrigation DSM project or a combination of different types? These include: load shifting, energy efficiency with an energy driver (energy governing factor), energy efficiency without an energy driver, combination of load shifting and energy efficiency, load prevention or clipping, and a combination of clipping and energy efficiency. What methods and approaches can be developed to overcome challenges with these?
 - How project information is handled and scrutinized by an M&V practitioner?
 - What insight will be valuable for project stakeholders (specifically utility and project investors) on the pitfalls which should be avoided with irrigation project?
 - What evaluation methods are required for new project decisionmakers to quickly evaluate the feasibility of a proposed DSM project at the very start?
 - What guidance can be given to M&V practitioners on what to look out for, what M&V strategy to follow and how to approach baseline development?
- What is programme level M&V and where is it applied? Also:
 - What M&V challenges need to be overcome with the Eskom irrigation Standard Product Programme (SPP) and what methods need to be developed to achieve effective M&V?
 - What method can be developed that will accurately determine how much of the SPP reductions achieved, actually occurred over the Eskom peak period?
- What is regional level M&V, where can it be applied and what is the advantage of using such an approach?
 - Are there challenges and pitfalls with regional level M&V and what methods and approaches can be followed or developed to overcome these?
 - Are there any case studies of a regional level M&V approach implemented and how were these executed?
- What are the typical challenges with M&V metering and sampling with irrigation ECMs and what can be done to overcome these obstacles?
- How can project level, programme level and regional level M&V be integrated to be more applicable to the Eskom SPP and related incentives?
- How can the South African section 12L tax incentive, and similar mechanisms, be applied to irrigation energy conservation and what can be proposed to extend the reach of these?
- Is the integration of water conservation quantification and greenhouse gas mitigation quantification possible with that of energy conservation quantification on project, programme, and regional level M&V while satisfying the requirements of current and the most common incentive mechanisms? What shortcomings are there and what can be proposed to overcome these?

1.6 VALIDATION, VERIFICATION AND ASSESSMENT

It is critical that the study content, the methods developed and the results obtained should undergo scrutiny through validation, verification and proper assessment. The study has a large focus and each

of the chapters (3 to 7) specialises in different key study component areas. Each chapter contributes in that area, has a specific novelty, as well as a unique application and shows results obtained. Therefore, each of these chapters needs its own scrutiny. In general, the following measures were incorporated for validation, verification and assessment to ensure authenticity of the methods followed, the approaches developed and the results obtained:

- Alignment and adherence to accepted and accredited international and local guidelines and standards:
 - These include among other standards the IPMVP, SANS 50015, SANS 50010 / ISO 50015, SANS 474 and NRS 057, UNFCCC CDM methodologies and ISO9001;
- Cross-check measures - following or developing methods which can substantiate the concepts and methodologies incorporated or the results obtained. Examples here include:
 - Data and result cross-verification through performance indicators,
 - Designing a method to verify the representativeness and conservativeness of crop load factors to establish savings under the Eskom SPP,
 - Designing a regional top-down method to establish the real impact of regional irrigation ECMs on the electrical grid, and
 - Bottom-up study comparison on the application of a regional top-down case study.
- Contribution from an M&V field expert: Christo van der Merwe
 - He is a Certified Measurement & Verification Professional (CMVP) and a Certified Energy Manager (CEM) with 15 years of field experience. Is also only one of two CMVP trainers in Sub-Saharan Africa.
- Independent external field expert peer reviews through papers published, in international accredited scientific journals as provided in Section 1.7 following;
- Independent external field expert peer reviews through peer reviewed international conference articles as provided in Section 1.7 following; and
- Developing and following M&V and M&V metering quality control procedures that successfully underwent several ISO 9001:2008 annual audits.

1.7 INTERNATIONAL PUBLICATIONS AND CONFERENCE ARTICLES FROM THIS STUDY

The following papers were published in international scientific (accredited) journals:

- Storm, M.E., Gouws, R. and Grobler, L.J. 2018. ***Novel measurement and verification of irrigation pumping energy conservation under incentive-based programmes***. Journal of Energy in Southern Africa, 29(3):10-21. ISSN 2413-3051

Abstract from paper: In most countries the agricultural sector, especially crop irrigation, is a considerable energy consumer. Farm irrigation studies in South Africa showed that energy and water is wasted on a large scale and there is a large potential for improving efficiency. The present study focusses on the measurement and verification (M&V) of irrigation pumping energy conservation measures (ECMs) under the Eskom Standard Product Programme funding mechanism in South Africa. A novel M&V methodology was developed to quantify ECM impacts under the Programme, which has special conditions and unique M&V requirements, which makes normal approaches inapplicable. Methods were designed to effectively determine conservative but representative impacts without continuous power demand profile measurement. The design involved unique methods to quantify operational demand reduction, annual energy consumption and annual average demand reduction impacts. The design was broadened to include pumps irrigating multiple crop areas and different kind of crops. The methodologies and techniques developed were validated and verified through establishing

independent cross-check measures. The paper discusses a regional top-down M&V approach to verify the actual total energy efficiency and load reduction on the electricity grid for a specific region

- Storm, M.E., Gouws, R. and Grobler, L.J. 2016. **Measurement and verification of irrigation pumping DSM projects: Application of novel methodology designs**. Journal of Energy in Southern Africa, 27(4):15-24. ISSN 2413-3051

Abstract from paper: 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. It further 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.

In addition to the paper publications, the following international conference articles were delivered:

- Storm, M.E., Gouws, R. Grobler, L.J. 2013a. **M&V of the Eskom irrigation pumping SPP Programme**. International Conference on the Industrial and Commercial Use of Energy. pp. 249-254. ISBN 978-0-9922041-1-2.

Abstract from article: Eskom Integrated Demand Management (IDM) initiated a funding mechanism termed the Standard Product Programme (SPP) to cater for smaller Energy Efficient (EE) projects. The impacts of these projects also need to be assessed though the Measurement and Verification (M&V) role has reduced to a mere verification and assurance function. The irrigation sector is a large energy consumer and in South Africa there is around 60 000 centre pivots alone. Not even considering other irrigation methods such as sprinklers and micros, there may be a large potential for energy efficiency. However, the average irrigation pump is relatively small which makes normal M&V too expensive for the possible attained savings. Therefore, these small irrigation pumps also need to be engaged under SPP. M&V performed on normal load shifting irrigation projects with full M&V already proved to be a challenge in the past. Moving to EE irrigation projects the M&V process is further complicated. Having irrigation EE projects under the SPP topology, is a very daunting challenge. Before Eskom can start with the Standard Product Irrigation Programme (SPIP), it is first necessary for M&V to assess the practicability of irrigation energy efficiency projects under the SPP. Therefore, a significant sample of irrigation pumping projects were assessed with case studies in order to verify project impact availability, project viability, achieved savings credibility and also long-term sustainability.

- Storm, M.E. Gouws, R. Grobler, L.J. 2013b. **M&V of the Eskom irrigation pumping SPP Programme: Evaluation of crop load factors**. South Africa Energy Efficiency Conference proceedings. Nov 2013. ISBN: 978-0-620-58204-9.

Abstract from article: Eskom Integrated Demand Management (IDM) also included irrigation in the Standard Product Programme (SPP) to cater for smaller irrigation Energy Efficient (EE) projects. The irrigation sector is a large energy consumer in South Africa and may have a large EE potential. The unique characteristics of irrigation projects create significant challenges for Measurement and Verification (M&V) under the SPP. Previous M&V studies assessed a large sample of irrigation pumping Variable Speed Drive (VSD) SPP projects. These assessments were conducted to verify project impact availability, project viability and achieved savings credibility. A further study was required to quantify attainable project impacts over the whole project life by

incorporating crop Load Factors (LF). This paper focuses specifically on the evaluation and validation of crop LFs as well as its applicability and use in SPP irrigation projects. The evaluation was conducted through a comprehensive crop LF analysis. The aim of this analysis was to determine the typical LF of a large sample of real-world pumps and compare these with the Eskom proposed crop LFs.

- Storm, M.E., Van der Merwe, C.A. and Grobler, L.J. 2008. ***M&V of an irrigation pumping project: Case study***. International Conference on the Industrial and Commercial Use of Energy. Conference proceedings. Cape Town, pp. 249-254. ISBN 978-0-9922041-1-2. Aug 2008

Abstract from article: This paper takes the reader through the M&V process and its various challenges experienced by the NWU M&V Team while performing the M&V activities on a DSM irrigation pumping load management project. The objective of the DSM project was to implement load control systems to shift the irrigation pumping load of a farming community. This was done so that all pumping activities are operated outside the Eskom evening peak periods from Monday to Friday.

- Storm, M.E. Van der Merwe, C.A. Grobler, L.J. 2008b. ***M&V of an irrigation pumping project: Case study follow-up***. South African Energy Efficiency Confederation Conference. Johannesburg, Nov 2008.

Follow-up article: During the performance assessment period it was observed that the intended evening peak DSM project targets were not met. Although the required switching occurred as planned the project underperformed on average close to 50%. This effect was investigated and all the possible reasons for such an occurrence evaluated. On inspection it was found that the actual cause of the load reduction was an unforeseen side effect of the DSM project itself. A probable alternative SLA methodology was developed that will more accurately capture the DSM switching impacts. This approach will not be influenced by the morning and evening load reduction due to water allocations.

- Storm, M.E., Dalgleish, A.Z. and Grobler, L.J. 2007b. ***Methodology Developed to M&V the Total Impact of the Accelerated DSM Initiative Implemented in the Western Cape***. International conference on the Industrial and Commercial Use of Energy conference proceedings, Cape Town, pp. 61-68. ISBN 0-9584901-7-1

Abstract from article: Eskom expected a supply shortfall of 400 MW during the 2006 winter months in the Western Cape. The main reason for this was due to the refuelling of one of the two Koeberg units. An integrated recovery plan was initiated by Eskom for the Western Cape to overcome this shortfall. The recovery plan included various accelerated Demand-Side Management (DSM) initiatives to reduce the amount of electricity consumed as well as to reduce the peak load. The North-West University M&V team was requested to do the measurement and verification of the accelerated DSM programme for the whole of the Western Cape. A top-down M&V methodology combined with the conventional M&V was used to M&V the impact of these initiatives. In May the average weekday evening peak DSM impact calculated with the top-down approach was 317 MW, 497 MW in June, 389 MW in July, 354 MW in August and in September the DSM impact was 237 MW. This paper describes the methodology and procedures that were followed for the M&V process used to calculate the DSM impacts obtained during the winter months in the Western Cape.

Lastly, the following paper was submitted to a scientific (accredited) international journal:

- Storm, M.E., Gouws, R. and Grobler, L.J. 2018. ***Novel enveloping integrated quantification methodology for irrigation conservation under incentive-based mechanisms***. Water SA, ISSN 1816-7950.

Abstract from paper submitted: There exist significant opportunities in the agricultural sector to improve on water and energy efficiency, however, a lack of incentives creates barriers hampering the adoption of irrigation conservation technologies and practices. This paper focuses on combining incentive mechanisms under water, energy and greenhouse gas to collectively overcome such barriers. An incentive here is broadly defined as a vehicle, that when implemented will enable, motivate or force an irrigator to reduce usage. Such vehicles can be water, energy or greenhouse gas reduction rebates, taxes, restrictions or take other forms. A critical

requirement of many incentive mechanisms providing monetary assistance is proper quantification of the actual conservation achieved. Water, energy and greenhouse gas have different challenges when it comes to conservation quantification. In many cases, the quantification methodology requirements of available mechanisms are too complicated or costly to implement. With this, studies with proper water accounting have shown water conservation attempts actually increased water usage instead of the aimed reductions. The paper provides a novel enveloping integrated measurement and verification methodology that can effectively quantify conservation on a project level, farm level, programme level and also regional level. The paper considers the quantification requirements of current incentive mechanisms, how these can be met or proposes alternative models that still enable sufficient quantification. The application of crop load factors in conservation estimates with a unique cross verification process is outlined. A unique regional quantification methodology is presented which incorporate electrical grid measurements and water source discharge measurements among other. A unique case study showing methodology implementation and the attained savings for an accelerated regional energy conservation programme is given.

1.8 WHY AN ELECTRICAL AND ELECTRONIC DEGREE?

The content of this study spans several fields e.g. agriculture, mechanics, chemistry, electrical engineering, electronic engineering, computer science, energy and hydrology. Some of the subjects discussed, or parts of the subjects, can be found in the certification training courses provided by the Association of Energy Engineers (AEE) (AEE web, 2018). The most relevant of these courses include: CMVP, CEM and Certified Carbon Reduction Manager (CRM). The AEE has a list of other certifications which may also be relevant, such as the Certified Demand-Side Manager (CDSM) and Certified Water Efficiency Professional (CWEP). However, except for CWEP, these others were not available in South Africa by the completion of this study.

CMVP, CEM and CRM professionals come from a variety of fields, similar to the list given in the first sentence of this section. Specifically considering the major outcomes necessary to realise water conservation, the question at hand is, why would this study qualify to be submitted as an electrical and electronic engineering degree?

The reality of the engineering field is that after graduate studies, an engineering candidate can become involved in a diversity of fields. This is essentially a required characteristic of an engineering candidate, i.e. to adapt at a high pace and be able to learn and succeed in other fields. It is often seen as a luxury in South Africa if an engineer stays purely and specialises solely in the original field of study. In this study, the incorporation of a significant span of expertise and fields was required. However, the key aspects that differentiate electrical and electronic engineering as the key fields fundamental to enable this study are:

- Reporting on electrical savings and electrical system optimization (VSDs, power factor correction on electrical motors);
- Understanding of electrical power grids - transmission, distribution and supply;
- Insight and knowledge on electrical metering and installation thereof;
- Knowledge of metering systems and the application thereof to enable smart meter solutions and expand the reach of normal M&V metering; and
- Design, development and commercialization of a complete metering solution (electronic data concentrator and data logger with remote communication and online AMR system).

1.9 SUMMARY

In order to address the water crisis in South Africa and other countries, several challenges need to be overcome. This study presents a solution through which the impact of related conservation incentive

mechanisms can be combined, and by this, water conservation can be utilised and realised in the agricultural sector. Through this, irrigators can invest in conservation technologies and implement conservation irrigation practices. However, the correct quantification methods and governing policies are considered in order to assess whether actual conservation can be achieved and sustained over the long term.

The greater focus of the study is to develop original methods and approaches that provide effective energy conservation on project level, programme level and regional level. In addition, a proper foundation on metering, quality and sampling, as well as an integrated M&V approach is presented. Through this the impact of incentives is combined with proper quantification so that the ultimate goal of realising water conservation in the agricultural sector can be achieved.

Chapter 2

Literature survey

2.1 INTRODUCTION

Chapter 1 provided the problem statement with background from which the focus and scope of this study was established. This chapter gives an encompassing and comprehensive literature survey which outlines and highlights the necessity and novelty of the study. Figure 2-1 gives a flow chart illustrating the contents of the literature survey.

The first topic (i) at the top of Figure 2-1 is irrigation water usage and efficiency in agriculture. The numbered topics (i) to (viii) align with sections in this chapter. Under topic (i), the first point addressed is establishing an indication of the water scarcity situation globally, and more specifically in South Africa. This emphasises the necessity of this study. Following this, the advantages of irrigation crops are considered which serves as background, and the question why irrigation is required for agriculture is addressed. Then insight is given on the irrigation water application path and partitioning which shows how administered water emerges at numerous destinations. This also provides the required background for crop water requirements which are essential for Chapter 4. In addition, water waste, inefficient use and possible improvements are investigated. A critical aspect is properly defining when water usage reduction and efficiency is an actual water saving. Water is much more complex than energy, and less water pumped does not directly imply a saving. Topic (i) is concluded by establishing the actual success of water conservation programmes implemented worldwide. This is important for formulating proper methods and guarding protocols for the integrated approach of Chapter 7. Although Chapters 3 to 5 focus solely on energy conservation quantification, irrigation water usage and efficiency in agriculture are important considerations to see how water saving quantification can be integrated with project level, programme level and regional level M&V in Chapter 7.

Below (i), topic (ii) in Figure 2-1 discusses irrigation energy use and efficiency in agricultural irrigation. The application of energy in irrigation is investigated with the factors that influence the quantity of energy used and also the efficiency of use. From this, energy waste, inefficiency practices and improvements are investigated. These focus on optimization that can reduce the amount of energy required for the same amount of water pumped. This is an imperative consideration for Chapter 4.

Topic (ii) is followed by topic (iii) which considers Greenhouse Gas (GHG) emissions in agriculture. Energy used for irrigation pumping can be directly connected to GHG emitted, and thus energy savings will also result in GHG mitigation. GHG emissions due to land use and cover change are also discussed. Several GHG reduction possibilities arise by changing farming operations and methods. Here GHG reduction offsets should be considered as an additional incentive as discussed in Chapter 7. Topic (iv) investigates incentive mechanisms for water conservation, energy conservation and GHG mitigation. Here valuable insights are given on incentive mechanism, subsidies, increased water/energy pricing and taxation. The pitfalls and interactive effects with such an incentive mechanism are highlighted and form a basis for the integrated concepts developed in Chapter 7. The available energy incentive mechanisms in South Africa are focussed on since these provide the requirements for Chapter 3, 4 and 5 with regard to assessment of impacts. This is essential since critical requirements of incentive mechanisms are assessment and quantification of the actual achieved reductions.

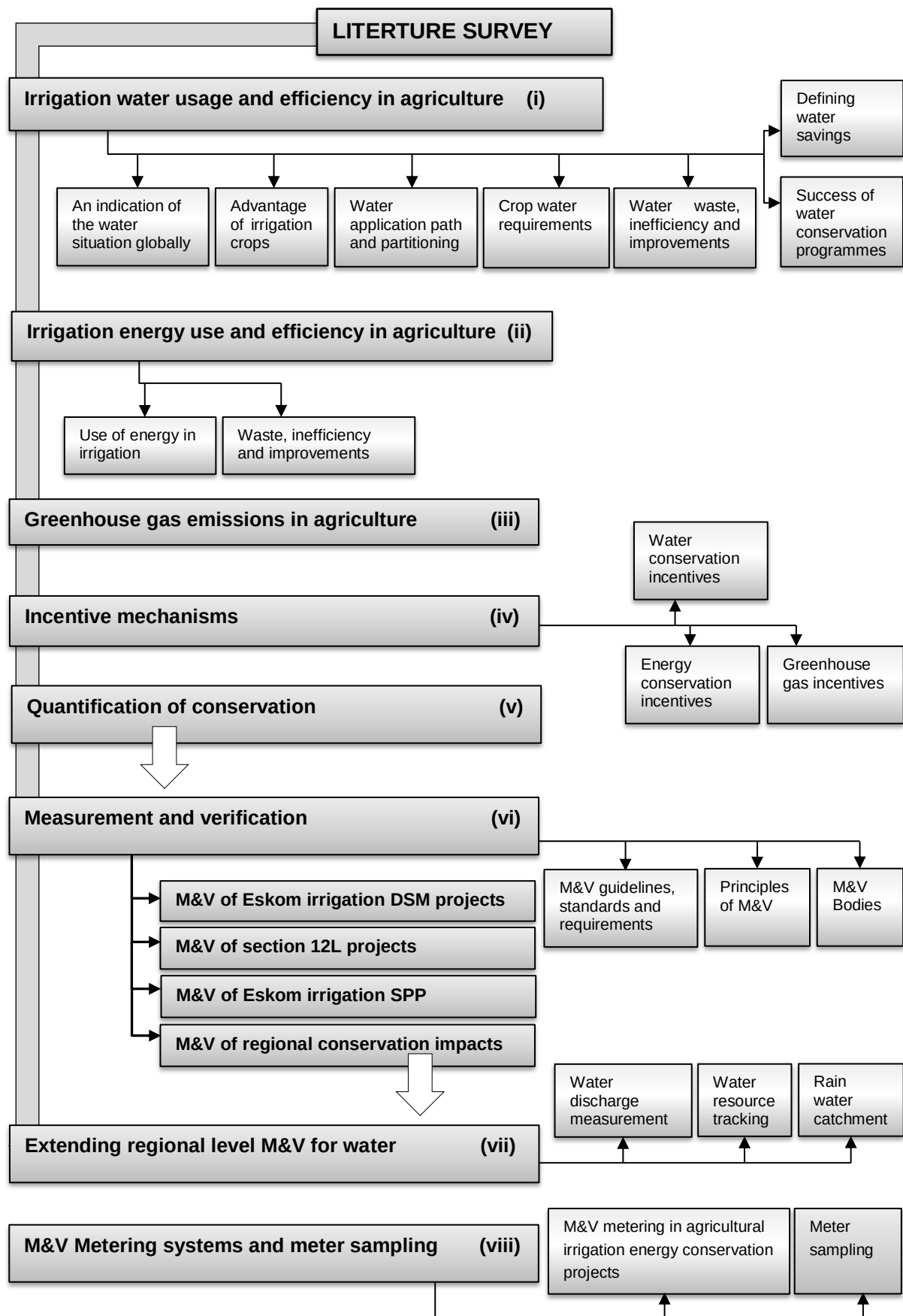


Figure 2-1: Flow chart of literature survey topics and content.

Topic (v) provides a broad perspective on typical quantification methods followed in agriculture. It shows that quantification of any conservation or efficiency initiatives on agricultural irrigation can be a complicated and cumbersome task. With this as a basis, topic (vi) in Figure 2-1 focusses on specific approaches to quantify conservation efficiency improvement impacts on energy, water, and the resulting greenhouse gasses due to conservation initiatives.

Measurement and Verification (M&V), topic (vi), examines the specialized field of M&V with the function of independently and objectively protecting the interest of all stakeholders by quantifying conservation project impacts, and the sustainability of impacts, over an agreed contractual period (IPMVP, 2012; Den Heijer *et al.*, 2010; Van der Merwe, 2012). Background is given on different international regulatory bodies, guidelines, associations, protocols, standards and requirements. Reviews are given in Chapter 2 on M&V guidelines, standards and journal articles for M&V of irrigation energy savings and quantifying water savings

Compliance to the M&V requirements of a specific incentive mechanism is very important, since this can vary between available incentive mechanisms. The principles of a proper M&V approach are also discussed. Topic (vi) further elaborates specifically on the M&V of Eskom irrigation pumping Demand-Side Management (DSM) projects, M&V of South African section 12L tax rebate projects, M&V of the Eskom irrigation Standard Product Programme (SPP) and M&V of regional conservation impacts:

- Collectively in the study, fifteen different irrigation-pumping DSM projects were assessed which included a total of 650 irrigation pumps and a combined evening peak reduction target of 15 MW. The M&V of these projects brought severe challenges and normal M&V approaches were ineffective. None of the available M&V guidelines and standards could assist here and intuitive designs of new methods were required to ensure effective M&V assessments;
- Thorough information is provided on the South African section 12L tax incentive rebate with an evaluation of its advantages and disadvantages. To date there have been no attempts for rebates by irrigation projects under 12L which questions its practicable application for irrigation conservation. This study investigates this and provides insights and proposals in Chapter 7;
- There is a general guideline for the M&V of Eskom SPP that includes energy efficient lighting, heat pumps, efficient lighting shower heads and solar water heating (Van der Merwe, 2012). However, irrigation SPP was a new addition and therefore no M&V guideline existed yet. Also, no standard tried and proven irrigation energy conservation technology was established at that point to be incorporated under the SPP. Therefore, this study provides an investigation and assessment into which energy conservation technologies and initiatives could be implemented that will lead to measurable and sustainable energy saving over the project life with a high confidence level. Also, as part of this study, a supplementary M&V guideline for irrigation SPP is developed to include agricultural irrigation conservation projects. This requires the design and testing of novel M&V techniques for effectively quantifying energy conservation impacts within the SPP boundaries; and
- No literature could be found on regional conservation impacts of similar type top-down conservation assessments and thus new methods needed to be developed. The technique that brought most valuable context was Short Term Load Forecasting (STLF) utilised by power utilities for power generation planning. The concepts and methods used in STLF provide very important insights and requirements when such an approach is used for M&V purposes.

Topic (vii) near the bottom of Figure 2-1 discusses the literature necessary for extending the regional level M&V concept, and also to quantify water conservation. It investigates water discharge measurement, water resource tracking and rain water catchment methods that can be applied in

Chapter 7. Topic (viii) is the last in Figure 2-1 and looks at M&V metering in agricultural irrigation energy conservation projects and metering sampling. Metering on irrigation Energy Conservation Measures (ECMs) can be challenging and a lack of proper metering guidance hinders or even prevents successful irrigation M&V projects. These challenges are addressed in Chapter 6 with appropriate guidance given.

2.2 IRRIGATION WATER USAGE AND EFFICIENCY IN AGRICULTURE

This section discusses the first topic in Figure 2-1; irrigation water usage and efficiency in agriculture. It addresses several aspects, starting by establishing an indication of the water scarcity situation in South Africa and globally, then it looks at water waste, inefficient usage and possible improvements. With this, properly defining water usage reduction and water efficiency to determine actual water saving are investigated. The actual success of water conservation programmes implemented worldwide is also examined.

2.2.1 Indication of the water situation globally and agricultural water usage

According to Manzoor (2011), predictions then showed that as much as two thirds of the world population will be living in conditions of water scarcity by 2025. In general, water is seen as the oil of the 21st century (Economist - Running Dry, 2008; Walsh & Dowding, 2012). The result of water scarcity was experienced hard in South Africa during 2017 and 2018, especially in the Western and Easter Cape provinces. Extremely high water restrictions were put on residents in the legislative capital of South Africa, Cape Town.

Here a daily 50 litters per person usage limit was enforced (City of Cape Town, 2018) for certain periods. Water scarcity in South Africa was ranked by the World Economic Forum (WEF) in 2017 as the third highest risk for doing business in South Africa (GreenCape, 2018; WEF, 2017). The water scarcity in many countries worldwide, with droughts more regular, is threatening water availability for irrigation in crop production. Gadanakis *et al.* (2015) states that studies on the effects of extreme weather conditions connected to climate change, concluded that water availability for agriculture is threatened in general (Daccache *et al.*, 2011; Defra, 2009; Environment Agency, 2008; Jenkins *et al.*, 2009). Gadanakis *et al.* (2015) further describes the situation in England:

- The impact of this will be spatially and temporally variable (Defra, 2009). Thus, reduced rainfall in the future during summer and spring time and the increase in temperature will bring about more frequent and extended drought periods (Charlton *et al.*, 2010); and
- During 2011 and 2012 water for abstraction was scarce in various catchments across England due to the dry period, and therefore the water resources of the United Kingdom (UK) suffered increased pressures (FAS, 2013).

According to FAO (2017), the Near East and North Africa (NENA) region has the lowest fresh water resource per-capita available compared to all regions of the world. The NENA region includes Algeria, Bahrain, Egypt, Iran, Iraq, Jordan, Kuwait, Lebanon, Libya, Mauritania, Morocco, Oman, Qatar, Saudi Arabia, Sudan, Syria, Tunisia, United Arab Emirates and Yemen (VOA news, 2014). FAO (2017) states that the NENA region will experience severe intensification of water scarcity in the coming decades due to more frequent, intense and prolonged droughts as a consequence of climate change (IPCC, 2014). This information is alarming and the reduction of water usage is a very urgent matter. This emphasises the necessity of the study.

Although water demand is significant in other sectors, agriculture irrigation globally accounts for 70% of freshwater consumption (Orum, 2010; Calzadilla *et al.*, 2008). In barren and semiarid regions, the value even reaches 90% (Tarjuelo *et al.*, 2015; Molden, 2007). As a result, irrigators are experiencing

pressure from other competing sectors to reduce water usage (Speelman *et al.*, 2008; Malano *et al.*, 2004). According to Clemmens *et al.* (2008), in the year 2000 the United States (US) geological survey estimated that around 189 billion m³ of freshwater were used/applied for irrigation purposes in the US (Hutson *et al.*, 2004) and represented 40% of all the freshwater used, or 65% when thermoelectric power water usage is excluded (Clemmens *et al.*, 2008). With irrigation water usage, 58% represented surface water, while 42% represented groundwater (Clemmens *et al.*, 2008). Irrigated agriculture in the NENA region consumes more than 85% of renewable fresh water resources (FAO, 2017).

The Department of Water and Sanitation's (DWS) 2013–2015 yearly strategic overviews of the water sector in South Africa, showed that 62% of South Africa's annual rainfall water yield was used in the agricultural sector (DWS, 2013; DWS, 2015). The usable mean annual rainwater runoff in South Africa is 13.2 billion m³ (Du Plessis, 2014; Statistics South Africa, 2000). Estimations show that by 2030 South Africa will experience a 17% supply-demand gap (GreenCape, 2018; WEF, 2017). Here it would seem easy to simply rule that significantly less water should be allowed for agricultural irrigation purposes. However, applying water to crops in addition to normal regional rainfall has major advantages.

Clemmens *et al.* (2008) stated that it is well recognised that water management and crop production are interconnected and just like many other inputs, water is a tool that can be used to acquire more production. Generally, yields can be increased by six times when irrigation is implemented for the larger crops and brings about gross margin that four-fold in comparison with profits of rainfed crops according to Tarjuelo *et al.* (2015). Also, in some areas farming would not be possible if there should only be relied on rain water. Crops with a higher water requirement will not be feasible at all. This will have a catastrophic effect on food supply.

Here FAO (2017) states that the solution to the water scarcity problems seem apparently straightforward: "Less water must be consumed, treated waste water should be reused, and whatever water is available should be used as productively as possible." However, the politics of this solution are far from simple as FAO (2017) further elaborated: "Who should reduce water use? Which country, region, sector, or farmer? What are the economic, social and food security implications of reducing water use?"

Therefore, focus should be placed on agricultural irrigation water waste prevention and efficient application. The next step is to examine the irrigation water application path and partitioning.

2.2.2 Water application path and partitioning

According to Burt *et al.* (1997), once water is administered to a crop, various segments of the total administered water emerge at numerous destinations, during different parts of the journey as described in the bullet points following. Figure 2-2 illustrates the application of rain or irrigation water.

- **Evaporation (E)** - Generally, the conversion of water from its liquid form to its vapor form is referred to as evaporation. Evaporation rate is dependent on the soil and atmospheric components along with water surface area. Altering the irrigation method or frequency, shading, mulching etc., could modify evaporation. See right bottom quarter of Figure 2-2.
- **Transpiration (T)** - Water that has moved through the plant's stomata and into the atmosphere in vapour form is known as transpiration. Transpiration is dependent on solar radiation, evaporation near/on plants and atmospheric conditions. Normally, if evaporation increases then transpiration decreases. See right top quarter of Figure 2-2.
- **Evapotranspiration (ET)** - The collective process of transpiration from plants and evaporation from soil and moistened surfaces of plants is known as evapotranspiration. This process is affected or controlled by atmospheric components, crop, soil and irrigation. The lack of evaporation from soil or the moistened surfaces of plants increases transpiration, while evaporation from the surrounding

regions decreases it. Individually, the E and T elements are difficult to measure and the joint ET is usually estimated by energy balance (aboveground) or soil water balance methods.

- **Crop evapotranspiration** - Crop evapotranspiration is defined as the quantitative quantity of E plus T within the cropped region of the field, and is related to the growth of crops. The calculated or published ET_c values often varies from the actual ET_c values due to variations in irrigation practices (dry soil opposed to moistened soil and stressed versus unstressed). One portion of ET_c is provided by irrigation water, the other by rainfall for nearly all climates.

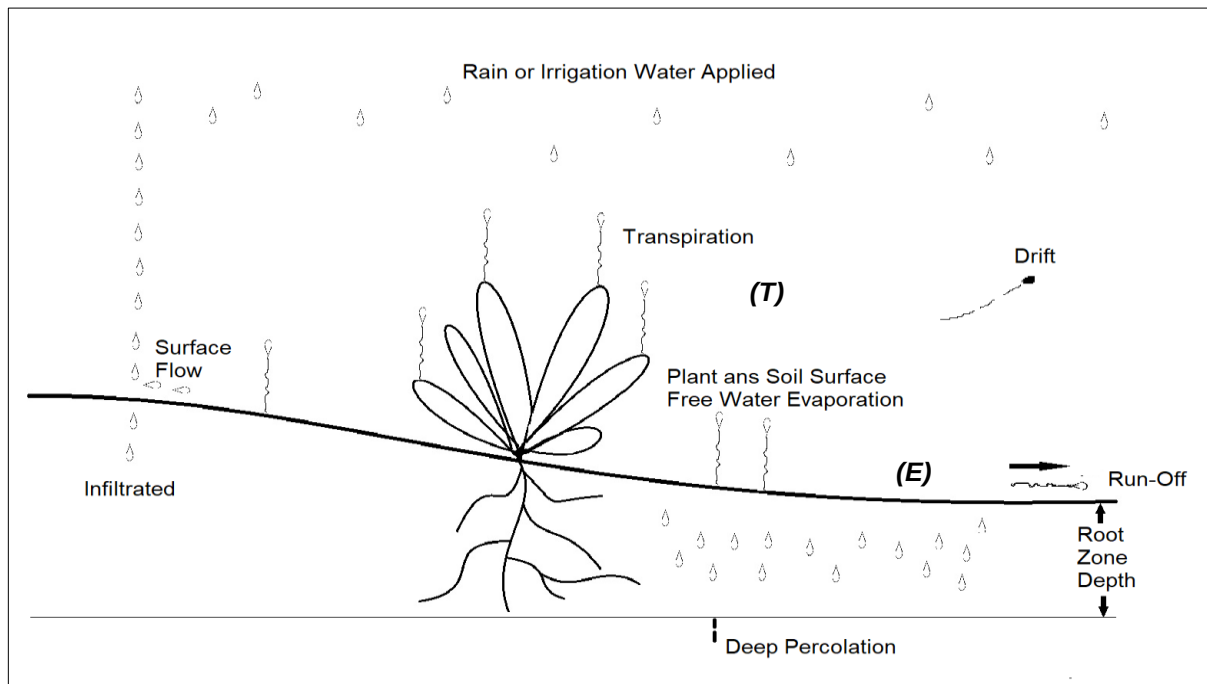


Figure 2-2: Application of rain or irrigation water (Adapted from Burt *et al.*, 1997; ASCE, 1978).

- **Infiltration** - The process of the movement of water across the soil surface into the soil matrix is known as infiltration as can be seen towards the bottom of Figure 2-2. All water is in motion when it infiltrates through the soil surface. While some immediately move through the root system into the plant and other portions, water up to or briefly exceeding the capacity of the soil, is stored momentarily in the root zone as soil water.
- **Deep percolation** - On the bottom of Figure 2-2 infiltrated water that moves beneath the root zone is shown. This is known as deep percolation. Once an irrigation cycle is complete, almost all deep percolation will take place in a short amount of time for crops that have active roots throughout the root zone.
- **Runoff** - Surface water leaving the subject area in liquid form is termed runoff water, as shown on the far right of Figure 2-2. Evidently, what creates runoff in a given area could be intended for transpiration and/or infiltration in a downstream area. The apprehension and re-appliance of surface water in the subject area are not labelled as runoff from the subject region. Take note of its temporary status with regards to energy usage during pumping or degradation in value, however, it doesn't factor into the water balance or considerations of effectiveness if it is apprehended and reapplied within the limitations (translocation).

The water application path and partitioning definition are imperative when focus is required on where water waste and water inefficient application occurs. Crop evapotranspiration is a very important factor which establishes crop water requirements as discussed in the following section.

2.2.3 Crop water requirements

Crop water requirements are one of the most important aspects to consider for irrigation efficiency since it is a vital part of agricultural planning according to Reddy (2015). Allen *et al.* (1998) defines crop water requirement as “the depth of water needed to meet the water loss through evapotranspiration (ET_{crop}) of a disease-free crop, growing in large fields under non-restricting soil conditions, including soil water and fertility, and achieving full potential under the given growing environment.”

Crop water requirements are a well-studied field with extensive research done on different methods to determine ET_{crop} with field measurements (Howell *et al.*, 2015; Hanson *et al.*, 2006) or remote sensing (Mateos *et al.*, 2013; Gibson *et al.*, 2013). Referring to Allen *et al.*, (1998), Reddy (2015) states that the most used approach for estimating ET_{crop} is the crop coefficient (K_c) approach:

$$ET_{Crop} = ET_0 \times K_c \quad \text{Eq. (2-1)}$$

Extensively developed software programs are available to assist farmers to determine representative crop water requirements. An example of this is CROPWAT (Banik *et al.*, 2014) and the South African SAPWAT (Heerden *et al.* 2016) that is based on (Allen *et al.*, 1998) with the CLIMWAT (Tegos *et al.*, 2017) weather data base comprising of 3262 weather stations from 144 countries.

According to Heerden *et al.* (2016), SAPWAT uses 50 years of weather data for calculating Penman-Monteith ET_0 values (Allen *et al.*, 1998) as well as rainfall. According to Tarjuelo *et al.* (2015), other platforms for monitoring, crop planning and water resource control include among other: STICS (Brisson *et al.*, 1998), ISAREG (Teixeira and Pereira, 1992), CropSyst (Stöckle *et al.*, 2003); AquaCrop (Stedutot *et al.*, 2009); DSSAT (Jones *et al.*, 2003) and MOPECO (Dominguez *et al.*, 2011).

Crop water requirements and the software programme, SAPWAT, are fundamental in determining crop load factors described and used in Chapter 4 Section 4.3.4.4.

2.2.4 Water waste, inefficiency and improvements

According to Gadanakis *et al.* (2015) the broad majority of papers and reports regarding research on water usage efficiency measurements concentrate on engineering and agronomic techniques. From this approach, efficient water usage can be defined as the production yield achieved from the water availability through rainfall, irrigation and soil water storage (Gadanakis *et al.*, 2015; Singh *et al.*, 2010). These approaches, however, do not regard water as an economic good, thus making it impossible to assess the level of economic water usage efficiency (Wang, 2010, Gadanakis *et al.* (2015).

Efficiency refers to the comprehensive relationship between all the production process' inputs and outputs, and evaluation based on individual efficiency measures, namely allocative, economic and technical efficiency, can be done to conclude the farm's performance (Speelman *et al.*, 2008; Díaz *et al.*, 2004b). According to Gadanakis *et al.* (2015), water usage efficiency can be improved by making use of a decision-making tool for irrigation planning and monitoring on the long and short term, thus driving farms towards the production frontier. Gadanakis *et al.* (2015) further states that:

- Decision-making tools could improve economic and water usage efficiency, and farming systems' environmental performance by providing farmers with the option of using management support (Khan *et al.*, 2010);
- Management practices, like in-field soil moisture measurements and water balance calculations, assist in scheduling irrigation better and hence applying water at the appropriate time and amount. Statistically speaking, however, these management practices have no impact on water usage efficiency; and

- Excessive use of water can be identified by using a benchmarking tool, like Data Enveloping Analysis (DEA), when comparing farms in the same region and identical characteristics with each other in order to improve water usage efficiency in the agricultural sector.

Water efficiency can be enhanced by improving irrigation practices, thus achieving an economic advantage while simultaneously decreasing environmental burdens (Levidow *et al.*, 2014). Irrigation pump setup and distribution system optimization and improvements vary from inexpressive leak repairing to costly equipment replacements. Water application efficiency can be improved by switching to pressurized systems: water usage was found to be approximately halved for all crops when centre pivot systems are used instead of flood systems, and a further reduction of 32% where drip is used (Jackson *et al.* 2010).

Application efficiency of 70% in sprinkler irrigation and 85% for sub-surface drip irrigation was reported (Orum *et al.*, 2010; Smajstrla *et al.*, 1991). Proper water application with correct crop water requirements can avoid over-irrigation by introducing irrigation management systems or advisory services. Reports on the implementation of the California Irrigation Management Information Services (CIMIS) showed that water usage decreased by 10-20%, 23% of growers' crop yield increased and the crop quality of 28% of growers improved (Tarjuelo *et al.*, 2015; Parker *et al.*, 2000). According to Burt *et al.* (1997) the main aspects to consider when looking at the irrigation performance are:

- The irrigation-water balance and determining the outcome of various segments of the total irrigation water that was applied;
- In what way the water is dispersed amongst the plants; and
- Determine the amount of remaining water that is recoverable and also what amount reaches ground water.

Some farmers can be reluctant to use improved irrigation systems, although, on paper, it may seem to be for their own good (Clemmens *et al.*, 2008). Not many farmers will employ a new irrigation method unless their water supply is limited or it increases production or profit, like lowering expenses for the same production (Clemmens *et al.*, 2008). Clemmens *et al.* (2008) also states that the choice of irrigation methods for the farmer can be quite difficult and some considerations to aid in this process follow:

- The farmer may lean towards irrigation methods that require less labour due to the declining quality and availability of the agriculture labour sector. Less labourers are required for pressurized irrigation methods (e.g. centre pivots) and these are rather easy to operate and manipulate. Although, several crops, the size of farming fields and the soil are not ready to accommodate centre pivots;
- Pressurized irrigation methods on new farm lands may cost less than surface irrigation, due to the required land grading that surface irrigation may need;
- On some of the crops, microspray or drip irrigation may be common, but better economics and yields with surface irrigation methods have been observed in some areas. In California's Reedley/Dinuba region, farmers converted to microspray and drip irrigation on stone fruits, but most of them have returned back to their furrow irrigation. In central Arizona, many farmers shifted to micro-irrigation on their cotton but returned to surface irrigation, because this added micro-irrigation system did not produce the expected increase in yield; and
- In practice, when the water supply is limited, pressurized irrigation methods may apply this limited water more efficiently than surface irrigation would.

According to Burt *et al.* (1997), although, there are conditions where improvements in irrigation efficiency and field application does not increase the quantity of available fresh water, there are however

still certain situations where real water savings are feasible from the improvements of irrigation systems. Hydrology, location and geology are all imperative factors. The general conclusions were according to Burt *et al.* (1997):

- Where there is good quality irrigation water and deep percolation that re-enter a freshwater aquifer, there could be little incentive and occasionally disincentives, to decrease the deep percolation;
- At the point where the water of deep percolation is of low value or a considerable amount of salt is gathered from the underlying rock and soil, decreasing the quantity of deep percolation could result in saving freshwater;
- Where runoff water re-enters the surface water supply at a place downstream, decreasing this runoff water is only beneficial when the water value is tainted by erosion or if in-stream flows, directly downstream of the diversion point, could be protected by decreasing the diversions;
- The recycling and storing of irrigation runoff and rainfall could be an efficient technique to save freshwater, if the runoff downstream isn't already recollected for other uses;
- Decreasing the quantity of irrigation diversions could save freshwater if the return flows don't augment the surface supply for other uses;
- The timing of stream flows is changed by irrigation diversions that re-enter surface water supplies, which could be an environmental benefit or liability;
- Field irrigation system improvements would typically improve the effectiveness of field irrigation, occasionally increase consumption of water and yields, and typically increase productivity of water and land; and
- Removing production from irrigated lands is often the only means to save considerable volumes of freshwater by decreasing the consumptive use factor, however, sometimes only the irrigation water that was previously consumed is saved, thus not all the diverted water is saved.

According to Gadanakis *et al.* (2015), efficient water usage for irrigation is demonstrated when the farmer is aware of the risks regarding increased crop disease and fertilizer leaching. Therefore, most farmers attempt to irrigate with the best use of a probable limited water resource in order to avoid over or under irrigation (Gadanakis *et al.*, 2015). In this study it was observed that water waste and over irrigation is also prominent in South Africa with significant improvement potential. Chapter 7 elaborates on this.

2.2.5 Defining water savings and the success of water conservation initiatives

As touched on in the previous sections, it is critical to note that water efficiency improvements or waste prevention do not inertly result in a true water saving. For any incentive mechanism, it is mandatory to quantify the actual water reduction savings, or recovery, due to such improvements within a specified boundary. Here the boundary can be an irrigation scheme or the flow of a river. It is important here to distinguish what exactly happens to water in order to define and quantify the actual water conservation savings.

This highlights the importance of a proper quantification method to quantify real attained savings. According to Burt *et al.* (1997), applied irrigation water can be partitioned by availability for recovery as follow:

- Consumptive uses: Irrigation water is considered irrecoverable if it winds up in the harvested plant's tissue or in the atmosphere. Here Clemmens *et al.* (2008) defines water consumption in terms of the "destruction and transformation" of water as it is converted from liquid to vapour through evapotranspiration; and

- Non-consumptive uses: Non-consumptive uses embody any other quantities of water that has left the selected application area like canal spills, runoff and deep percolation. Non-consumptive segments could be reapplied somewhere else, however, it might be degraded in quality.

Irrigation efficiency is defined by Burt *et al.* (1997) as:

$$\text{Irrigation eff} = \frac{\text{Volume irrigation water beneficially used}}{\text{Volume irrigation water applied} - \Delta \text{ storage of irrigation water}} \times 100\% \quad \text{Eq. (2-2)}$$

Jensen (1993) introduced the term Irrigation Consumptive Use Coefficient (ICUC), which is defined as the ratio of the volume of consumed irrigation water to the total volume of irrigation water which have left the area, both in a stated time period and is conveyed as a percentage (Burt *et al.*, 1997).

$$\text{ICUC} = \frac{\text{Volume irrigation water consumptively used}}{\text{Volume irrigation water applied} - \Delta \text{ storage irrigation water}} \times 100\% \quad \text{Eq. (2-3)}$$

According to Burt *et al.* (1997), with the concern of how well the usage of applied water is, the larger concern is how uniformly the water is spread to the crops or soil (pre-irrigation). Thus, a non-uniform distribution of water could deny parts of the crop of necessary water, but can also over-irrigate parts of a field, which could lead to plant injury, water-logging, transference of certain chemicals to the ground water and salinization (Solomon, 1983).

Unfortunately, FAO (2017) showed that in most cases water saving attempts are unsuccessful with water reduction not achieved but water usage actually increased. The conservation of water has been the spoken objective of various government-funded projects which usually concentrate on irrigation system improvement or the irrigational scheduling on the farms (Burt *et al.*, 1997). Burt *et al.* (1997) further states:

- The general aim of water conservation programs is usually to decrease current diversion rates or volumes through a particular use with the intent of creating “new” water for new diversions for the same use or other uses. The conservation of water on a global or basin scale, ought to have the objective of decreasing the consumptive component (Allen *et al.*, 1996, 1997);
- Yet, conservation programs seldom concentrate on consumption. If, even locally, this consumptive component is not lowered by conservation, then all these conservation efforts will not be able to free up any new water. For instance, an irrigation system with decreases in water leakage/seepage that eventually, at some point, resurfaces to the stream as return flows may decrease local diversions, leaving the water in the stream;
- Locally, this result may be good, although downstream at some point there could be no net change that occurs in stream flows, because the return flows may decrease just as much as the reductions in diversion did. Consequently, the conservation program may demonstrate little benefits as the scale of valuation increases; and
- It is necessary to comprehend the objective of the water conservation programme and the course the applied irrigation water will take, thus where does the water eventually end up going?

A very important point to address here is the “rebound effect” known as the Jevons Paradox (York and McGee, 2015; Berbel *et al.*, 2014; FAO 2017): “In 1865, the English economist William Stanley Jevons observed that technological improvements that increased the efficiency of coal-use led to the increased consumption of coal in a wide range of industries. While common intuition suggested that if less of a particular input was required to achieve a given outcome, the demand for that input would fall, while the observed reality was that with the fall in the effective price of the input fell, demand increased.” This is unfortunately also very applicable to water conservation attempts which are clear from the study of

FAO (2017). This is a fundamental aspect for consideration in both energy and water with emphasis on conservation initiatives and the importance of proper impact quantification.

The Clean Development Mechanism (CDM) methodologies under the United Nations Framework Convention on Climate Change (UNFCCC) listed in Section 2.7.2 have compensation or prevention techniques for rebound effects. Davis (2008) and Nyatsanza (2008) also show the rebound effect with energy DSM programs. Section 2.5.2.1 elaborates on this.

2.3 IRRIGATION ENERGY USE IN AGRICULTURE

Following the examination on water usage in agricultural irrigation, it is very important to analyse how energy is used in irrigation and which areas are prone to waste and inefficiency. The following section discusses the application of energy and is followed by a section on irrigation energy waste, inefficiency and improvement methods.

This is necessary to distinguish between improvement options that can be effectively quantified and sustained. With programme type incentive mechanism such as the Eskom Standard Product Programme (SPP), discussed in Section 2.5.2.1, this is a crucial consideration. The SPP in irrigation energy conservation projects is in detail analysed in Chapter 5.

2.3.1 Use of energy in irrigation

With irrigation systems, energy is used to lift water from a water supply point, pressurise the water and then move it through a piping network for application through centre pivots, sprinklers or other application methods. According to Orum *et al.* (2010), the energy consumed by the pump motor is a function, based on Basford (2009), that depends on the pump operating time, the amount and rate (m/s) of water pumped for irrigation, head (m) of the irrigation system, motor and pump efficiency, and water gravity and density fixed at 102.5 (m x 1/s /kW). See Eq. (2-4) below.

$$\text{Energy use (kW)} = \frac{\text{Operation hours} \times \text{flow rate} \times \text{head}}{102.5 \times \text{eff}} \quad \text{Eq. (2-4)}$$

According to Jackson *et al.* (2010) the energy requirements for pumping is dependent on the water requirements of the crop, total dynamic head, flow rate and the efficiency level of the irrigation system (Jackson *et al.*, 2010; Lal, 2004). An expansion of Bernoulli's equation was used to determine the power demand required for pumping and pressurizing water:

$$P(\text{kW}) = \frac{h_A \times y \times Q}{1000 \times \text{pump eff} \times D_r} \quad \text{Eq. (2-5)}$$

The variable in Eq. (2-5) is defined as:

- P (kW) - energy application rate to the water. Power use (kWh) is $P(\text{kW}) \times$ pumping hours;
- h_A (m) - sum of pressure head and elevation head;
- y is the water weight assumed to be 9810N/m³ at 15 °C and Q is the flow rate measured in m³/s;
- Pump efficiency - operation efficiencies of large pumps usually varies within 74-85% (Faour, 2001); and
- D_r - is the engine deration and takes into account the efficiency losses. Depending on altitude, temperature and motor condition, the derating factor is approximately 80% and 75% for, respectively, electric and diesel motors (Faour, 2001).

From Orum *et al.* (2010), examples of power requirements and energy costs per m³ of water are presented in Table 2-1 as a function of pumping capacity and head. It includes source water lifting, nozzle or drip line pressure and friction losses from a 1000m long pipe with a diameter of 200mm.

Sprinkler and drip irrigation require a pressure of 2 to 4 bar (with a 20 to 40m head) and 0.7 to 1 bar (with a 7 to 10m head), respectively, and consequently the energy use might be reduced by 0.08 kWh/m³ with a 2 bar reduction from sprinkler to drip irrigation.

The vertical distance from the source to the field will contribute to the total energy usage with 0.02 kWh/m³ in 5 m and 0.20kWh/m³ in 50 m. The friction losses, with typical pipe lengths, are responsible for less than 0.5 bar (5m head). This is the same amount of energy usage for 0.02 kWh/m³ of water. Depending on whether the distance from the water source to the field is 5 or 50m, the sprinkler system and drip irrigation has a total head of 45 or 90 m, and 25 or 70m, respectively. Either way, head is reduced by 20 m and energy costs by 0.01 €/m³ when shifting from a sprinkler system to drip irrigation (Orum *et al.*, 2010). According to Tarjuelo *et al.* (2015), advanced low-pressure centre pivot sprinklers are developed and should be evaluated since pressure is reduced from 3.5 bar to between 1 and 2 bar, and may have an effect on the uniformity of the system and losses on drift and evaporation (Ortiz *et al.*, 2010; Singh *et al.*, 2010).

Consumption of energy, water and other such inputs can be improved by some of the foremost tools like conventional irrigation system management and design, promotion of the application and usefulness of Irrigation Advisory Services (IAS) and web Geographic Information Systems (GIS) platforms to communicate actual-time based information and feedback with farmers according to Tarjuelo *et al.* (2015).

Table 2-1: Pumping energy cost as related to head and required flow (Adapted from Orum *et al.*, 2010).

Flow (l/s)	Head				Power (kW)	Energy (kWh/m ³)	Cost (€/m ³)
	Lift (m)	Nozzle (m)	Friction - losses from 1km long pipe with 0.2m pipe diameter	Total (m)			
30	5	10	15	30	13.6	0.13	0.015
15	50	10	5	65	14.8	0.27	0.033
15	5	10	5	20	4.5	0.08	0.01
30	5	30	15	50	22.7	0.21	0.025
15	50	30	5	85	19.3	0.36	0.043
15	5	30	5	40	9.1	0.17	0.02

2.3.2 Waste, inefficiency and improvements

As discussed in the previous section, with farm irrigation or any water pumping setup, being industrial and mining, there is an inherent relation between water pumped and energy consumed. Thus, systems and strategies that conserve water will also reduce energy that is used for pressurising and transporting water (Orum *et al.*, 2010).

Considering Eq. (2-5), inefficiency and waste in power demand (kW) and power consumption (kWh) occur in several areas. Of course, any crop irrigation water wastage will directly result in an energy waste due to longer pump motor operating time. With this, non-optimum delivery pressure or an unnecessary high head will lead to needless high power demand and consumption. In Eq. (2-5) the efficiency of the pumping system is a very important variable.

By addressing the energy efficiency and waste areas, significant energy consumption and reduction can be achieved. There are multitude pump set, distribution, delivery and water application system efficiency improvement methods (Morris *et al.*, 2006; Zhang *et al.*, 2013; Brent *et al.*, 2016) that can be

implemented. ATTRA (2006) and Tolvanen (2007) provide the following list of areas where focus can be put to realise energy savings on irrigation pumping systems:

- Improve pump setup to have a concentric expansion and prevent a sudden change in the pipe diameter. This will reduce head loss, turbulence as well as air pockets;
- Ensure that the discharge valve is used with the same diameter as the mainline;
- On the pump suction side:
 - Screened pump that keeps debris out;
 - Airtight suction joints under vacuum and no high spots where air can collect;
 - Ensure a suction line velocity of between 0.6 to 0.9 meter per second;
 - Have a suction entrance at minimum two pump bell diameters before pump inlet;
 - Suction lift must be less than 6 meters;
 - Install an eccentric reducer to prevent trapped air; and
 - A vacuum gauge can show if the primer is establishing a vacuum or just moving air.
- On the discharge side:
 - Have a valve diameter the same as the main line; and
 - Ensure a discharge line velocity of below 2.1 meter per second.
- Other important considerations:
 - Ensure the right pump is used for the right application – an over or underside pump will not operate efficiently;
 - Regular maintenance to check if impellers are not out of adjustment or if the screen is not unplugged and if there are no leaking gaskets or other leaks, dry bearings or pump packing and no worn nozzles etc.;
 - Use an energy efficient 1800 revolutions per minute pump motor with 15% safety factor;
 - Prevent pump cavitation;
 - Proper designed mainlines. If the mainline diameter is not sufficient for the water pumped, it reduces efficiency and contributes to a higher head requirement;
 - Mainline flow velocity of below 1.5 meter per second is recommended; and
 - Prevent throttling through using Variable Speed Drives (VSD)s. With throttling, producing 70% of the flow requires even up to 90% of the full speed energy used.

According to Brent *et al.* (2016), in order to ensure sufficient capacity, pumps with safety margins are usually selected to ensure adequate capacity. Although the selected pump may be efficient, there is generally a waste of energy. Regardless of the pump type used for an operation, there are factors that can aid in saving water (Brent *et al.* 2016):

- Reduce excess flow rates by installing pumps that operate according to the required system flow rate;
- Reduce the pipe resistance by minimizing the amount of bends, T's in the pipe and fittings; and
- Bring about efficient motor control by installing VSDs where it is necessary.

According to Jackson *et al.* (2010), more than 60% of irrigation systems in Australia are pressurized and between 1998/99 and 2003/04 there was a conversion from travelling gun irrigators and flood irrigation systems to centre pivot and drip irrigation systems (EconSearch, 2006).

Jackson *et al.* (2010) further states that studies showed that using pressurized systems in groundwater dependent regions can reduce energy consumption (Hodges *et al.*, 1994; Srivastava *et al.*, 2003):

- Energy consumption was reduced by between 12% and 20% due to the conversion of installing centre pivot irrigation systems instead of flood systems; and
- Reductions between 25% and 44% when changing from flood to drip (Jackson *et al.*, 2010).

Speelman *et al.*, (2008) lists various studies, providing more insight, that have analysed the efficiency of agricultural production in developing countries, citing: Haji, (2006); Malana and Malano, (2006); Abay *et al.*, (2004) and Binam *et al.*, (2004). This study examines efficiency improvements through VSDs in Chapter 4 with case studies on the attainable savings.

2.4 GREENHOUSE GAS EMISSIONS IN IRRIGATION

Significant amounts of Greenhouse Gas (GHG) emissions are generated for energy used for irrigation pumping (Tarjuelo, 2015). Irrigation water pumping, the energy used and GHG emitted as a result are closely related. Thus, an energy use reduction will also have a direct carbon emission reduction, being either it a Scope-1 emission or indirect Scope-2 emissions (Wbcsd, 2004). Here Scope-1 refers to onsite emissions such as diesel engine pumps and tractors, and Scope-2 refers to where emissions are offsite, like a power station. Greenhouse gas emissions can further be linked to pesticides, tillage, soil erosion, planting, harvesting and other farm operations (Lal, 2004).

Emissions in the agriculture sector are significant, combined with land use and cover change contributing to around 20% of global figures (IPCC, 2001; Lal, 2004). According to Brent *et al.* (2016) the South African wine industry is experiencing pressure to consider interventions for energy management to, among other things, reduce energy consumption, thus being more competitive, more self-reliant and to bring about a decrease of carbon footprint in the agriculture sector.

It is important to notice that there are several greenhouse gas emission reduction possibilities by changing farming operations and methods. By just reducing water and energy use through conservation methods, it will already have a direct result in GHG emission reduction.

2.5 INCENTIVE MECHANISMS

According to Gadanakis *et al.* (2015) the Sustainable Intensification (SI) of agricultural production is a mechanism that can simultaneously balance two objectives and mitigate any conflicts that can be experienced between objectives. Specifically, the SI of agricultural production implores farmers to increase production yields for future food demands and at the same time decrease environmental pressures caused by the production process (Gadanakis *et al.*, (2015); Garnett and Godfray, 2012).

Gadanakis *et al.* (2015) suggests that the new legislation should encourage farmers to increase efficiency by improving management practices and to improve farm level water storage by making use of rain harvesting and reservoirs. According to Tarjuelo *et al.* (2015), depending on the country, the government normally helps farmers by providing loans for a high investment cost percentage. In most cases a financial aid of 45-50% for the main infrastructure and 30-35% of the total cost of the irrigation system can be covered by the administration in Spain (Tarjuelo *et al.*, 2015). Therefore, it is crucial to establish the values for water productivity and the environmental, economic and social advantages in order to compare them with the required large investment and the growth in energy usage (Tarjuelo *et al.*, 2015). Depending on the country, there can be a variety of programmes, funding options or incentive mechanisms available which aims to advance conservation.

The following sections investigate water conservation, energy conservation and greenhouse gas mitigating incentives in general. However, there is specific focus placed on what energy incentives available in SA.

2.5.1 Water conservation incentives

Conservation incentive mechanisms can be introduced and applied in many ways. Even better regulation sometimes results in reduced pumping activities. This study shows in Chapter 3 Section 3.8.1 that farmer pumping activities significantly altered since Irrigation Water Board flow meters were installed on river water extraction points. Water pricing mechanisms may include volumetric, area, input or output pricing, quotas and water markets (Orum *et al.*, 2010, Johansson *et al.*, 2002; Tsur and Dinar, 1997). Orum *et al.* (2010) notes the following:

- If the farmer controls the delivered water supply, volumetric pricing will be better, since it gives an incentive for efficient irrigation with efficient strategies and irrigation systems, citing Bos *et al.* (1990);
- Although water taxes may result in efficient irrigating, raising water prices gives concerns in the political reaction and risk to increased food prices, competition with international markets and changing nature of stable food prices, citing Molle (2002); and
- Water taxes may have an adverse result on land use, citing Berbel *et al.* (1999). Farmers might invest in different crops or stop irrigating, instead of adopting new technologies and strategies to save water.

According to Levido *et al.* (2014), investments in irrigation technology improvements can often result in higher water prices, however, with the full potential benefits not achieved through water efficiency. Governments can have cleaner and improved production programmes with the aim to reduce irrigation farm water usage by concentrating on irrigation system improvements.

Unfortunately, according to Orum *et al.* (2010), overall these investments have benefited the farmers, although not all the objectives of the conservation of water have been met (Orum *et al.*, 2010; Huffaker, 2008). This can easily occur if proper water accounting and impact quantification methods are not incorporated to track conservation and keep incentive beneficiaries accountable. Orum *et al.* (2010) further provides valuable insights on water subsidies, increased water prices and taxation:

- Technology efficiency improvements assist in better irrigation efficiency; however, crop input and production subsidies tend to be perverse to farmers, citing (OECD, 2006);
- Market price support encourages agricultural production but support for irrigation infrastructure, operation, maintenance and lower water supply charges again does defeat efficient water usage;
- If water prices should be raised in Spain, for example, farm income will decrease by 25-40% before there will be a significant decrease in water demand (Berbel and Gomez-Limon, 1999). Furthermore, there will be a smaller range of crops available for farming in these conditions, meaning less alternative farming strategies, and the agricultural sector would be more vulnerable – technically and economically speaking. As a result, on-farm employment opportunities are expected to decrease, as well at processing facilities. There will be need for supplemental irrigation, since vegetables, like potatoes, have high water requirements (Fabeiro *et al.*, 2001);
- In Serbia water is not traded and consequently there is no explicitly established marginal production cost or water value. Thus, society can decide to provide water for irrigation for free or to subsidise investments in drip irrigation and Partial Root Drying (PRD). Considering this situation, while investments might be financed by water taxation, more efficient irrigation systems and strategies to conserve water might decrease the farmers' dependence on investments;

- Socioeconomically speaking, the marginal cost of extra water provided to farmers should mirror the marginal value of extra water in the agricultural production. If farmers could be provided with extra water at a lower cost than the marginal cost of extra water from water conservation, society should provide more water instead of subsidising the investments of farmers in water conserving systems; and
- Speaking from farmers' view, even if investments in water conserving systems and strategies were completely subsidised, free water is the better option. Although subsidies could encourage investments in new irrigation systems, the farmers' incentive to conserve water and the discipline regarding irrigation practices holds the greater potential for water saving. Therefore, water taxation or quotas should contribute to investment subsidies.

According to Clemmens *et al.* (2008), local water rights, state water laws and interstate compacts could have a considerable effect on the outcome of the water conservation programs and also for the parties that profit from any localized savings:

- Several water law systems in the western part of the world permit the use of a single diverter or a group of common diverters for internal improvements to the systems, so that existing internal flows of surplus water can be apprehended and put to advantageous use within the existing borders of the application region (in other words, no extension of the water rights is permitted);
- Thus, from an individual diverter's viewpoint, the individual water supply may be increased by a conservation program. Though hydrologically, there can be no newly created water added to the total basin water supply and downstream users, outside the area of this conservation program, could suffer a decreased supply of water; and
- Sometimes, these conservation programs have decreased consumption of water, causing an increase in system flows, only to observe that these flows are being diverted by third parties, because they have existing higher-priority rights which permit them to legally divert any water that is appearing in the stream.

According to Speelman *et al.* (2008), results suggest that water usage efficiency of small-scale farmers in South Africa do not reach their overall levels of technical efficiency. This might be because of the absence of pricing mechanisms for water (Nsanzugwanko *et al.*, 1996), and farmers do not have the financial incentive to invest in technologies to save water or to limit water usage.

Although there is a significant up rise on the awareness of water conservation in South Africa, currently there is no general agricultural incentive mechanism for water conservation or water usage taxation. However, water quotas, water restrictions and usage control are performed by Irrigation Water Boards. The success of this is largely dependent on the ability of the Irrigation Water Board to control water flow. Section 2.8.2 discusses water resource information and tracking.

2.5.2 Energy conservation incentives

Similar to water, energy incentive mechanisms can take on many forms and can be driven by different stakeholders. It can be energy efficiency rebates, tax rebates or energy efficiency trading mechanisms like white certificate schemes (Tyler *et al.*, 2011). Population growth worldwide has led to increased energy use resulting in electrical supply shortfalls and excessive strain on electrical networks. Due to this, governments and electrical utilities initiated partially or fully funded DSM projects implemented through Energy Service Company (ESCO) projects (Eskom IDM, 2016).

The irrigation sector can also benefit here since on-farm pumping is responsible for the consumption of between 23% and 48% of direct energy allocated for crop production (Jackson *et al.*, 2010; Hodges *et*

al., 1994; Singh *et al.*, 2002; Lal, 2004). Depending on country, the percentage can be much higher. Bolt *et al.*, (2014) sketches various government incentives and taxes for cleaner production and energy conservation technologies in the South African mining and manufacturing context. Unfortunately, only some of these are relevant to agricultural irrigation conservation.

According to Jackson *et al.* (2010), policies could link the best management practices with energy tariff management. The utility bill of a farmer associated with energy consumption (kWh) and energy demand (kW) can differ according to time of day, day type and season. This is applicable if a utility supply point is billed according to a ToU (Time of Use) tariff structure.

Though country dependant, smaller farm utility supply points are normally billed a flat rate (only kWh used), while larger points have ToU structures. The aim of ToU is to assist power utilities with peak demand control realised through lower kWh cost outside peak periods and specific maximum demand costs. Chapter 3 elaborates on the Eskom ToU tariff structure surrounding agriculture. An incentive vehicle can here simply be assisting to move a farmer from flat rate to a ToU utility bill metering point structure. The following section will investigate energy conservation incentive mechanisms in South Africa related to its only power utility, Eskom.

2.5.2.1 Eskom's Energy Efficiency EEDSM incentive programme

According to the Eskom website (Eskom IDM), programme brochures (Eskom performance contracting brochure) and the Industrial Efficiency Policy Database (IEPD web), Eskom Integrated Demand Management's (IDM) Energy Efficiency and Demand-side Management (EEDSM) incentive program, has/had the following energy efficiency funding options available:

- **Performance contracting** - Performance contracting remunerates for verified bulk savings achieved over a three-year period on a quarterly basis. This is for energy efficient solutions over multiple sites and may include many different technologies. Remuneration is performance-based up to an agreed maximum value which is equal to the South African Rand (ZAR) value of the total forecast energy savings over three years, plus 10%. Focus is on weekdays from 06:00 to 22:00, however, out of this period and weekends, savings is acknowledged but remunerated at a lower rate.
- **ESCO process** - Funding of large projects with potential electricity savings of 500kW or more for transition to energy efficient technologies and processes. The programme is aimed at Eskom accredited project developers specialising in specific target markets. These project developers find energy efficiency prospects for achieving reductions in electricity consumption and execute projects. ESCO projects require full conventional M&V. See Section 2.7.4 for the M&V of irrigation DSM pumping projects that was implemented under the ESCO process.
- **Standard Offer Programme** - The Standard Offer Programme (SOP) funds the implementation of large projects with savings from 50kW to 5MW which enable moving to energy efficient technologies and processes. These include Building Management Systems (BMSs), hot water systems, Solar Water Heating (SWH) systems for both industrial and commercial application, process optimisation systems, energy efficient lighting and small-scale demand-side renewable technologies. The focus is on electricity usage during weekday daytime hours of 06:00 to 22:00. The SOP requires conventional M&V methods (Hibberd, 2011; Den Heijer *et al.*, 2010).
- **Standard Product Programme** - The SPP provides funding for small and medium-sized projects to be implemented that enables the transition from commonly used energy inefficient technologies to standard off-the-shelf efficient alternatives. These include for example, Light Emitting Diode (LED) lighting, water and energy saving shower heads and installing a heat pump instead of a normal geyser. The SPP was established to provide rebates for these small projects and fast-track

implementation and associated performance assessments at a lower overall assessment cost. A comprehensive list of applicable technologies is provided on the Eskom website (Eskom IDM). Savings to be achieved range from 1 kW to 250 KW. According to Van der Merwe (2011) these SPP small-scale projects require a generalised assessment approach that gives an acceptable saving impact indication instead of normal project type M&V. Thus, the approach recognises a deemed saving rather than a measured saving. Section 2.7.6 describes the M&V process involved with SPP while Chapter 4 Section 4.3 discusses how the SPP was also applied to irrigation ECMs.

- **Aggregated Standard Product Programme** - This not a SPP replacement but rather an expansion whereby program project developers are able to aggregate individual energy efficiency projects under the SPP, but through a single contract. The target sectors are similar to that of the SPP and the contract size range from 1 MW to 5 MW.

Except for the SPP, all these incentive programmes involve full M&V and M&V practitioners over the full contractual life. Significant impacts were reached with these across all sectors, see Figure 1-4 in Chapter 1, but unfortunately there is currently a very limited number of projects and programmes active under Eskom EEDSM. New projects are also not coming of the ground and there is currently a general feeling under M&V practitioners and ESCOs that these programmes are barely alive. Also, SPP irrigation implementation ceased shortly after case studies have been concluded.

On another side, a rebound effect with the Eskom DSM program showed that the actual savings in energy demand are often less than expected, making these costly programs ineffective and results in even increasing consumption (Davis, 2008). Here proper quantification, not only on project level but on regional level, is required to examine effects like these. Section 2.7.8 elaborates on this.

2.5.2.2 South African 12L tax incentive

In 2009 Section 12L of the Income Tax Act was introduced to establish a special allowance for taxpayers through Energy Efficiency (EE), which promotes energy security, while combating climate change, through incentivising taxpayers to use energy more efficiently (Seligson, 2015). The following sections provide background on section 12L and describe the environment and roll players. Section 2.7.7 gives the applicable regulations and discusses the advantages and disadvantages of 12L.

Background on 12L - In November 2013 the South African National Treasury published a section 12L replacement in Government Gazette No. 37019 which placed into operation deductions of proven EE savings according to the terms of the income tax act 85 of 1962 (De Lange, 2014a; South Africa Government Gazette, 2013; Seligson, 2015). According the South African National Energy Development Institute's (SANEDI) website, in order to implement 12L, several institutions were put in place by the South African government to guarantee efficiency transparency and cohesion.

Stakeholders - Stakeholders and other include (SANEDI, De Lange, 2014b):

- SANEDI itself:
 - Implements and oversees the application process of the incentive claimant to the issuing of the 12L tax incentive certificate at the application approval;
 - SANEDI also evaluates energy saving reports from the M&V professionals; and
 - Issues tax certificates to organizations for submission to SARS to claim section 12I and 12L tax incentives - www.saneditax.org.za.
- South African National Accreditation Systems (SANAS):
 - Accreditation of M&V Bodies (see Section 2.7).
- South African Revenue Services (SARS) and National Treasury:

- Providing financial incentive using the normal annual tax return process.
- The Department of Energy (DoE); and
- Measurement and Verification Council of South Africa (MVCSA) (see Section 2.7.1) - a voluntary membership-based body that:
 - Houses the contact information of M&V professionals; and
 - Takes on the role of ensuring a capable, credible, transparent and efficient M&V. Section 2.7.7 elaborates on the M&V requirements surround impact quantification.

2.5.3 Greenhouse gas incentives

With greenhouse gas emissions, there have been a global drive for reduction and several mechanisms introduced to motivate cleaner production. Some of these include:

- Carbon trading like the CDM (UNFCCC, Winkler *et al.*, 2007) and other similar carbon voluntary standard include among other (National Treasury South Africa, 2014; WWF Germany, 2008):
 - Verified Carbon Standard (VCS) (Verra web, 2018);
 - Gold Standard (GS) (Gold Standard web, 2018);
 - The Climate, Community and Biodiversity Alliance (CCBA) standard (CCBA web, 2018);
 - VER+ standard for Verified Emission Reductions (VERs). Also written as VERplus (CORE web, 2018);
 - Voluntary Offset Standard (VOS). flexible compliance mechanism under a cap-and-trade system. Many voluntary offsets are done according to standards, such as the Voluntary Carbon Standard (VCS), although it is not required (GreenBiz web, 2009);
 - Plan Vivo System. The Plan Vivo Foundation is an international Edinburgh-based charity that created a set of requirements for smallholders and communities wanting to manage land and natural resources more sustainably (PlanVivo web, 2018);
 - ISO 14064-2. Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements. (ISO 14064-2:2006);
 - WRI/WBCSD GHG protocol for project accounting. World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD) jointly convened protocol (WRI & WBCSD, 1998).
- Carbon tax and or carbon capping such as the upcoming South African carbon tax (Department of National Treasury South Africa, 2015). Trading is also normally allowed under these schemes; and
- Vertically Integrated National Appropriate Mitigation Actions (V-NAMAs) (Dazé *et al.*, 2016).

These mechanisms normally have quite stringent monitoring and quantification requirements before carbon credits can be claimed. Unfortunately, the requirements and the post-2012 low carbon reduction price may make these CDM type programmes rarely worthwhile. However, where greenhouse gas emissions schemes are available, benefits from these in the irrigation sector should be considered.

Several CDM projects were implemented in South Africa; the biggest of these are probably the Eskom CFL CDM projects and CFL Programme of Activities (PoAs). See Chapter 6 Section 6.5.1 for more information on this. In this chapter, Section 2.7.2 provides information on the standards used and methodologies available surrounding irrigation GHG mitigation.

2.6 QUANTIFICATION OF CONSERVATION AND EFFICIENCY

All types of incentive mechanisms normally have requirements for evaluation and quantification of attained savings. In South Africa for instance, public funding was provided by the National Energy Regulator of South Africa (NERSA) for Eskom DSM projects, and therefore, all project and impacts needed to show credibility (Van der Merwe, 2011) through quantification methods.

Quantification of any conservation or efficiency initiatives on irrigation can be a complicated and cumbersome task. It is difficult to determine the efficiency of water usage in irrigated agriculture, because it is a “multiple input- multiple output process,” and water should not be regarded as a resource in isolation (Speelman *et al.*, 2008; Malana *et al.*, 2006; Díaz *et al.*, 2004b). Gadankis *et al.* (2015) states that there are mainly two approaches used to estimate efficiency at farm level, namely parametric and non-parametric techniques.

Parametric techniques, like Stochastic Frontier Analysis for example, estimates a parametric production function which is representative of the most advanced technology available (Chavas *et al.*, 2005). Gadankis *et al.* (2015) further states that DEA, a non-parametric technique, is preferred for the analysis of technical and specific input efficiency. Speelman *et al.*, (2008), states the following on DEA analysis:

- Compared to the econometric approach to efficiency measurements, the DEA methodology has considerable advantages. Assumptions need not to be made regarding the frontier technology's functional form or the distribution of the inefficiency term, since the DEA methodology is non-parametric. Also, the DEA allows the construction of a surface over data, which makes it possible to compare one production method with others to determine performance;
- The disadvantages of DEA, on the other hand, are that it is deterministic and sensitive to measurement errors and noise data, even though comparison studies have shown that results from both methodologies are closely correlated (Arlene and Zeller, 2005; Thaim *et al.*, 2001; Wadud and White, 2000); and
- By increasing the amounts of input will not consequently result in an increased amount of outputs in the case of agriculture.

According to Gadanakis *et al.* (2015) DEA is the preferred method for analysing technical and specific input water usage efficiency in the East Anglian River basin catchment due to its flexibility:

- Since DEA is a non-parametric technique it simultaneously avoids parametric specifications of technology and assumptions made regarding distribution efficiency, while allowing impositions for curvature conditions;
- Decision Making Units (DMUs) convert multiple inputs into multiple outputs, and DEA is used to evaluate the DMU's performance efficiency. This technique contributes a straightforward approach and with estimations from observations of efficient firms' inputs and outputs, the differences between farmers' behaviour from the most productive practices can be measured (Lansink *et al.*, 2002; Wang, 2010). A piecewise linear envelopment is used to assemble the production frontier from the observed data points. In other words, farms using the least inputs to achieve their levels of outputs are identified as the farms with the best performance;
- Combinations, linear or convex, of the best performing farms construct the production frontiers. The estimated production frontier of the best performing farms is then used to measure the farms' efficiency (Lilienfeld and Asmild, 2007); and
- The DEA method for measuring the efficiency of water usage have been used in various research projects in areas, like Mauritania, Tunisia, South Africa and other areas with a dry

climate where water for irrigation purposes is problematic in securing economic, environmental and social sustainability (Borgia *et al.*, 2013; Chebil *et al.*, 2012; Chemak, 2012; Frija *et al.*, 2009; Lilienfeld and Asmild, 2007; Mahdi *et al.*, 2008; Speelman *et al.*, 2008; Veetil *et al.*, 2011; Wang, 2010).

As proposed by Färe *et al.* (1994), a sub-vector DEA model was mostly used to approximate excess water usage. The DEA system takes into account the relation between all inputs and outputs, and makes it possible to calculate the farm's approximate efficiency and its position relative to the ideal situation (Speelman *et al.*, 2008). DEA is an important benchmarking tool that can assist in establishing farm efficiency indicators. This will be discussed further in Chapter 7. With farm level efficiency, all aspect should be considered since conservation in a certain area may result in a loss in another area. In a broader sense, a proper solution incorporates all available conservation and optimization mechanisms to establish an efficient, but balanced and profitable farm.

With this as a basis, Section 2.7 further focuses on specific approaches to quantify conservation efficiency improvement impact on energy, water, and the resulting greenhouse gasses due to conservation initiatives.

2.7 MEASUREMENT AND VERIFICATION

The area of conservation quantification is a specialized field on its own and is referred to under many terminologies. Some of these include: Measurement and Verification (M&V), Evaluation, Measurement and Verification (EMV or EM&V), Monitoring and Evaluation (M&E) and Measurement, Reporting and Verification (MRV). With water, there is generally referred to the term water accounting. The purpose of these is in general is to independently evaluate and quantify conservation impacts over a specified project life. The term monitoring and verification is also commonly used, however, there is an important technical difference between "measurement and verification" and "monitoring and verification". Monitoring is more aligned to the act of measuring and then acting or changing operation due to what is seen. In this study the terminology M&V will be further used for conservation quantification.

According to IPMVP (2012) of the Efficiency Valuation Organization (EVO), Measurement and Verification (M&V) is defined as: "The process of using measurement to reliably determine actual savings created within an individual facility by an energy management program. Savings cannot be directly measured, since they represent the absence of energy use. Instead, savings are determined by comparing measured use before and after implementation of a project, making appropriate adjustments for changes in conditions."

Here the word savings is defined by IPMVP (2012) as: the reduction in energy use or cost; physical savings may be expressed as avoided energy use or normalized savings; and monetary savings may be expressed analogously as 'cost avoidance' or 'normalized cost savings'. Savings are not the simple difference between baseline and reporting period utility bills or metered quantities. The definition and meaning of words in different standards and specialization fields may vary.

2.7.1 Measurement and Verification bodies

There are many associations, regulatory bodies, protocols and standards for conservation in water, energy and greenhouse gas mitigation. Figure 2-3 provides a summarised description of several. Some of the prominent associations, regulatory bodies, protocols and standards include: The American Society of Heating, Ventilating, and Air Conditioning Engineers (ASHRAE) on top of Figure 2-3; the Federal Energy Management Program (FEMP) from U.S. Department of Energy; the California Measurement Advisory Council (CALMAC); CDM under the UNFCCC; and, the GHG Protocol for project accounting (ASHRAE; FEMP; CALMAC; UNFCCC; GHG Protocol). With M&V protocols and guidelines,

the International Performance Measurement and Verification Protocol (IPMVP) is very widely accepted (IPMVP, 2012). In 2013 there were already 2894 Certified Measurement and Verification Professionals (CMVPs) in 48 countries. In South Africa there is the Measurement and Verification Council of South Africa (MVCSA). The MVCSA, among other, provides assurance that a registered M&V professional is knowledgeable and skilful enough to perform M&V activities.

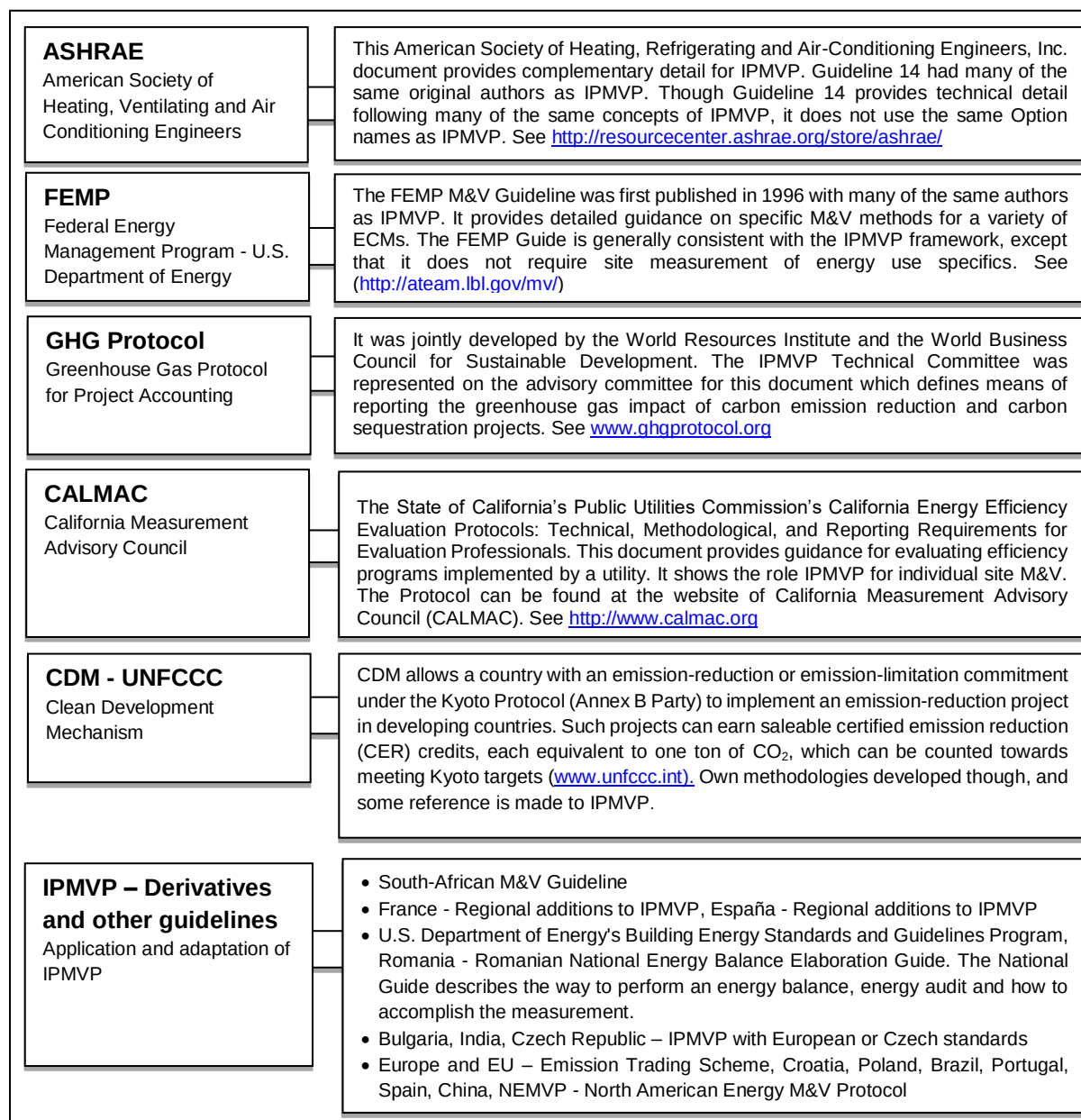


Figure 2-3: Flow chart illustrating some of the different M&V protocols and the relationship with IPMVP (Adapted from IPMVP, (2012); UNFCCC web).

2.7.2 M&V guidelines, standards and requirements

With any efficiency initiative it is important to adhere to the regulatory body requirements and M&V guidelines of the specific incentive mechanism. For instance, carbon reduction under CDM should follow specific methodologies provided by the UNFCCC. Where a new incentive mechanism is introduced in a country, stakeholders can decide on the most appropriate M&V protocol or a combination of several

can be used. It is critical though that the process used should be official policy, and M&V activities should be present early in any project.

In essence M&V and energy audit methodologies (Jackson *et al.*, 2010; Canakci *et al.*, 2005; Hatirli *et al.*, 2006; Fluck, 1992) comes down to: (1) determine and evaluate a boundary around the specific process (narrow boundaries may be needed to obtain significant results); (2) all inputs that are crossing the boundary should be identified and quantified; (3) all inputs, both direct and indirect, should have energy values assigned to them. The M&V methodology specifications are largely dependent on the incentive mechanism used, the stakeholders and project funding sources. As an example, the South African section 12L tax incentive provides an allowance for businesses to implement energy efficiency through a tax deduction on proven energy conservation (South Africa Government Gazette, 2013) as described in Section 2.5.2.2 and Section 2.7.7

Project baseline measurement and savings quantification must be performed by an M&V body accredited by the South African National Accreditation System (SANAS). The M&V standards used in this study is the IMPVP 2012, SANS 50 010:2018, SANS 50 015:2015 / ISO 50015:2014 which provide options for retrofit isolation (key-parameter or all-parameter measurement), whole facility or calibrated simulation. Despite the flexibility given in measurement options, the SANS 50 010 standard does not allow programme level evaluation for section 12L type projects. See Section 2.5.2.2 for information on the South African 12L tax rebate. Also, the SANS 50 010 requirement for calibrated metering and high M&V body cost puts limitations on the type and size of projects that can be included.

Another example is the UNFCCC CDM registry which contains well developed and approved M&V methodologies to establish Certified Emission Reductions (CERs). For irrigation and pumping related efficiency there are the following methodologies:

- Baseline methodology for water pumping efficiency improvements (AM0020 v2, 2007);
- Demand-side energy efficiency activities for specific technologies (AMS-II.C v15, 2016);
- Energy efficiency and fuel switching measures for agricultural facilities and activities (AMS-II.F v10, 2012); and
- Energy efficiency pump-set for agriculture use (AMS-II.P v10, 2012).

AM0020 is applicable to large scale projects while the other three is for small scale projects with PoAs as provided in AM0020 (2007). Small scale is defined as a project where the combined quantified conservation does not annually exceed 60 GWh or 60000 Ton CO₂ equivalent. CDM is only for quite large projects since 60 GWh relate to more than a 6.8 MW load operating 24 hours for a full year, and smaller projects do not justify CDM associated project cost.

PoAs allow project activities on many irrigation pumps spread over large areas and even countries, depending on the project design document and approval. In the methodologies there are specific requirements for baselining, efficiency evaluation and monitoring. The general requirements for monitoring and sampling are a 90/10 confidence/precision level, although a 95/10 is sometimes required (UNFCCC Guidelines for sampling, 2012). There are also specific instructions for ex-post monitoring surveys and metering. Establishing conservation in any project should follow proper M&V principles to ensure project success. Figure 2-4 gives a flow chart with some of the most essential principles for proper M&V. All these principles are required to establish a trustworthy process with a traceable and auditable data collection and processing path. Here two very critical aspects in Figure 2-4 are conservativeness and transparency. These are the fundamental aspects whereon the M&V methods described in Chapters 3 to 6 were based on.

2.7.3 M&V of agricultural irrigation pumping conservation

Although there exist very well designed and thorough M&V standards and protocols, none provide the relevance, background and guidance for the difficulty of quantifying irrigation conservation initiatives. The challenges specific to irrigation, the agricultural environment, necessitates the developing of the new and unique M&V methods of this study to effectively enable proper assessments. See also Section 2.7.4 following on Eskom DSM irrigation pumping projects.

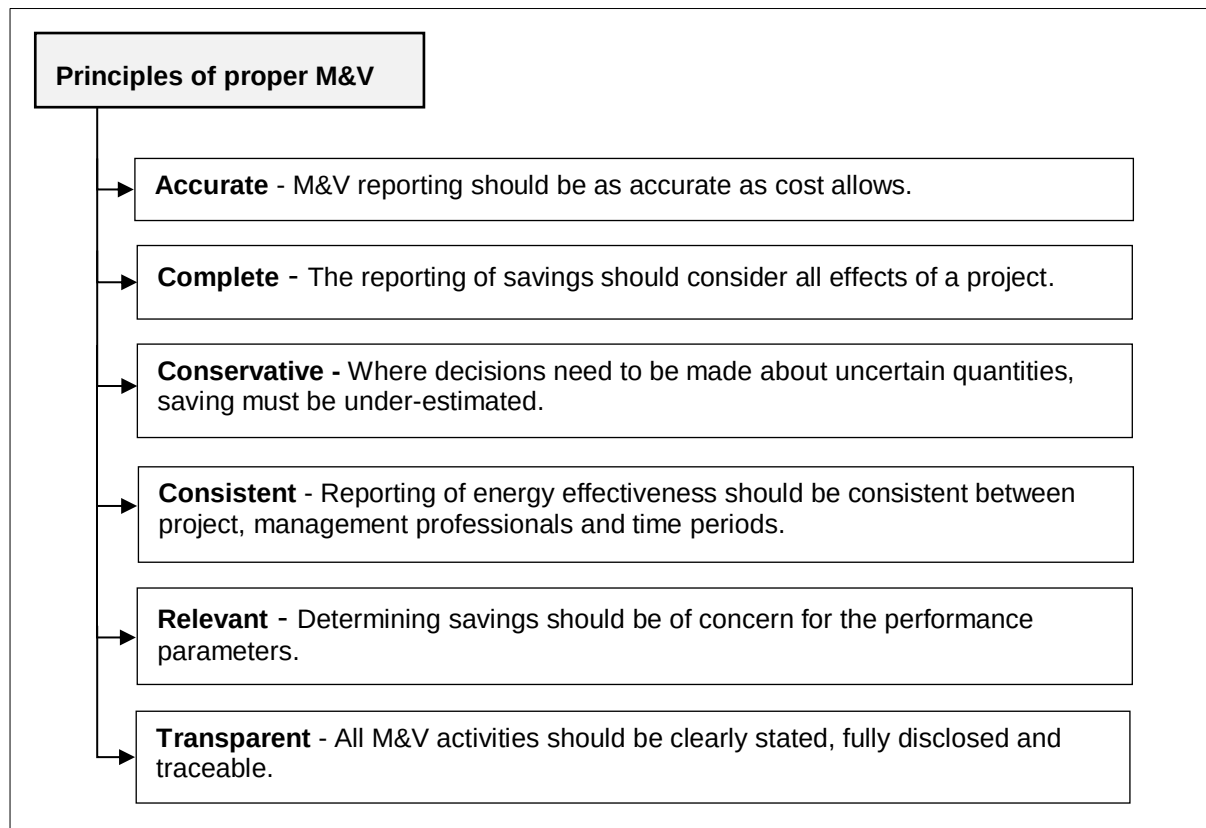


Figure 2-4: Flow chart of proper M&V principles. Adapted from IPMVP (2012).

The IPMVP (2012) extends beyond energy to also include water savings quantification. Unfortunately, except for the reference of water, not much was added to the IPMVP to address water specifically. Rather, concepts explained for energy are extended to water or there is mentioned that it is also applicable to the M&V of water. In many cases this is true, but it does not provide the insight this study requires.

The FEMP M&V Guidelines for M&V on performance-based contracts (FEMP M&V Guide, 2015) gives guidance on the M&V of plumbing and other water consuming equipment, but nothing agricultural irrigation related. However, it does discuss M&V assurance activities for VSD ECMs on pumps. As discussed in the preceding section, the UNFCCC CDM registry provides methodologies with possible agricultural irrigation application. The last two were registered in 2012 and there is no record of these being implemented yet.

Thus, there is no Project Design Documents (PDD) or related information surrounding practical implementation. With this, GHG reduction in all four methodologies is related to energy use reduction and provides no insight in the M&V of operational demand profiles. Therefore, these give very limited value to this study. However, the quantification requirements of these will be considered and incorporated in the integrated approach of Chapter 7.

Here it should be clearly stated that if conservation projects or programmes are not accompanied with strict governing policies, accounting, set limits and project maintenance, conservation attempts will most probably be fruitless or not sustainable as explained in Section 2.2.5. This is especially the case with water. According to FAO (2017), the essential sequence of actions for adequate and sustainable water resource is:

- 1) Establish a proper water accounting system providing quantitative water balance estimates;
- 2) Set well designed water allocation limits; and
- 3) Motivate and assist users to maximise the benefit of water allocated. Here improved irrigation methods and conservation initiatives will be applicable.

This was also seen with diminishing DSM impacts under Eskom DSM programs as discussed in Section 2.5.2.1. The above again shows the importance of M&V to provide a proper accounting through appropriate water and energy conservation quantification. The three points are imperative for formulating proper M&V methods and guarding protocols with policies. This is necessary for the integrated approach of Chapter 7. The following sections focus solely on energy conservation quantification under the incentive mechanism discusses in Section 2.5.2, however, it is important to already also consider how water conservation can be connected with these. This is also an essential part of Chapter 7.

2.7.4 M&V of Eskom irrigation pumping DSM projects

Since 2004, Eskom's DSM programmes actively engaged farmers to reduce peak period power usage. Farmers with higher power (electrical energy) 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 M&V assessments were made to establish the actual attained savings over the contracted project life (Den Heijer, 2010). M&V was performed on many other DSM projects in different sectors. 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.

As part of this study, 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 (Bosman *et al.*, 2006; De Villiers *et al.*, 2007; Storm *et al.*, 2007b). These projects were in different South African provinces, but most were in Mpumalanga. The largest project with an aimed demand reduction of 4.5 MW entailed all river pump stations that draw water for the Crocodile River in Mpumalanga.

The water allocations for the river pump stations are regulated by the Crocodile River Major Irrigation Board. The water is pumped from the river to numerous irrigation farms to irrigate crops ranging from citrus and nut trees to sugar cane. The Crocodile River Major Irrigation Board includes a 28 000 Ha area, 600 farms and lots, with a total water allocation of 309 Million m³ meters per year (Storm *et al.* 2008; Venter, 2008). The water consumption needed to be regulated in both volumetric consumption and time when the consumption occurred. Before the project, there was no volumetric or time of consumption monitoring or control in place. The first project site was located just after the Kwena dam in the Dulstroom area, Mpumalanga. The project area stretched from the Kwena dam for around 200 km to Komatipoort.

The objective of the DSM project was to enable the Crocodile River Major Irrigation Board to schedule water and electricity consumption so that all consumers will only operate out of the Eskom evening peak period. Therefore all irrigation points participated in load management through pumping restrictions in the evening peak period. This was made possible through the ESCOs by implementing the necessary infrastructure and control equipment. The DSM installation included water extraction monitoring equipment and control interface for the peak switching (Venter, 2008):

- Pump sets - Automated the stop/start sequence;
- Water piping - Installation of water meters for volumetric and time-based management;
- Irrigation Equipment - Automated primary pumping to irrigation equipment enabling automated switching; and
- Base station control equipment - Implementation of a centralised pumping load control base station.

The M&V of this irrigation DSM project, as well as many others, brought with severe challenges and normal M&V approaches were ineffective. None of the available M&V guidelines and standards could assist here and an intuitive design of new methods was required to ensure effective M&V. This is thoroughly discussed in Chapter 3. With the M&V challenges, M&V metering also had significant challenges and problems which is elaborated on in Chapter 6.

2.7.5 M&V of Eskom Standard Offer Programme projects

The Eskom SOP as described in Section 2.5.2.1 is similar to Eskom ESCO programme but was designed to have an accelerated approach to address energy shortfall through energy efficiency projects (Hibbert, 2011). Hibbert (2011) further elaborated in the SOP pilot M&V guideline on the following:

- The SOP was not intended to replace the ESCO programme system but provide opportunities for projects cases that would not have been eligible or cost effective before;
- The same M&V standards are applicable; however, SOP requires a streamlined process and therefore the M&V process also needed to be streamlined and made more cost effective;
- This was done through among other, only delivering one short scoping-M&V-plan report (instead of two thorough written reports separately) and also a simplified baseline measurement and baseline development approach and report;
- Performance assessments and tracking was also made simpler than the ESCO project process through only having one performance assessment and only four performance tracking assessments.

The initial pilot program that was launched in May 2010 focussed only lighting initiatives and therefore a much-simplified M&V approach could be followed. There were also SWH, irrigation and other project types that were later included.

2.7.6 M&V of Eskom SPP irrigation projects

The main content of this section was adapted from the Standard Product Measurement and Verification Guideline – version 2 revision 3 (Van der Merwe, 2012). This document was developed by the North-West University (NWU) M&V team for the Assurance and Forensic Department of Eskom.

The foremost function of M&V in SPP project saving evaluation is to provide an assurance to the projects stakeholders that a deemed saving calculated by using the SPP Toolkit is acceptable and credible for reporting and application in the SPP of Eskom IDM. This is attained by executing an audit-

related verification/assurance on the SPP Toolkit itself, and also the data incorporated into the toolkit. An SPP project's size and cost is too small for justifying the cost of any normal or conventional M&V activity (SANS 50 010 or IPMVP-guided M&V activity).

Thus, reduction impact savings are defined as "deemed" savings where Eskom IDM has the responsibility of ensuring proper data gathering, quality checking and use of project information. This ensures that credible deemed savings are established using the latest and validated IDM Toolkit. It is very important to note here that although the M&V assurance function gives the credibility needed for the deemed savings that need to be reported on, care should be taken that deemed savings and conventional M&V findings are not reported on together. Reporting on these should be clearly and distinctively done separately.

The SPP required a generalised approach that provides an acceptable and agreeable approximation of the saving impact instead of a guaranteed saving result. Therefore, the M&V approach was branded as a "deemed savings" approach. This approach can also be described as a technique that estimates an energy reduction saving (or energy-demand saving) outcome for a single unit of an energy efficiency, or renewable energy, measure that was developed from analytical methods and data sources that are widely considered acceptable for the measure and purpose.

The SPP M&V process was designed to inherently provide impartial quantification and assessment of project reduction impact savings (kWh, kW, cost and environmental). The basis of an effective SPP M&V result is built on the established notion that impacts can be quantified to a degree of accuracy with trustworthiness and cost which is acceptable to the project stakeholders. Although "deemed savings" are given, the M&V objective should still be to provide credible, impartial, transparent and a replicable assessment procedure.

When a new type of technology has promise of providing electrical savings and needs to be incorporated in the SPP, but no M&V has been done in the past to backup these claims, conventional M&V activities and/or appropriate research must be performed on a pilot study to verify the actual attainable deemed savings of this new technology.

Since no standard tried and proven irrigation energy efficiency technology was yet established to be incorporated under the SPP, a part of this study was an investigation and assessment of irrigation inefficient practices, and possible ECMs was performed. The evaluation study considered what energy conservation technologies and interventions can be implemented that will lead to a measurable and sustainable energy saving over the project life with a high confidence level. This is described in Chapter 4 Section 4.3.1.1 Further, an M&V methodology and procedure was required to quantify energy conservation impacts under the SPP. This is addressed under Section 4.3 of Chapter 4.

A major shortcoming of the SPP M&V evaluation methods is that it can only determine the operational demand reduction and from this the annual energy savings. Thus, there is no real indication on when energy is saved and what it contributes to peak period load reduction. Therefore, this study also focused in Chapter 4 Section 4.4 on the development of a novel calibrated simulation M&V model to establish the peak load reduction contribution of irrigation energy conservation.

2.7.7 M&V of section 12L projects

Section 2.5.2.2 gives background on the South African section 12L tax rebate. This section gives the applicable regulations, M&V requirements and discusses the advantages and disadvantages of 12L.

➤ Regulations and standards

According the SANEDI website, tax deduction on EE for all types of energy sources (exception of renewable energy sources) are allowed. However:

- Measurements must be kWh equivalent;
- The verified and measured EE reduction (saving) must be over a period of 12 months:
 - This is the implementation/assessment period which is compared in contrast with the 12 months of baseline measurement.
- The baseline measurement and savings are verified and measured through a SANAS accredited M&V Body which assigns an M&V professional; and
- The 12L allows deductions calculated at 45 cents (ZAR) per kWh electricity or kWh equivalent of energy efficiency savings. The 45 cents were later increased to 95 cents.

The following standards and requirements are critical within the 12L environment according to De Lange *et al.* (2014):

- ISO 17 020:1998, "General criteria for the operation of various types of bodies performing inspection.";
- SANS 50 010:2011, "The measurement and verification of energy savings", founded on international best practice and is based on the IPMVP; and
- SANAS TR81-01, "Technical requirements for the application of SANS/ISO/IEC 17 020:1998 in the assessment of inspection bodies' application of SANS 50 010:2011."

➤ **Advantages and disadvantages**

When looking at the advantages and disadvantages of 12L, it is important here to contemplate the experience of actual 12L applicants. Cambell *et al.*, (2017) gives the following insights from an industrial perspective:

- The application process for a 12L tax reduction can be very challenging, citing Steyn (2015);
- 12L requires adherence to strict rules during application with reference to:
 - National Tax Act and taxation laws - Republic of South Africa (2012).
 - Regulations in terms of section 12L of the Income Tax Act, National Treasury (2013).
 - Standard Measurement and Verification of energy savings, SANS 50010:2011.
- EE savings must be measurement and verified and data must be traceable, transparent and accurate;
- This M&V needs to be done by an independent SANAS accredited verification M&V body, which can incur a significant financial expense, citing GreenCape (2015); and
- There is a limited number of SANAS accredited M&V bodies in South Africa. Having only nine M&V bodies increases the potential costs of the application process.

Considering the above, the specific rules and regulations have both advantages and disadvantages. It allows for strict control of the project process and ensures accurate and quality reporting. This is exceptionally important since a tax deduction and any inconsistencies can have legal ramifications. However, having this strict control and the need for using accredited M&V professionals do make the M&V process laborious and expensive.

The M&V standard used, SANS 50 010:2011, provides options for retrofit isolation (key-parameter or all-parameter measurement), whole facility or calibrated simulation. This gives significant flexibility on measurement approaches compared to other incentives with methodologies (like CDM). Despite the flexibility given in measurement options, the standard does not allow programme level evaluation. Here CDM projects are specifically for programmes of activities. See Section 2.7.2. Another critical requirement is calibrated metering. This has a great advantage for ensuring that accurate data is

accumulated and used for baselining and saving reports. However, the need for calibrated metering and high M&V costs put limitations on the type and size of projects that can be included. According to Green Times (2013) 12L would most likely be viable if a 1GWh saving for an assessment year can be achieved. This relates to just over a 114kW demand reduction 24 hours a day for the full assessment year. Note that the Green Times (2013) statement was before the increase to 95 cents (ZAR).

According to Van der Merwe (2018), the cut-off points for 12L viability in 2018 is around 0.5 GWh (at 95 cents ZAR) which ties up with the value given by Green Times (at 45 cents). The 0.5 GWh gives a 12L amount of 475 000 ZAR and 133 000 ZAR (calculated at a 28% company tax rate) in avoided tax on this. The applicant also has the advantage of the kWh reduction itself which is not billed by the electrical utility.

2.7.8 M&V of regional conservation impacts

No additional literature could be found on a top-down type conservation assessment method. The only published and official literature is a 2008 conference paper from this study as listed in Section 1.7 of Chapter 1 and work part of the PhD thesis of Dalglish, (2009). Even here the research work was performed alongside Dalglish (2009) where new and original methods were developed. Bottom-up results of the impacts achieved relevant to this study were performed by Botha, (2007). The nearest technique that brought valuable context on further studies was Short Term Load Forecasting (STLF) utilised by power utilities for power generation planning.

Short Term Load Forecasting (STLF) (Yuill *et al.*, 2010; Du Plessis, 2007; Vermaak & Botha, 1998; Delson & Caston, 2012) is a critical function used by power utilities for power generation planning. It is essential for establishing economic, reliable and secure power operating strategies for electrical power systems (Srivastava *et al.*, 2016). Load forecasting can be categorised as follows, depending on the time zone of planning (Papalexopoulos & Hasterberg, 1990; Srivastava *et al.*, 2016):

- Very short-term load forecasting;
- Short-term load forecasting; and
- Mid-term load forecasting.

The forecasts in these time ranges are important inputs for the generation of scheduling functions, security assessment on the power system and power system dispatching according to Srivastava *et al.* (2016). Also, in South Africa this is part of the national power grid control to balancing electricity demand and supply, and involves (Du Plessis, 2007):

- The STLF provides predictions of the quantity of energy that needs to be produced and at what time it needs to be produced;
- In order to achieve this, extensive operational investigation and research need to be conducted to find the primary drivers in the energy market. These affect the system demand and supply equilibriums;
- The objective of STLF is to have accurate forecasting with proper confidence in the forecast information produced; and
- Here communication between market participants is critical since customer and stakeholder cooperation is key to enhancing confidence in the STLF.

A STLF requires a number of inputs and variables through which the accuracy and confidence of the model can be improved. The more information with proper detail is available, the better it can be applied to the prediction models used. Variables include (Du Plessis, 2007):

- Seasonality – seasons of the year;

- Day type – day of week;
- Weather – temperature, humidity, precipitation and thunder showers. With this cloud cover and wind speed and direction is also important;
- Holidays – school holidays and public holidays;
- Public events – strikes and sport events; and
- Anomalies – supply interruption such as Demand Marker Participation (DMP), DSM, transmission and generation constraints, trading, tariffs and pricing.

As discussed in Section 1.3.2.3 of Chapter 1, a similar regional top-down method is required to see the actual effect of regional irrigation energy conservation projects on a higher level. The concepts and methods used in STFL provide very important insights required when such an approach is used for M&V purposes. Chapter 5 discusses the design and application of a unique method to establish the regional or area level impact of irrigation energy conservation

2.8 EXTENDING REGIONAL LEVEL M&V FOR WATER CONSERVATION IMPACTS

The section considers literature which can provide background and insight for extending the regional level M&V approach, discusses above and in Chapter 5, to also quantify water conservation. Water discharge measurement, water resource tracking and rain water catchment methods are looked at which can be applied in Chapter 7.

2.8.1 Water discharge measurement

Several methods exist for water discharge measurement and it is common practice in many countries. According to Tazioli (2012), the quantity, value, characteristics and temporal variability of basin surface outflow is determined by discharge measurements in natural watercourses. Stošić *et al.* (2012) states that the area-velocity method is the standard adopted internationally for discharge measurements.

Conventional measurement methods involve determining the mean section flow velocity by immersing a water current meter in different points on a cross-section. From this, the discharge can be calculated mathematically (Tazioli, 2012). Tazioli (2012) also states that the ISO-748 standard provides the specifications for the correct measurement approach that must be followed.

Discharge estimate uncertainties with the area-velocity method can be evaluated according to the ISO1088 prescription (Stošić *et al.*, 2012). Flow velocity measurement is reliable in most situations, except during high discharge like floods, when there is insufficient water to immerse meters, the flow velocity is too low or there is excessive turbulence. Then alternative methods such as artificial tracers can be used to measure discharge (Tazioli, 2012).

Rossenberg *et al.* (2013) developed a network design approach for enhancement of statistical streamflow forecasting. This approach was applied to the expansion of the Natural Resources Conservation Service (NRCS) of the United States' Department of Agriculture, and was used for the water supply forecast publication (Rossenberg *et al.*, 2013; Paganoet *et al.*, 2009). Discharge information should be available through water resource information and tracking discussed in the following section.

2.8.2 Water resource information and tracking

Regional water resource initiatives are dependent on reliable water resource and discharge information systems; regionally and nationally, which includes data exchange and dissemination additional to collection and analysis (Andrews, 1999). Hamilton (2012) highlights the importance of data availability,

accuracy and reliability from water monitoring programmes, and lists five critical components of a hydrological programme: (1) Quality management system with standard governing data production and consistency; (2) Network design effectively filling data voids within a growing network where exiting measurements stations are discontinued and new stations established; (3) Selecting technology effectively; (4) Training of personnel; and (5) Data management.

Unfortunately, Hannaford (2011) cites Vörösmarty (2002) and Mishra *et al.* (2009) stating that hydrometric monitoring networks are declining worldwide due to financial constraints. Stošić *et al.* (2012) proposes that where resources are scarce, optimizing river discharge measurements can be done by using the Monte Carlo Markov Chain. Also, other options for discharge measurements include remote sensing such as satellite (Beighley *et al.*, 2016).

According to Bonthuys (2017), Water Administration Systems (WAS) are used in South Africa for operating procedures on rivers, canals, pipelines and dams for irrigation schemes that operate on a water demand system. Such a system captures the schematic layout of rivers and canals with sluices, pumps, slopes, capacities and measuring structures which allow tracking of water flow, distribution and losses from source to individual user (Bonthuys, 2017). By using a properly implemented WAS, water distribution losses were reduced by 20% (Benade, 2018; Bonthuys, 2017).

2.8.2.1 Rain water catchment

A more challenging task may be to quantify rain water catchment in the region. Rainfall measurement methods are important and need to take mutability into account for minimizing errors and uncertainty found in recorded data (Dai *et al.*, 2017), and:

- Rain gauge measuring network design needs to determine the right number of gauges and locations with the frequency in time of sampling in order to minimize uncertainty; and
- With this, other factors of rain catchment areas that also require attention are the catchment nature and typographic influences, drainage patterns, accessibility, suitability, installation cost and maintenance costs.

As a power station is a power generation source in a regional energy conservation M&V approach, a rain water catchment area for instance, can be seen as a water supply source in a regional water conservation boundary. For a regional water conservation M&V approach, water resource information in combination with exiting WAS and the rain catchment area, can establish the boundary for a region similar to the electrical grid boundary discussed in Chapter 5.

2.9 M&V METERING SYSTEMS AND METER SAMPLING IN AGRICULTURAL IRRIGATION ENERGY CONSERVATION PROJECTS

This section discusses M&V metering in agricultural irrigation energy conservation projects and sampling methods which provides the necessary background for Chapter 6. Metering on irrigation ECMs is especially challenging and problematic, and it was found that it often hinders or even prevents successful M&V. The IPMVP guideline and the SANS 50015 and SANS 50010 standards for instance, provide very good guidance on M&V, data transparency, integrity and correctness of project metering data (IPMVP, 2012; SANS 50015:2015; SANS 50010:2018).

Other standards like the SANS 474 and NRS 057 provide a code of good practice for the installation of electrical metring (SANS 474:2009; NRS 057:2009). With water flow meters and other M&V metering there also exit specific standards and installation specifications. Here the IPMVP guideline appendixes provide information and standards for different types of meters and summarises some key types of meters, and provides comments on M&V matters (IPMVP, 2012). However, the above do not

necessarily provide guidance and solutions to the practical aspects and challenges experienced with metering. In addition, the usefulness of these documents to a non-technical person, or the availability thereof can be a problem. In some cases, it was found that project stakeholders and even M&V practitioners were not aware of the existence of such documents. This necessitated the contribution in Chapter 6 on M&V metering.

Of course, specific metering equipment are supplied with operational and installation instructions with troubleshooting guidelines. These do assist with specific metering installation parameters and requirements; for instance, the allowable distances before and after a flow meter for any obstruction in a water pipe, or how to use a flow pulse counter reader. Unfortunately, these regularly have limitations, and advanced installation and operational information is not provided. Here it is important though that a meter supplier should be reachable and should provide the necessary technical support when required.

Looking wider for other literature, the Energy Reference M&V Handbook (AFCEA, 1998) takes the material of the North American Energy Measurement and Verification Protocol (NEMVP) and the M&V guideline for FEMP, and applies the guidelines and protocol to specific energy system technologies. The handbook gives valuable information on the importance, needs, benefits, and options for M&V with specific procedures, metering option requirements and metering points. Except for metering on VSDs, no assistance is given towards irrigation conservation metering however. The Kingdom of Saudi Arabia's (KSA) energy savings M&V user guide (KSA M&V guide, 2017) provides background on issues related to metering equipment and systems, but also does not provide practical guidance for practical in-the-field problem solving. With this, no information is also given towards irrigation related metering. These and the severe challenges experienced with irrigating ECM metering necessitated the metering contribution of Chapter 6.

When considering sampling and uncertainty, the IPMVP guideline document (IPMVP, 2012), SANAS Guideline for reporting uncertainty in M&V (SANAS TG 50-2, 2017), the UNFCCC sampling guidelines (UNFCCC sampling guide, 2012) and many other provide very proper information on sampling approaches and the relevant statistics to be used. This literature survey does not intend to repeat the information provided in these, but the study in Chapter 6 focuses on designing concepts that can give simplified methods for irrigation ECMs sampling.

2.10 SUMMARY

This chapter provides a comprehensive and encompassing literature survey of the problem statement and scope of study as outlined in Chapter 1. For each of the sections in Chapter 1, relevant literature was researched and surveyed to establish specialized field background to obtain appropriate and substantial material. This was systematically contemplated and analysed to find existing methods and facts on which new methods and approaches can be designed and developed to answer the key research questions in Section 1.5 of Chapter 1.

Through this analysis, the necessity and original contribution of each part of this study was shown. Chapters 3 to 5, following, focus specifically on the project level, programme level and regional level M&V of irrigation ECM. Chapter 6 focusses on metering and sampling, while Chapter 7 gives an integrated approach of Chapters 3 to 6, together with the content of Chapter 2, to use ECM and other incentives as leverage to realise water conservation in the agricultural sector.

Chapter 3

Project Level M&V

The Measurement and Verification (M&V) of Demand-Side Management (DSM) Energy Conservation Measure (ECM) projects generally have problems that complicate project assessments. However, exceptional evaluation difficulties were experienced and cumbersome M&V methodology challenges were encountered with agricultural irrigation pumping DSM projects. Conventional baseline development methods were ineffective and unique M&V methods were devised, developed and implemented. Further development was done to provide a complete M&V solution for any type of irrigation DSM project or a combination of different types. This chapter focusses on project level M&V which is defined as the full contractual life evaluation of a project making use of full-time metering of key project parameters.

The different aspects of baseline development, from the baseline boundaries to saving calculations are discussed. Also, different pumping setups and different project types, and the combinations of project types, are discussed with novel baseline development methods presented. The different project types and the combinations thereof include: load shifting, energy efficiency with an energy governing factor, energy efficiency without an energy governing factor, a combination of load shifting and energy efficiency, load prevention or clipping and a combination of clipping and energy efficiency. This chapter also intends to give guidance to M&V entities, project investors, utilities, clients and project implementers on what is required for proper M&V. Through this, project stakeholders can pre-emptively ensure that the correct mechanisms for a successful DSM project are in place. It also gives guidance to ensure that proper and sufficient M&V is already implemented from the DSM project planning phase. Here the aim is to:

- Inform project stakeholders how project information should be handled and scrutinised by an M&V practitioner and give insight on the pitfalls of irrigation pumping projects;*
- Provide evaluation methods for new project decision makers to quickly evaluate the feasibility of a proposed DSM project at the very start; and*
- Provide guidance for M&V entities on what to look out for, what M&V strategy to follow and how to approach baseline development.*

Chapter related publications and conferences

- ❖ Storm, M.E., Gouws, R. and Grobler, L.J. 2016. Measurement and verification of irrigation pumping DSM projects: Application of novel methodology designs. Journal of Energy in Southern Africa, 27(4):15-24. ISSN 2413-3051*
- ❖ Storm, M.E., Van der Merwe, C.A. and Grobler, L.J. 2008. M&V of an irrigation pumping project: Case study. International Conference on the Industrial and Commercial Use of Energy, Cape Town, pp. 249-254. ISBN 978-0-9922041-1-2.*

3.1 INTRODUCTION

The term conservation is widely used across sectors and in each area, the aim and focus of conservation can cover a variety of aspects. With any resource supplied, be it energy, water, cooled fluids, heated fluids or an element in an industrial value stream, there is normally both supply side and demand-side inefficiencies with optimization potential. Optimization improvements can often be costly and stakeholders would prefer to see the real impact of any optimization intervention, instead of only relying on technology supplied figures. Measurement and Verification (M&V) principles can be applied on any such optimization intervention project to establish and report on the conservation achieved. With energy, there can be conservation in the power generation (supply side) and then also by the users (demand side). The focus of this section is to design M&V methods on the demand side; however, some of these principles can also be applied on the supply side.

It was observed in several countries that power supply utilities are the main driver or initiator of energy conservation. In South Africa the only power utility, Eskom, started with Demand-Side Management (DSM) Energy Conservation Measure (ECM) interventions. Here the goal was not to reduce energy use but only to release strain from the national power grid. Later the focus moved to also include Energy Efficiency (EE). The Eskom DSM programme was over the residential, commercial, industrial, mining and agricultural sector. Across these sectors conservation projects were implemented through Energy Services Companies (ESCOs) with public funding. Eskom DSM later became Eskom Integrated Demand Management (IDM).

Since public funding was provided by the National Energy Regulator of South Africa (NERSA) for the Eskom initiatives, all projects needed to show credibility and therefore M&V had to be applied to evaluate attained impacts (Van der Merwe, 2011). Thus, intensive M&V was performed on these projects to assess project impacts and report to the stakeholders. The function of M&V is to independently and objectively quantify project impacts and sustainability of impacts over an agreed contractual project life (Den Heijer, 2010). All M&V practices were based on the International Performance Measurement and Verification Protocol (IPMVP Committee, 2012). From this, South African M&V practice guidelines (Den Heijer, 2010) were developed and finally national standards were established, namely the SANS 50010 (SABS, 2018) and SANS 50015 (SABS, 2015).

This thesis looks at the M&V of energy conservation DSM projects, more specifically the focus is on probably the most challenging environment: energy conservation on agricultural irrigation pumping. Although the novel M&V approaches in this thesis were specifically designed for the unique circumstances of agricultural irrigation pumping, the principles and techniques presented can be applied to a wider field than irrigation pumping. Since 2004, Eskom's DSM Programmes actively engaged farmers to reduce peak period power (electrical energy) usage. Farmers with higher power usage were also assisted to move from the 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 primarily focused on large farms making extensive use of irrigation or jointly implemented with a regional irrigation board.

The M&V of DSM projects normally has problems that complicate project assessments, but even taking this into account, exceptional evaluation difficulties were experienced and cumbersome M&V methodology challenges were encountered with agricultural irrigation pumping. Normal baseline development methods were ineffective and as part of the thesis unique M&V methods were devised, developed and implemented. Further development was done to provide a complete M&V solution for any type of irrigation DSM project or a combination of different types. This chapter describes project level M&V, defined as the full contractual life evaluation of a project which can be one pump, several pumps or a project consisting of hundreds of pumps. The terms normal and conventional M&V methods

are also commonly used and involve physical metering of all or key project parameters over the whole contractual period of the project. In the context of this chapter, project level M&V makes use of long-term full metering (demand profile metering) or appropriately sampled pumps for metering. For non-key parameters, spot measurements are acceptable. Here project level M&V aligns with the following SANS 50010:2018 methodologies: retrofit isolation with key-parameter measurement, retrofit isolation with all-parameter measurement and a whole facility approach (IPMVP Options A, B and C respectively).

Figure 3-1 shows a flow chart with the contents of this chapter. Within project level M&V, the different types of irrigation projects and combination of types are evaluated (left of Figure 3-1). Using load shifting as an example, the project level M&V fundamentals that need to be applied are discussed.

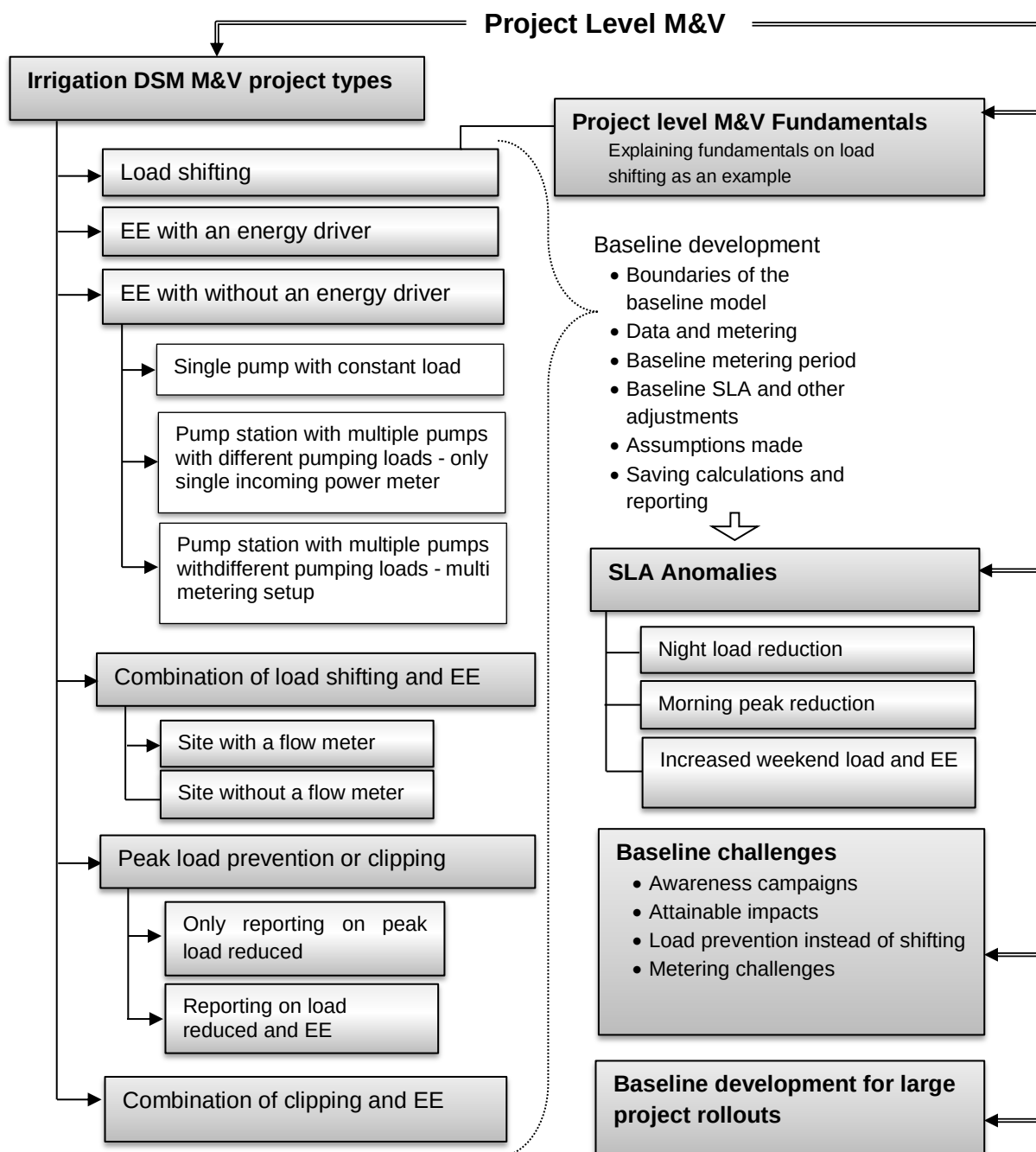


Figure 3-1: Flow chart of chapter contents.

This is done since most of the Eskom DSM irrigation projects were load shifting which uses the simplest M&V approach. The M&V fundamentals provide specific important principles that should be followed for proper project evaluation. It is necessary to look at the elementary building blocks which are the foundation for effective development of an M&V baseline and saving calculations method.

In order to establish a representative baseline, a typical representative operational profile needs to be established. Depending on the industry, a baseline may differ according to day type, month, season etc. The operations will also determine the time period required to develop an effective baseline with variations captured. Here there can be quite a variety of approaches to follow which is dependent on the operations, stakeholders, the project budget and the reporting requirements. On project level M&V it is customary to report not only on the amounts saved but also on exactly when savings were achieved. This depends on the focus of the project and the stakeholders implementing the project.

Considering each project type, this chapter looks at the different aspects of baseline development, from the baseline boundaries to saving calculations. Also, different pumping setups are discussed with proper baseline development methods designed and presented. Following this, Service Level Adjustment (SLA) anomalies found with actual projects with alternative baseline methods are given. Also, the baseline development challenges found in the field are discussed.

On top of the development of unique methods, this chapter intends to give guidance to M&V practitioners, project investors, utilities, clients and project implementers (ESCOs) on what is required for proper M&V. Through this, project stakeholders can pre-emptively ensure that the correct mechanisms for a successful DSM project are in place from the very beginning.

It also gives guidance to ensure that proper M&V is actioned from the DSM project planning phase to avoid common pitfalls. For this purpose, the last section of the chapter specifically performs an analysis on the typical information an ESCO would provide to a proposed irrigation DSM project. Here the aim is to accomplish the following:

- Inform an ESCO and stakeholders how project information is handled and scrutinized by an M&V practitioner;
- Provide insight for project stakeholders (specifically utility and project investors) on the pitfalls which should be avoided with irrigation project;
- Provide evaluation methods for new project decisionmakers to quickly evaluate the feasibility of a proposed DSM project at the very start;
- Provide guidance for M&V practitioner on what to look out for, what M&V strategy to follow and how to approach baseline development.

Within this chapter, and following chapters, several standards and protocols were adhered to, followed or referred to. These include in alphabetical order:

- International Performance Measurement and Verification Protocol (IPMVP, 2012);
- SANS 50010:2011 Edition 1 - Measurement and verification of energy and demand savings (SABS, 2011);
- With the latest edition of the above: SANS 50010:2018 Edition 2 - Measurement and verification of energy and demand savings (SABS, 2018);
- SANS 50015:2015 Edition 1 / ISO 50015:2015 Edition 1. Energy management systems – Measurement and verification of energy performance of organizations – General principles and guidance (SABS, 2015); and
- South African M&V Framework document, 2010 (Den Heijer, 2010).

3.2 IRRIGATION DEMAND-SIDE MANAGEMENT M&V PROJECT TYPES

With agricultural irrigation, as with other sectors, it is important to define the different DSM energy related conservation methods since the M&V approach on each can differ significantly. The type of information and data available are also determining factors on which M&V methodology should be followed. The last deciding factor is the stakeholder reporting requirements. The following DSM project types and combinations are discussed in this chapter:

1. Load shifting - Only moving the load out of the power utility peak usage periods to off-peak periods during the rest of the day or to weekends. Thus, there is no difference in the amount of kWh used but only when it is used. Load shifting is specific to daily Time of Use period (ToU) reporting.

2. Energy Efficiency with an energy driver (energy governing factor) - There are many ways to implement efficiency in irrigation. However, it mainly comes down to reducing the amount of energy required to move the same amount of water and/or reducing the amount of water pumped. In this scenario an energy driver, the pumped water measurements, are available. It is important to notice here that less water pumped (thus water conservation - reducing the amount of water irrigated per crop type) will also directly result in energy efficiency. However, here only energy efficiently moving the same amount of water is considered. Energy use reduction due to less water used is discussed in Chapter 4. For energy efficiency with an energy driver, reporting may consist of:

- Only reporting on kWh conservation, or
- Reporting on kWh conservation and time of day at which the resulting kW demand reduction was achieved.

3. Energy Efficiency without an energy driver - Here no energy driver reference is available and alternative unique methods need to be developed for irrigation pumping. Reporting:

- Only on kWh conservation, or
- On demand reduction achieved as a result of the energy conservation (in ToU periods); and
- On kWh conservation and time of day at which the kW demand reduction was achieved.

4. Combination of load shifting and energy efficiency - In addition to load shifting switch gear, energy efficiency can also be implemented on a pumping system. Reporting:

- On load shifted (in ToU),
- On demand reduction achieved as result of the energy conservation (in ToU periods), and
- On the kWh conservation achieved.

5. Load prevention or clipping - Here the load reduced during the peak period is not recovered at a later stage, thus a kWh saving is also achieved. Load clipping is specific to daily ToU period reporting. Here only the clipping demand impact is reported on and any EE impact is ignored.

6. Combination of clipping and energy efficiency - Other energy efficiency initiatives can also be implemented with load clipping. This consists of load clipping reporting, as in point 5 above, but reporting on the kWh savings is also required.

- Report on load clipped (in ToU period);
- Demand reduction achieved as result of the clipping and energy conservation (in ToU periods), and
- The kWh conservation achieved.

Each of these DSM project types are discussed separately in Sections 3.3 to 3.7. In the following section the fundamentals of project level M&V are explained by using load shifting as an example.

3.3 LOAD SHIFTING - PROJECT LEVEL M&V FUNDAMENTALS EXPLAINED

Figure 3-2 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) and is used when maintenance is done on Pump 4. The crop circles and micro blocks have different crops and irrigation schedules.

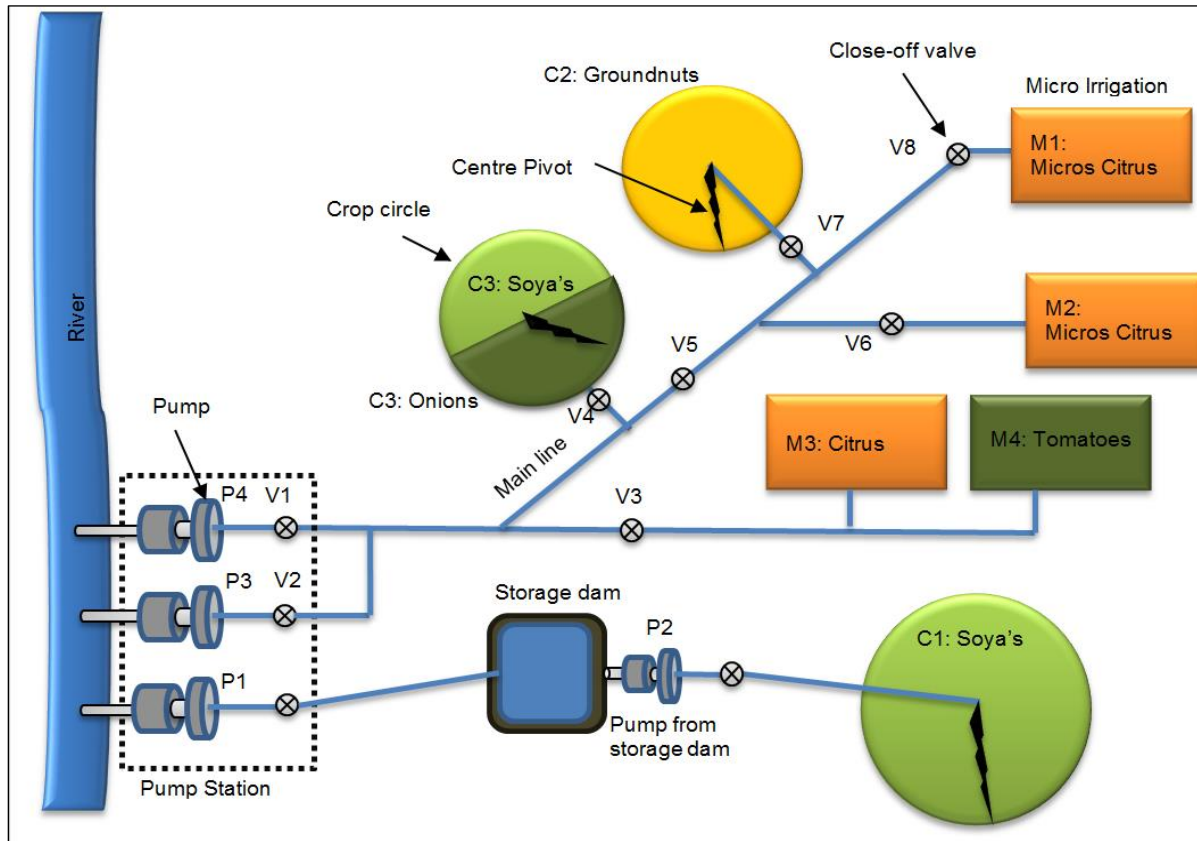


Figure 3-2: Typical irrigation farm pumping setup.

On this irrigation setup a DSM project is implemented to shift all pumping loads from the Eskom evening peak period (weekdays 18:00-20:00). See Section 3.3.4.2 for the Eskom peak periods. This is achieved by retrofitting the irrigation pump with timers and equipment to allow automatic shutdown and start-up. The M&V practitioner is required to assess the actual impacts attained through this intervention and the assessment is preceded by developing a baseline and baseline model. In the following section and the rest of Chapter 3, no specific details are provided on expected accuracy and allowable budget for a M&V project. The Chapter aims to provide relevant solutions to irrigation challenges that can be applied, depending on the project budget and required accuracy. The analysis of a specific project and its evaluation of results thus falls out of the scope of Chapter 3. M&V cost versus accuracy are discussed in Section 4.4.3 while Chapter 6 Section 6.5 looks at metering sampling plans.

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. Thus, it is accepted that for this project the amount of energy required to move water before and after intervention is the same. The aim of the irrigation DSM project is not to reduce or influence pumping activities, but solely to shift pumping activities out of the evening peak.

The following steps provide the process that should be followed in the M&V process and reporting. It starts off by first clearly establishing and stating the exact DSM objective from which the M&V strategy can be decided upon. These, and all other steps should be part of a formal report which should be agreed upon by all stakeholders.

3.3.1 DSM project objective

As mentioned, it is very important to clearly detail the exact DSM project objective since this will determine the M&V strategy and baseline development methodology. It is important that the technology used to enable the DSM intervention should be specified and as much details possible given. Alongside this, any other equipment or actions that may be implemented with a DSM intervention must also be provided. Even if something may not seem relevant to the ESCO or stakeholders, it may have severe interactive effects on the project. Here is an example of such a case:

Example: *The objective of a DSM project was to enable the Witlaagte Irrigation Board to schedule water and electricity consumption so that all irrigators operate out of the Eskom evening peak period (between 18:00 and 20:00). All farmers will thus participate in load management through pumping restrictions in the evening peak period. According to the ESCO an annual average of 7407 kW will be moved out of the Eskom peak period. This will be made possible through the ESCO implementing the necessary infrastructure and control equipment. The DSM installation includes river water extraction flow meters and control interface for the peak switching. The manage-and-control system installed at a pump station will send the recorded data to a main control room.*

In the example some points may seem to be unimportant at first, but may prove to be useful for proper M&V planning or when anomalies are observed later during post-implementation M&V assessment. The fact that there will be river water extraction flow meters installed may have a major interactive effect. It was observed with similar projects that river water extraction monitoring changes the pumping behaviour of the farmers. See Section 3.8.1.

3.3.2 M&V plan and reporting objective

From the DSM objective, the M&V objective should be clearly defined. This will be dependant of the project and stakeholder reporting requirements. The following is an example of a typical M&V objective for an irrigation DSM project:

Example: *The objective of the M&V project is to measure and verify the electricity demand, demand savings, cost savings and emission impacts due to the DSM activities implemented on the Witlaagte farming area river pump stations. The impacts need to be determined to verify the cost savings for the client and the ESCO, as well as the DSM impacts obtained for Eskom.*

An M&V practitioner scoping site visit is always strongly recommended since this brings much light on the project characteristics. From this the M&V approach and M&V plan document can be developed. This document must provide as much possible info with clear and transparent details on the points listed below. For clear and exact guidelines of what to include in the M&V plan there should be referred to SANS 50015 or the IPMVP.

- DSM objective;
- DSM intervention details and detail of the project site(s);
- M&V objective;
- M&V strategy to use as per M&V standard applied;
- M&V methodology for the project based on the M&V strategy;

- Metering plan;
- Baseline development method and baseline Service Level Adjustment (SLA);
- Assumptions and other baseline adjustments; and
- Post-implementation saving determination method.

As mentioned, it is important that all stakeholders should agree on the M&V plan before the post-implementation M&V project impact assessment period start. A proper stated M&V objective and well-developed M&V plan agreed upon and signed by all stakeholders, can prevent and assist with later M&V project disputes.

3.3.3 M&V Strategy

With the M&V objective clarified, the M&V strategy can be decided upon from the M&V standard used. As an example, this project has been analysed and classified according to the guidelines set out in the South African M&V Framework document and Option B of the IPMVP will be followed (Den Heijer, 2010; IMPVP, 2012). Only a summary of the classification is provided here.

According to the Option B classification, an M&V project in this group has the following characteristics:

- In all cases the post-operating hours may not be used for the baseline;
- In all cases the post-service level requirement may be used for the baseline; and
- The system efficiencies remain unchanged.

This implies that the measures implemented are considered to have impacted (changed) the operating hours of the system. It is consequently necessary to determine a baseline for the operating hours.

Based on this classification, the M&V plan should focus on the following areas:

- Determine a baseline for the operating hours of the system – pre-implementation;
- Determine the operating hours of the system – post-implementation; and
- Determine the load/requirement of the system – post-implementation.

The following sections describe metering and the processes involved in developing a project baseline. Also, the sections describe how a baseline is adjusted, after DSM implementation, to reflect the old operational conditions. This is done through service level adjustment (SLA).

3.3.4 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 consist of daily 30-minute or hourly average 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 3-3 shows a flow chart of the baseline development process described in the following sections.

3.3.4.1 Boundaries of the baseline model

From the top left of Figure 3-3 the first important step is to set the boundaries of the baseline model. The closer the boundary can be to the DSM intervention, the less complicated and more accurate the baseline model will be. Most of the Eskom DSM irrigation projects consisted of load-shifting interventions on the irrigation pumps of one farm or of several farms.

The project scope is restricted to the irrigation pump stations; thus, the baseline boundary only includes the power demand and use (demand profiles) of the pump stations. In Figure 3-2 the boundary is drawn around the river pump station and around the pump at the storage dam.

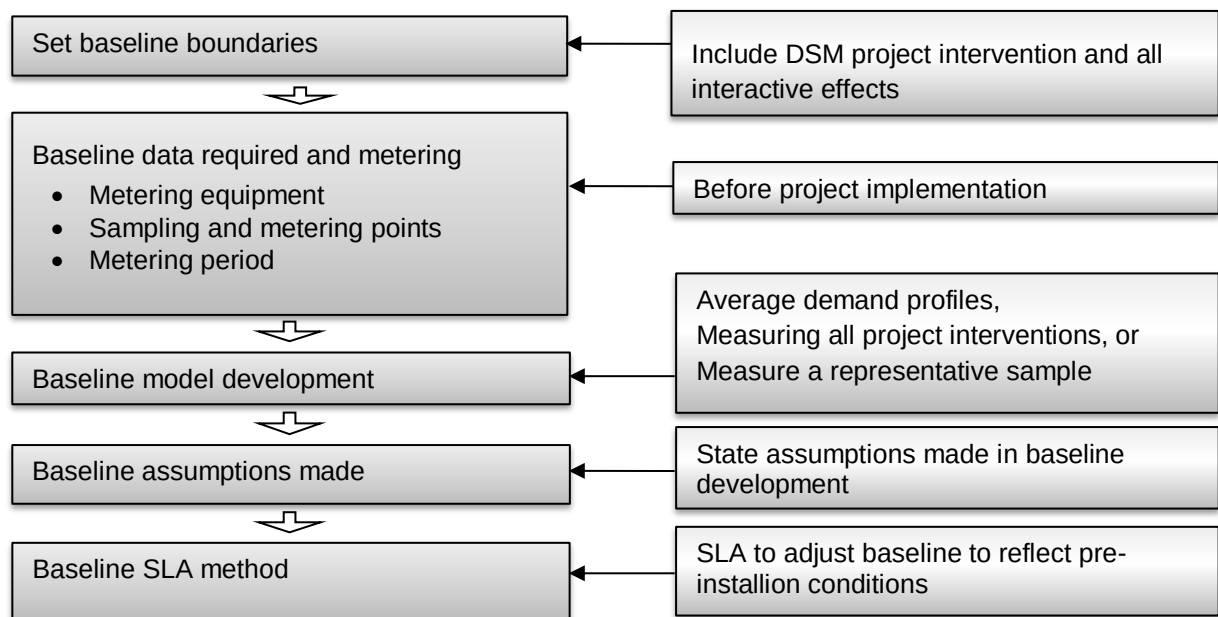


Figure 3-3: Flow chart of baseline development process.

3.3.4.2 Baseline data required and metering

With the project boundary set, the baseline data and metering required need to be specified. The characteristics of irrigation pumping project level M&V necessitate the usage of continuous power demand metering, unlike many other types of DSM projects. The latter, like industrial, mining and commercial projects, frequently involve constant load demand. Here 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 with rainfall and soil types complicating matters.

Sometimes data can be obtained from the utility power supply point meter (permissions may be required). For M&V purposes, it is ideal if the utility power supply point only supplies the pump station under evaluation and has an existing utility ToU profile power meter. If provided access, 30-minute or hourly profile demand data of several months can be retrieved from the meter. Also, from the utility data repository system, data of several years may be available from the supply point.

Eskom has the MV90 system from which Eskom can retrieve historical profile data of ToU points (obtaining of data is dependent on Eskom and supply point client authorization). A drawback of using a utility meter is that more than one pumping load may be supplied by the utility point. Other loads like packing houses, residences and other non-pumping loads may also be captured by the utility power meter. If no utility profile meter data is available, a profile power meter can be installed on the pump motor Distributing Box (DB). This will isolate the pump motor and prevent that other loads are also being measured. However, a long baseline metering period may be required as discussed in the next section.

With demand profile metering, each 30-minute or hourly reading will be an integrated backward or forward filling value depending on the system. Backwards means that the value given at 13:00 is the integrated value of 12:30 to 13:00, while forward filling is the integration of 13:00 to 13:30. It is very

important to distinguish between these and also to standardise on what is reported. If care is not taken, a time shift can occur and reporting can be out with the measuring interval. It is at this stage essential to discuss ToU and how it is central to DSM and M&V reporting. The aim of ToU is to assist power utilities with peak demand control realised through lower client kWh cost for outside peak period operations. With this there are specific maximum demand (kVA) costs. Figure 3-4 is applicable to the Eskom Megaflex, Miniflex and Ruraflex tariff structures (Eskom Tariff and Charges booklet, 2017/18) for the low demand season. The tariffs slightly differ for the high demand season. The energy cost significantly varies between the Peak, Standard and Off-peak periods and the ToU breakdown is also different for weekdays, Saturdays and Sundays (valid for Megaflex, Miniflex and Ruraflex).

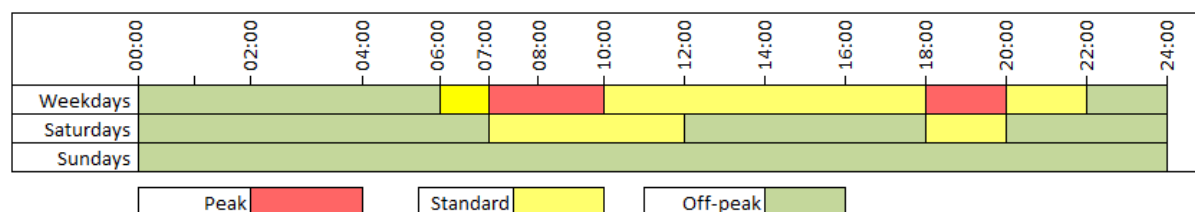


Figure 3-4: Eskom low demand season time of use periods. Adapted from the Eskom tariff and charges booklet of 2017/2018 (Eskom Tariff, 2017).

Thus, the utility bill of a farmer associated with energy consumption (kWh) and energy demand (kW) can differ according to time of day, day type and season. This is applicable though if a utility supply point is billed according to ToU. It is country dependant, but smaller farm utility supply points are normally billed a flat rate (only kWh used), while larger points have ToU structures.

Here a vehicle to reduce peak demand will simply be to assist moving a farmer from flat rate to a ToU utility bill metering point structure. However, this can be costly since ToU power meters need to be installed among other. The Eskom IDM standard M&V reporting structure entailed reporting on the Megaflex structure. Thus, impacts are calculated within the time periods specified by the power utility ToU tariff structure. Power utilities, to an extent, prefer load shifting projects since it has the advantage of peak load reduction without losing electrical usage kWh sales.

3.3.4.3 Baseline metering period

A proper baseline profile considers all operational conditions and seasonal variations. It should be noted here that irrigation pumping operations can also significantly differ from year to year. The baseline measuring period must be chosen so that measurements are representative of the typical operations.

The baseline measuring period for some DSM projects (in other sectors) can be a few days, others requiring months and even years. It was observed in general that for irrigation projects more than a year of data may be required. The historical data from Eskom MV90 pump station measuring points revealed significant variation in yearly operations and the overall pump load factor.

A hard reality is that with many irrigation projects, utility meter point data or a long enough baseline metering period may not be possible to attain. Here it is traditional that the M&V practitioner have to do as much possible with the time available for baseline metering.

3.3.5 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 much for agricultural purposes. However, Saturday and Sunday demand profiles generally differ significantly from that of weekdays, see Figure 3-5, Figure 3-6, and Figure 3-7. Using weekday, Saturday and Sunday profiles also allows effective reporting on the ToU periods (Figure 3-4).

3.3.6 Demand profiles

Figure 3-5, Figure 3-6, and Figure 3-7 show the weekday, Saturday and Sunday measure demand profiles with averages. In these figures the y-axis shows the demand in kW and the x-axis the time of day from 00:00 to 24:00. Large variances in the weekday demand profiles can be observed. On Saturdays the pumping demand is already lower than weekdays and on Sundays it further reduces. The average demand profile for each day type is shown in bold in Figure 3-5, Figure 3-6, and Figure 3-7. These average profiles are used as the project baseline profiles.

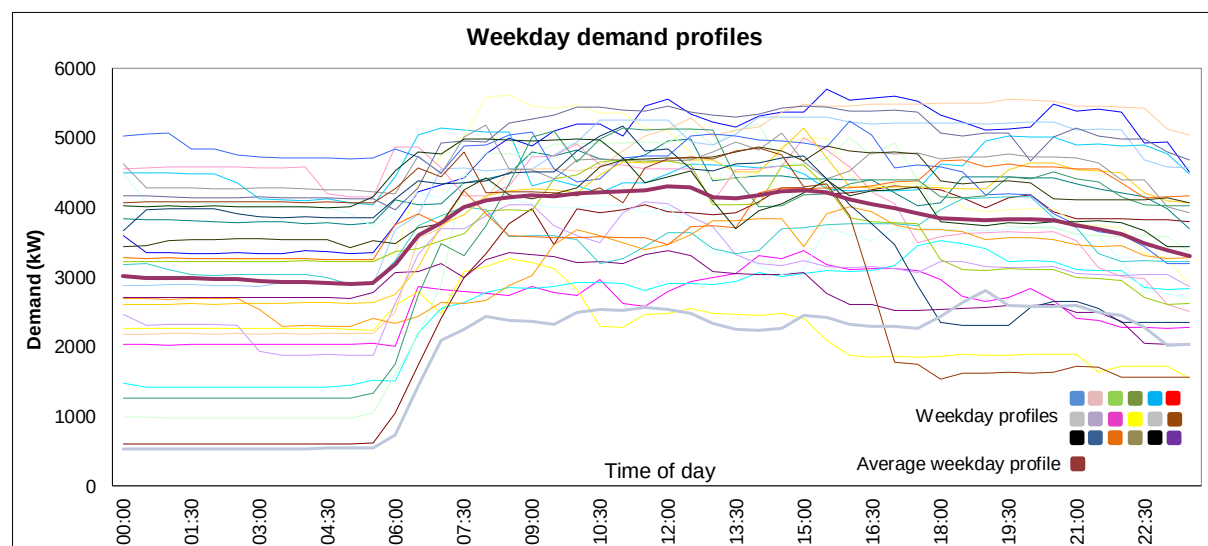


Figure 3-5: Weekday demand profiles with average.

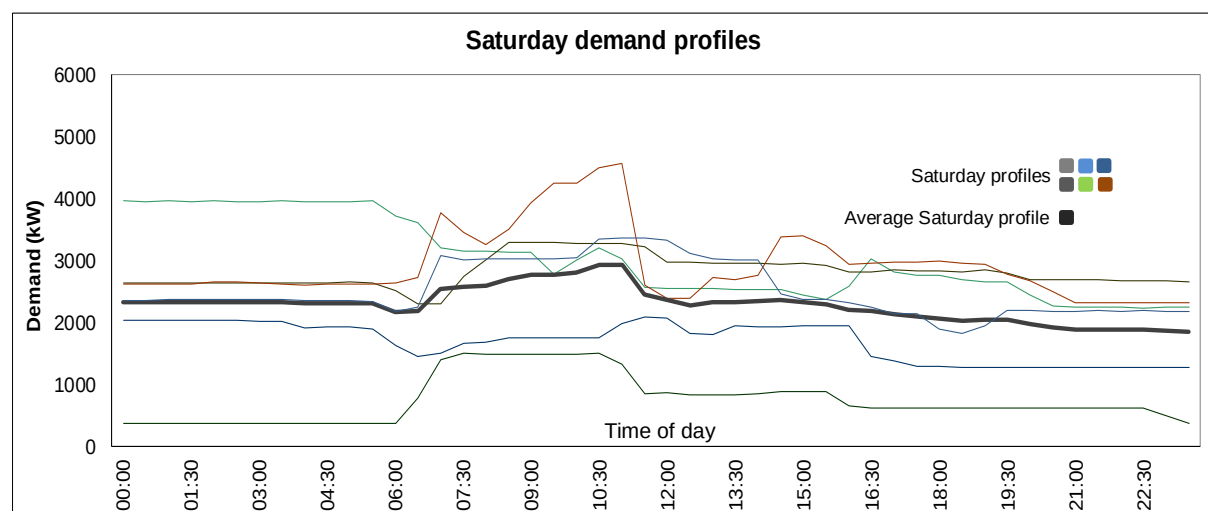


Figure 3-6: Saturday demand profiles with average.

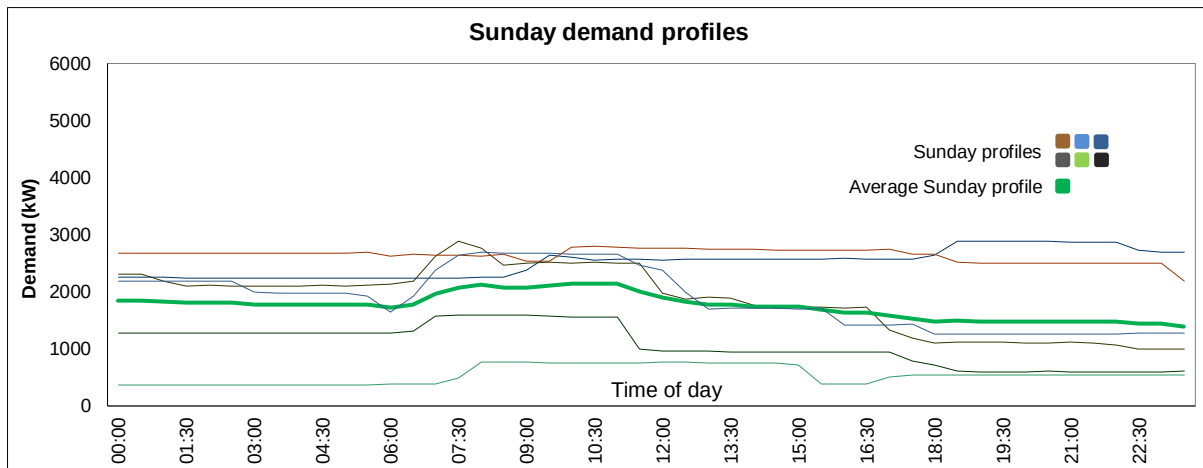


Figure 3-7: Sunday demand profiles with average.

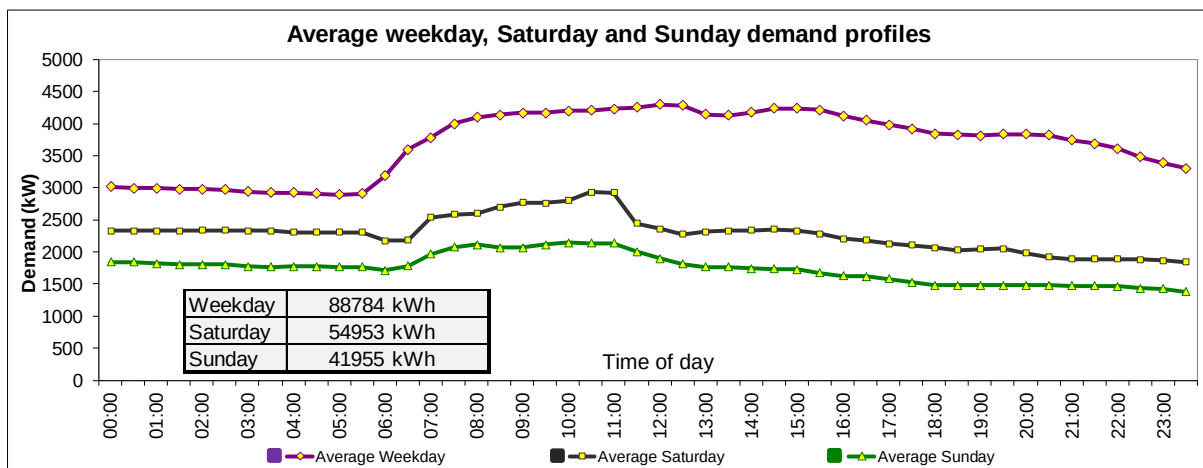


Figure 3-8: Project baseline profiles with reference kWh per day type.

3.3.7 Baseline service level adjustment

Data from the same measuring points as used for baseline development has to be collected for the post-implementation assessment period. Project performance assessments and reporting can be done on any interval the stakeholders require. It is normal practice to have monthly or quarterly project performance assessments. A baseline adjustment must be done to reflect the 'would have been conditions' before the savings can be calculated.

This is done by using a 24-hour energy neutral SLA. Figure 3-9 provides an explanation of the baseline adjustment process. On the top left of Figure 3-9 an example baseline profile is shown, while on the right the post-implementation average actual demand profile is shown.

In step A the reference kWh under the baseline profile is calculated and the result is used as the divider (step B) for the SLA_{factor} . The same process is used in step C to calculate the kWh of the actual demand profile. In step D the results are used as the numerator in the SLA_{factor} . The baseline demand profiles can be scaled up or down according a 24-hour energy neutral SLA_{factor} .

Thus, the daily baseline kWh is equal to the actual demand profile daily kWh: $kWh_{baseline} = kWh_{actual}$. Using these two values, the SLA_{factor} can be calculated to find the scaling ratio. The Figure 3-9 example shows that a SLA_{factor} of 1.04 was calculated.

The SLA_{factor} scaling ratio is multiplied with each 30-minute baseline profile value to scale the baseline as shown in step E. By doing this daily adjustment, aspects such as a seasonal higher demand is automatically taken into account. A value close to one indicates that the same amount of energy was used during the actual period as during the baseline period. A value below one will result in the baseline being downward adjusted while a value above one will give an upward adjustment, see Figure 3-10 and Figure 3-11.

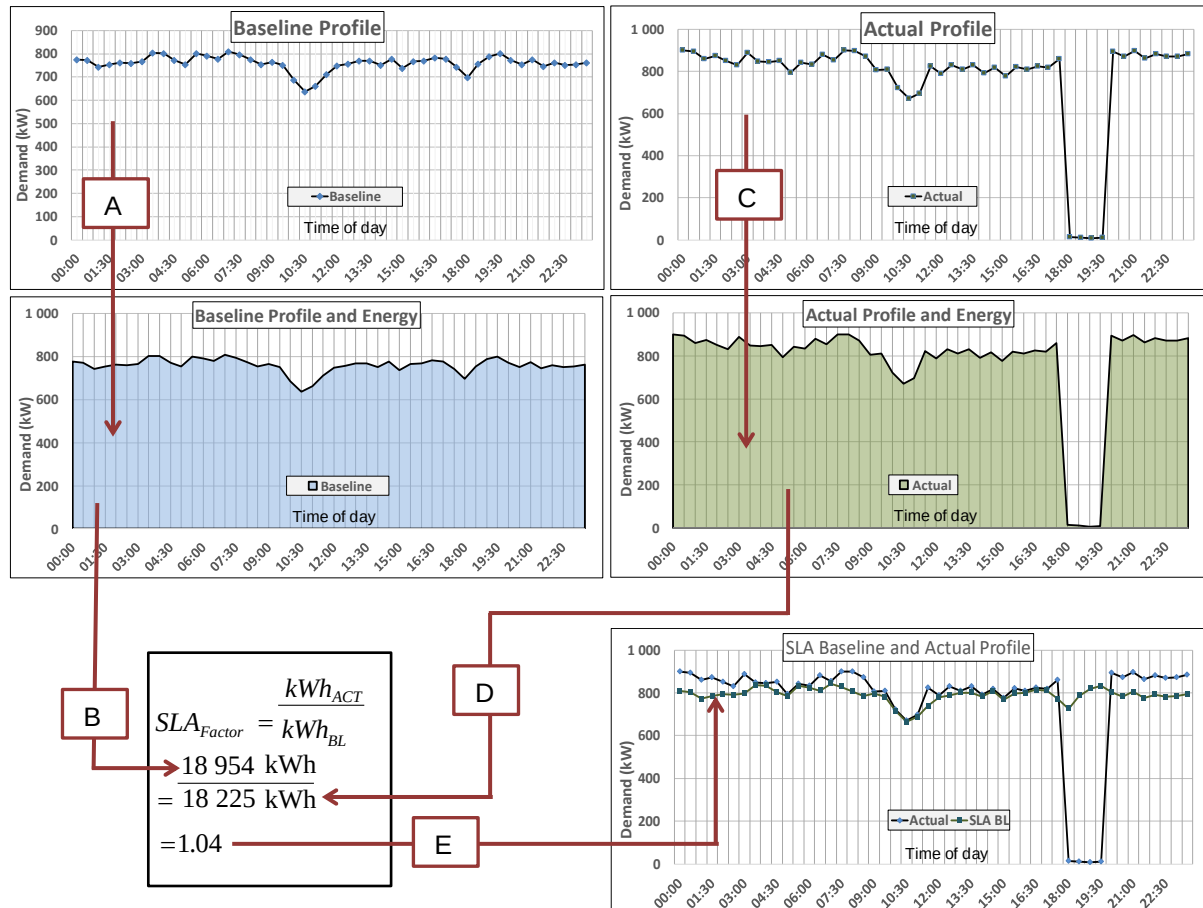


Figure 3-9: Example of a baseline service level adjustment.

3.3.8 Saving calculations and reporting

After the baseline adjustment was completed, the post-implementation demand profile can be compared with the adjusted baseline profile to calculate savings. The following steps need to be taken to determine the project impacts after project implementation:

- Step 1:** Retrieve the actual demand profiles after project completion and divide the data into weekdays, Saturdays and Sundays;
- Step 2:** Calculate the daily kWh of the actual demand profiles;
- Step 3:** Use the SLA_{factor} to scale the baseline profiles up or down; and
- Step 4:** Compare the SLA baseline and actual demand profiles in order to calculate the energy and demand impact of this project.

Figure 3-10 and Figure 3-11 give the daily SLA baseline and actual profiles of the first two weeks of the assessment period. A significant variation in pumping activities can be seen on a daily basis and the baseline profile is effectively adjusted daily up and down according to the SLA ratio.

On weekdays the evening peak impact due to the pump switch gear can be observed in Figure 3-10. Over weekends the switchgear is not active since there is no evening peak reduction required. During some days of Week 1 in Figure 3-10 the pumping demand exceeded 6 MW due to several pumps running simultaneously. During the second week in Figure 3-11, the overall pumping demand was much less, probably due to rain or other conditions on the irrigation farms.

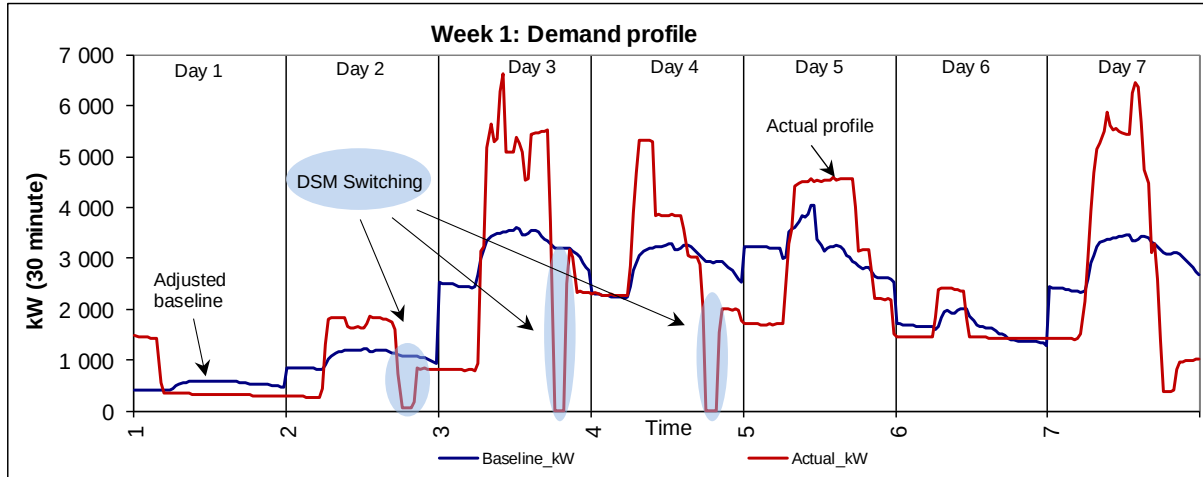


Figure 3-10: SLA baseline and actual profile of Week 1.

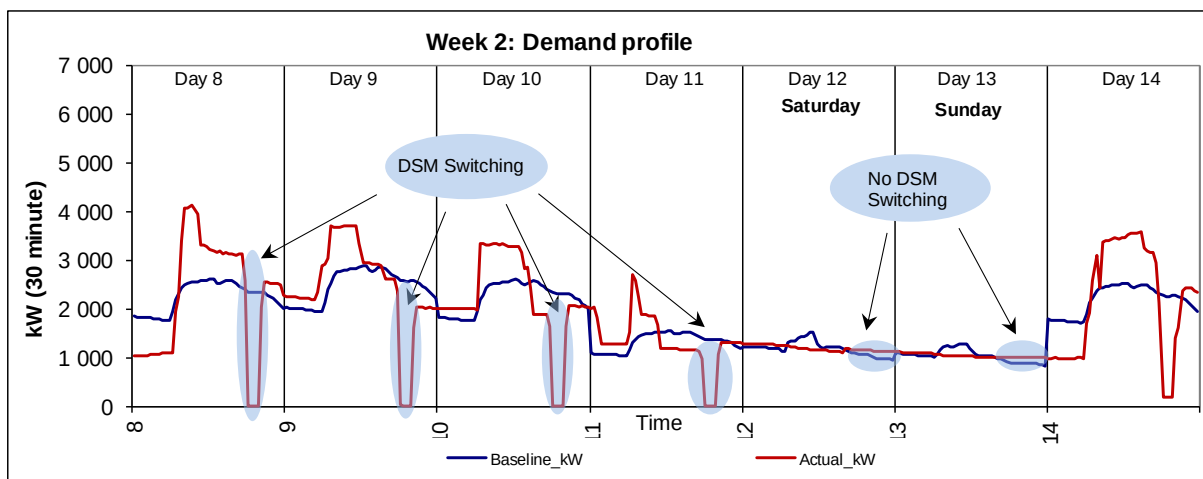


Figure 3-11: SLA baseline and actual profile of Week 2.

From the daily actual and adjusted baseline, the average weekday, Saturday and Sunday profiles can be calculated. The baseline profiles can be seen in Figure 3-12, Figure 3-13 and Figure 3-14. Pumping activities are significantly less over weekends.

Although the pumping demand in Week 1 was very high as shown in Figure 3-10, the average actual demand profile is not that high. It can also be observed that not the entire load was shifted from the evening peak. This can be due to several reasons:

- Other loads may also draw from the measuring point and these are not switched off during the evening peak;
- Switchgear on different pumps may not be working effectively or may have an incorrect clock resulting in a time shift; and
- The farmer can manually override the switchgear to pump over the evening peak.

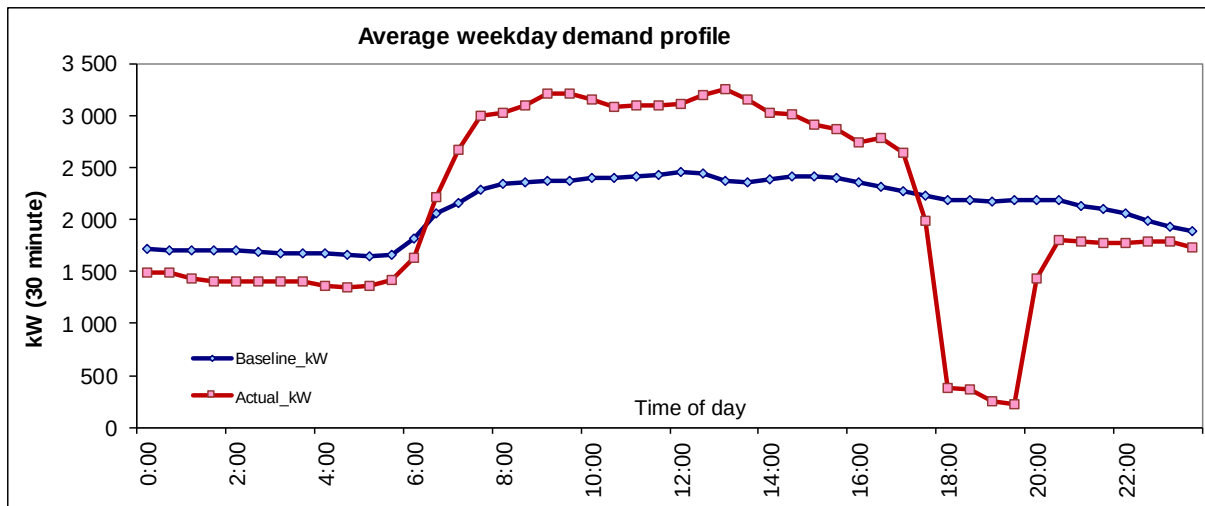


Figure 3-12: Average weekday adjusted baseline and actual profile.

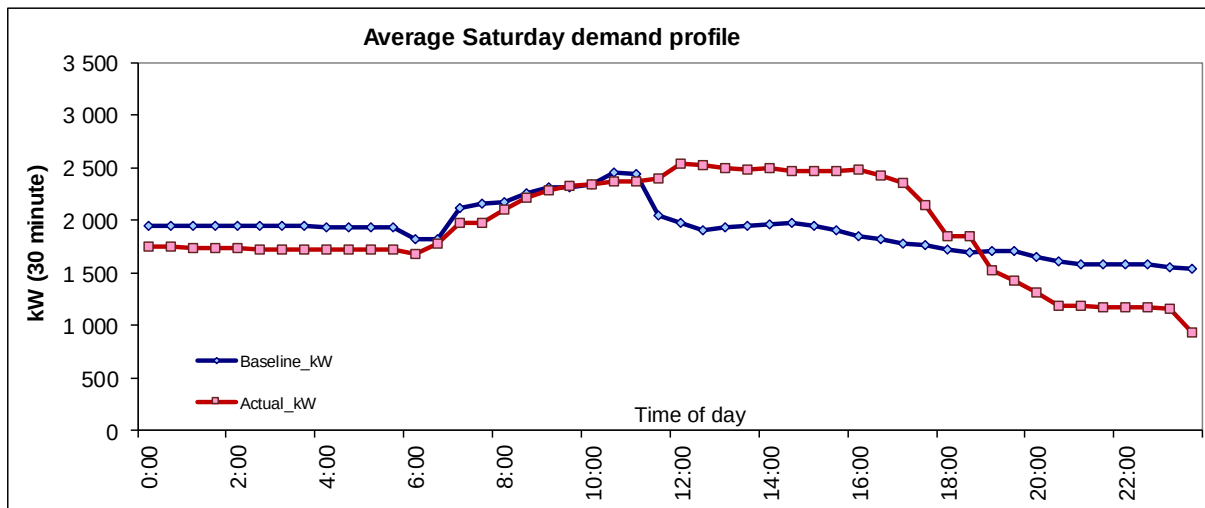


Figure 3-13: Average Saturday adjusted baseline and actual profile.

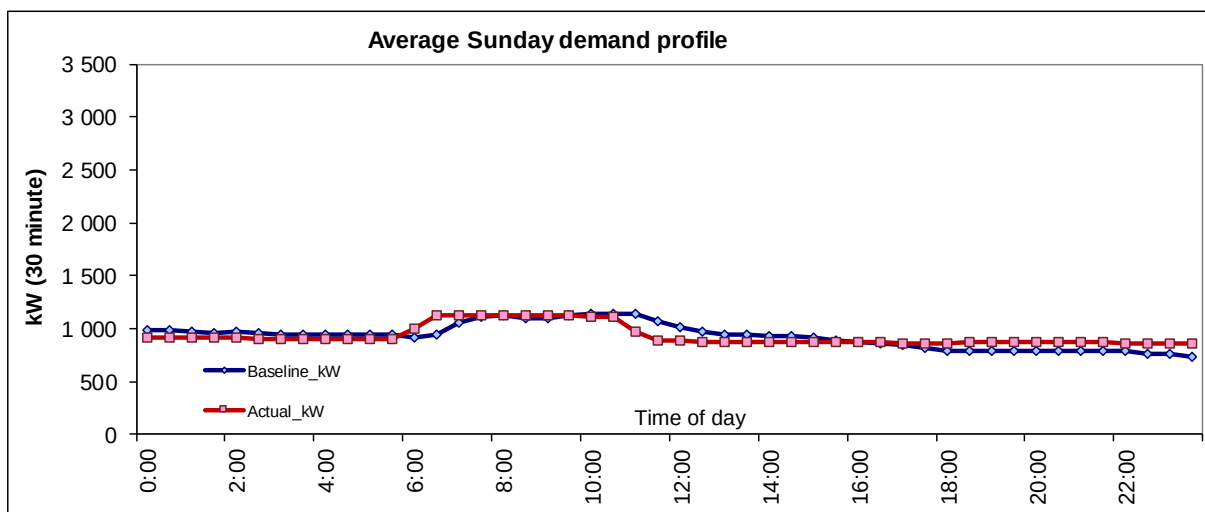


Figure 3-14: Average Sunday adjusted baseline and actual profile.

The daily 30-minute demand profile data can be divided into the ToU periods to report on the project targeted savings. This project has a contracted 4.5 MW evening peak DSM reduction that needs to be achieved. Due to the energy neutral baseline SLA, only an impact during the evening peak should be observed since the baseline is kWh neutral over the rest of the day.

Table 3-1 gives the weekday ToU impacts, while Table 3-2 gives the Sunday and Saturday impacts. Here the Saturday and Sunday impacts should also be zero due to the kWh neutral SLA. The actual average weekday demand reduction seen in Table 3-1 was 3.7MW, 1.55MW (83.22%) under the target.

Table 3-1: Weekday ToU impacts.

	Weekday (MW)						
	<i>Morning Off-peak</i>	<i>Morning Standard</i>	<i>Morning Peak</i>	<i>Midday Standard</i>	<i>Evening Peak</i>	<i>Evening Standard</i>	<i>Evening Off-peak</i>
Target	0	0	0	0	4.50	0	0
Actual	0.27	0.01	-0.72	-0.57	3.70	0.45	0.19
Deviation	-0.27	-0.01	0.72	0.57	1.55	-0.45	-0.19
% Deviation	na	na	na	na	82.22	na	na

Table 3-2: Saturday and Sunday ToU impacts.

	Saturday (MW)					Sunday (MW)
	<i>Morning Off-Peak</i>	<i>Morning Standard</i>	<i>Midday Off-peak</i>	<i>Evening Standard</i>	<i>Evening Off-peak</i>	<i>Sunday Off-peak</i>
Target	0	0	0	0	0	0
Actual	0.19	0.03	-0.55	0.05	0.42	0
Deviation	-0.19	-0.03	0.55	-0.05	-0.42	0
% Deviation	na	na	na	na	na	na

3.3.9 Assumptions and other baseline adjustments

It is critical that all assumptions made regarding operation conditions of the project should be clearly stated during the baseline developing phase. Variables or circumstances that may influence the project performance cannot all be measured or monitored with a DSM project, thus certain assumptions must be made and agreed upon between stakeholders. Where changes may occur, the necessary baseline adjustments for compensating or incorporating these changes should be determined.

3.3.9.1 Assumptions made

Typical assumptions made during irrigation pumping baseline development include:

- The baseline measuring period is representative of the typical project irrigation pumping;
- The average irrigator water profile will not be altered due to this DSM project. Meaning that the typical water usage profile will stay the same whether this DSM project is implemented or not.
- Sample pumps that were measured reflect the whole group's operations; and
- System pumping resistance or system efficiency is not affected by the DSM project.

3.3.9.2 Other required baseline adjustments

Baseline adjustments will be mandatory when:

- Additional project activities outside the given scope of the DSM project are implemented on pumps within this DSM project;
- There is a significant reduction in pumping capacity;

- There are significant changes in the electricity use and demand profile (or typical water usage profile) of the project pumps;
- There are significant changes in the weekend pumping operations indicating that the farmer shifted weekday pumping activities to weekends due to pumping system limitations.
 - When this occurs, the additional energy over weekends need be shifted to the weekdays using a weekend kWh to weekday kWh ratio. However, a thorough investigation first needs be done to evaluate the sudden change in pumping behaviour since this should not be a natural result of the DSM intervention.
- There are changes to the piping layout and in motor sizes.

The following sections consider the other irrigation project types listed in Section 3.2 with the first energy efficiency where an energy driver is available. Specific focus is given on the baseline development process and SLA method.

3.4 ENERGY EFFICIENCY WITH AN ENERGY GOVERNING FACTOR

Section 3.3 discussed the project type load shifting while also explaining the M&V fundamentals. With these provided, Sections 3.4 to 3.7 describe energy efficiency with an energy governing factor, energy efficiency without energy governing factor, combination of load shifting and energy efficiency, load prevention or clipping and a combination of clipping and energy efficiency. However, focus is only placed on the baseline development process and the SLA method developed for each.

From Chapter 2 Section 2.3.2 there are many ways to improve energy efficiency on a farming irrigation system. Such an improvement can be referred to as an ECM, an Energy Savings Measure (ESM) or an Energy Performance Improvement Action (EPIA). The following example considers system efficiency that results in a direct reduction of the operational demand of the electrical pump with the same amount of water pumped. Here the ECMs may include:

- An energy efficient motor;
- Variable Speed Drive (VSD) installed on pump motor replacing choking practices;
- Improved and more efficient pump sets;
- Optimised system pressure; and
- Main line and distribution line optimised design to lessen friction.

3.4.1 Baseline development

The first step in the baseline development is to establish the main energy driver to which energy usages can be related. Of course, with irrigation pumping it would be the amount of water pumped. This energy driver (or energy governing factor as referred to in SANS 50010 and SANS 5015) will be used post-implementation to determine what the energy use 'would have been' if the energy efficiency intervention changes were not implemented. A sufficient baseline measurement time period is required to establish a proper energy use and water shift relationship. Figure 3-15 shows a pump station with a single pump extracting water from a river.

The water is delivered via a mainline to a centre pivot irrigating soya beans. There are two other crop fields with centre pivots but water is delivered from other pumps. This isolates the pump station in being a single extraction point and a single delivery point setup. Taking the example pump station of Figure 3-15, an incoming power meter needs to be installed on the DB or data should be obtained from the utility supply point meter. Since the project focus here is solely on energy efficiency, only daily total kWh values will suffice and thus a profile power meter is not required.

However, a profile power meter provides valuable insights on power use (electrical energy use) and maximum demand. A flow meter needs to be installed before the pump or on the main water pipeline before any branches or tap offs. Section 3.9.2.2 and Chapter 7 Section 7.3.1.3 also elaborates on flow meter installations and cautions that need to be taken. In Figure 3-15 an appropriate position would be just after the pump on the main line. From the flow meter, the total daily water use or profile water use readings are required. An Automatic Meter Reading (AMR) system would be very useful on both the power meter and the flow meter to ensure that daily meter readings are taken on the exact same time, or even to provide profile data that can be recorded. Refer to Chapter 6 Section 6.3 for recommendations on AMR systems and data quality procedures.

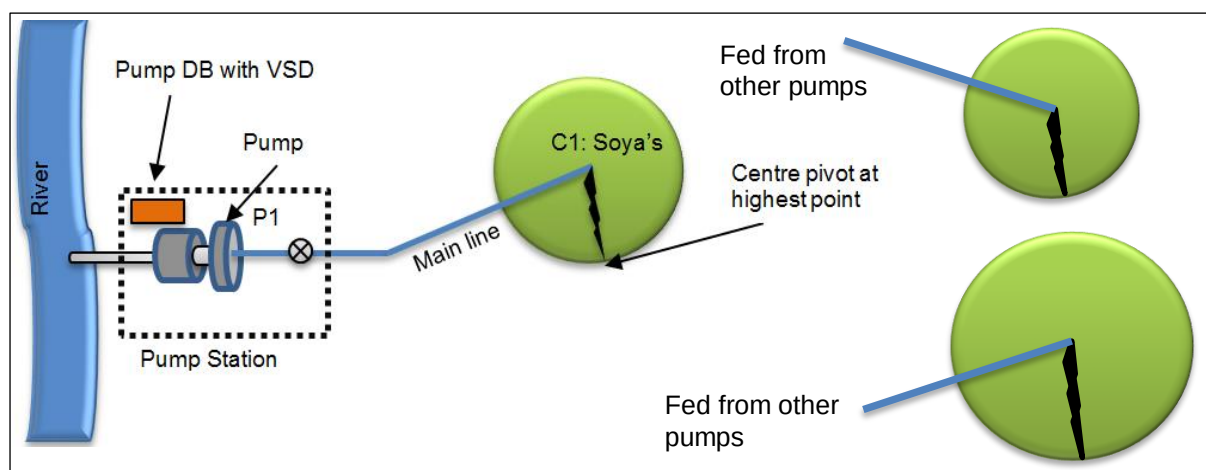


Figure 3-15: Simple farm irrigation setup.

For this example, profile power meter data were obtained from the utility meter but only daily total water meter readings were gathered. Figure 3-16 gives the average weekday, Saturday and Sunday baseline demand profiles with the average reference kWh values. Similar to what was seen in the Section 3.4.1 example, a large weekday load is observed while very little activity is seen over weekends.

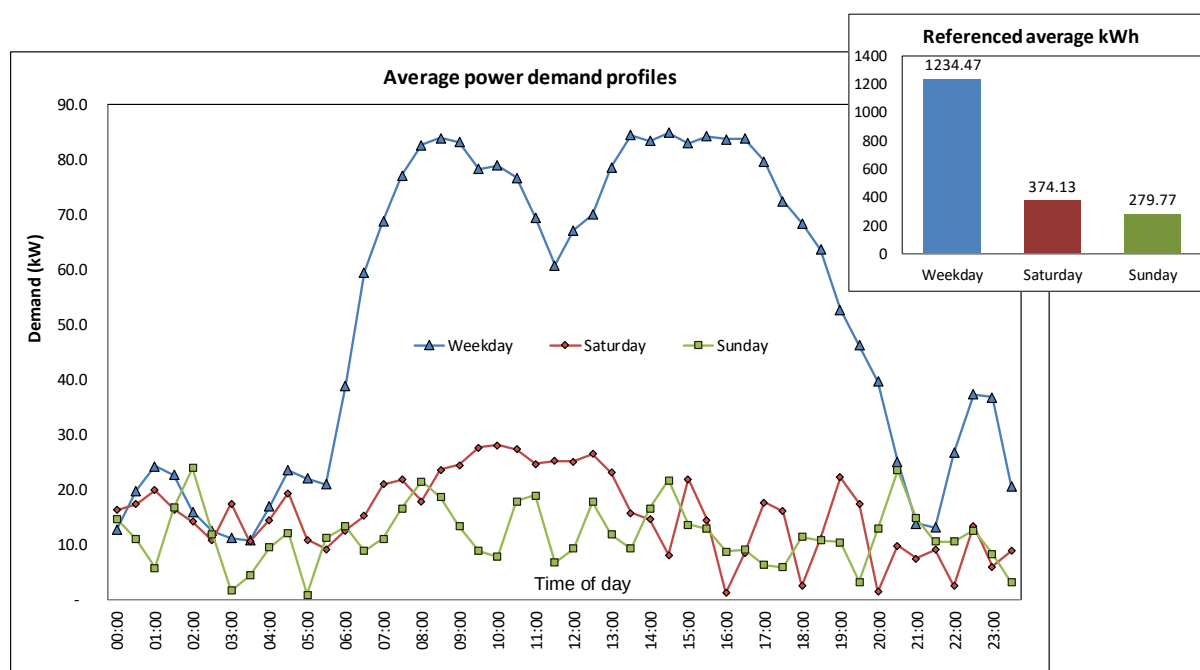


Figure 3-16: Average weekday, Saturday and Sunday baseline profiles with average reference kWh.

Figure 3-17 gives the normalised power and water use values of an example pump station. Here daily total power (electrical energy) use and daily total water pumped values were collected for almost six weeks. Normalisation was done against the period's maximum daily values, both for daily energy use and water pumped. The period proved to be sufficient since it captures all possible pumping variations, conditions and system configurations. Figure 3-17 was normalised so that the energy use and water pumped can be effectively compared on one graph. A repeating relationship between the energy use and water pumped can be seen every day with the lowest activities over weekends.

Figure 3-18 provides a scatter plot comparing the daily energy use to the daily water pumped. Here the relation seen in Figure 3-17 is confirmed and a clear connection can be observed on how the energy use changes according to the amount of water pumped. The R^2 value of 0.97 shows a very good data correlation on the trend line drawn through the data set.

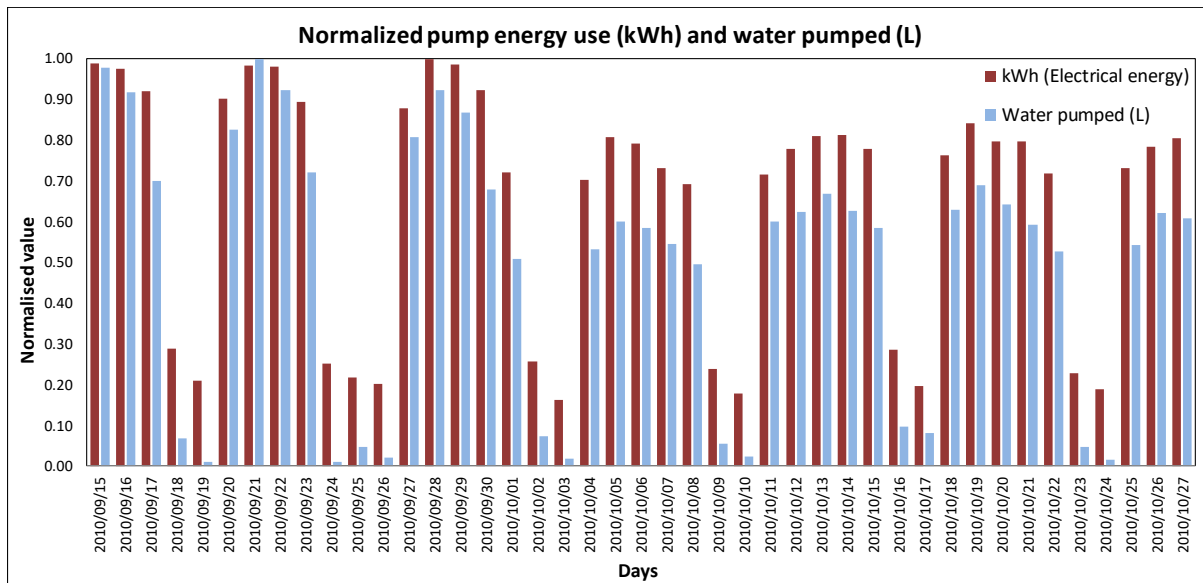


Figure 3-17: Normalised pump energy use and water pumped bar chart.

Two distinct data groupings can be seen at the bottom left of Figure 3-18 and middle to the top right. The bottom left grouping shows energy used while very little to none water was pumped. This may be a result of other loads also measured by the utility power meter (like packinghouse lighting, security lighting, warehouse loads, farming residences etc.) on days when not much water was pumped.

The points closest to the y-axis in Figure 3-18 show around a 300 to 400 kWh baseload, thus, energy was used but no pumping occurred. These loads may also be present on days with a high pumping load but are included in the daily totals and are not visible. If such loads skew the data or prevent that a proper relationship can be established, it might be considered to have a power meter installed on the pump DB to ensure that only pumping operations will be measured.

However, this will require the baseline measuring period to be repeated. A very vital aspect here is to confirm if these other loads are business as usual. Thus, whether these loads persist the same after the intervention. If this is the case, and a proper energy use and water pumped relation could be established even with these loads present as seen in Figure 3-18, the data set is sufficient and can be used for baseline development.

Eq. (3-1) below was derived from Figure 3-18 and will be used for the SLA during the post implementation phase. The symbol W refers to the water pumped daily.

$$\text{Referenced baseline energy consumption}_{(\text{kWh/day})} = 0.0338 \times W_{\text{Litre per day}} + 304.39 \quad \text{Eq. (3-1)}$$

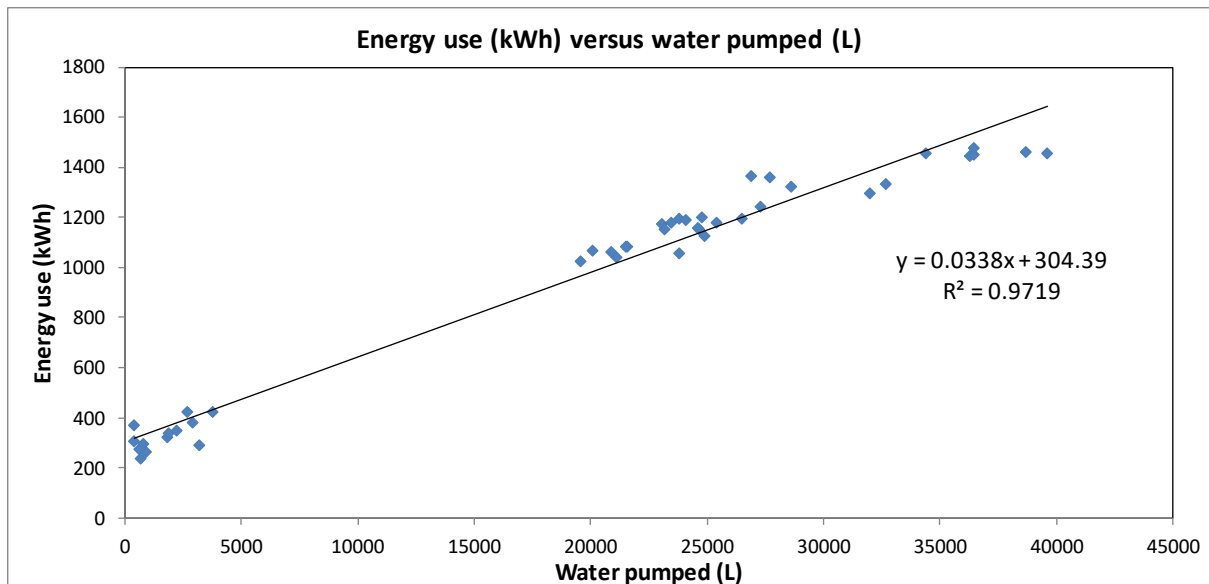


Figure 3-18: Scatter plot of energy use compared with water pumped.

3.4.2 Saving calculations and reporting

After the energy efficiency intervention was implemented during the post-implementation assessment period, Eq. (3-1) can be used to establish the ‘would have been’ energy usage to pump the same amount of water. The following steps need to be taken for determining the baseline power demand profiles after project implementation:

- Step 1:** Retrieve the actual power demand profiles and daily water consumption data from the AMR system;
- Step 2:** Divide the data into weekdays, Saturdays and Sundays;
- Step 3:** Use the scatter plot and Eq. (3-1) to find the ‘would have been’ electrical-kWh;
- Step 4:** Use the SLA_{factor} to scale the baseline profiles up or down as shown in Figure 3-19. The same needs to be done for the Saturday and Sunday baselines.

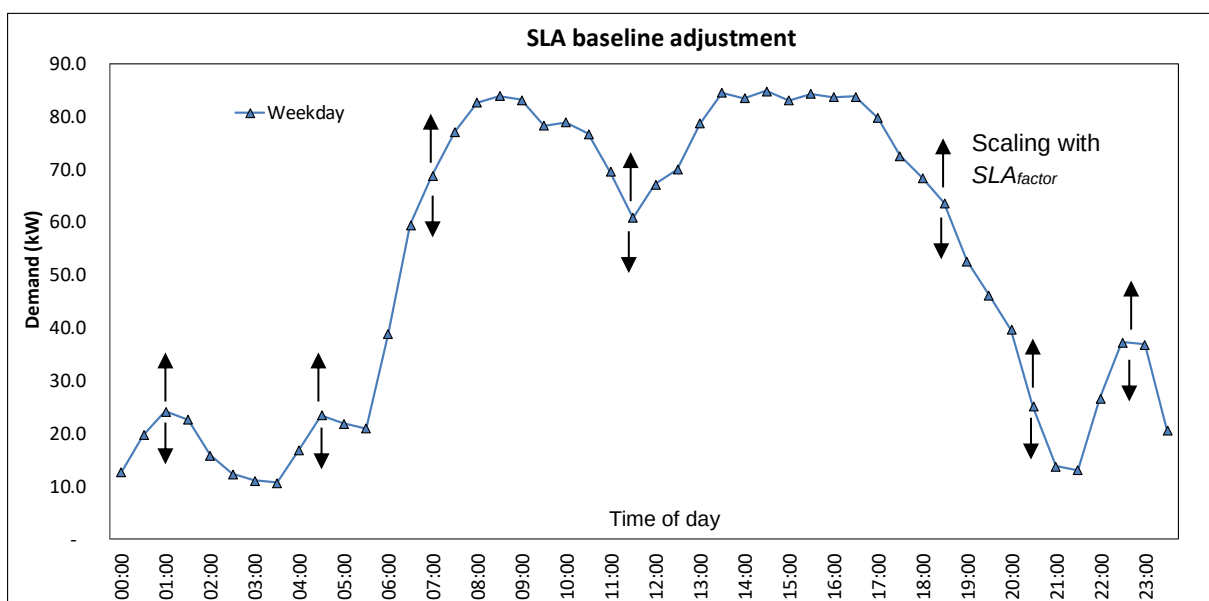


Figure 3-19: Scaling of the baseline profile according the SLA factor.

After the SLA baseline adjustment was performed, the exact same process can be followed as described in Section 3.4.2 to calculate the savings for reporting. Since this is an energy efficiency project, there will be an energy efficiency improvement impact shown over all the ToU periods of Table 3-1 and Table 3-2.

3.5 ENERGY EFFICIENCY WITHOUT AN ENERGY DRIVER

Unfortunately, with many projects a flow meter may not be available or could not be installed for the project. In such a case, intuitive methods are required for baseline development and an SLA to still effectively report on the project energy efficiency impact.

The previous two cases, load shifting and energy efficiency with water as an energy driver, use historical data to develop a baseline profile. This profile is shifted up and down according to the SLA method applied. However, with an energy efficiency project where no energy driver is available, the baseline 'would have been' conditions need to be inferred from the actual post-implementation data. The pre-implementation data is only used to establish operational conditions, operational levels and to determine the energy efficiency demand reduction needed for SLA method.

The following three scenarios are discussed:

- A single pump with a constant load;
- A pump station with multiple pumps having different pumping loads - with only a single incoming power meter; and
- A pump station with multiple pumps having different pumping loads - with a multi-metering setup.

3.5.1 Single pump with constant load

With irrigation systems there are many scenarios where a single pump motor is operated at a relative constant load, like a pump moving water to a dam, a centre pivot on a level field or a crop with micro irrigation. The pre- and post-implementation demand difference as a result of the energy efficiency project intervention needs to be determined.

This can be done by measuring a full pre-intervention pumping cycle and repeating this after the intervention. It is critical that the pre- and post-implementation cycle measurement must be done with the exact same pumping conditions and preferably the same cycle length.

Figure 3-20 shows measurements taken for a full irrigation cycle (six days) before and after the intervention. In this scenario there was no operation on the seventh day of the week and therefore is not displayed. In Figure 3-20 the magnitude of the pre-implementation pumping demand profile is fairly constant although the time of day the water is pumped differs.

This is the same during the post-implementation period although the demand is lower due to the energy efficiency intervention. On the left of Figure 3-20 the grey areas indicate the fairly constant load before and after implementation. This constant load persists for each of the days shown on the rest of the graph. The lined areas between the graphs indicate the energy efficiency impact in Figure 3-20.

The average demand difference can be established by comparing the pre- and post-implementation daily demand profile magnitude (while the pump is running). From the magnitude of the average difference, an SLA ratio factor can be determined. See Day 3 in Figure 3-20 for an illustration. The SLA factor is given by Eq. (3-2):

$$SLA_{Factor} = \frac{After\ Demand\ Average}{Before\ Demand\ Average} = \frac{11.3}{22.8} = 0.496 \quad \text{Eq. (3-2)}$$

For impact calculations after project implementation, the baseline can be inferred by applying the SLA ratio to the actual (on a daily basis) to each 30-minute interval when the pump is running. In this case it can be done on every 30-minute interval, since when the pump is not running, the demand profile will be zero.

However, if other non-pumping loads are also captured by the power meter, the adjustment should only be done when the pump is running. Also, the pre- and post-implementation demand measurements should reflect the same non-pumping load.

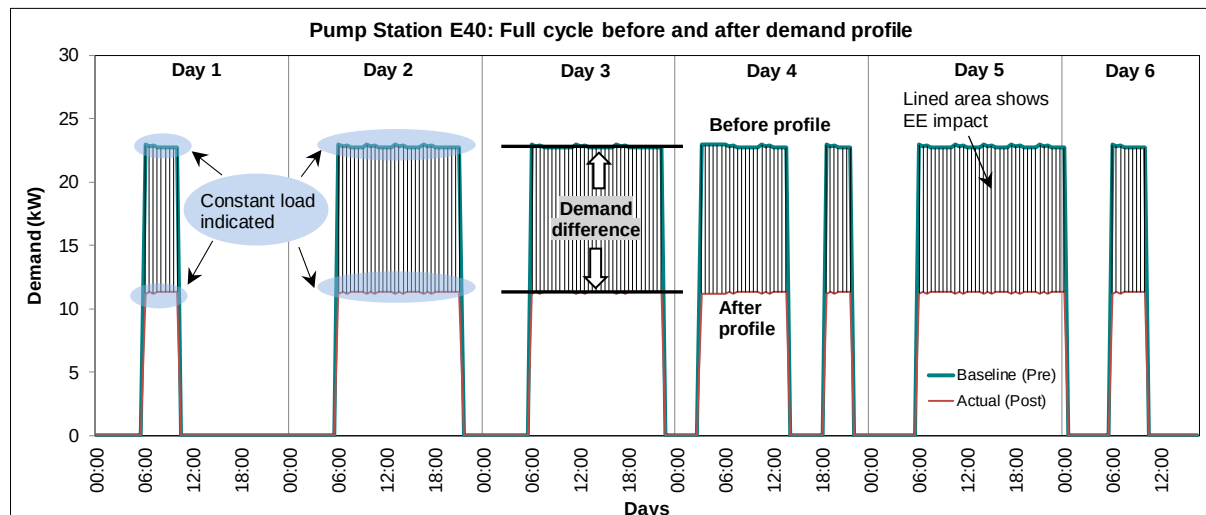


Figure 3-20: Single pump with constant load before and after intervention demand profiles.

3.5.2 Pump station with multiple pumps having different pumping loads - only single incoming power meter

When a pump station consists of multiple pumps with different pumping loads, the baseline determination and SLA method becomes much more complex. There may be a large variety of pumping demand profiles over the measuring period. Referring back to Figure 3-2 in Section 3.3, a typical pump station is shown with several pumps and many different crop fields irrigated. With this type of irrigation layout, the power meter measuring the entire pump station can have many different demand profiles.

With Eskom irrigation DSM projects, it was often found that only a single main incomer ToU power meter or utility meter is available. In many cases, there is no power meter or only a disc type kWh meter present. Therefore, power meters need to be installed and baseline data gathered. However, as experienced with many Eskom irrigation DSM projects sites, only an incomer power meter could be installed on the pump station due to budget restrictions. In addition, due to the time frame of the DSM project implementation, there was limited time available to gather baseline data. Situations such as these regularly occur and an M&V practitioner should make the best of the data and time period measured.

Keeping this in mind, it is critical that the following requirements are met for proper project impact quantification:

- The measurement period should show each different pumping scenario for each individual pump in the pump station - with a load profile of full pump cycle for each pumping scenario; and
- The measurement period should show each possible combination of pump operations together - with load profiles of full pump cycles for each pump combination scenario.

3.5.2.1 Establishing operational levels

In this example, utility power meter data for a week was gathered wherein all pumping scenarios were captured. Figure 3-21 provides the pump station daily total demand profile with all pumping scenarios and combined operations over a week. During each day the demand profile varies as different pumps are operated alone or simultaneously irrigating different crop fields. In Figure 3-22 the seven days of Figure 3-21 are put onto one graph so that the daily profiles can be compared. The grey areas indicate the six different combinations of pumping operational levels observed.

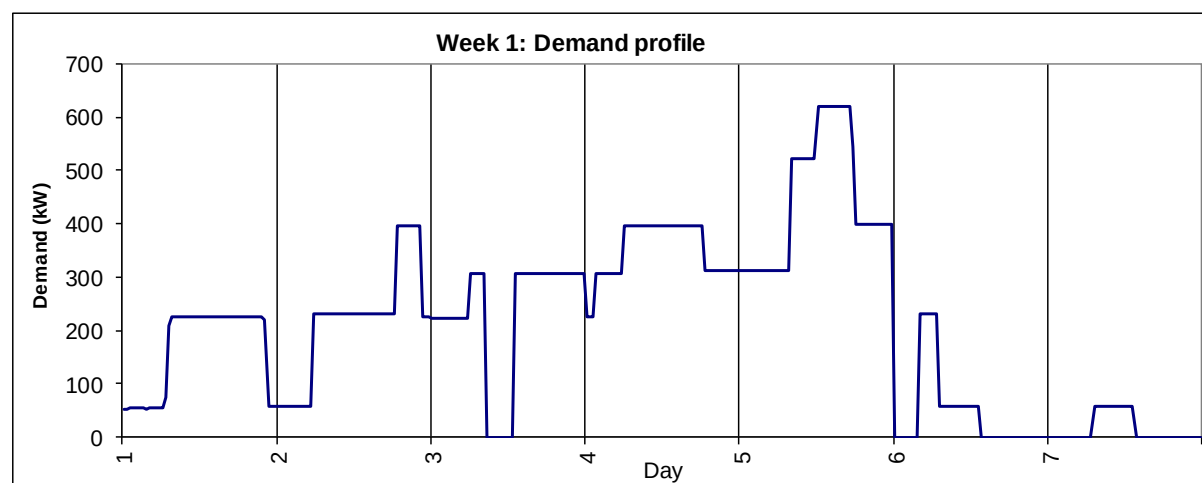


Figure 3-21: Week pumping demand profile of incoming meter on combined pumping operations.

3.5.2.2 Determining EE impact on every operational level

Having this, the demand reduction achieved on each of the six different pumping operational levels needs to be determined. Since there are different pumps, and different water distribution and irrigations setups, the efficiency intervention may not be the same on all setups and the impact may differ between each. The demand reduction can be determined by repeating each of the pumping operational levels after the project intervention was completed. From the pre- and post-implementation demand profiles the efficiency impact of each pumping operational level can thus be determined.

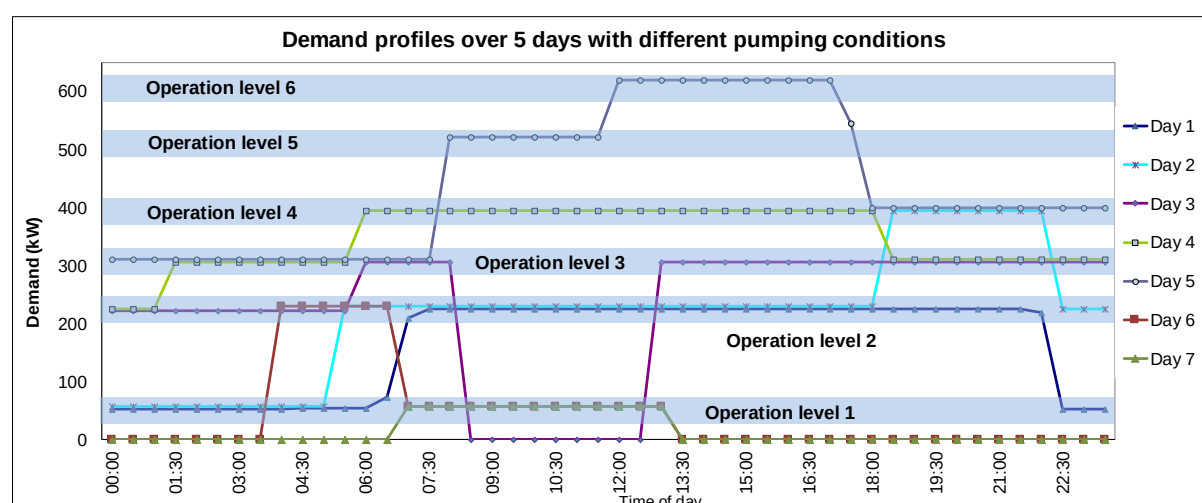


Figure 3-22: Daily pumping demand profile of incoming meter on combined pumping operations.

Figure 3-23 compares the baseline week operations to the post-implementation period by exactly repeating the irrigation cycle. Thus, the same pumps were operational over precisely the same time

periods as during the baseline week. The lined area between the profiles shows the demand reduction and achieved efficiency impact. Similar to Section 3.5.1., the demand reduction and SLA for each operational level can be determined.

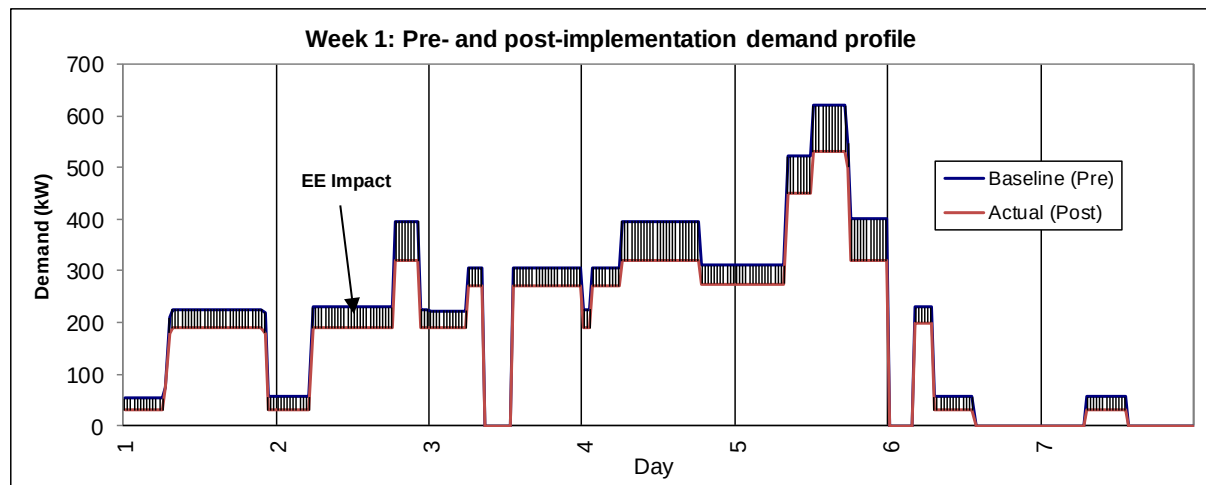


Figure 3-23: Seven day pre- and post-implementation pumping demand profiles.

3.5.2.3 SLA on operational levels

With the demand reduction determined for each operational level, an SLA factor can be determined for each Operational Level (OL). The same approach can be followed as with the single pump discussed in Section 3.5.1.

- $OL1 \rightarrow SLA_{Factor1}$
- $OL2 \rightarrow SLA_{Factor2}$
- $OL3 \rightarrow SLA_{Factor3}$
- $OL4 \rightarrow SLA_{Factor4}$
- $OL5 \rightarrow SLA_{Factor5}$
- $OL6 \rightarrow SLA_{Factor6}$

With the SLA factors established, the same process as described in Section 3.5.1. can be used during the assessment period to infer the baseline on each operational level. From here the baseline and actual profiles can be compared in order to calculate the savings.

3.5.2.4 Operational level variations and boundaries

As a new example, Figure 3-24 and Figure 3-25 give pre- and post-implementation demand profiles of two other irrigation pump stations where energy efficiency interventions were also implemented. In Figure 3-24 distinct operation levels can be identified from the pre-implementation demand profile over a week measuring period for the first pump station. Except for a short variation in the beginning of the one operation level, the demand profile of the different operational levels is quite level.

Figure 3-25 shows the second pump station where more significant variations can be observed during an operational cycle. Below the demand profiles in Figure 3-25, two close-up views are provided of these variations. The variation in the left close-up is due to a centre pivot irrigating an uneven field. Here a VSD torque control is performed to ensure the same amount of water is distributed when the pivot moves over parts of the crop field with higher and lower elevation. The variation in the close-up on the right is due to water valves moved to irrigate another field.

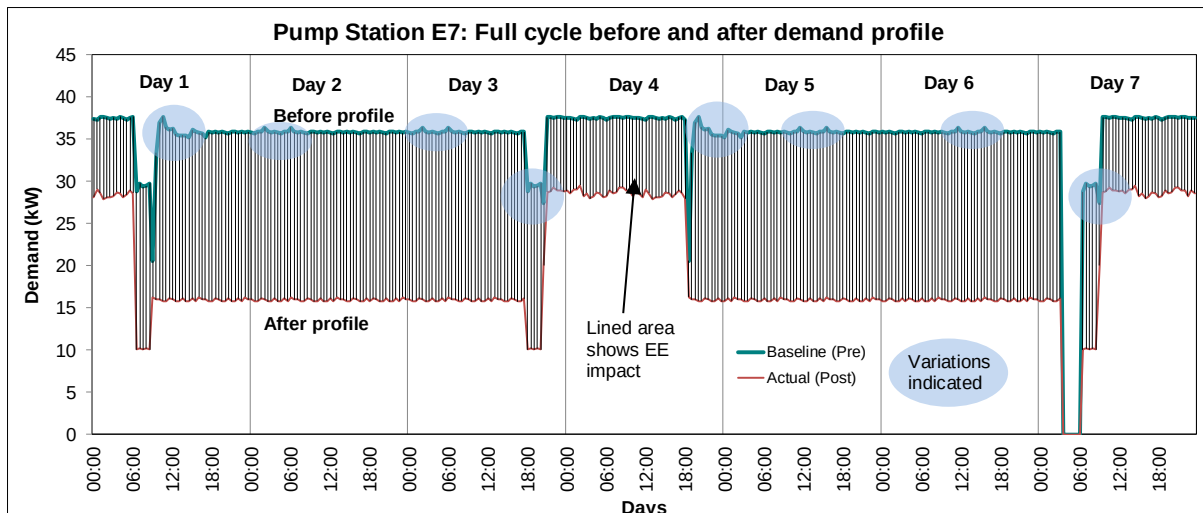


Figure 3-24: Week pre- and post-implementation pumping demand profiles.

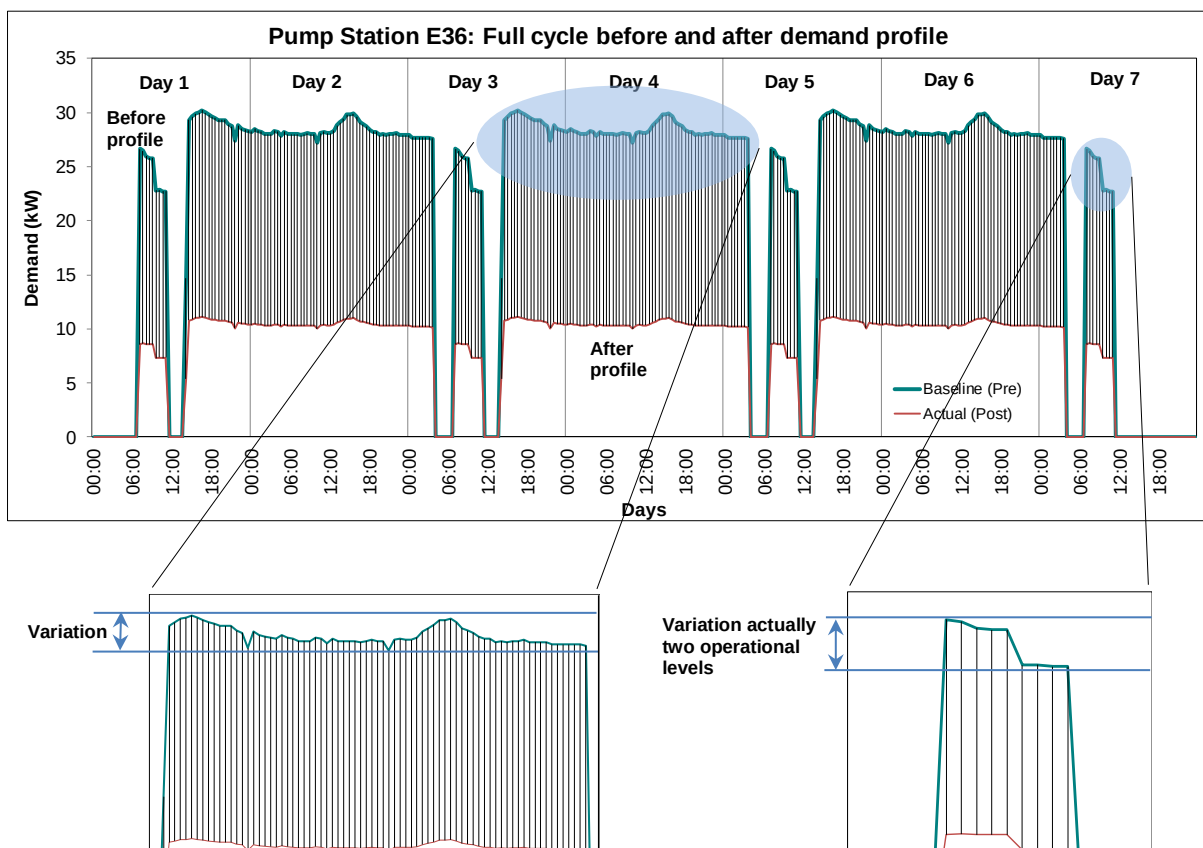


Figure 3-25: Variations on operational level.

Both the variations shown in Figure 3-24 and Figure 3-25 should be closely investigated. Variations can be problematic for an SLA method if these get close to other operation levels (as in the previous section). Clear and distinct operation boundaries should be established for each operation level that does not overlap or are too close to that of another operational level.

Figure 3-26 shows boundaries for three different operational levels identified. Operational Level 3 near the top of Figure 3-26 has a wide margin due to the demand profile variation. Level 2 has a much smaller margin than Level 3, with Level 1 having an even smaller margin.

The safety perimeter between Level 3 and Level 2 is almost too small and slight changes on the pump operation can result in the boundaries overlapping. Narrow safety parameters should be avoided as far possible since it can result in the wrong SLA factor being used for the operational level. Cross checks would be required here to ensure correct saving reporting.

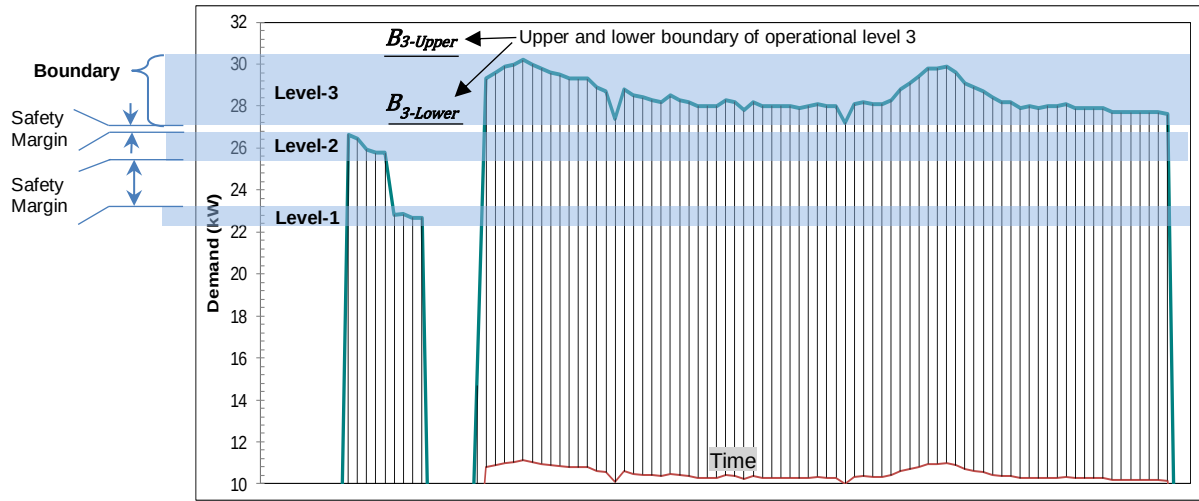


Figure 3-26: Boundary for each operation level of Figure 3-25.

The operational level SLA factors can be determined and then expanded to include the operational level boundary as shown in Figure 3-26:

- $OL1 \rightarrow SLA_{Factor1}$ with boundary $B_{1-Lower}$ and $B_{1-Upper}$;
- $OL2 \rightarrow SLA_{Factor2}$ with boundary $B_{2-Lower}$ and $B_{2-Upper}$; and
- $OL3 \rightarrow SLA_{Factor3}$ with boundary $B_{3-Lower}$ and $B_{3-Upper}$.

3.5.2.5 Saving calculations

With the SLA factors established and the boundaries defined, the post-implementation assessment saving calculations can be done by following these steps:

- Step 1:** The actual profile needs to be analysed to establish the pumping operational level of the complete assessment period;
- Step 2:** From the operational level analysis, the correct SLA ratio must be chosen;
- Step 3:** Ensure that the operational level stays within the upper and lower boundary limits. Any outside-of-boundary conditions need to be examined;
- Step 4:** From the actual profile and the SLA ratios, the baseline can be generated by multiplying each 30-minute point with the correct SLA factor; and
- Step 5:** Compare the baseline and actual demand profiles to calculate savings.

Mathematically, the energy efficiency saving achieved, for any such irrigation setup, can be calculated by applying the formula shown in Eq. (3-3).

This ensures that an average of the variation is not used, but allows that a function can be established (linear or polynomial) which best fits the operation profile of the operational level. Eq. (3-4), Eq. (3-5) and Eq. (3-6) provide formulas for each of the variables in Eq. (3-3).

$$Period\ Total\ EE_{Impact} = OL1\ EE_{Impact} + OL2\ EE_{Impact} + \dots + OL_N\ EE_{Impact} \quad Eq. (3-3)$$

With

$$OL1 EE_{Impact} = \sum_0^k \int_S^E ((SLA_{Factor1} \times f(x1_k) - f(x1_k))dx \quad \text{Eq. (3-4)}$$

$$OL2 EE_{Impact} = \sum_0^k \int_S^E ((SLA_{Factor1} \times f(x2_k) - f(x2_k))dx \quad \text{Eq. (3-5)}$$

:

$$OLN EE_{Impact} = \sum_0^k \int_S^E ((SLA_{FactorN} \times f(xN_k) - f(xN_k))dx \quad \text{Eq. (3-6)}$$

Where

k – Pumping events

S – Pump event Start time

E – Pump event End time

N – Operation level number

3.5.3 Pump station with multiple pumps having different pumping loads - multiple metering setup

The scenario required an approach consisting of multiple metering points and possibly an intelligent multiple meter setup. Instead of relying on operational level conditions and boundary limits that may be problematic, each pump is separately monitored in this scenario. With this, additional condition sensors can be applied to indicate another pumping condition, which further produces accuracy and data reliability. There are two drawbacks to this approach though:

- There will not be historical data available with such detail; and
- An intelligent multiple meter setup can be complex and expensive.

Chapter 6 Section 6.4 provides a design and option for an intelligent multi-meter approach. In essence it establishes a metering setup that can capture and identify all different pumping scenarios and combinations. Here variation and changes in the pump's operational level will not lead to SLA factor conflicts like in the previous section.

Conventionally, these advanced metering solutions are very expensive; however, Chapter 6 Section 6.3 and 6.4 provide intuitive design to provide a cost-effective solution for M&V purposes. Details are provided on how these can be applied to a complex pump station setup and the handling of data. The different metering points replace the SLA operational levels in Section 3.5.2.3.

However, the rest of the methods in Sections 3.5.2.3. to 3.5.2.5 can be applied here to perform impact calculations. Instead of having one single incoming meter, the data and calculated impacts from the different metering points will be used to establish the total pre- and post-profiles with impacts. The incoming meter can still be used to cross verify the data and information from the sub metering points and sensors used to quantify savings.

3.6 COMBINATION OF LOAD SHIFTING AND ENERGY EFFICIENCY

With pure load shifting projects, a strait forward energy neutral baseline as explained in Section 3.3.7 is used. In the case where a DSM project involves energy efficiency, a baseline developed and SLA method as described in Section 3.4.2 are used. However, when the DSM project focusses on both load shifting and energy efficiency, the baseline development and SLA method becomes more complex.

Figure 3-27 provides an example of a project where both load shifting and energy efficiency were implemented. The original average weekday baseline is shown with the post-implementation average weekday actual profile. The original baseline was developed from an appropriate time period. After the project intervention, the first assessment period's data was retrieved and an average weekday actual profile constructed as seen in Figure 3-27. From Figure 3-27 the following can be observed:

- The evening peak load reduction was achieved. Although not visible on the graph, the evening peak period water pumping was shifted to the rest of the day;
- On top of this, energy efficiency reduced the overall demand profile over the whole day; and
- The energy efficiency intervention also had to overcome the evening peak load shifted to the rest of the day to show a reduction.

Two scenarios are discussed next; a site with a flow meter and a site without a flow meter.

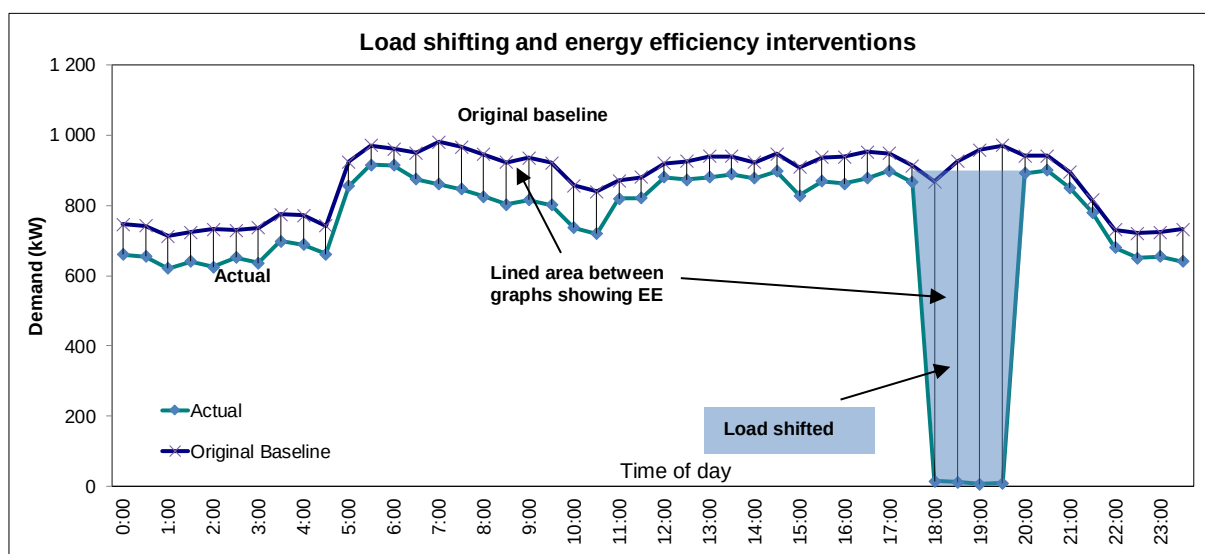


Figure 3-27: Baseline and weekday average post implementation demand profile.

3.6.1 Site with a flow meter

If the project site has an existing flow meter or a flow meter could be installed for the DSM project, a similar SLA and saving determination method described in Section 3.3.9 can be used. A water pumped and energy used relation can be established during the baseline period and applied to adjust the baseline in the post-implementation period.

3.6.2 Site without a flow meter

When there is no flow meter or quantity of water pumped data available, there is no energy driver that can be used for the SLA. It is important to notice again the two last bullet points mentioned in the beginning Section 3.6. Energy efficiency reduced the overall demand profile and also overcame the evening peak load shifted to the rest of the day. Thus, the difference between the original baseline and the post-implementation actual profile in Figure 3-27, shows only a part of the energy efficiency achieved.

A similar method used in Section 3.5.2. for pump stations with multiple pumps having different pumping loads and only a single incoming power meter, can be applied. If a multiple power meter setup is viable, the approach in Section 3.5.3. can be applied.

3.7 PEAK LOAD PREVENTION OR CLIPPING

With load shifting projects the usage that would have occurred during the peak period is shifted to the rest of the day. However, with load prevention (clipping) projects the load reduced during the peak period is not recovered at a later stage. During the time the clipping occurs, a demand reduction and kWh energy saving are achieved. Depending on the focus of the project, the stakeholders might be interested in reporting on the demand and energy use reduction.

3.7.1 Only reporting on peak load reduced

With load clipping the operations do not change and the pump is simply switched off during the peak period. Water not pumped during that period will not be recovered at a later stage. Although such irrigation projects are rare, these do sometimes occur. It is a good indication though that pumping operations are not optimum, and electricity and water is wasted.

With certain Eskom irrigation 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. In the past these farmers pumped over the morning and evening peak. Although the DSM project was only aimed at reducing the evening peak, the farmers decided on their own to also perform morning peak switching. Considering this, Section 3.7.1.1 discusses the baseline and performance assessment profiles while Section 3.7.1.2 provides an SLA alteration.

3.7.1.1 Baseline and performance assessment profiles

Figure 3-28 shows the project baseline profile, a 24-hour energy neutral SLA baseline profile and actual post-implementation assessment period profile of the project. The original baseline profile represents a typical irrigation profile with higher day pumping demand.

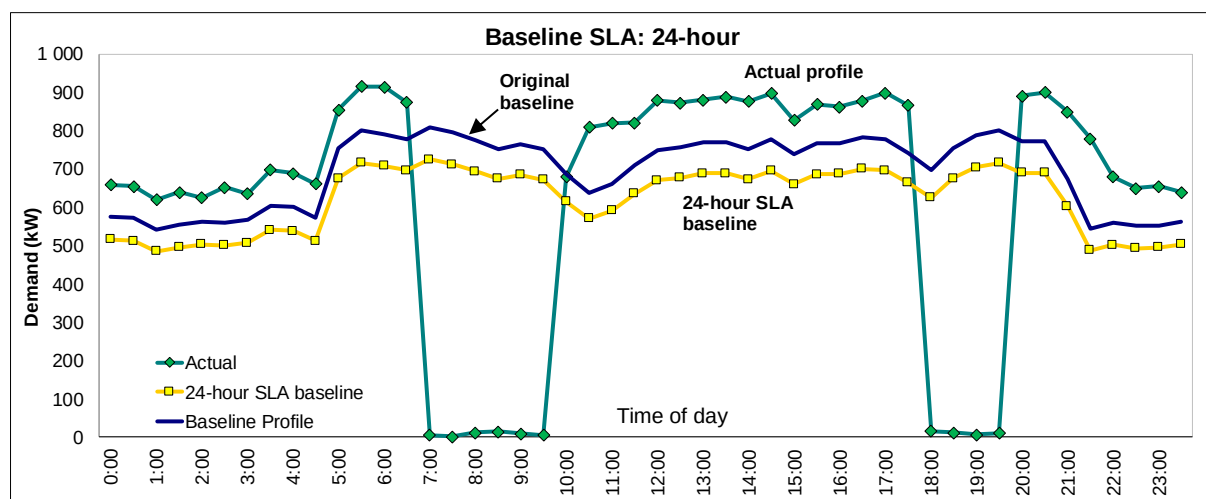


Figure 3-28: Average weekday developed baseline, actual, 24-hour SLA baseline and the new operational-hour SLA baseline.

The SLA baseline was drastically reduced and did not capture the actual DSM evening switching that occurred. The culprit here was morning additional peak switching that also occurred. The farmers took advantage of Ruraflex and stopped their irrigation practices during the morning peak. Here it is important to note that morning pumping load was here not intended to be moved to another part of the day, or to the weekend, but not to be recovered at all.

However, when examining Figure 3-28, the actual profile does run considerably higher than the original baseline profile. Thus, it seems that the morning load was not clipped but shifted to the rest of the day. If the load was shifted, it is not a clipping project. However, further investigation revealed that the actual profile was from months during the high pumping demand season which explains the higher profile.

3.7.1.2 The SLA alteration

An SLA alteration that would not be affected by the additional morning peak switching was needed here. 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. The baseline setting was, therefore, made equal to the actual setting.

The SLA excluded the morning peak period and the baseline was energy-neutral from 00:00–6:00 and 10:00–24:00. Figure 3-29 shows the new SLA baseline with the original baseline and the performance assessment actual profile. The altered SLA baseline is shown to be higher and more accurately quantified the DSM evening peak impact. Here a special energy neutral SLA excluding the morning peak hours was used. A similar approach can be followed for a load clipping project that only reports on peak demand reduction.

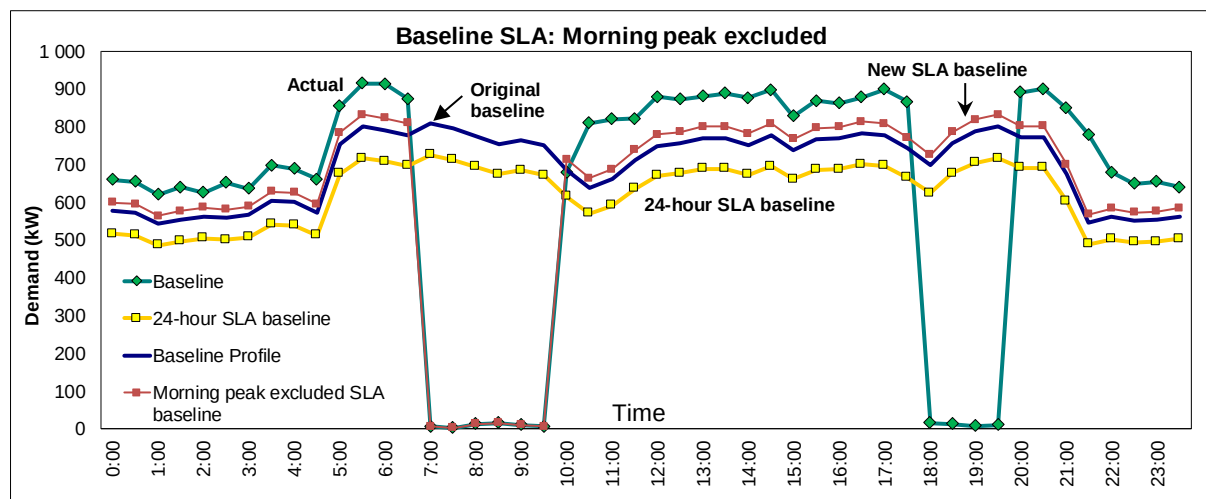


Figure 3-29: Original baseline, 24-hour neutral SLA baseline and new morning peak excluded SLA baseline and actual profile.

3.7.2 Reporting on load reduced and energy efficiency

At the later stages of the Eskom DSM programme, emphasis was also placed on energy efficiency, and reporting on this became relevant. In this case, the 'would have been' demand profile over the peak periods (clipped after implementation) also needs to be scaled and not excluded as in Section 3.7.2.

An outside peak period (00:00-07:00, 10:00-18:00 and 20:00-24:00) energy neutral baseline is required here. Figure 3-30 shows the adjustment of the baseline profile according to this SLA method. The lined areas between the graphs show the energy efficiency impact due to the clipping.

Here it is critical though to confirm that the water not pumped during the clipping periods is not recovered at a later stage. It may also be necessitated to establish a cross verification method to ensure that this does not occur later in the project. As mentioned in Section 3.7.2, operations that can allow clipping is running inefficient, and electricity and water is wasted.

If there is an existing flow meter, the before and after clipping intervention water use can be monitored or an additional cross verification SLA method like in Section 3.4.2 can be followed. Otherwise,

comparing the daily total kWh consumption of the post-implementation period to that of the baseline period can also provide an indication. In this scenario though, the water not pumped during the morning peak was not recovered later, thus resulting in load clipping.

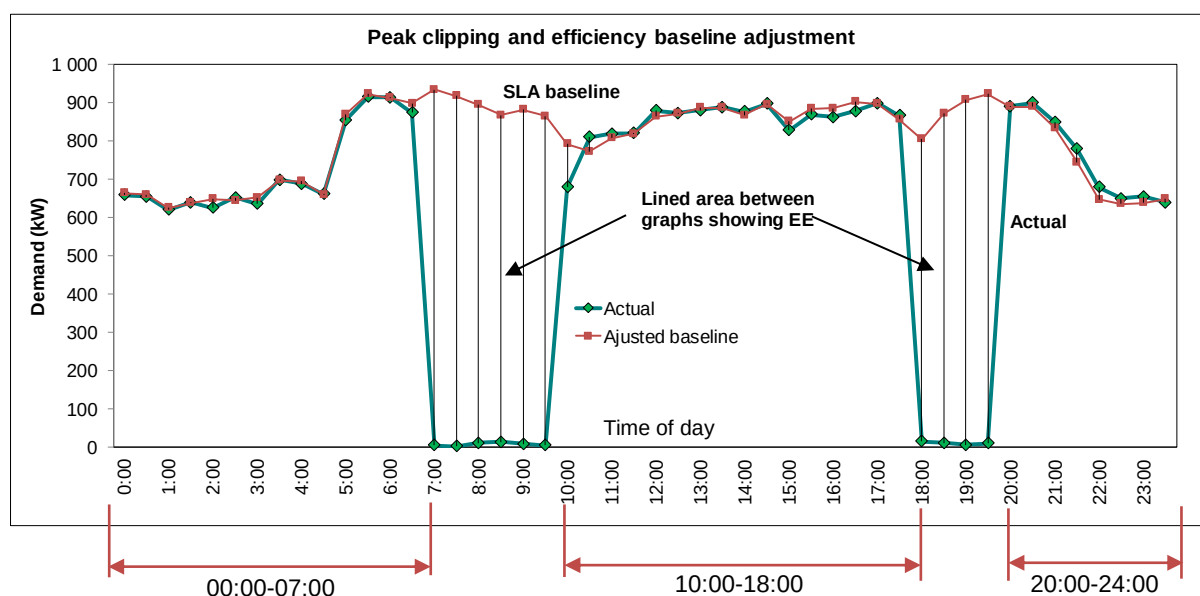


Figure 3-30: SLA baseline for clipping and energy efficiency.

3.8 SERVICE LEVEL ADJUSTMENT ANOMALIES AND BASELINE CHALLENGES

With several Eskom irrigation DSM projects, the post-implementation assessments revealed unexpected results. Although the 24-hour SLA method (described in Section 3.3) is in general a very good method, certain anomalies observed rendered it ineffective. The following section describes several of the anomalies found and gives intuitive SLA alternatives developed to determine the impact of these projects.

3.8.1 Night load reduction

It was observed that the planned evening peak DSM targets were not met during the Performance Assessment (PA) period of a specific irrigation DSM project. The project consisted of more than 100 pumps distributed over irrigation farms in an irrigation district. Automated switchgear was installed to shift the evening peak pumping load to the rest of the day. The project underperformed at an average of 50% despite the required DSM switching occurring as planned. This underperformance was investigated and all the possible causes evaluated.

3.8.1.1 Baseline and performance assessment profiles

Figure 3-31 shows a graph comparing the DSM project developed average weekday baseline profile with the actual average weekday profiles of the PA months. From the left of Figure 3-31, the baseline profile is the top bold line, while the performance assessment profiles are the thinner lines. During the morning hours from 00:00–06:00, 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 (20:00–00:00) after the Eskom evening peak.

From 07:30 in the morning and onwards the pumping load increased drastically as the farmers started to irrigate crops. Between 18:00 and 20:00 the pumps were switched off again automatically for the evening peak period.

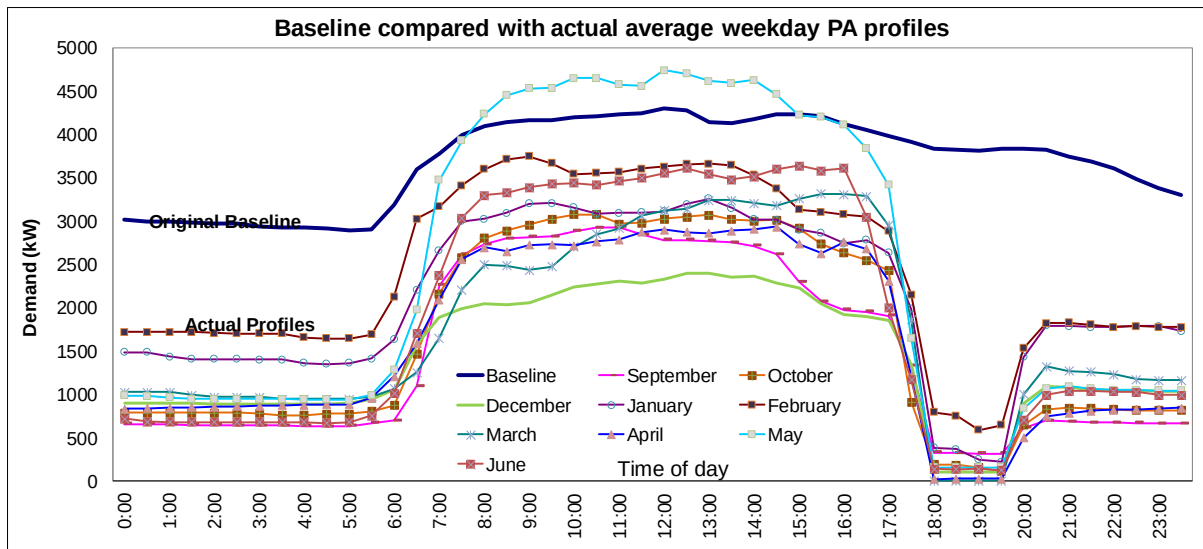


Figure 3-31: Average weekday baseline compared with actual average weekday PA profiles.

3.8.1.2 Effects of pumping load reduction on DSM project impacts

Figure 3-32 shows the original baseline (thick dark line on top), the 24-hour neutral SLA baseline (lighter line in the middle - same shape) and the actual profile of one assessment month (June). The June actual profiles suggest that the evening peak switching made a large evening DSM impact. However, Figure 3-32 shows that the 24-hour energy neutral SLA adjustment method severely lowered the SLA baseline profile from the original baseline profile.

This significantly reduced the available DSM evening peak impact, despite evidence of large switching from the switch-off drop in the actual profile. The severe downward adjustment was due to the much lower early morning and night pumping load as can be seen in Figure 3-32. An investigation on this anomaly was launched.

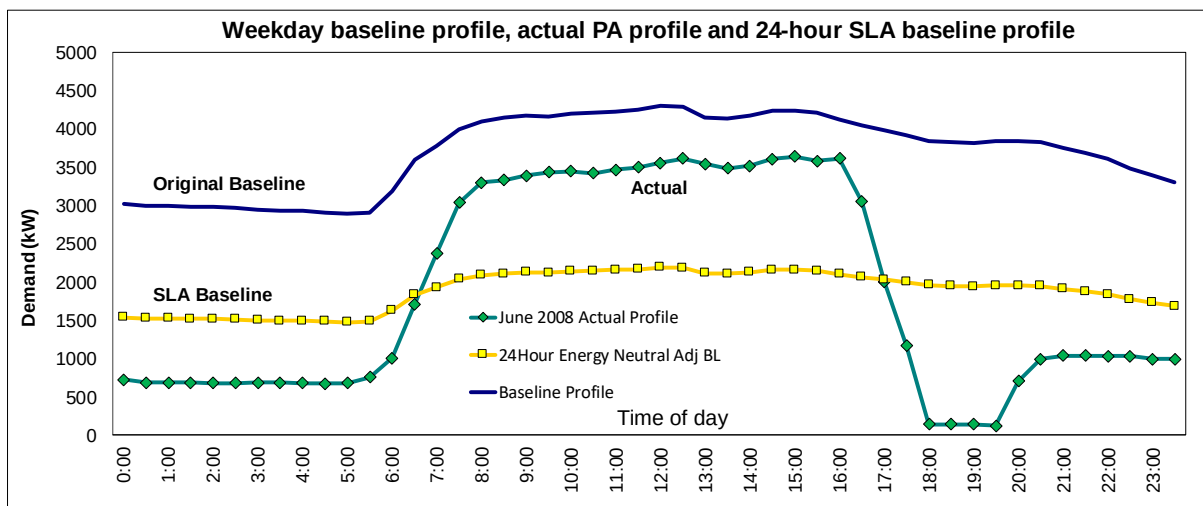


Figure 3-32: Average weekday baseline profile, actual PA profile and 24-hour SLA baseline profile.

3.8.1.3 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. These water meters were then utilised by the regions' Irrigation Board to track 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 3-32. Afterwards, during the PA period, the farmers had to comply with the water allocations and therefore altered pumping practices to only occur during the day time.

3.8.1.4 Operational hour 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 3-33 shows that between 08:30 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 can, therefore, be used as the kWh neutral time period.

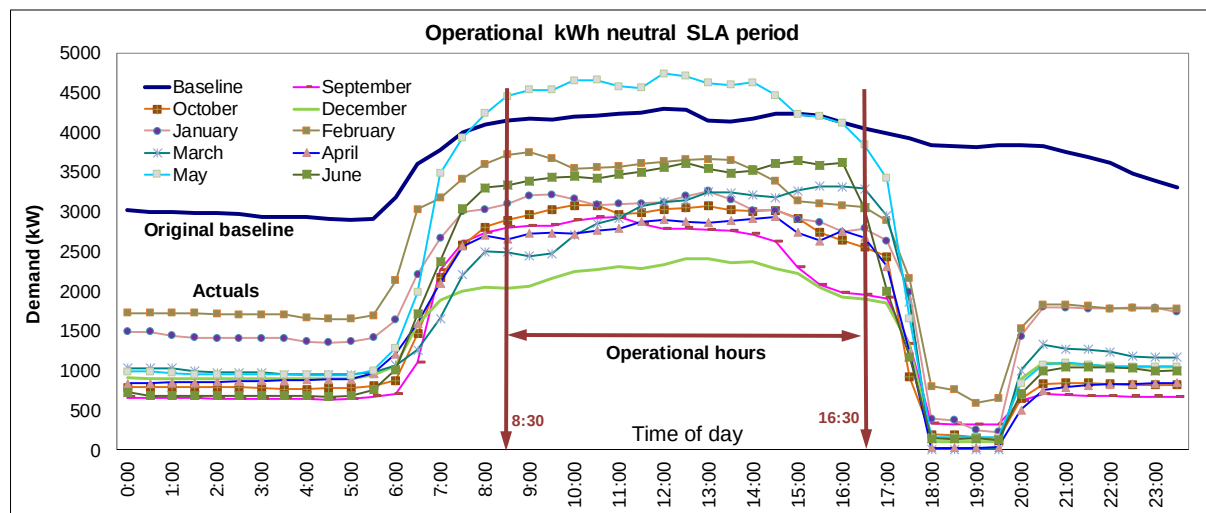


Figure 3-33: Operational kWh neutral SLA period.

The SLA factor calculation procedure of Section 3.3 is altered as given by Eq. (3-7).

$$SLA_{Factor} = \frac{kWh_{ActOperational}}{kWh_{BLOperational}} \quad \text{Eq. (3-7)}$$

The kWh of the actual PA profile was divided by the kWh of the baseline profile between 08:30 and 16:30 to obtain the operational-hour SLA factor. The SLA factor was, finally, applied over the 24-hour baseline profile by multiplying with each 30-minute baseline profile point. The new service level-adjusted baseline was consequently achieved.

Figure 3-34 shows the original baseline profile, the June actual PA profile, the old 24-hour SLA baseline, and the new operational-hour SLA baseline. The new SLA baseline does not undergo the drastic 24-hour SLA downward adjustment but is significantly higher. Thus, a much larger DSM impact is quantified. This new operational-hour SLA method more accurately portrays the DSM switching impacts and is not influenced by the morning and evening load reduction.

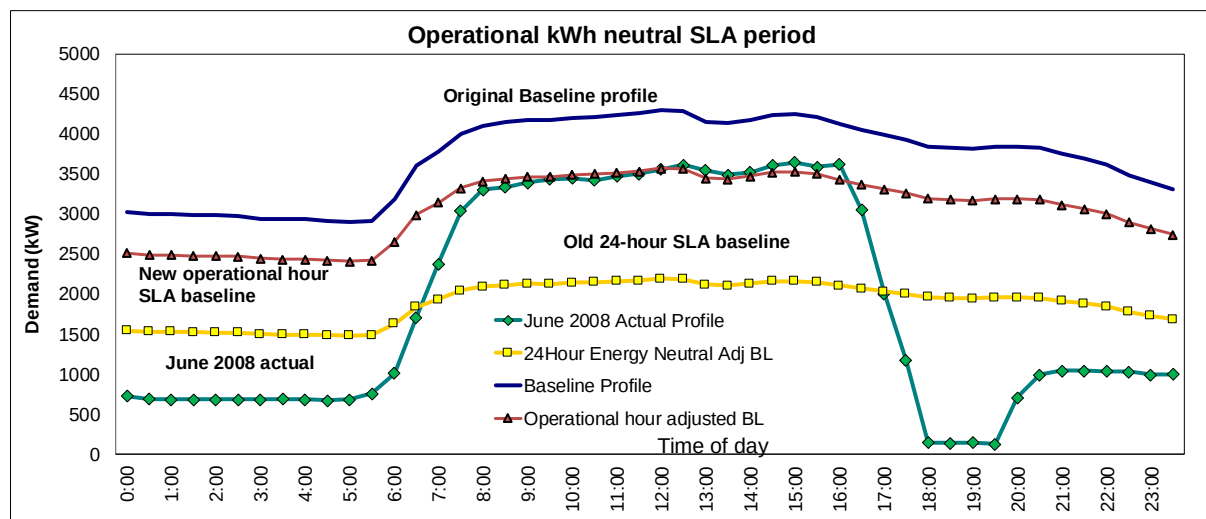


Figure 3-34: Original weekday baseline, June Actual, 24-hour SLA baseline and the new operational-hour SLA baseline.

3.8.2 Other SLA anomalies

With irrigation DSM M&V projects several other SLA anomalies and baseline challenges were also experienced. The following sections describe these and discuss the actions that were taken to ensure that M&V could still be effectively performed.

3.8.2.1 Weekend loads increased

During the post-implementation period of a certain DSM project, it was observed that the weekend pumping load unexpectedly increased. This was a result of:

- **1) DSM pumping schedules** - During the high pumping seasons the daily water demand is too high and the farmer could not always keep to the evening peak switch-off pumping schedules. In addition to the DSM target not always being met, the farmers also increased weekend irrigation to make up for the weekday evening peak pumping lost during the week.
- **2) 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 irrigation activities from weekdays to weekends.
 - o In both situation 1) and 2) some of the load is moved to weekends and the weekday load would have, hypothetically, been even higher. Thus, a higher evening peak switching impact could have been achieved than that which was reported on. In these cases, an alternative SLA method was introduced which determines the amount of energy use that was moved to the weekend and adjusts the weekday demand profile accordingly.

3.8.2.2 Energy efficiency interventions with the evening peak switching DSM project

During the scoping phase of an irrigation DSM project, it was observed that an energy efficiency intervention project was also implemented with the evening peak switching project. This entailed improving the pipeline efficiency. The lower operational demand, due to the energy efficiency intervention, caused a lower evening peak switch-off load. Thus, the energy neutral SLA showed a lower attained evening peak DSM impact.

- Due to the implementation stage of the project, project conditions, M&V budget limitations and availability, the techniques described in Section 3.6 could not be introduced. An alternative SLA method was developed that also incorporates the efficiency demand reduction. This avoids a negative effect on the evening peak DSM impact. This was done by analysing the pre- and post-pumping operations to exactly establish the demand difference the energy efficiency intervention created. This demand difference was incorporated in the SLA to adjust the baseline to the proper 'would have been' conditions.

3.8.3 Baseline challenges

During the baseline development period, several challenges were experienced with irrigation DSM projects which 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** - An intuitive study of hundreds of pumps included in different irrigation DSM projects was performed to evaluate the typical available evening peak switching load compared with pump motor installed capacities. The reason behind this was that project implementers do not always perform effective project viability assessment metering beforehand. In these cases, the pump motor installed capacities were used to establish a project evening peak demand reduction target.
 - The study concluded that only 15–30% of the installed capacity relates to an average annual operational load that is available for evening peak switching. With certain outliers, a 40% available value was observed. The study 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. Chapter 6 Section 6.2 elaborates on this.

3.9 ANALYSIS OF PROPOSED IRRIGATION DSM PROJECTS

This section investigates an example of the typical information provided by an ESCO to the stakeholders when a new irrigation project is proposed. In light of the project level M&V content already given in the previous sections, this section analyses the information to identify the caveats and challenges that could

complicate the project. On these, suggestions, preventative measures, problem handling propositions and possible solutions are given. The section aims to accomplish the following:

- Inform an ESCO on what project information is required by an M&V practitioner, how this information is handled, scrutinised and what it reveals. This can assist an ESCO at an early time, even still in the project planning phase, to ensure the correct and appropriate information and data are gathered. It will also assist in the process of better determining the DSM impact target.
- Inform all stakeholders (utility and project investors) of the caveats and challenges that should be looked out for with irrigation projects. In addition, the probable viability of a DSM project can be assessed just from the information provided initially, instead of discovering project underperformance or issues only after the project was implemented.
- Provide guidance to M&V entities on irrigation DSM projects, what M&V strategy to follow and how to approach baseline development and SLAs.

3.9.1 Project details

The information given in the following sections is an example of the typical information gathered and provided by an ESCO to the project stakeholders when a new irrigation DSM project is proposed.

3.9.1.1 DSM project summary

The DSM project aims to reduce the weekday peak load of the Langlaagte irrigation area pumps by installing pump automated switch gear. The DSM target is an average annual morning and evening peak reduction of 12.2 MW.

3.9.1.2 Project pumps operations

The irrigation pump information below was provided on the type of pumping operations and number of pumps. Pumping occurs from:

- Boreholes directly to irrigation fields (45 pumps);
- Boreholes to holding dams (15 pumps);
- Canal to centre pivots or micro irrigation (155 pumps);
- Canal to holding dams (27 pumps);
- River to irrigation fields (208 pumps);
- River to holding dams (54 pumps);
- River to relay pump stations (8 pumps);
- Holding dams from which pumps distribute water (68 pumps);
- Holding dams are that gravity fed (number of dams - 12);
- Holding dams that are gravity fed and pumps distribute water to higher lying areas (36); and
- Farms that have mini river hydro power generation setups.

3.9.1.3 DSM project details

On these irrigation pumps, a variety of pump sizes (5.5 kW to 300 kW) were found and a mixture of the Landrate, Ruraflex and Nightsave Eskom tariff structures. Irrigation is mainly for citrus and a few other high-water demand crops. The irrigation farms are located in an area with moderate summer rainfall.

DSM activities entail morning, evening and peak period load shifting of all irrigation pumps. Pump switchgear and control valves, that will allow fully automated switching (morning and evening peak) of pumps, will be installed. The switchgear is equipped with an emergency bypass function. Also, the pump controller has the functionality that the pump can be remotely switched via an SMS. All river pump stations will also be equipped with billing class impeller type water extraction flow meters. DSM project funding pays for the automation upgrades and the advantages it has for the farmer. In return the farmers agree to oblige to the automated morning and evening peak switching period.

3.9.1.4 DSM project target and time span

The DSM target is an average annual morning and evening peak reduction of 12.2 MW. The target should be reached for a three-year period. The project implementation will run over 22 months.

3.9.1.5 Pump station details and sample measurements

With the details in the bullets above, the ESCO provided the following information to motivate the target impact.

- Full list of farms and all pump stations included in the project;
- Breakdown of installed capacity of pumps in each pump station;
- Total installed capacity of all project pumps is 25.4 MW;
- Tariff structure of each pump station, see Table 3-3 below;
- Excel spread sheet of processed pumping profile data. The pumping data was obtained from the following sample pumps (sample size also shown in Table above):
 - Manual download of 22 Ruraflex utility power meters providing data of 6 months (September to February);
 - Manual download of 15 Nightsave utility power meters providing data of 4 months (November to February); and
 - Temporary installation of 10 power meters which was moved around. In total, 30 pumps were measured for four weeks at a time between October and February. These were all installed on pumps with the Landrate tariff structure.

Table 3-3: Tariff structure of pump stations.

Tariff Structure	Number of pumps	Sample size
Landrate	145	30
Ruraflex	204	35
Nightsave	85	23
Total	434	88

3.9.2 Analysis of project details provided

The project details provided are analysed and scrutinised in the following sections.

3.9.2.1 Analysis of project pumps operations

The type of pumping operations and number of pumps provide valuable insight. The following should be considered for the M&V approach and M&V metering decisions:

- 1) Borehole pumping is not dependant on water limits or quotas when compared to pumping from a canal. Except in cases where borehole water levels drop significantly during dry seasons, the

farmer is not limited by water regulations. It should be noted that pumping profiles during the year might differ between pumping from a borehole to pumping from a canal.

- 2) As noted above, canals and river pumps may be affected in dry seasons due to water scarcity or quotas. Historical information on water restrictions can assist to evaluate how much this does occur and how it might affect pumping operations.
- 3) Pumping profiles of pumps moving water to holding dams will most probably differ from that of pumps directly irrigating fields from a river or canal. The buffer of a holding dam can allow the farmer to move water outside the costly peak periods (if on Ruraflex or Nightsave) into the dam.
- 4) Relay pumps will always pump in conjunction with the main pump. The demand profile of the main pump will be representative of the relay pump profile.
- 5) Pumps irrigating from a holding dam will take longer to be affected by water restrictions.

3.9.2.2 Analysis of DSM project details

On the DSM project detail section, the following should be noted:

- 1) It is stated that crops with a high water demand are irrigated, thus a higher load factor is expected from the pumps and consequently a higher pumping demand profile is also expected. This can also relate to a possible higher shiftable peak load. This is an important consideration for an ESCO in order to set achievable load shifting targets.
- 2) The pumping profiles between Ruraflex, Nightsave and Landrate tariff structures can greatly differ. Farmers on the Landrate tariff structure do not have the advantage of reduced peak tariffs and therefore would pump over the peak periods.
- 3) The DSM project aims to do both morning and evening peak switching. This is a concern since morning and evening peak switching might not be achievable the whole year due to the high load factor expected. See point 1) above. The morning peak is from 07:00 to 10:00 and the evening peak from 18:00 to 20:00. This removes 5 hours from the daily critical pumping periods. Especially the morning peak switching in certain times of the year will be very problematic. Farmers may attempt to bypass the switchgear during high pumping demand months.
- 4) Here, a necessary but troubling piece of equipment is the switchgear bypass function mentioned in the project detail. This allows the farmer to bypass the mandatory morning and evening peak automated switching in an emergency. The trouble is though; implemented DSM projects showed that some farmers experience emergencies for several months on end. Especially in high pumping seasons, the probability is high that such emergency bypass or other bypass tampering may occur. Even after the high pumping demand period is over, the farmer will not necessarily deactivate the emergency bypass. When the pumping demand is high, farmers tend to quickly ignore pumping period agreements.

Suggestions outside scope of M&V

It is suggested that certain bypass modes should be provided on the pump controller. This can assist the farmer during higher pumping periods, but still ensures that some of the switching does occur. It would be even better if these functions can be activated remotely by a control authority (ESCO or Irrigation Board) and the farmer should apply for this before it can be activated.

The application process should not be cumbersome (smart phone app based preferably) though, otherwise farmers will revert to creative bypass tampering. Having all applications on record, the control authority can allow different farmers on different days (or even parts of the peak period) to pump in/over the peak period. Hereby, peak period demand control can still occur to an extent. Functions may include:

- Quick - will allow one pumping period bypass;
- Morning peak bypass - Allows morning peak bypass for three days when activated. After the three days it will revert back again to normal settings;
- Morning and evening peak bypass - Allow morning peak bypass for two days when activated. After the two days it will revert back again.
- Emergency bypass - When pressed on the controller the control authority needs to be notified and the farmer would need to provide an explanation (required for veldt fires and other emergencies).

- 5) Flow meters are also implemented as part of the DSM project. Here are three very important things to notice:
 - Impeller type flow meters are not suitable in general for irrigation projects. These are accurate and cost-effective flow meters but the impeller is problematic. Even small impurities will get stuck in the impeller and no flow values will be measured. If the flow meter is installed after the pump and cleaning filters, this may work. However, at this point there are normally already other water tap-offs from the pump setup and more than one flow meter may be required.
 - It is general practice to install a flow meter on the suction pipe between the river and pump station. However, this requires expensive electromagnetic flow meters with no impeller.
 - The presence of a flow meter on a river extraction point might significantly influence the pumping operations. See Section 3.8.1 on the baseline alteration that was required for such a situation.
- 6) As stated, the DSM project funding pays for the automation upgrades and the advantages it has for the farmer (subjected that the farmer agrees to comply with the switching schedules). Note that there are specific challenges here to ensure compliance.

Suggestions outside scope of M&V

Here two important points are suggested which relates to bypassing of the switching system:

- There need to be very specific contractual agreements in place with penalty clauses to ensure farmer compliance. Otherwise project targets will not be met; and
- Compliance monitoring - it is ideal if the pump switchgear controller can provide feedback if the day's scheduled switching did occur on the pump station.

- 7) Although there is a target contract, there is no mention made of a maintenance contract which will ensure the equipment stay functional so that the target can be reached end out.

Suggestions outside scope of M&V

Careful attention should be given in the contractual agreement to ensure that the ESCO will keep the entire project period equipment in proper condition. It is also important for the ESCO to include these in the project scope from the beginning.

Proper equipment insurance against theft, lighting, floods and other equipment losses should be in place. A farmer will not necessarily replace or repair damaged equipment and if proper mechanisms are not in place, the impact from that farmer can easily be lost. With irrigation M&V projects it was several times observed that the pumps or entire pump stations (with M&V metering) were washed away due to floods.

After the three-year period, an ongoing maintenance contract on the long term is advised, otherwise the large project investment and DSM impact may be lost after the 3-year period ends. The project impact can dwindle over time as was seen with most of these types of projects in South Africa.

3.9.2.3 Analysis of DSM target impact and project implementation

On the DSM target and the project implementation period the following should be noted:

- 1) It is stated that the project will be implemented over a 22-month period. Thus, it will be almost two years between the intervention started on the first pump stations till the last are completed.

Suggestions outside scope of M&V

A progressive project evaluation M&V approach can be introduced whereby the pump stations that were already completed can be evaluated, and the impacts reported on while the rest of the pumps are completed. Thus, impacts can already be presented to stakeholders and project M&V issues can be identified and addressed early in the project life.

- 2) It is stated that the DSM target is an average annual morning and evening peak reduction of 12.2 MW and that the target should be reached for a three-year period. This means that the average demand reduction over a year, across low and high pumping demand seasons, will be 12.2 MW for the morning peak period and 12.2 MW for the evening peak period. Also, this target will be reached for three years. The information provided also states that the total installed capacity of all project pump stations is 25.4 MW. It should be noted that the target of 12.2 MW is 48% of the 25.4 MW total installed capacity. This is a very high percentage since:
 - Irrigation pump motors rarely run at 100% of its installed capacity since, in most cases, pumps are over designed;
 - Not all pumps in a pump stations are always operational since some act as backup pumps;
 - There are pump stations on the Ruraflex and Nightsave tariff structure that will already make use of the lower cost out peak period pumping benefit. This will reduce available load that can be shifted from the evening peak.
 - It was observed with irrigation DSM projects that ESCOs rely too much on the installed capacity of pumps as reference and thus judge the attainable target too high. According to Section 3.8.3., only 15–30% of the installed capacity relates to an average annual operational load that is available for evening peak switching. Thus, the 48% is very optimistic and will probably not be reached.

3.9.2.4 Analysis of pump station details and sample measurements

On the pump station details and sample measurements the following should be noted:

- 1) An Excel spreadsheet of processed pumping profile data was provided. This is problematic. M&V should as far possible always get hold of the raw data files.
- 2) It may not be the case, but data can be manipulated to make the project impacts more attainable.
- 3) The sample data information of Table 3-3, (repeated below) is analysed in Table 3-4:
 - Manual download of 35 Ruraflex utility power meters providing data of 6 months (September to February).
 - Manual download of 23 Nightsave utility power meters providing data of 4 months (November to February).

- Temporary installation of 23 power meters which were moved around. In total 30 pumps were measured for four weeks at a time between October and February. These were all installed on pumps with the Landrate tariff structure.

From the sample information it seems that the ESCO have gone to much trouble to collect enough sample data over a wide spectrum to support the project target impact. From the analysis in Table 3-4 the following interesting facts surfaces though:

- Considering such a large project, quite large sample sizes were used for data gathering for each tariff structure, between 17.2 and 27.1%. In total 20.1% of all pumps were measured, which is quite a good sample.
- However, here it is important to look at what the pumps (in that tariff structure) contribute to the overall project installed capacity and not at the number of pumps. The last two columns of Table 3-4 show the total installed capacity of the pumps for each tariff structure. Although the sample size of Landrate and Nightsave is high, these only contribute to 18% and 15% of the installed capacity. In contrast, Ruraflex with the lowest sample size contributes 67% of the total project installed capacity. The question should be asked here; why did this uneven sampling occur; was it by accident, due to circumstances, or was there a deeper motive?

Table 3-4: Sample data analyses.

Tariff Structure	Pump quantity	Sample size	Sample %	Total project Installed Cap	Installed Cap %
Landrate	145	30	20.7%	4.5	18%
Ruraflex	204	35	17.2%	17.1	67%
Nightsave	85	23	27.1%	3.8	15%
Totals	434	88	20.3%	25.4	

- 4) As noted in point 2) in Section 3.9.2.3., the Ruraflex and Nightsave tariff structures will already make use of the lower cost out peak period pumping. The highest sample size was for Nightsave, however, it only contributes 15% to the total project installed capacity. In contrast, Ruraflex that contributes two thirds of the total project installed, and which will be the most affected by already out of peak pumping, has the lowest sample size. This further raise suspicions. Now the sample time period needs to be evaluated.
- 5) The selected data gathering period ranges between four weeks and six months depending on the metering utilised. Here it seems that the ESCO have done the best with available resources. However, the selected time period of September to February is interesting. This time period, coincidentally, falls over the area's high pumping demand season when farmers frequently pump night and day to keep up with crop water requirements. Thus, even pumps on Ruraflex will be running over the Eskom peak periods although the higher ToU cost is involved.
- 6) Points 4 to 5 raise concerns and it should be considered if the sampling and selected time period was not done selectively to boost confidence on the attainable impact.
- 7) It should be noted that the different time periods measured by the Landrate temporary meters that were moved around, will complicate the baseline development. Irrigation pumping operations can significantly differ between months and the data gathered may not be representative. Here it would have been better to keep five meters fixed on specific pumps for the entire metering period and to move the other five around between pumps. With this monthly variation can be evaluated

on the specific pumps and used as reference for the meters that were moved around. The meters moved around will provide information on the variety of pumping operations.

3.9.3 M&V metering for the example DSM project

It is important to notice here that this DSM project consist of hundreds of pump stations disturbed over many farms. With such large DSM projects, it is not possible to measure operations of all pumps that form part of the project since the metering and M&V cost will be too high. Of course, there are trade-offs between accuracy and claimable savings. Chapter 6 Section 6.5 gives guidelines on metering sampling.

3.10 SUMMARY

This chapter illustrated the challenges project level M&V of agricultural irrigation pumping DSM interventions can have, with regards to baseline development and the post-implementation impact assessments. Here project level M&V is defined as project evaluation through metering of key project parameters over the full contractual life. Aspects of baseline development were discussed and novel M&V methods illustrated with different project types and even combinations of these, which included; load shifting, energy efficiency with and without an energy governing factor, a combination of load shifting and energy efficiency, load prevention or clipping and a combination of clipping and energy efficiency.

With actual projects conventional baseline development methods proved to be ineffective and alternative approaches needed to be conceived. From these, unique SLA methods were developed and applied which enabled affective quantification of the intervention impacts. This chapter also provides guidance through which project stakeholders can pre-emptively ensure that the correct mechanisms for a successful DSM project and proper M&V are in place. It also shows M&V practitioners the important project aspects to be careful of and what measurement and verification approaches to follow.

The following chapters consider programme level M&V where little to no metering can be done, and regional level M&V which is performed over a whole area, or region of a country, through assessing the utility power lines among other. This is followed by M&V metering, data quality and metering sampling which gives a unique contribution to a very challenging area, especially with irrigation M&V. The final chapter incorporates all of the above, and more, to provide an integrated approach through which the advantage of several incentive methods can be combined.

Chapter 4

Programme Level M&V

Project level Measurement and Verification (M&V) described in Chapter 3 provides comprehensive methods for establishing Energy Conservation Measure (ECM) impacts on projects. These are usually only large projects that can justify the high M&V cost associated with full project level M&V. However, the largest agricultural irrigation energy conservation potential is on smaller irrigation points which cannot justify project level M&V. Similar to the industrial, commercial and mining sectors, smaller fixed type ECM technology rollouts or retrofits can be done through large incentive-based programmes over hundreds of irrigation pumps. Here project level M&V is not possible and an M&V method is required to quantify ECM programme impacts.

One such irrigation programme, the Eskom Standard Product Programme (SPP) in South Africa is investigated in this chapter. The present study focusses on the M&V of irrigation ECMs under the SPP funding mechanism. A novel integrated programme level M&V methodology was developed to quantify ECM impacts under the programme, which has special conditions and unique M&V requirements, making normal project level approaches infeasible. Programme level M&V is defined here as a method of quantification that does not use continuous metering, but incorporates a deemed savings approach and/or a calibrated simulation model to establish ECM impacts over the programme contractual life. Unique methods were designed to effectively determine conservative but representative impacts without continuous power demand profile measurement. These developed methods and techniques were validated and verified through establishing independent cross-check measures.

The Eskom SPP and the developed M&V evaluation method was limited to only determining the operational demand reduction, though, and from this the annual energy savings. Thus, there is no indication of when energy is saved and what it contributes to peak period load reduction. This chapter also focusses on the development of a novel calibrated simulation M&V model to establish the available peak load for load shifting ECMs. This approach can accurately determine the available peak period load and also the load reduction achieved. This increases the value of the SPP by accurate reporting on peak reduction. The calibrated simulation method can also help project developers to evaluate the load shifting potential of pump stations in an irrigation area even before any project interventions have started. Further, it can assist in identifying irrigation sites with proper potential where peak switching can be implemented with energy efficiency projects. The method can also assist in strategized rollouts and can assist project implementers to first focus on the regions, areas and farms where the best ECM results can be obtained.

Chapter related publications and conferences

- ❖ Storm, M.E., Gouws, R. and Grobler, L.J. 2018. Novel measurement and verification of irrigation pumping energy conservation under incentive-based programmes. *Journal of Energy in Southern Africa*, 29(3):10-21. ISSN 2413-3051.
- ❖ Storm, M.E., Gouws, R. Grobler, L.J. 2013a. M&V of the Eskom irrigation pumping SPP Programme. *International Conference on the Industrial and Commercial Use of Energy*. pp. 249-254. ISBN 978-0-9922041-1-2.
- ❖ Storm, M.E. M&V on irrigation SPP with load factors. 2013b. *South Africa Energy Efficiency Conference proceedings*. Nov 2013. ISBN: 978-0-620-58204-9.

4.1 INTRODUCTION

Following the large Eskom Demand-Side Management (DSM) projects discussed in Chapter 3, small-scale energy efficiency projects were implemented to reduce energy consumption for cost saving. The Eskom Standard Product Programme (SPP) was established to provide rebates for these projects and fast track implementation. Under the SPP, an energy saving rebate is paid to participating parties upon the implementation of a standard and proven Energy Efficiency (EE) technology to replace a standard old inefficient technology. The initial technologies allowed under the SPP included energy efficient lighting, heat pumps, efficient lighting shower heads and solar water heating (Van der Merwe, 2011).

An Eskom Integrated Demand Management (IDM) energy advisor team (Scheepers *et al.*, 2013) also set out to establish an Eskom programme for irrigation demand reduction and EE. Here, some larger projects fit under the Eskom Standard Offer Programme (SOP), which still required conventional M&V (Hibberd, 2011; Den Heijer *et al.*, 2010). Conventional M&V is defined here as project level M&V and consists of the practices discussed in Chapter 3. The largest portion of potential irrigation projects needed to fit under the SPP. According to Van der Merwe (2011) these SPP small scale projects require a generalised M&V approach that gives an agreeable and acceptable saving impact indication. This M&V approach recognises a deemed saving rather than a measured saving as with conventional M&V. Several projects could be implemented per site subject to a single project size, each limited to a 100 kW average demand reduction during weekdays, and a maximum total of 250 kW impact per site. Conventional M&V of irrigation projects have already shown to be exceptionally challenging as discussed in Chapter 3. In addition, the special conditions and requirements of the Eskom SPP, make normal M&V approaches infeasible. Considering this and the significant difference between conventional project level M&V and programme level M&V, a new and unique M&V methodology was therefore required to quantify ECM impacts under the SPP.

A novel M&V methodology was developed to quantify ECM impacts under the SPP. This involved designing methods to effectively determine conservative, but representative impacts without continuous power demand profile measurement. The design involved unique methods to quantify operational demand reduction, annual kWh and annual average demand reduction impacts. The design was broadened to pumps irrigating multiple crop areas and different kinds of crops. The methodologies and techniques developed were validated and verified through establishing independent cross-check measures. A unique regional top-down M&V approach is introduced which can be incorporated to verify the actual total energy efficiency and load reduction impact on the electricity grid.

The main focus of the SPP programme, and therefore also the M&V evaluation method developed, was determining the annual kWh energy savings. The resulting limitation here is that the method cannot show when energy is consumed by the pump during the day. Therefore, it is not possible to determine if the demand reduction related to the SPP kWh saving occurred over the Eskom peak periods. It would be valuable if there was a method that could accurately determine how much of the SPP reductions that were achieved, actually occurred over the Eskom peak period.

Herby the SPP can also show what contribution it made to peak reduction. It would be even more valuable if there was a method that could also show what irrigation peak pumping load there is available for possible load shifting projects. In light of these needs, a novel calibrated simulation M&V model is also designed and developed in this chapter. It presents a special variable confidence level approach which realises cost-effective implementation of different applications. These range from irrigation area load availability impact feasibility studies to SPP like programmes (with load shifting) each with different levels of accuracy. Although this chapter focusses on the Eskom irrigation SPP, the processes followed can be used on any similar type of programme rollout incentive-based mechanism worldwide.

4.2 PROGRAMME LEVEL M&V VS PROJECT LEVEL M&V

There is a large difference in the approaches followed with programme level M&V, when compared to project level M&V or conventional M&V as it is sometimes referred to. According to Coetzee *et al.* (2012) a project and a programme essentially differs in that a programme is an ongoing roll-out of a fixed technology over many sites, where instead a project considers a set target defined over certain site(s). A project is also not limited to a specific technology.

Project level M&V methods are normally applied on ECM projects with a large demand or energy efficiency reduction. This was common practice on large irrigation projects under the Eskom DSM programme as discussed in Chapter 3. Here the ECM intervention cost is high and the total M&V cost involved is only a fraction of the total project. The large energy efficiency or demand reduction achieved, relates to large incentives paid to the ECM project owners. Many demand reduction projects implemented in South Africa, each moved several Megawatt (MW) from the Eskom evening peak period to other periods of the day. Within such an environment, it is important for all stakeholders to have very accurate M&V results with a high confidence level. Also, the exact project performance must be tracked over the entire project life to ensure that the project targets are met. Here exact M&V is critical and the associated high cost easily justifiable. The M&V process on these projects requires the following critical components and actions:

- Properly define the baseline boundary, which includes ECM intervention and all interactive effects;
- Define an energy driver (or energy governing factor) against which baseline can be referenced;
- Proper M&V demand profile metering (billing class in most cases) is required;
- Functional baseline metering period to capture all project variations and circumstances – this can be a period of a few months to several years;
- Baseline model development. The baseline typically consists of average weekday, Saturday and Sunday demand profiles;
- Baseline assumptions made on project parameters and conditions wherein the baseline is applicable;
- Baseline service level adjustment method to adjust the baseline to the operation conditions it would have been if the ECM was not implemented. This is done by using the referenced energy driver; and
- Calculate savings over the project life. Performance assessments are customarily done on a monthly or quarterly year basis. The project's participating members receive incentives based on the results of M&V project performance reports.

This project level M&V method requires extensive baseline and full project life metering. Metering and data gathering cost can be cumbersome and also very expensive. With this, independent M&V specialists are required throughout the project life to track the ongoing savings. Programme level M&V, such as required for the SPP, fundamentally differs in the following aspects from project level M&V:

- No profile metered baseline period and no reference energy drivers;
- No ongoing metering is performed on the ECM after implementation;
- No profile baseline development; and
- The incentive is paid to participating parties at the beginning of the project, on a projection of the savings over an agreed project life (three years in the case of the SPP). Therefore, there is no ongoing tracking of the project performance.

Considering these, SPP has very unique requirements, which make conventional project level M&V approaches inapplicable. A new and unique M&V methodology was required to assess SPP ECMs and to quantify projected impacts. This should be achieved without conventional M&V methods while still having an acceptable confidence level.

4.3 NOVEL INTEGRATED M&V METHODOLOGY FOR THE ESKOM SPP

A novel integrated M&V methodology was developed to conservatively quantify load reduction and energy efficiency resulting from ECMs under the SPP. The scientific approach was developed through a comprehensive study of all SPP requirements, project parameters, system boundaries and approach limitations. The integrated methodology includes the key components displayed in Figure 4-1. Also, specific methodology design validation and verification parameters were set as seen in Figure 4-1(a), (c) and (d).

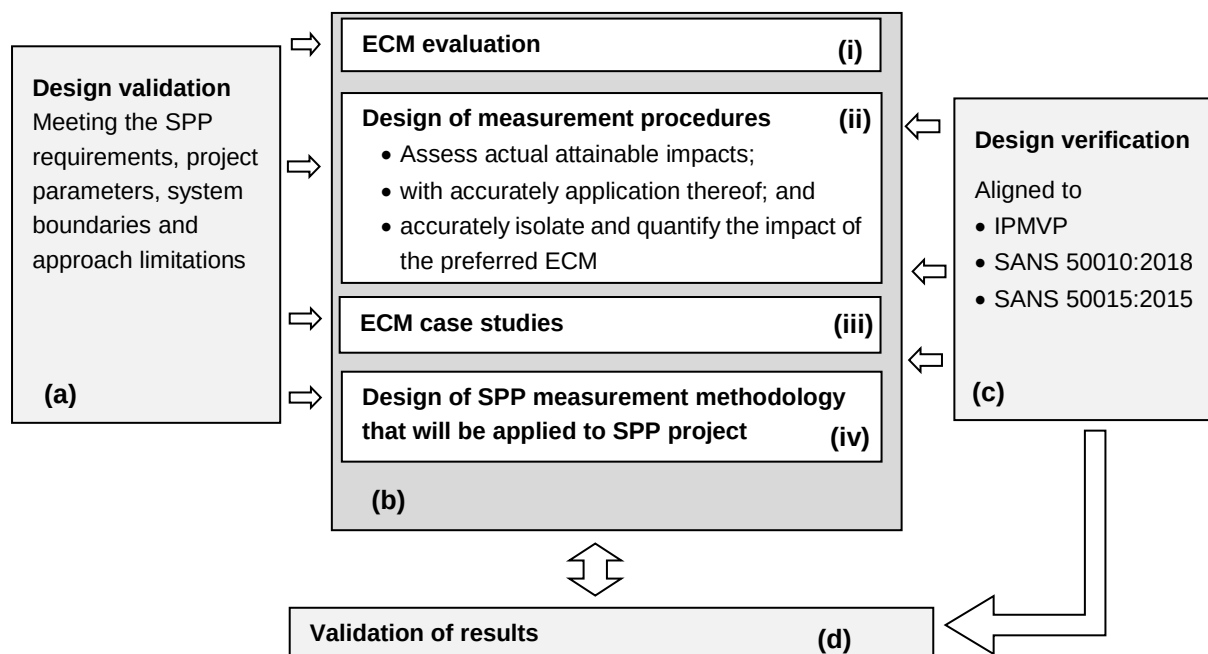


Figure 4-1: A novel integrated measurement and verification methodology with design validation and verification, with (a) = the design validation; (b) = key concepts of integrated methodology; (c) = the design verification; and (d) = the validation of results.

Figure 4-1(b) shows the key concepts of the integrated methodology described in the present study. The ECM evaluation looked at how an evaluation criterion can be devised to assess different ECM approaches to ultimately find a sustainable and quantifiable ECM.

This then considered how this ECM was applied and how it led to demand reduction and energy saving. The design of assessment/measurement procedures examined the following:

- Design of a measurement procedure to assess actual attainable impacts through the chosen ECM;
- Design of a measurement procedure to accurately apply the aforementioned even when the ECM was already implemented, and no baseline measurements were possible; and
- Design of a measurement procedure to accurately isolate and quantify the impact of the preferred ECM where other ECMs were also implemented.

Case studies following compartment (iii) of Figure 4-1(b) were performed to evaluate the actual attainable impacts of the chosen ECMs. Compartment (iv) shows the design of a SPP measurement methodology that includes:

- Establish a measurement method to quickly and effectively quantify a conservative but representative load reduction without profile measurement. Broaden this method for an irrigation pump feeding multiple crop areas and having more than one crop type per centre pivot; and
- Establish a functional method to quantify annual conservative but representative energy use impacts of an irrigation pump from the load reduction values. Then broaden the method to an irrigation pump feeding multiple crop areas and having more than one crop type per centre pivot.

Figure 4-1(a) shows that design validation is done by adhering to the SPP requirements, project parameters, system boundaries and approach limitations. As a design verification in Figure 4-1(c), all methods and procedures must be aligned with international M&V protocols and standards. Here, the International Performance Measurement and Verification Protocol (IPMVP), SANS 50010:2011 (and now SANS 50010:2018) and SANS 50015:2015 were applied. Not all the steps are fully discussed in this study because of the size and complexity of the development. Figure 4-1(d) gives an independent method to validate the SPP M&V methodology and the actual results obtained from ECMs under the SPP. This is discussed in Section 4.3.4.5.

4.3.1 ECM evaluation

Compartment (i) in Figure 4-1(b) presents ECM evaluation as the first key concept of the integrated M&V methodology. This section considers an ECM evaluation by discussing what ECM technologies can be implemented and how these can be applied to lead to demand reduction and energy saving.

4.3.1.1 ECM evaluation criteria

Since no standard tried and proven irrigation energy efficiency technology was yet found for the irrigation SPP, a study on irrigation inefficient practices and possible ECMs was performed. The evaluation study considered what ECMs can be implemented that will lead to measurable and sustainable energy saving over the project life with a high confidence level. The number of areas to improve energy efficiency on a single irrigation system complicates the M&V process necessary to quantify the savings. Inefficiency practices investigated were divided into the three groups:

- **Group-1:** Water losses - leaks in irrigation system;
- **Group-2:** Incorrect irrigation practices - such as over irrigation; and
- **Group-3:** System design - inefficient pump system design and setup.

The question at hand was what energy efficiency initiative can be implemented on which group for the SPP that will lead to measurable and sustainable energy savings over the project life with a high confidence level? Since M&V only reports on conservative savings, a lower confidence level will directly result on lower savings reported.

Considering Group 1, water leaks can be fixed to prevent water losses. However, there is no guarantee that the system will be maintained and that new leaks will be attended to by the farmer. When considering Group 2; even if the farmer is introduced to more effective irrigation methods and provided the technology; there is no easy measurable guarantee that the farmer will keep using the efficient practices.

Considering Group 3; system design improvements can lead to measurable savings and a considerable confidence level. With these improvements the farmer will save energy when the pump is used for all normal pumping practices. A combination of the groups further increases the initial savings assessment complexity.

Table 4-1 lists energy related inefficiencies observed during the evaluation performed by the Eskom IDM energy advisor team (Scheepers *et al.*, 2013). Here system design improvements can improve the operational energy efficiency. Table 4-1 also provides the corrective action to correct or improve these inefficiencies. Here an M&V practitioner as part of this study independently validated these observations. Some of the inefficient practices observed are shown in Figure 4-2 and Figure 4-3. It is important to note here that focus is placed solely on system setup and operational energy inefficient practices and does not include the multitudes of water leaks, water waste and water use improvement opportunities that were found.

Table 4-1: Irrigation system energy inefficiency conditions and practices with corrective actions.

Irrigation system	Energy Inefficiency	Corrective action
Pump motor	- Under or oversized - Old motor (windings bearings) - Poor power factor - Faulty motor bearings	- Replace with a correct sized motor - Replace with an energy efficiency motor - Size motor or install PF capacitors - Replace motor bearings
Water pump	- Inefficient pump - Pump choking - Restrictive manifold - Damaged rubber couplings - Incorrect pump orientation - Cavitation - Faulty bearings - Unnecessary bends in suction and delivery pipes - Incorrect pump/motor line-up - Incorrect suction pipes and layouts - Flow restrictive manifolds - Incorrect eccentric couplings	- Change to a more efficient unit - VSD implementation - Improve manifold - Replacement - Correct orientation - Change pump setup - Replace pump bearings - Change pipe layout - Correct line-up - Correct to efficient design - Replace with streamlined manifolds - Change to correct ones
Centre pivot, mainline and distribution pipes	- Small diameters of main lines - Pivot pressure too high; - Faulty sprayer pressure regulators are not replaced - Use of wrong sprayers or end gun	- Thicker pipe to decrease water friction - Decrease to optimal level with VSD - Change pressure regulator and nozzle improvement - Only use efficient design



Figure 4-2: a) Restrictive Manifold, b) Pipe bends and manifold, c) Incorrect eccentric fitting.



Figure 4-3: a) Incorrect suction fitting, b) Damaged Fenner Coupling, c) Inefficient pivot extension.

The study concluded that pump system design and setup system improvements in Group-3 can best satisfy the SPP requirements. The standard technology chosen here was Variable Speed Drives (VSDs), through which the pumping system can be optimised to achieve demand reduction and energy saving. As mentioned, the evaluation study also observed much water inefficiency and waste which falls into Group 1 and Group 2. Although these do not fit under the SPP, there will also directly be energy saved when water waste and inefficiency are stopped. However, these are separately discussed in Chapter 7 Section 7.3.1.3.2. Section 2.2.5 of Chapter 2 elaborates on the complexities related to quantified water savings. To evaluate the credibility of possible savings that can be achieved, VSDs retrofit case studies were implemented at numerous farms as discussed in the following section.

4.3.1.2 Application of the ECM: how it leads to demand and energy saving

It is important to note that a VSD on its own will not necessarily improve energy efficiency. The VSD however, is the ‘tool’ enabling energy efficiency, which is not possible with standard pumping equipment. Figure 4-4 shows a centre pivot commonly found on irrigation farms. As discussed in Section 4.3.1, irrigation setups like these were found to have several optimization opportunities. Here a VSD can be implemented to significantly optimise irrigation practices.



Figure 4-4: Centre pivot is shown which irrigates a maize crop.

Figure 4-5(a) shows a centre pivot while running in pre-ECM implementation conditions. Generally, it is found that centre pivots are over-pressured, resulting in ineffective irrigation. In these conditions, the sprinklers create a fine mist, which increases water evaporation. Thus, water is wasted and the pump motor is subjected to a higher load due to the higher system pressure. In South Africa, it is often found that irrigation engineers overdesigned an irrigation system. This is especially the case with older

systems. In addition to overdesigning, the engineers also over-specified the required centre pivot pressure. The system can be optimised by installing a VSD and reducing the motor speed with the VSD, so that the choked valves can be opened 100% according to Scheepers *et al.*, 2013. The water delivery rate is now controlled by the VSD and no more choking is required. Also, the pumping system is further optimised by reducing the centre pivot pressure to an optimum level. As shown in Figure 4-5(b), the centre pivot is now running optimally with the pressure significantly reduced. This optimal pressure changes the water mist to larger droplets, which have less 'in flight' evaporation (Morris & Lynne, 2006). Since the pump is not choked anymore and the pressure is lower, a demand reduction as well as energy efficiency is realised. The lower pressure also results in less water irrigated and less water wasted due to evaporation.



Figure 4-5: (a) Pre-implementation conditions - over pressured centre pivot resulting in fine mist, (b) Post-implementation conditions - fine mist significantly reduced.

4.3.2 Design measurement procedures

Compartment (ii) in Figure 4-1 presents the design of measurement procedures as the next key concept. These design procedures are necessary to quantify the actual attainable impacts through SPP ECMS. The measurement actions described relate to the conventional M&V methods described in Section 4.2. Although these methods will not be used in actual SPP M&V project impact projection, these are required in the present study to evaluate what real-world impacts can be achieved. Full M&V of Chapter 3 is, therefore, used to provide a sampled impact result according to certain project characteristics. This can then representatively be applied to other similar projects to ascertain likely VSD EE impact results.

4.3.2.1 Measurement procedure to assess actual attainable impacts

The procedures involved baseline audits through independent validators and proper baseline, and post-implementation profile measurements by means of reliable metering, as described below.

➤ Baseline conditions audit

An independent validator is required to visit and assess a pump station and the irrigation system setup before any EE initiatives are considered or discussed with the farmer or any farmers in the region. This can be done through independent audits in an area well before any ECM programme. This is necessary to establish proper baseline conditions without interference. It is important that the baseline conditions may not be influenced for example, any discussion with the farmer might influence him to start operating more efficiently, thus changing the baseline operation. And the moment the typical ECM implementation procedures become available or common knowledge, 'creative savings' may surface through changing the system baseline conditions to run more inefficiently before auditors arrive. It is important during the audit that the exact operational conditions are recorded. This includes different crop areas and circles

fed by a specific pump, the valve positions for each pumping scenario, and the operational pressure of each irrigation setting.

➤ Metering installation and verification

Before the ECM is implemented, pump station operational data should be collected through reliable meters installed on each pump in a station. The correctness of all installations must be verified through calibrated check metering. As an example, a case study of a pump irrigation system with three centre pivots will be discussed as shown in Figure 4-6 (a). In Figure 4-6(b) and (c), the meter installation is verified by using a calibrated handheld and a temporary Fluke power meter.



Figure 4-6: (a) Pump station 1, (b) Measurements done by M&V with a calibrated handheld meter, (c) Fluke power meter - measurements compared with M&V meter.

➤ Baseline measurements

After metering equipment installation verification, full baseline data capturing can be started. For sufficient baseline data, the centre pivots go through the full irrigation cycle. With this, all different pumping scenarios and conditions can be recorded. Figure 4-7 shows the full cycle pre- and post-implementation demand profiles of one of the case study pump stations.

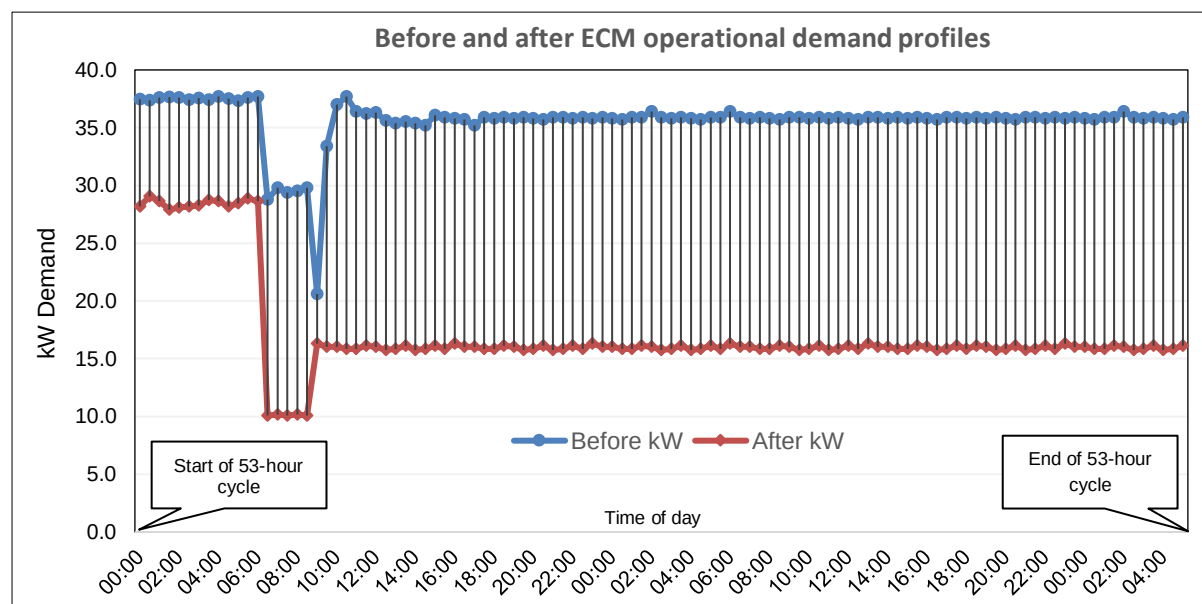


Figure 4-7: Full cycle pre- and post-implementation after demand profiles of a pump station.

The top line shows a 53-hour full irrigation cycle energy demand profile of the irrigation pump, revealing three distinct operational scenarios: the profile starts at around 37 kW, then drops to about 29 kW for about three hours, and then stabilises to near 36 kW for the rest of the period. These three different

demand conditions are caused by the pump irrigating three different centre pivots. Water supply is moved to specific crops through supply lines by changing valves.

➤ **Post-implementation metering**

After the ECM was implemented and the system optimised, the same irrigation cycle should be repeated with the different pumping scenarios. The bottom line in Figure 4-7 shows the post-implementation demand profile fitted onto the same graph. For most of the irrigation cycle there was a typical 20 kW difference. The lined area in between the two profiles represents the demand reduction achieved over the full irrigation cycle.

4.3.2.2 Assessment where baseline measurements were not possible

In cases where it was not possible to install temporary baseline metering before the ECM, an alternative approach was required to quantify the attained impacts. A measurement procedure was established for determining impacts when the ECM was already implemented. In such cases, valid information from a proper baseline audit is required as in the previous section. The pumping system can be brought to pre-implementation (baseline) conditions by setting the VSD back to 50 Hz and returning pipeline valves to the pre-chocking settings and system pressures, thus essentially 'eliminating' the presence of the VSD. Now baseline measurements can be done and compared with post-implementation data to reveal the actual impact.

This approach can easily be misused if proper baseline audits were not performed. If baseline audits are not possible, historical data for three months to a year is needed before any ECM implementation is essential for suitable M&V. This historical data can be obtained from utility Time of Use (ToU) profile power metering on the Eskom Ruraflex or Nightsave tariff structures. From this data, the baseline conditions can be verified. Smaller utility points are, however, not always equipped with profile power meters, but rather with cumulative energy consumption disc meters in kWh as discussed in Section 3.3.4.2 in Chapter 3. In these situations, additional baseline metering may be required.

4.3.2.3 Assessment where other ECMs were also implemented

In the case where other ECMs were implemented with the VSD, a similar approach as in Section 4.3.2.2 can be followed to accurately isolate and quantify the impact of the VSD. Other ECMs may include an energy efficiency pump motor or pipeline efficiency improvements.

Comparing the results from proper baseline measurements with the post-implementation results will give the demand reduction due to the VSD and other ECMs. However, in cases where proper baseline measurements were not possible, repeating the method of Section 4.3.2.2 and comparing these results with the post-implementation results will produce the impact of the VSD only.

This essentially isolates the VSD impact and excludes the efficiency contribution of other ECMs. With some ECMs, like pipeline efficiency, the exact baseline conditions may not be achieved by applying Section 4.3.2.2. The pipeline efficiency may result in a lower operational demand, with the same baseline valve positions and operational pressure. Thus, the impact due to the pipeline efficiency improvement may be missed due to the quantification method followed. If there is historical data available from the utility point, this can assist to quantify the additional pipeline efficiency demand impact.

4.3.3 Case studies of actual attainable impact

The measurement procedures described in Section 4.3.2, were applied in case studies on actual ECM projects implemented on irrigation farms. This section discusses the case studies and investigates the actual attainable impacts achieved.

4.3.3.1 Case studies where VSDs was implemented

Case studies were done on 19 VSDs installed on farms in several different areas and provinces in South Africa. The aim of these case studies was to quantify the actual attainable demand impacts with thorough metering. The measurement procedures of Section 4.3.2.1 were thus implemented to assess and verify impacts.

Figure 4-8 and Figure 4-9 show some of the pump stations assessed during the case study. Figure 4-8(a) shows the inside of a pump station with the pump set and enclosed control gear mounted on the wall. The ECM activities entailed installing a VDS as seen in Figure 4-8(b) and a water line pressure transducer, Figure 4-8 (c).



Figure 4-8: (a) Inside irrigation pump station, (b) VSD in enclosure, (c) Water line pressure transducer.

Figure 4-9(a) shows a pump station with several irrigation pumps irrigating different crops under centre pivots and micro irrigation. Figure 4-9(a) and (c) show the VSD setting panel and the testing setup. The measurement procedures were followed as prescribed in Section 4.3.2. A Fluke power meter was installed to capture the before and after ECM implementation power readings.

Figure 4-10(a) shows an example of the before implementation readings taken during case study assessments. The before ECM per phase instantaneous demand here was around 10.8 kW, thus 32 kW in total with a 0.93 power factor.



Figure 4-9: (a) Pump station with 6 pumps, (b) VSD controller, (c) Equipment setup.

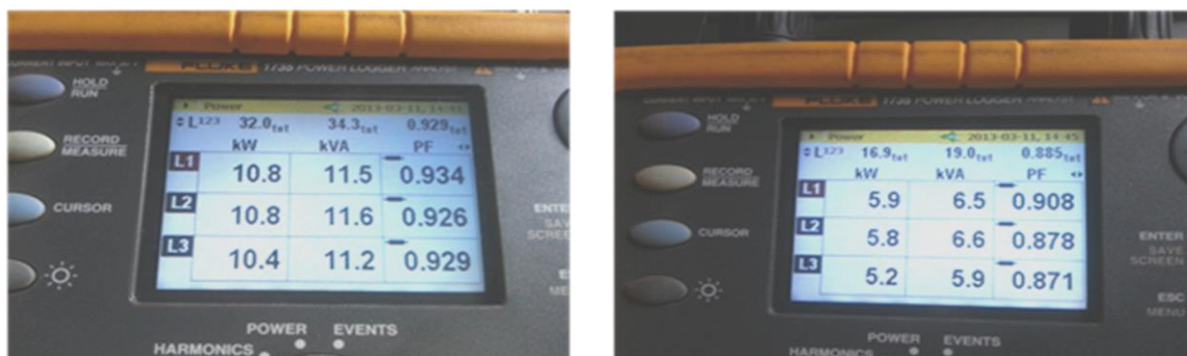


Figure 4-10: (a) Fluke reading before installation at (50Hz), (b) After installation reading at (41Hz).

The system optimization was done by setting the pump speed to optimum pumping conditions. For this the VSD was set to an optimized 41 Hz to only deliver the right amount of water at the optimal pressure. Afterwards the instantaneous demand was around 5.8 kW per phase. See Figure 4-10 (b). The total per phase demand was 16.9 kW at a 0.88 power factor. The instantaneous demand reduction observed here is 47.2% with still an acceptable power factor.

4.3.3.2 Demand reduction results from case studies

The pre- and post-implementation demands measured at each case study site, with the actual demand reductions are summarised in Table 4-2. From the profile measurements, an overall representative demand reduction for the irrigation pump can be calculated. This was done to portray a single figure of the attainable demand reduction impact of the 19 case study pumps.

Profile measurements were not possible at all pumps and a unique method establishing conservative instantaneous values was used. See Section 4.3.4.1. In Table 4-2 the first column lists the test site, while the second column lists the pump station name and the installed capacities of the irrigation pump motors.

Table 4-2: Achieved demand reductions on 19 pump stations (Scheepers *et al.*, 2013).

Test site	Pump station and installed pump	Instantaneous demand measured			
		kW Before	kW After	kW Reduction	% Reduction
Farm 1	P36 (30 kW)	36	16	20	55.6
	E4 (30 kW)	27.5	11.3	16.2	58.9
	E40 (55 kW)	54	42	12	22.2
	E40 (30kW)	23	13	10	43.5
	P1 (30 kW)	34.4	14.7	19.7	57.3
	P1 (30 kW)	32	16.9	15.1	47.2
	P17 (22 kW)	25.7	7.3	18.4	71.6
	P17 (75 kW)	66.8	30.8	36	53.9
Farm 2	Dam pump (110 kW)	99	53.2	45.8	46.3
Farm 3	75 kW	74.9	50.7	24.2	32.4
	75 kW	62.4	40.8	21.6	34.6
	75 kW	61.7	44.1	17.6	28.5
Farm 4	37 kW	38.1	35.4	2.7	7.1
Farm 5	P1 (30 kW)	46.8	28.8	18	38.5
	P2 (30 kW)	51	25.3	25.7	50.4
	P3 (30 kW)	68.7	33.5	35.2	51.2
	P4 (30 kW)	46.4	31.4	15	32.3
	P5D (30 kW)	45.8	33.7	12.1	26.4
	P6 (30 kW)	44.6	25	19.6	43.9

The next two columns show the before and after ECM instantaneous kW, while the kW and percentage demand reduction is given in the last two columns. The lowest demand reduction was seen at Farm 4 (7.1%) and the highest demand reduction was measured at pump station P17 on Farm 1 (71.6%). Taking all 19 sites into account, the average demand reduction achieved was 42.2%. For all measurements, the pre- and post-implementation conditions were kept the same.

When viewing Table 4-2, a definite and significant demand reduction can be seen. With the project circumstances in mind, it can be safely concluded that the implementation of a VSD to optimize the irrigation system can lead to real, tangible and significant demand reductions. The achieved demand reductions will directly result in kWh saving, and in most cases, water saving as well due to water usage optimization.

4.3.3.3 Further assessments

The 19 pump stations were not the only pumps engaged by the energy advisors, although these were the only ones independently verified. A total of 46 farms and farm sections formed part of a large testing study over South Africa. With collaboration between M&V and the energy advisors, a standard site M&V evaluation criterion, as for the 19 pump stations, was agreed upon to be used for all other farm pump stations. Very similar demand reductions to that of the 19 pump stations were obtained. Figure 4-11 gives a bar chart of the combined results obtained from the energy advisors. However, only the reduction percentages are shown.

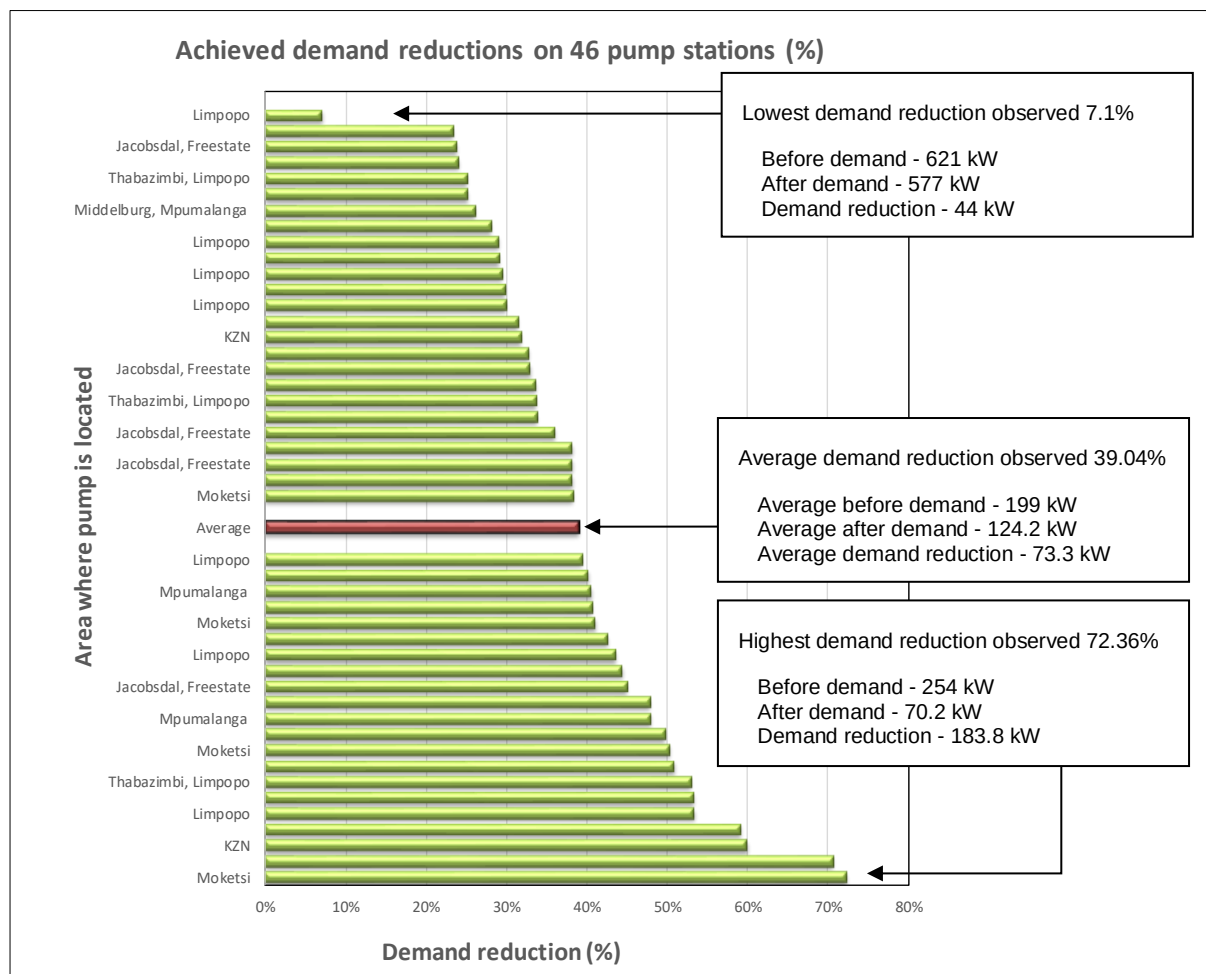


Figure 4-11: Achieved demand reductions on 46 pump stations.

The impacts are listed from the lowest at the top to the highest impact listed at the bottom. Figure 4-11 also includes the 19 independently evaluated pump stations. Just as seen in Table 4-2, a variety of impact percentages are observed in Figure 4-11. Between all 46 sites, the lowest impact was still the 7.1% and the highest seen was 72.36%. The information blocks on the right of Figure 4-11 gives the before and after demand with the kW load reduction and percentage. In the centre of Figure 4-11 the average demand reduction over all 46 sites is shown as almost 40%.

It is critical to note that the Table 4-2 savings figures and that of the other 37 can only be used as a guide on what can possibly be achieved and not as a national or area specific representation. The pump stations used, did not undergo proper statistical sampling (Carstens *et al.*, 2014; IPMVP Committee, 2012; Xia & Zhang, 2013; UNFCCC CDM Executive Board, 2012) and were assessed as projects were implemented and evaluation sites became available. For a national or area specific representation, a thorough statistical model needs to be developed which considers all factors and variables. Section 6.5 in Chapter 6 elaborates on statistical analysis and processes.

4.3.4 Design of a unique SPP measurement, verification and validation methodology

Section 4.3.2.1 described the design of measurement procedures to quantify the actual measured impacts of SPP irrigation ECMs. In Section 4.3.2.3 these procedures were applied to case studies, where the focus was to assess and quantify the real world impacts due to the implication of VSDs on irrigation pumps. Here measurement practices related to conventional M&V methods were applied. However, the SPP cannot financially justify such extensive measurements on all projects and a quick standardised assessment method is required to realise attainable demand and kWh reduction.

4.3.4.1 Establishing a unique quick measurement method for demand reduction

A method needed to be established for the SPP to quickly measure a conservative, but representative load reduction, without profile measurement. With centre pivots, a conservative approach is to let the centre pivot turn till it reaches the lowest elevation point on the crop circle according to Steyn *et al.* (2013). Here baseline instantaneous demand measurements before the VSD intervention should be done with a calibrated handheld power meter. This lowest point is the location where the irrigation pump demand is also the bottommost since the static head is effectively the lowest. This measurement must be repeated after the ECM implementation at exactly the same centre pivot bottommost point and the results can be compared for the demand reduction. The impact calculated will be the lowest possible saving that is still attainable. With centre pivots on severely angled crop circles, multiple measurement points may be considered if a typical reduction needs to be assessed.

Crops under micro or sprinkler irrigation have a constant static head and instantaneous handheld power meter measurements can be taken any time after the system is stabilised from pump start-up. Irrigation pumps which irrigate multiple crops, as in Figure 3-2 of Chapter 3, require a separate assessment for each crop. Thus, a load reduction for each crop should be determined since the irrigation setup may differ. This approach effectively realises a unique quick and cost-effective approach to establish an accurate conservative demand impact due to a VSD or other system efficiency implementation. As per SPP requirement, this does not need ongoing profile power metering and can provide the same results as seen in Table 4-2 and Figure 4-11. This energy efficiency demand reduction can be used to calculate the annual energy (kWh) demand reduction.

4.3.4.2 Assessment method for annual average demand and kWh reduction

Determining the annual kWh energy reduction under the SPP is a difficult study, since the SPP does not allow continuous measurements and the kWh saving needs to be determined for a specific crop in

a specific area. Without continuous measurement, several other aspects may need to be considered when determining the kWh and average demand reduction. These aspects can include:

- Location, climatic region and typical annual rainfall;
- Crop types: Irrigation of summer and/or winter crops - more than one type of crop during a single season;
- Irrigation methods and soil type; and
- Are water allocations/registrations active in the area?

From studies, it surfaced that the best approach is to incorporate crop water requirements to establish crop load factors (Scheepers *et al.*, 2013). Through this, representative irrigation requirements for a crop and its pumping load can be realised.

- **Crop water requirement factors:** Crop water requirement is one of the most important aspects to consider for irrigation efficiency since it is a vital part of agricultural planning according to Reddy (2015). Allen *et al.* (1998) defines crop water requirement as: “the depth of water needed to meet the water loss through evapotranspiration (ET_{Crop}) of a disease-free crop, growing in large fields under non-restricting soil conditions, including soil water and fertility, and achieving full potential under the given growing environment.”

Crop water requirement is a well-studied field with extensive research done on different methods to determine ET_{Crop} with field measurements. Section 2.2.2 and 2.2.3 of Chapter 2 elaborates on this. Extensively developed software programmes are available to assist farmers to determine representative crop water requirements. An example of this is CROPWAT (Banik *et al.*, 2014) and the South-African SAPWAT (Heerden *et al.*, 2016) that is based on (Allen *et al.*, 1998) using the CLIMWAT (Tegos *et al.*, 2017) weather data base comprising of 3262 weather stations from 144 countries. For the SPP the software program SAPWAT was utilised, which among many other aspects, incorporated 50 years of weather data of specific areas, to calculate a crop water requirement and then a crop load factor for a specific area and crop type. Of course, crop water requirements can also be applied to benchmark an irrigation setup to assess the possibility of increasing efficiency.

- **Crop load factors:** A crop load factor essentially combines the crop water requirement with a pump load factor. Here the load factor can be defined as an operational requirement to supply the amount of water annually, compared with the operation or installed pump motor capacity.

From the crop load factor, irrigation system setup and ECM load reduction, the annual kWh saving with the annual average demand reduction can be estimated. In the following sections crop load factors are investigated and also a unique cross verification method to validate crop load factors.

4.3.4.3 Applying crop factors to realise crop load factors

Part of the Eskom SPP study, regional crop load factors were developed (Scheepers *et al.*, 2013) that can be used to calculate representative annual average operation demand of the pump stations. This was done by collection of field data and using SAPWAT as mentioned in the previous section. Having the crop load factor and the average demand reduction that can be achieved through an energy efficiency initiative, the annual kWh energy saving can be calculated.

Table 4-3 shows the regional crop load factors developed for two regions, the KwaZulu Natal (KZN) and Mpumalanga provinces of South Africa, that were evaluated under the Eskom SPP. The left side of Table 4-3 shows alphabetical crop selection B to N while the right-side shows O to W. Crops with higher water requirements have a corresponding higher crop load factor. The aim of the developed Eskom irrigation load factors was to establish conservative values from which conservative savings can

be calculated. With a conservative demand reduction measured as described in Section 4.3.4.1 (or measurements used to establish Table 4-2), the kW value can be multiplied by the associated crop load factor and hours in a year to produce the annual kWh energy reduction. For instance, in Table 4-2 the first 75 kW pump station showed a 24.2 kW demand reduction due to the VSD installed. Thus, taking the 8 760 hours in a year (365 x 24) and multiplying it by the 24.2 kW demand reduction with a maize crop load factor of 0.18 in Region-1 from Table 4-3, it gives a 38,158 kWh saving annually. A crop with a higher crop load factor like Citrus with 0.35 in Region-1 or Vegetables with 0.36 also in Region-1, a much higher energy saving can be achieved. Here the crop load factor essentially indicates the percentage of a year the pump is operational to irrigate the specific crop.

Table 4-3: Eskom developed crop load factors for Region-1 (in KZN) and Region-2 (in Mpumalanga).

Crop selection (B to N)	Region 1	Region 2	Crop selection (O to W)	Region 1	Region 2
Beans	0.18	0.17	Onions	0.21	NA
Cabbage (Summer)	0.13	0.08	Grazing (Perennial)	0.22	0.19
Cabbage (Winter)	0.13	0.12	Grazing (Seasonal)	0.28	0.23
Cassava	NA	0.27	Potatoes	0.31	0.27
Citrus & Subtropical Fruit	0.35	0.23	Soft Fruit	0.35	0.22
Cotton	0.19	0.15	Soya Beans	0.16	0.15
Grapes	0.25	0.17	Sugar Beet	NA	0.19
Green Peas	0.13	0.11	Sugar cane	NA	0.21
Groundnuts	0.2	0.15	Tendrils crops	0.11	0.12
Lucern	0.28	0.21	Tomatoes	0.4	0.15
Maize	0.18	0.15	Vegetables	0.36	0.24
Nuts – Almonds	0.21	0.17	Wheat	0.18	0.15
Nuts – Pecan	0.15	0.06			

4.3.4.4 Intuitive crop load factor cross verification method

Since farmers would receive a rebate under the Eskom SPP through using crop load factors, independent evaluations were required to verify if the Eskom developed crop load factors represent real world conditions and indeed provide conservative saving calculations. In order to perform such a study accurately, intense long-term site measurements and detailed studies on a large and representative sample sites are required. Since this was not possible, an alternative intuitive method was required that could validate the crop load factors on a high level. An innovative method was developed through a study that incorporates and analyses data from utility ToU profile powers.

Four years of 30-minute profile data of 169 points were collected from the Eskom MV90 system. Smaller irrigation points not on the MV90 system with M&V profile power metering were also incorporated, although only data of 16 points could be incorporated. The combined 185 points used were distributed over the regions and provinces under question.

The data was processed and analysed through algorithms to provide the irrigation measuring point load factor on a monthly and annual basis in each region. On a single irrigation power supply point, there may be more than one pump connected and also multiple types of crops irrigated from one pump. Considering this, the aim of the study was to determine the typical load factor of an actual irrigation point and if the crop load factors could representatively, but conservatively compare with the study results. The study was further complicated since the evaluation team could only visit a very small percentage of the measure point evaluated. Thus, the irrigation point could not be associated to the number of pumps connected, what type of crops was irrigated and how many crop fields were irrigated

from these pumps. A load factor is commonly related to the pump motor kW installed capacity. With the study, the pump motor sizes under the irrigation supply point could also not be determined for most of the pumps. In order to determine pump actual load factors, another intuitive approach was required. Instead of installed capacity, the supply point maximum demand was annually analysed. The load factor was thus developed from the average annual demand and the annual maximum demand as in Eq. (4-1).

$$LF_{\text{Supply point}} = \frac{kW_{\text{Annual average demand}}}{kW_{\text{Annual maximum demand}}} \quad \text{Eq. (4-1)}$$

Table 4-4 lists the operational load factors determined over four years for Region-1 and Region-2 using Eq. (4-1). The data collected was of September 2008 to August 2012. This was divided into four years as shown in the first column of Table 4-4. Column two and three show the load factor established for each region over the four-year period. With the Eskom developed crop load factors in Table 4-3 and the regional annual average operational load factors determined as given in Table 4-4, these should be compared to evaluate if the Eskom developed crop load factors are indeed conservative. This was quite a daunting task with the limited amount of regional and MV90 pump station point information, crop data and resources available.

Table 4-4: Region-1 and Region-2 annual average operational load factors determined.

Period	Region-1 (KZN)	Region-2 (Mpumalanga)
Sep 2008 to Aug 2009	0.26	0.231
Sep 2009 to Aug 2010	0.257	0.228
Sep 2010 to Aug 2011	0.233	0.211
Sep 2011 to Aug 2012	0.267	0.251
Whole Period	0.249	0.226

The best approach, considering the information available and evaluation conditions, was to compare the Table 4-4 data with the Table 4-3 crop factors in previous sections by dividing these into seven factor ranges. These ranges are 0 to 0.1, 0.1 to 0.2, 0.2 to 0.3, 0.3 to 0.4, 0.4 to 0.5, 0.5 to 0.6 and 0.6 and above. Thus, the aim was to see what percentage of the Eskom developed crop load factors fall within these ranges. Also, the percentage of measured MV90 operation load factors were also evaluated according to these ranges. The bar charts in Figure 4-12 and Figure 4-13 compare the results of Region-1 and Region-2 following this approach.

Looking at Figure 4-12, 58.3% of the Eskom developed crop load factors conservatively fall within the 0.1 to 0.2 range with 8.3% even falling between the 0 to 0.1 range. Only 33.3% of the crop load factors fall within the 0.2 to 0.3 range while none is above that. With the MV90 measured operation load factors, almost 78% combined are in the 0.1 to 0.2 range or above. Only 22.1% are in the 0 to 0.1 range. In Figure 4-13 Region-2 has no Eskom crop load factors in the 0 to 0.1 range and 50% falling in the 0.1 to 0.2 range. The 0.2 to 0.3 and 0.3 to 0.4 ranges have 27.3% and 18.2% of the Eskom load factors respectively. The 0.4 to 0.5 range have 4.5% of the Eskom crop load factors.

The measured MV90 operation load factors have 11.5% in the 0 to 0.1 range with 33.6% in the 0.1 to 0.2 range and 32.4% in the 0.2 to 0.3 range. Combined, the measured MV90 operation load factors have 22.5% in the range 0.3 and above with some even in the 0.5 to 0.6 and 0.6 and above ranges. Considering both the Region-1 and Region-2 comparison, the Eskom developed crop load factors indeed do seem to be conservative. It would have been ideal if the crops irrigated under the MV90

measurement points could have been known. This would have allowed a more direct comparison of the Eskom developed crop load factor of the crops under the MV90 point and the measured results.

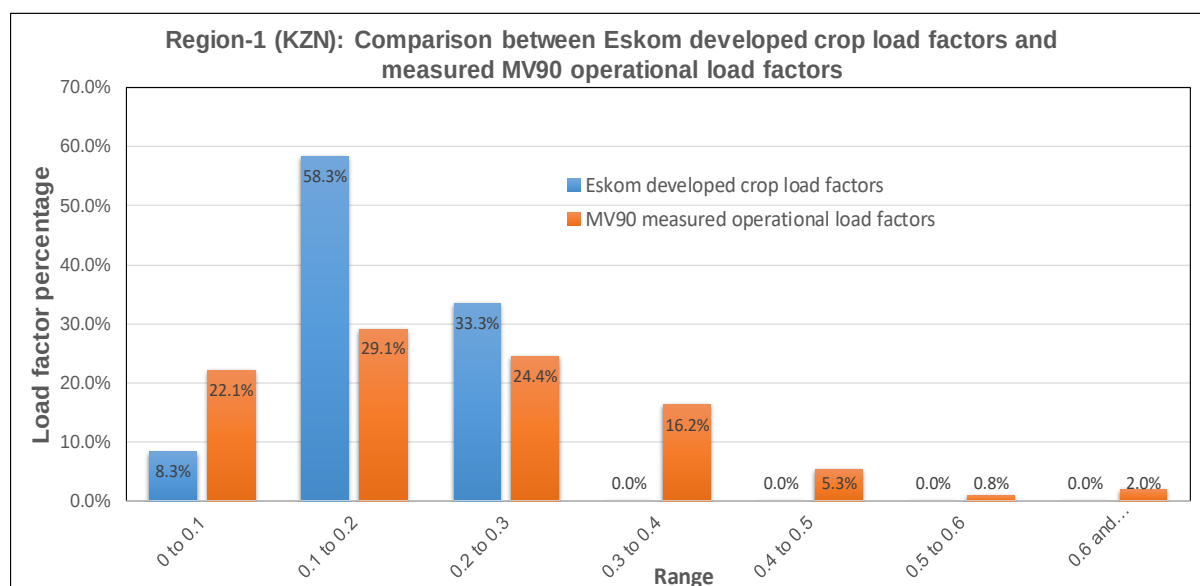


Figure 4-12: Comparing the four-year load factors with crop load factors of Region-1 (KZN).

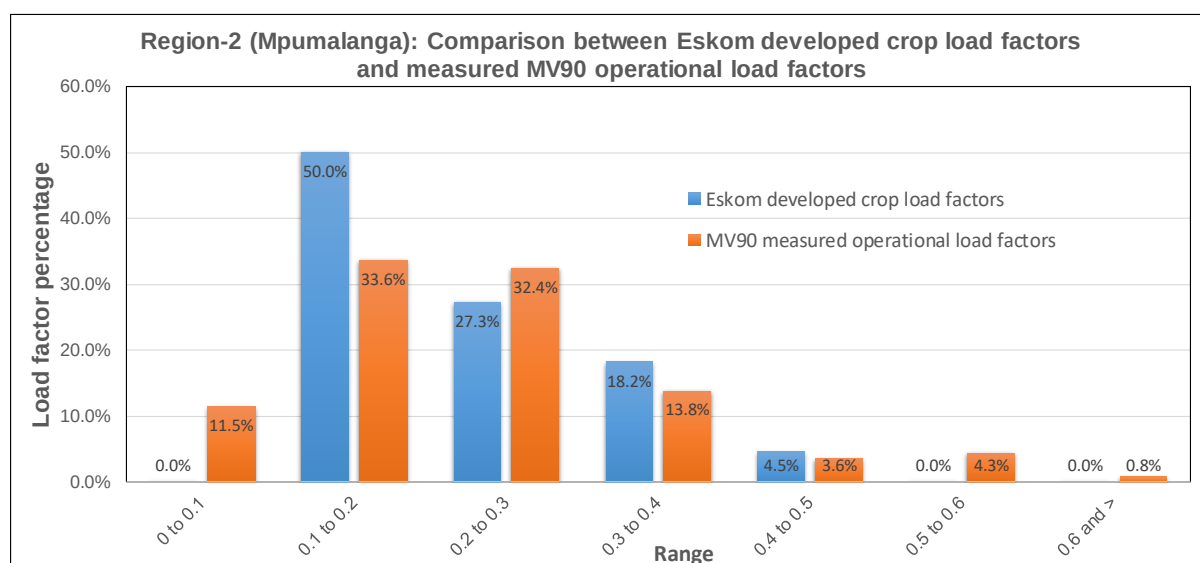


Figure 4-13: Comparing the four-year load factors with crop load factors of Region-2.

A more informative evaluation would also have been reached if the MV90 points could be connected to a precise area in each region. Hereby the typical crops planted in that area can be more closely evaluated and compared with the MV90 results. However, the location information was also unavailable. Thus, in conclusion, the Eskom developed crop load factor was verified to be conservative considering the information available. The following section discusses a unique method of how the actual total attained SPP savings can be quantified. Through this the Eskom developed crop load factor and the saving calculated from this can also be validated.

4.3.4.5 Validation of methodology through actual electrical grid impacts

Although ECMs under the SPP will result in probable short to medium term (one to three years) representative reductions, the question is if these will actually be achieved and how these impacts will

be sustained over longer periods? From other types of energy efficiency projects evaluated, it surfaced that interactive effects affected the real attained savings. An example of this is the dwindling of industrial and irrigation related DSM impacts over time and rebound effects of Eskom residential energy efficiency projects, and also CDM projects (Pandaram, 2006; UNFCCC CDM Executive Board, 2010). With residences, once a homeowner realises that the ECMs such as a SWH, geyser switch, geyser blanket or energy efficiency lighting reduces the electricity bill, the residents often tend to use more electricity on other household appliances. Thus, effectively cancelling any attained savings. This can also be observed in other sectors.

Normal M&V models do not always capture these effects since the measurement boundary is only around the equipment under the project scope. Here CDM methodologies have additional methods and calculations to account for interactive effects such as leaking and free riding (UNFCCC CDM Executive Board, 2010). It is imperative that programmes such as the SPP must have regulation, policies and other safeguards in place to avoid interactive effects. Old ineffective equipment must be collected and destroyed otherwise these will only be used at another place. Ultimately, the aim of SPP and other DSM initiatives is to reduce demand and overall achieve a kWh reduction that is visible on the electrical power grid and can thus validate the calculated savings. A unique regional and area top-down M&V method that quantifies what the actual impact is on the electrical grid due to SPP and/or other ECMs is presented and thoroughly discussed in Chapter 5.

4.4 NOVEL CALIBRATED IRRIGATION PUMPING ENERGY CONSERVATION SIMULATION MODEL

The SPP programme and the M&V evaluation method developed, focused on determining the annual energy savings. However, there is no indication on when energy is consumed by the pump during the day. Thus, it is not possible to evaluate if the demand reduction achieved occurs over the weekday peak periods. The Eskom energy advisors at that stage for reporting purposes, considered a probability approach that some percentage of the energy efficiency load reduction is occurring during the evening peak. It will be very valuable if there is a method which can much more accurately determine the evening peak reduction and can also show what peak load there is available for possible load shifting projects.

This will increase the value of an SPP approach, since it also could report on peak demand reduction and also assist project developers to identify good sites where peak switching can be implemented with energy efficiency projects. It would be even better if such a method could be used to evaluate the load shifting potential of pump stations in an irrigation area even before any project interventions started. This will further assist for strategized rollouts and project implementers focussing on areas and farms first where the best results can be obtained. This section designs a novel calibrated simulation model for establishing the available DSM peak load for shifting projects. This approach will provide the available load more accurately and thus allow adding load shifting to SPP and also provide an M&V method to determine the savings from the model.

4.4.1 Calibrated simulation model

Within an irrigation area, utility power profile data can be obtained from irrigation Ruraflex ToU points to exactly establish the available load of that point. Refer to Chapter 3 Section 3.3.4.2 Figure 3-4 for more detail. However, for the very large number of irrigation points which are under the Landrate, flat kWh usage rate tariff structure with disc type meters, no power profile data is available. The model uses data from hundreds of the Ruraflex points in an area over a two- to four-year period, or even longer if data and information is available, to establish two things:

- Operational load factor of each Ruraflex point (daily, monthly and yearly) as discussed in Section 4.3.4.4; and

- Daily, monthly and yearly load profiles of weekdays, Saturdays and Sundays.

The model further incorporates information of Landrate points and monthly energy consumption (from utility bills) of these. The model has different levels of evaluation that can be application specific and requires different levels of data inputs and data intensity requirements. This is further discussed in Section 4.4.2 with optimal inputs and variable confidence levels for different applications. The simulation model uses a BIG Data processor which performs data analysis and runs characterization algorithms. Figure 4-14 gives a flow chart showing the inputs for the BIG Data processor. From the middle left of Figure 4-14, irrigation point MV90 profile data, irrigation setup and crop information data of pump stations over different areas are collected. In each area the different farms with the pumps stations on each are specified. Then for each pump station, a specific list of data is collected as shown on the bottom right of Figure 4-14.

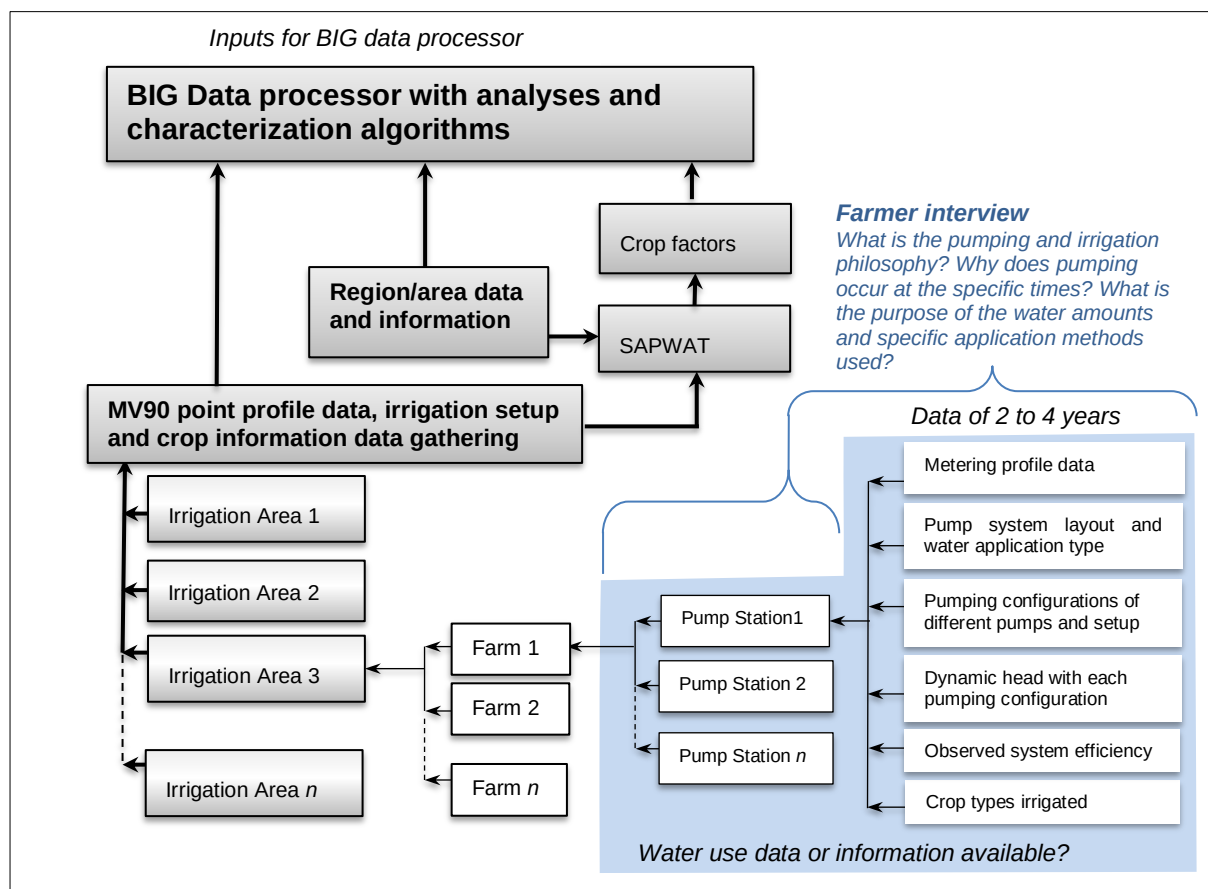


Figure 4-14: Flow chart showing inputs for BIG Data processor.

It is preferable that as precise possible data of two to four years of historic data is collected. This data includes information on the type of crops irrigated, pump system layout, pumping setup, pumping configurations and observed system efficiencies. The more data collected, the better a farm or pump station can be categorised, characterized and also benchmarked. As shown in top right of Figure 4-14, a key aspect is an interview with the farmer. The aim is to gather information and gain insight on the pumping and irrigation philosophy. Questions that should be asked include among other:

- Why does pumping occur at the specific time of the day and why pumping activities are performed on specific days of the week?
- What is the purpose of the water amounts (concerning over/under irrigation) and the reason a specific application method, such as flood irrigation, is used instead of other?

- Why is the specific pumping layout and system setup used?

This information can be very valuable to understand and characterise the pumping profile data. Only considering data and the system setup, the operations may seem inefficient and non-optimal but these might have practical reasons in reality.

4.4.1.1 BIG Data processor

With this, information of the area and region is collected on the typical irrigation practices, crops planted, water resources, soil types, area specific challenges and weather data. These assist to establish accurate crop water requirement factors through using the software programme SAPWAP as discussed in Section 4.3.4.2. Figure 4-15 expands the Big Data processor of Figure 4-14 and shows a flow chart of the internal processes and algorithms incorporated.

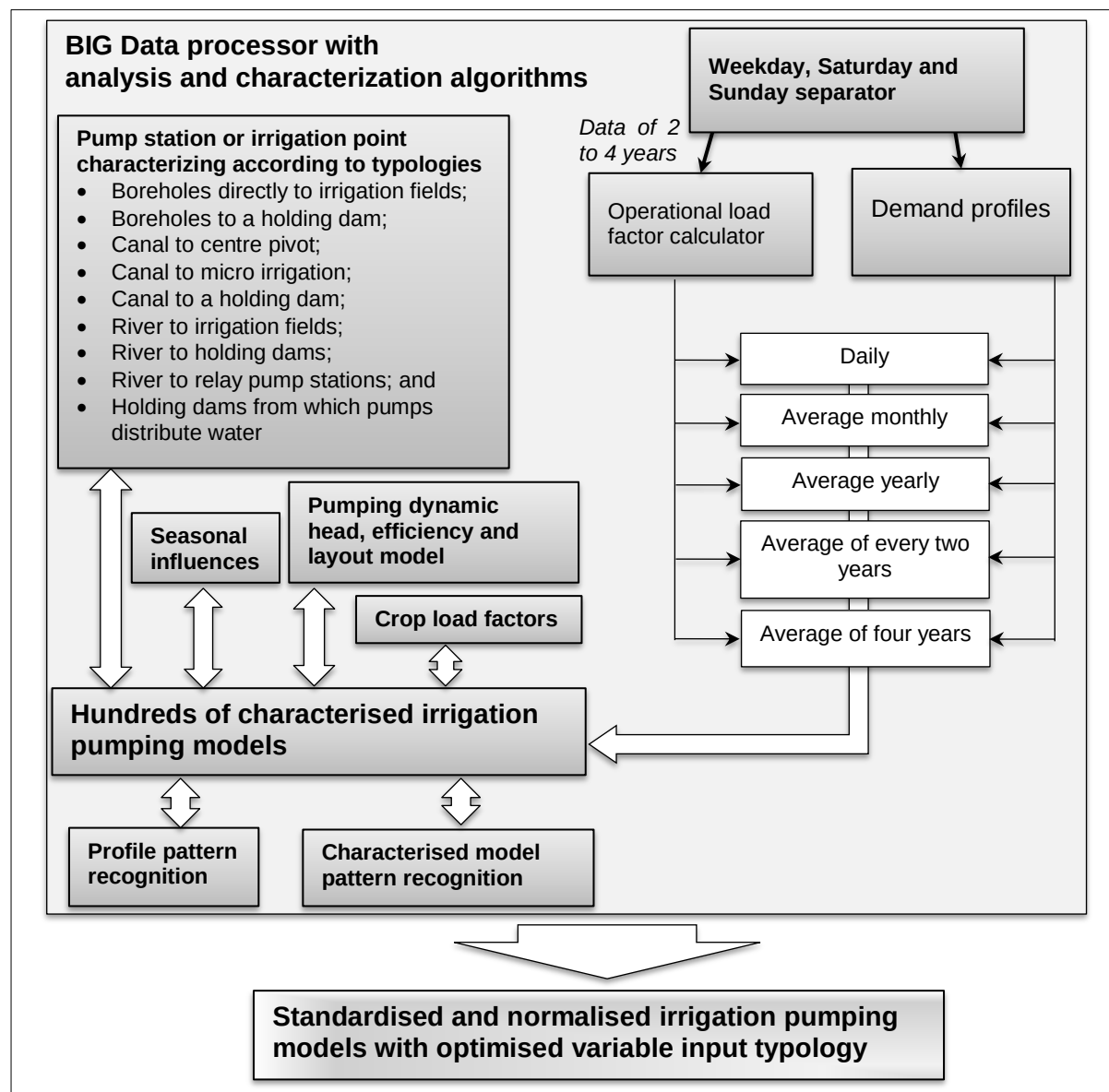


Figure 4-15: Flow chart of methodology pilot implementation.

The top left block in Figure 4-15 shows pump station or irrigation point characterization according to typologies that varies from borehole irrigation fields to pumping from holding dams. Each of these typologies can have a different type of pumping profile and different characteristics. This is touched on

in Section 3.9.1.2 of Chapter 3. The MV90 data from the irrigation Ruraflex point is run through a weekday, Saturday and Sunday separator which has a day type operational load factor calculator and demand profile output. This is shown on the right of Figure 4-15. These outputs are separated into daily outputs from which monthly, yearly, every two years and full four-year period averages are calculated.

An example of this is shown in Figure 4-16 with the average monthly profiles of a metering point from middle 2010 to middle 2012 for weekdays. It is imperative to be able to view how the average monthly profile is constructed from the daily demand profiles. An example of this can be found in Chapter 3 Section 3.3.6. This is important for data analysis since detail can become lost or obscured due to averaging.

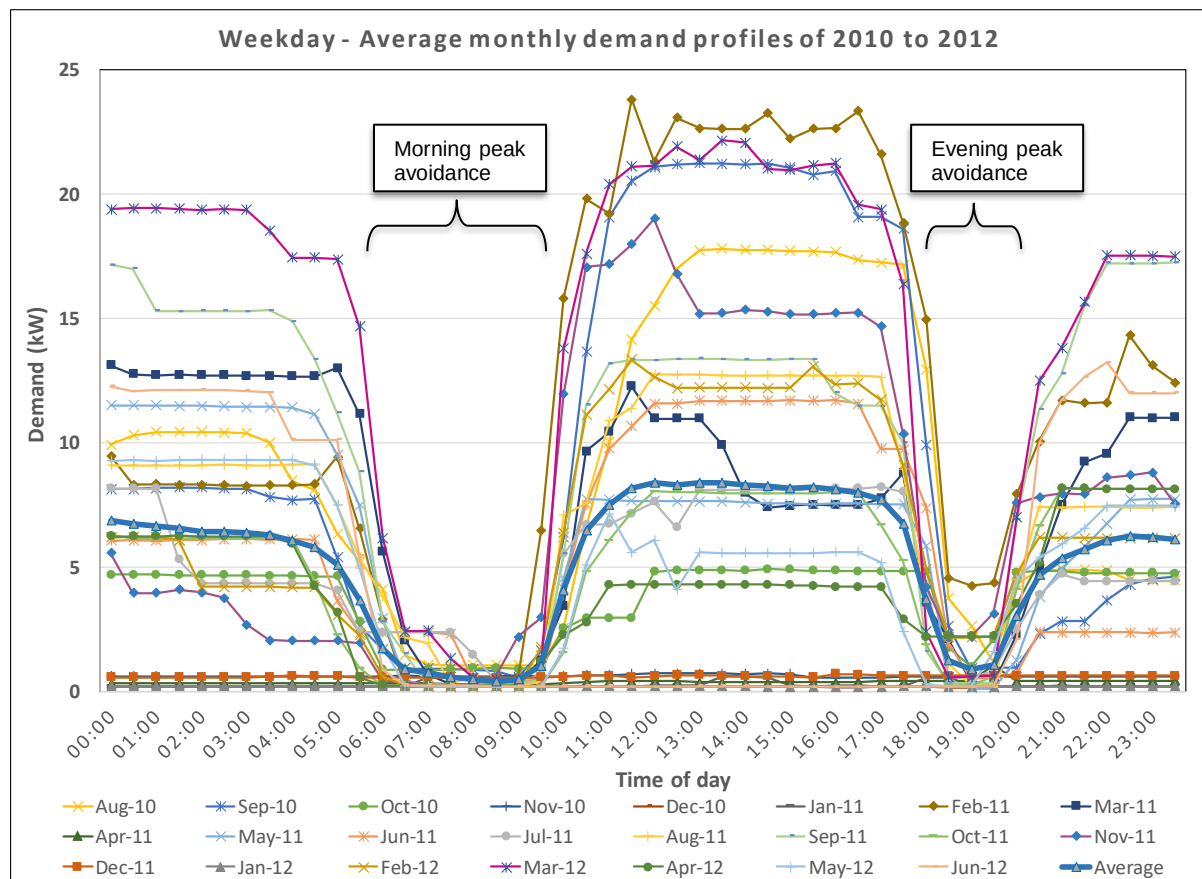


Figure 4-16: Graph of average monthly demand profiles.

In Figure 4-16 seasonal variation is clearly visible with months with high demand, medium demand and months where no pumping occurred. The farmer took advantage of the Ruraflex lower out-of-peak electricity cost and almost fully avoided pumping over the morning and evening peaks. Figure 4-17 provides a bar chart of the operational load factors for the period shown in Figure 4-16. As described in Section 4.3.4.4, the operational load factor is obtained from the demand profile data.

From this, even the installed capacity can sometimes be inferred. For instance, the data analysis shows the pump station under the metering point in Figure 4-16 has most probably a single 45 kW pump motor. This is not visible from the average monthly profiles in Figure 4-16, but from the daily profiles operation load this can be concluded. In Figure 4-17 some months have an operational load factor as low as 0.4% with the high demand months surpassing 20%. March 2012 had the highest operation load factor of 31.6%. When comparing the pumping profiles of February and March 2011 with that of February and March 2012, the significant difference year to year can be seen. In 2011, February has the higher

operation load factor while in 2012, March is higher. This emphasises the need for long periods of data, preferable four years and even longer. However, longer periods also have the disadvantage that it can capture data before significant changes have been made to an irrigation setup or crops that were cultivated in the past, but were seized.

Thus, it may reflect conditions that are not applicable yet. However, proper data analysis and a farmer interview will easily reveal this and such data can be excluded. Looking again at Figure 4-15, the site data and information collected, depicted in Figure 4-14, are used to characterise the irrigation point and develop standardised irrigation pumping models. This incorporates profile pattern recognition and characterisation model pattern recognition among other. From this, standardised and normalised irrigation pumping models with optimised variable input typology are developed as illustrated on the bottom of Figure 4-15.

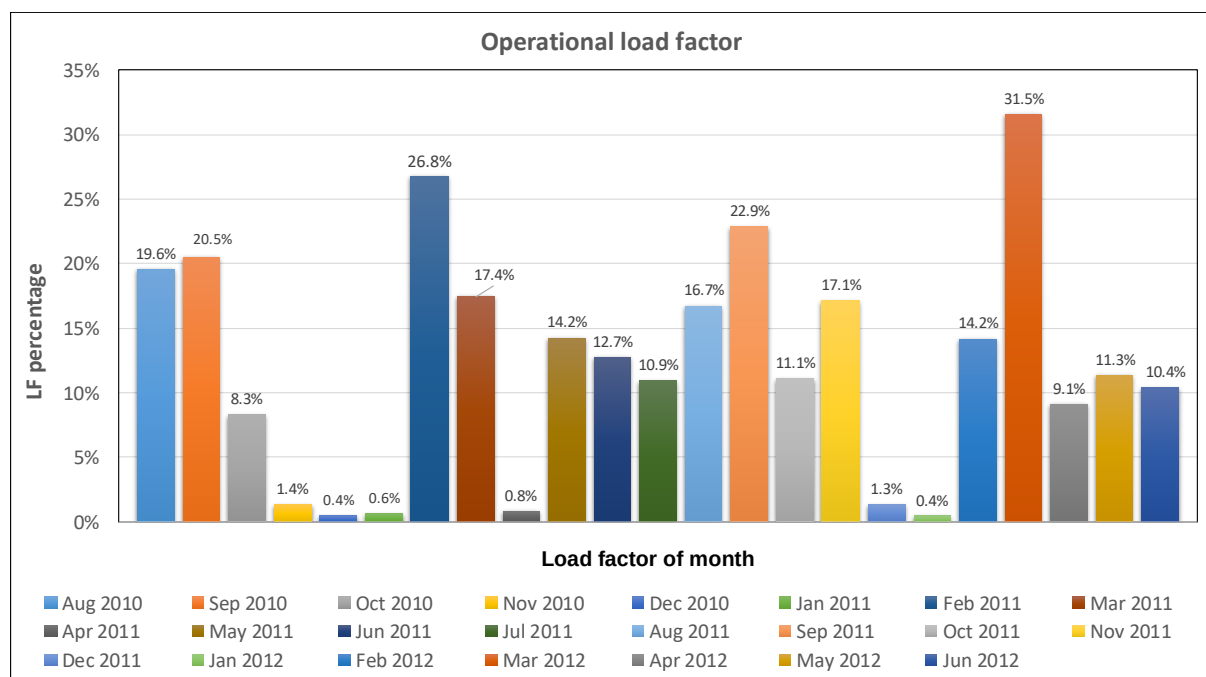


Figure 4-17: Bar chart showing operational load factors for each month.

The more MV90 irrigation points can be analysed the larger database can be built with characterised irrigation pumping models. Here the models can also be compared between areas or regions to investigate similarities and possible fusion of area models. It is important to note that the design of the standardised and normalised irrigation pumping models also focusses on an optimised variable input typology. Through this the system analyses the contribution of different variables and the effect it has on the accuracy of the models.

Hereby the key variables can be identified which are most relevant. This is important for an approach with stages of accuracy and confidence levels. Thus, a site with less a saving potential can have a least cost and least variable approach with corresponding conservative reporting on the expected margin of error. Section 4.4.2 elaborates on this. Figure 4-18 provides a demand profile analysis of six actual Irrigation Points (IPs) processed with the day type separator in Figure 4-15.

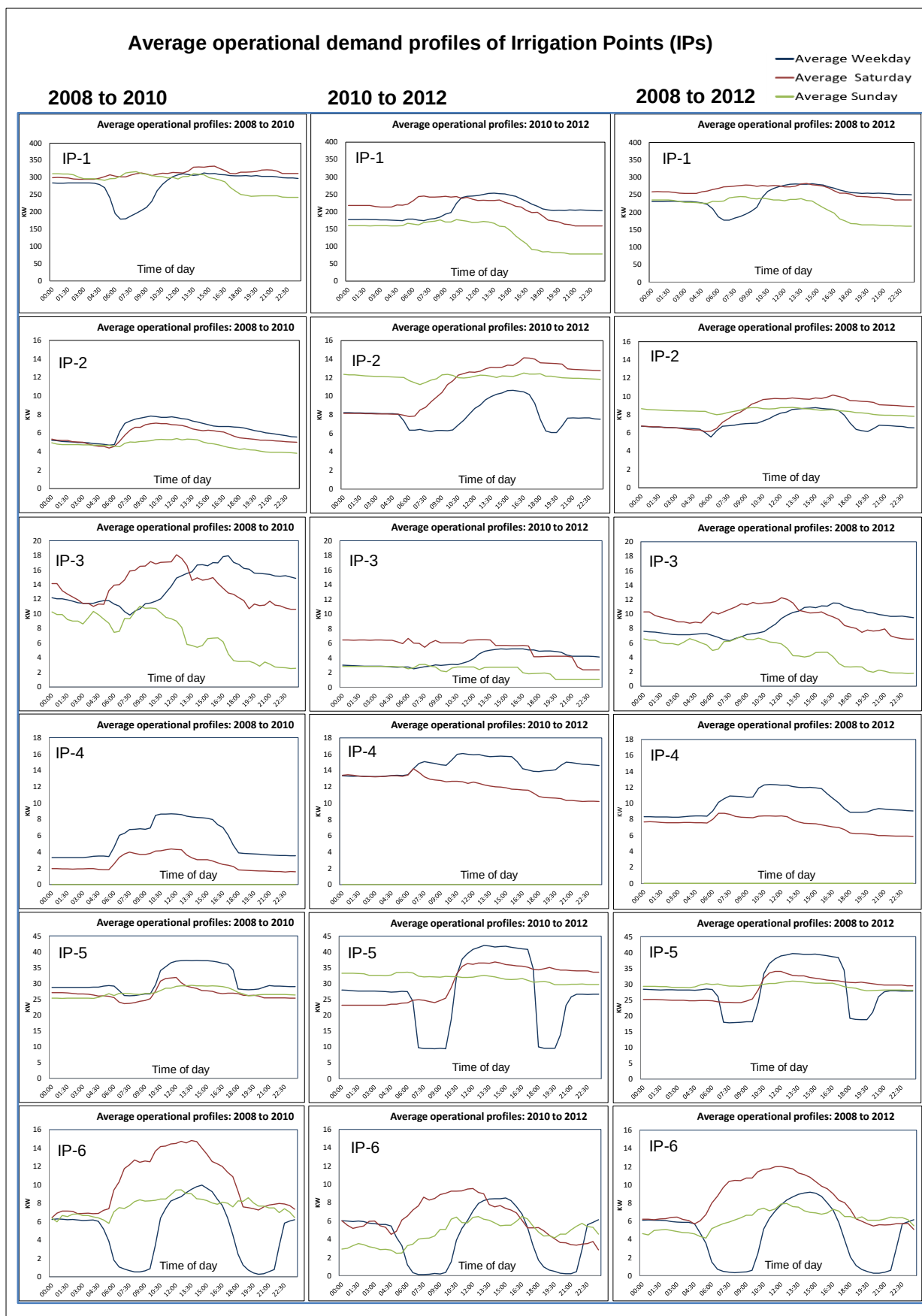


Figure 4-18: Demand profiles of six irrigation points with data of 2008 to 2012.

This provides insight in the vast differences seen with irrigation points. The graphs on the left of Figure 4-18 show the two-year average analysis of data from September 2008 to August 2010. The graphs in the middle show the same but for the period September 2010 to August 2012. The graphs on the right provide the average over the full four-year period. The three graphs of each metering point have the same y-axis scale so that profiles can be compared.

Considering irrigation point-1 (IP-1) on top of Figure 4-18, the period 2008-2010 shows higher pumping activity compared to 2010-2012. This is also the case with IP-3 and IP-6. However, the three other irrigation points show the opposite. During 2010-2012 IP-2 and IP-4 started with some peak switching while IP-5 mostly avoided the peak periods. IP-6 fully utilised the financial benefit of not pumping over the peak periods. Through analysing and characterising hundreds such irrigation points, a proper data base can be established with representative pumping models. From these, very important model components can be derived and developed, which include:

- Ruraflex mathematical models for determining and projecting available peak loads to which possible ECM project demand reduction can be connected;
- Deducing Landrate profiles from the Ruraflex demand profiles; and
- Generate a Landrate baseline model for a Landrate point for projecting available peak loads to which possible ECM demand reduction can be connected.

4.4.1.2 Ruraflex mathematical models

From the characterised model database, standardised and normalised Ruraflex profiles for different typologies can be developed. These models need to be mathematically interpreted for the next steps. On top of Figure 4-19 a standardised and normalised weekday Ruraflex profile developed from more than 50 irrigation points is shown. The demand profile is very interesting since very little demand reduction is observed over the morning and evening peak. Here peak avoidance is expected, due to the out of peak pumping financial benefit the Ruraflex provides, but not much avoidance did occur. It is very good news though for utilities and project implementers since there is a significant morning and evening peak load available for load shifting.

Thus, conservation projects and programmes can focus on both energy efficiency and load shifting. Due to the shape of the load profile shown on top of Figure 4-19, fitting a mathematical equation across the entire profile is not feasible. Even a sixth order polynomial equation does not properly fit the profile. Also, depending on application, it is not the entire profile that is important but rather certain subsections. A better approach is to divide the demand profile into the Ruraflex ToU periods as shown in the middle of Figure 4-19, which aligns with the colours of Figure 3-4 in Chapter 3 Section 3.3.4.2. The colours used in Figure 4-19 are a shade lighter though for transparent display purposes. The sections are:

- **ToU Section-1 (20:00 to 06:00)** green: Complete evening out of peak period. Instead of having two out of peak sections of 00:00 to 06:00 and 20:00 to 06:00 this is combined into one profile of 20:00 to 06:00;
- **ToU Section-2 (06:00 to 10:00)** yellow and red: The morning standard from 6:00 to 7:00 is too short to have a profile of its own and is therefore combined with the morning peak of 07:00 to 10:00;
- **ToU Section-3 (10:00 to 18:00)** yellow: Day standard from 10:00 to 18:00; and
- **ToU Section-4 (18:00 to 20:00)** red: Evening peak form 18:00 to 20:00.

The sections can be structured on any other way which is best fitting to the application and the outcome of the mathematical models. For irrigation purposes and the focus of this study, the above four sections proved to be the best approach. From these four ToU periods mathematical equations can be

developed as shown on the bottom of Figure 4-19. The four different graphs provide the profile of that ToU section, a fitted polynomial with a mathematical equation and also a R^2 value. Except for section-1, the fitted equations show proper R^2 values above 0.97. The section-1 evening peak equation R^2 value can be improved by increasing the polynomial order to 4 or 5. However, with the evening out peak period being lower priority, the lesser complicated equation will suffice.

Since most of the pumping activities occur during the day period (section-3), a higher order polynomial was used for maximum accuracy. With the shape of the section-2 profile, a fourth-order polynomial does not better fit the data points and the less complex third order polynomial function was used. The important evening peak (section-4) has a very proper fitting simple second-order equation.

The mathematical equations of the four sections are as follows:

– Section-1 (20:00 to 6:00): $f(x_1) = 4E05x_1^3 - 0.0014x_1^2 + 0.0096x_1 + 0.5695$ Eq. (4-2)

– Section-2 (06:00 to 10:00): $f(x_2) = 0.0006x_2^3 - 0.0066x_2^2 + 0.0311x_2 + 0.4338$ Eq. (4-3)

– Section-3 (10:00 to 18:00) $f(x_3) = -2E05x_3^4 + 0.0005x_3^3 - 0.0051x_3^2 + 0.0288x_3 + 0.59$ Eq. (4-4)

– Section-4 (18:00 to 20:00): $f(x_4) = 0.007x_4^2 - 0.0357x_4 + 0.5988$ Eq. (4-5)

The morning peak conservation possibilities from Eq. (4-3) can then be expressed as below in Eq. (4-6) and Eq. (4-7). The evening peak conservation potential can be similarly expressed. Eq. (4-6) shows the amount of energy that may be moved from the morning peak to the rest of the day and over the weekend. Note that the integral of Eq. (4-6) is only over 07:00 to 10:00, so that excludes the 06:00 to 07:00 standard period. Eq. (4-7) provides the important average demand impact that can be achieved by shifting the load.

$$\text{Energy moved (kWh)} = \int_{07:00}^{10:00} f(x_2)dx \quad \text{Eq. (4-6)}$$

With the:

$$\text{Average shiftable load (kW)} = \frac{\text{Energy moved (kWh)}}{\text{hours}} \quad \text{Eq. (4-7)}$$

It must be considered here that the mathematical equations of the morning and evening peak shiftable load can be simply replaced by an average value as is done in standard M&V ToU reporting. However, there are several advantages mathematical equations provide here:

- These provide detail over the spectrum of the ToU period, for instance showing the load variation during the peak period;
- These show the slope of when the ToU period starts and ends which provide detail of the load preceding and following;
- These show if there is a possible time shift in the ToU period. This happens when peak switching equipment is not time synchronised and peak switching starts late or early;
- These equations will be used standalone (without the other equations or the demand profile) – thus a unified R^2 is not necessary.

In order to further assist in the above, the equations can be designed so that the ToU periods slightly overlap. Thus, the following ToU section uses the last point(s) of the preceding ToU section. This will provide more detail in a single ToU equation. However, this is purely dependant on the requirement and output of the mathematical model. In this case, the model explained above and in Figure 4-19 is sufficient.

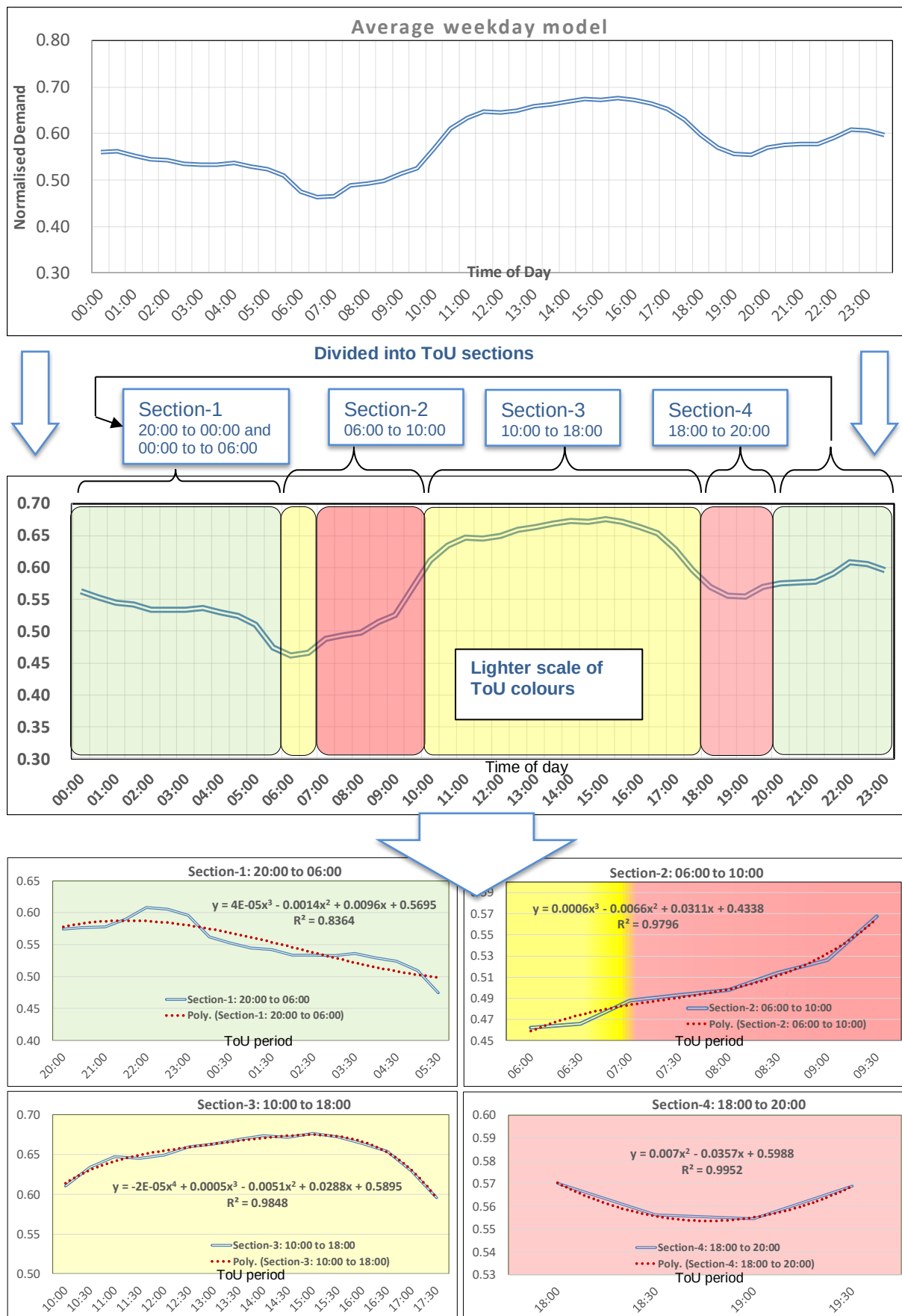


Figure 4-19: Mathematical interpretation of Ruraflex standardised models.

4.4.1.3 Key irrigation practice differences between a Ruraflex and Landrate points

Since Landrate points have no profile metering, only the monthly total power (electrical energy) use is available from the utility electricity bill. Thus, the sum amount of the monthly electrical power consumption is known but not what part of the day and what day type irrigation pumping occurred. Unfortunately, many irrigation points are on Landrate and these contribute a significant part of the irrigation load in an area. A unique method is required which can deduce Landrate demand profiles and pumping models from the Ruraflex demand profiles. Here the key differences between Ruraflex and Landrate points resulting from the tariff structure should be identified.

A Landrate irrigation point is not influenced at all by ToU billing and the irrigation pumping activities can solely be aligned to a farmer's preferences of irrigation scheduling or other pumping specific requirements or limitations. A Ruraflex utility point in contrast gives a financial incentive for a farmer to avoid peak periods and keep the load limited during the day and rather perform pumping activities during the night and over weekends. Ruraflex points also have a maximum demand rate which can influence a farmer not to run certain pump sets together to keep the maximum demand as low possible.

Here the important question though is if farmers actually make use of the financial benefits Ruraflex can offer. From analysis of many Ruraflex irrigation points, the following 10 tendencies were observed (some of these can also be seen in Figure 4-18):

- 1) Farmers totally ignore the Ruraflex financial benefits and pump whenever. Here farmers are only bound to the same pumping specific requirements or limitations as Landrate points;
- 2) No peak avoidance but lower overall weekday pumping with high weekend pumping;
- 3) Weekday daytime (06:00 to 18:00) pumping avoidance with high weekday evening pumping and also high weekend pumping;
- 4) Weekday daytime (and in some cases weekend daytime) pumping avoidance with high weekday evening pumping and also high weekend pumping;
- 5) Lower weekday daytime pumping, weekday peak period avoidance with high weekday evening pumping and also high weekend pumping;
- 6) High weekday and Saturday pumping activities with little to no pumping on Sundays. No peak avoidance;
- 7) Everyday irrigation cycle pumping, sinusoidal related. During the day there are two to three peaks and dips. These are not peak switching related, but rather changing of irrigation points;
- 8) High weekday and weekend pumping with only morning or evening peak partial avoidance;
- 9) Partial peak avoidance. Peak avoidance is then typically only done in seasons with a lower pumping demand. During seasons with high pumping demand, pumping occurs over the peak periods. This is usually an indication of limited irrigation pumping capacity and the farmer thus needs to pump day and night to keep up with crop water requirements; and
- 10) Full peak avoidance. This is normally associated with higher weekend pumping.

Considering the above, Landrate irrigation point pumping activities can directly relate to tendencies 1), 3), 6), and 7) since these are not Ruraflex benefit related. With tendency 3), the lower weekday daytime pumping can be Landrate related due to crops and certain advantages of irrigating during the night. However, if the lower weekday daytime pumping is followed with higher weekend pumping, it is Ruraflex benefit related and not Landrate related. Here it is important to notice that the practice of the 10 tendencies may differ from area to area. In some areas there might be more focus on Ruraflex benefits and in other areas less.

4.4.1.4 Landrate demand profile simulation model

With the key Landrate and Ruraflex differences and irrigation pumping tendencies specified, a Landrate simulation model can be developed through the following steps:

- Step-1: Characterise the Landrate pumping point setup according to the method and typologies described in Section 4.4.1.1 and Figure 4-15;
- Step-2: Obtain the standardised Ruraflex pumping profile models for each typology from the database; and
- Step-3: Search in the database for specific Ruraflex points that follow tendencies 1), 3), 6), and 7) listed in the previous section.

The advantage of tendencies 1), 3) and 6) Ruraflex points, is that the demand profiles of these can be used in most cases to directly model a Landrate irrigation point profile. Since there might not be enough (or none at all) of such points in each pumping typology, the profiles of these points may need to be combined with the Ruraflex pumping profile models of Step-2. By doing this the probable Landrate pumping profile can be developed.

The standardised and normalised weekday profile of Figure 4-19 is shown on the top graph in Figure 4-20 with the normalised Saturday and Sunday profiles. In order to provide a model development example here, the characteristic of the typography model (river to irrigation fields chosen in this case) will be adjusted accordingly to generate the expected Landrate normalised demand profile. From the analysis of the typography, the simulation model does the following adjustments to simulate a Landrate irrigation point here:

- The weekday's peak period avoidance dips are filled with energy from the rest of the day and from weekends as shown on the bottom graph. The high night pumping load should be lowered as can be seen on the far left and far right of Figure 4-20. This creates a new weekday profile;
- The weekday profile needs to be scaled upwards since less pumping will occur over weekends and this needs to be moved onto the weekday profile. See Figure 4-20 and Figure 4-21; and
- Consequently, the Saturday and Sunday profiles will be adjusted downward for the energy that moved to the weekday profile as shown in Figure 4-20.

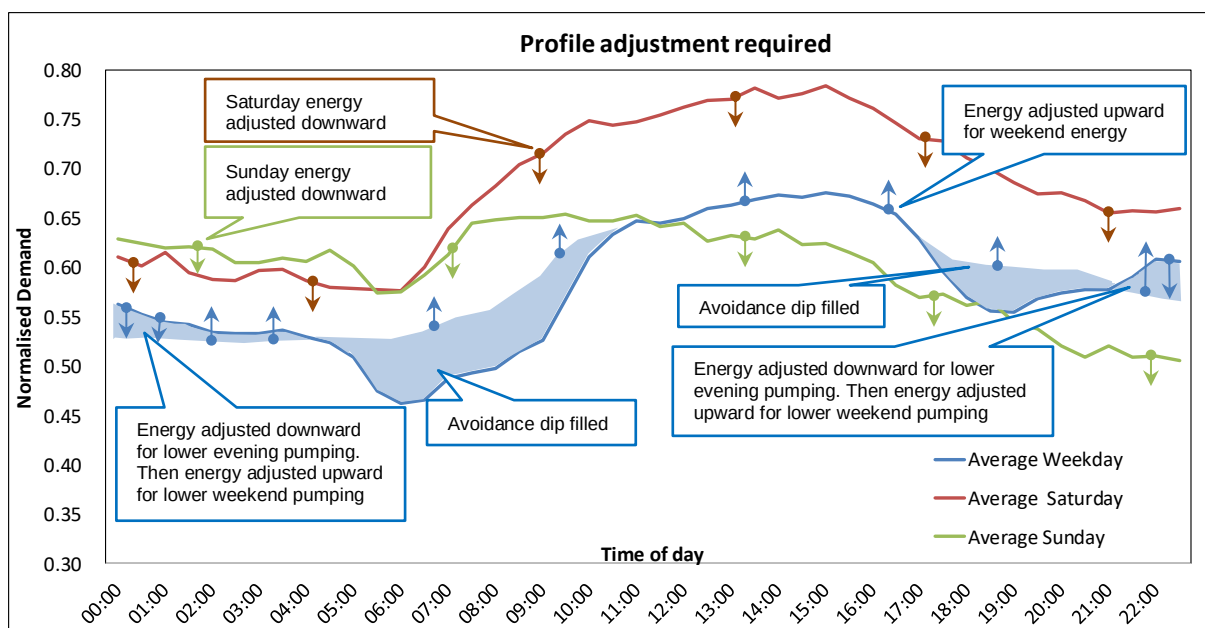


Figure 4-20: Ruraflex to Landrate profile adjustment.

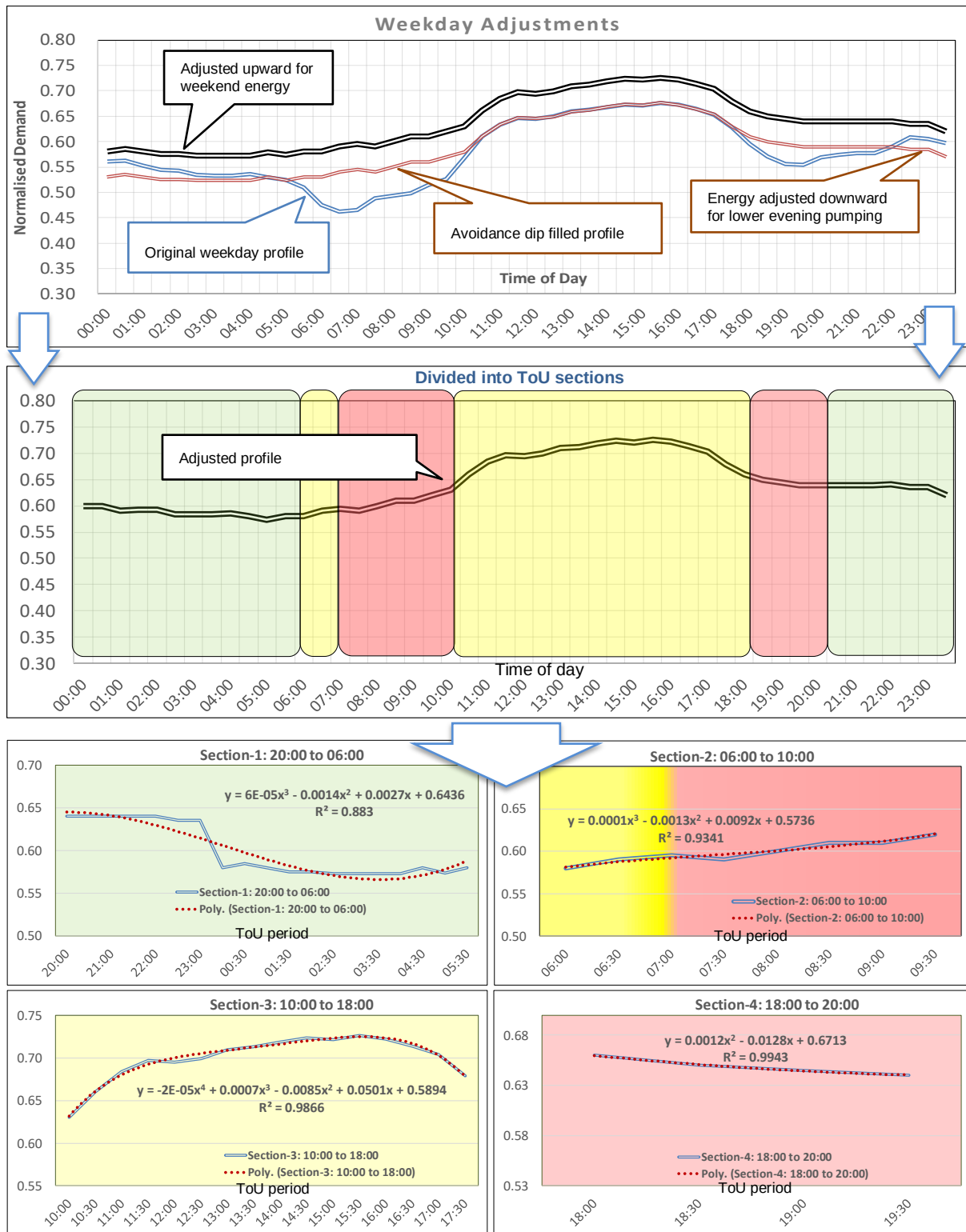


Figure 4-21: Mathematical ToU interpretation of generated Landrate weekday profile.

The top graph in Figure 4-21 shows the original normalised Ruraflex profile, the avoidance dip filled with lower evening pumping profile, and the final upward adjusted profile for weekend energy. The mathematical equations, Eq. (4-2) to Eq. (4-5) of Figure 4-19, are changed due to the profile adjustment to provide new equations as seen in Figure 4-21. The new mathematical equations of Figure 4-21 are given in Eq. (4-8) to Eq. (4-11) as:

- Section-1 (20:00 to 6:00) adjustment:
 - (Eq. 4-1) adjusted to $f(x_1) = 6E05x_1^3 - 0.0014x_1^2 + 0.0027x_1 + 0.6436$ Eq. (4-8)
- Section-2 (06:00 to 10:0) adjustment:
 - (Eq. 4-2) adjusted to $f(x_2) = 0.0001x_2^3 - 0.0013x_2^2 + 0.0092x_2 + 0.5736$ Eq. (4-9)
- Section-3 (10:00 to 18:00) adjustment:
 - (Eq. 4-3) adjusted to $f(x_3) = -2E05x_3^4 + 0.0007x_3^3 - 0.0085x_3^2 + 0.0501x_3 + 0.59$ Eq. (4-10)
- Section-4 (18:00 to 20:00) adjustment:
 - (Eq. 4-4) adjusted to $f(x_4) = 0.0012x_4^2 - 0.0128x_4 + 0.6713$ Eq. (4-11)

The adjusted weekday Saturday and Sunday profiles are shown in Figure 4-22. This simulates the operations of a Landrate irrigation point in this typography. Eq. (4-8) to Eq. (4-11) represent the standardised and normalised irrigation pumping mathematical model within this Landrate typography. Now, the process needs to be repeated in order to establish mathematical models for each irrigation typography observed in an area or region.

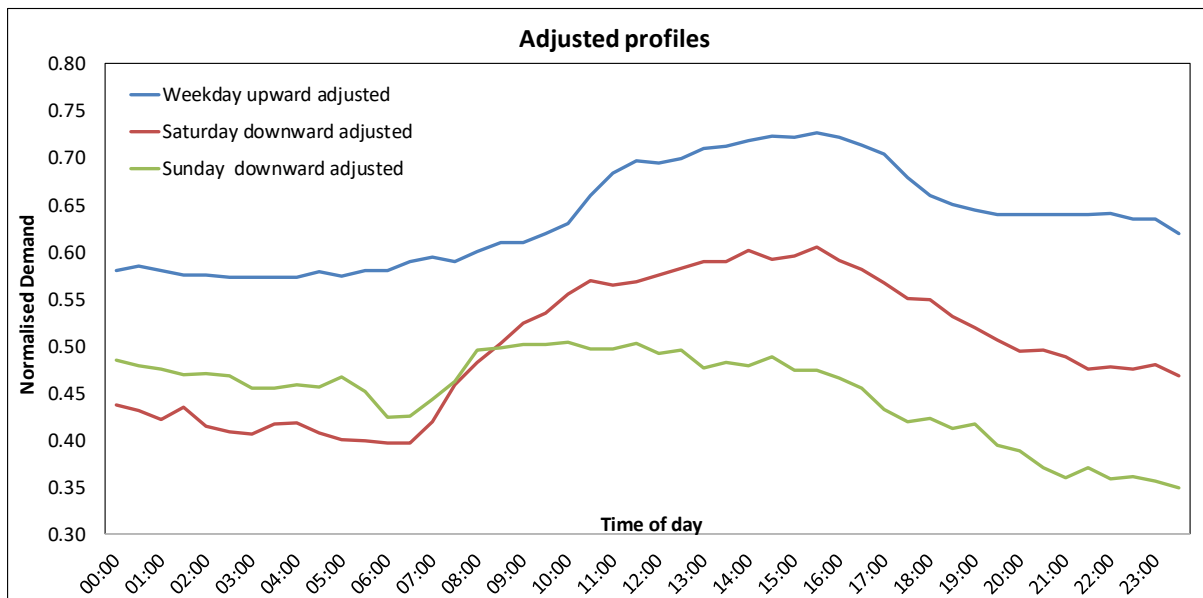


Figure 4-22: Adjusted normalised profiles to simulate a Landrate irrigation point in the chosen typography.

4.4.1.5 Applying the Landrate demand profile simulation model

With the mathematical models of the irrigation typographies (or only the most relevant ones) developed, it can be applied to real word situations. Figure 4-23 describes the process for generating a simulated Landrate average weekday, Saturday and Sunday operational profile baseline model for a specific Landrate point. The information that should be gathered for the most accurate simulation is listed in the top left of Figure 4-23. All this information may not always be available and therefor the model allows variable accuracy with degrees of full, optimal and least data input scenarios. Refer to Section 4.4.2 for a further elaboration on this. The data and information required are mostly the same information needed for a Ruraflex point as shown on the bottom left of Figure 4-14 at the beginning of Section 4.4.1. Here the exception is that for a Ruraflex point demand profile data is obtained from the utility AMR system

(Eskom MV90), while with Landrate points the monthly consumption data is retrieved from the farmer's utility point bill. Such monthly consumption data may also be available from the power utility system. A very valuable insight on the Landrate irrigation point can be obtained from an interview with the farmer. Here the farmer can be polled on what the farm's water pumping requirements are and what irrigation philosophy is used.

Questions can be asked on when do pumping activities normally occur and what is the purpose of the water amounts and specific application methods used. This can be very informative to classify the irrigation point, its energy efficiency potential and also the practicality of energy efficiency conservation implementation at that Landrate point. Some irrigation approaches may seem to be inefficient from a stance, but there can be practical reasons for the chosen approach.

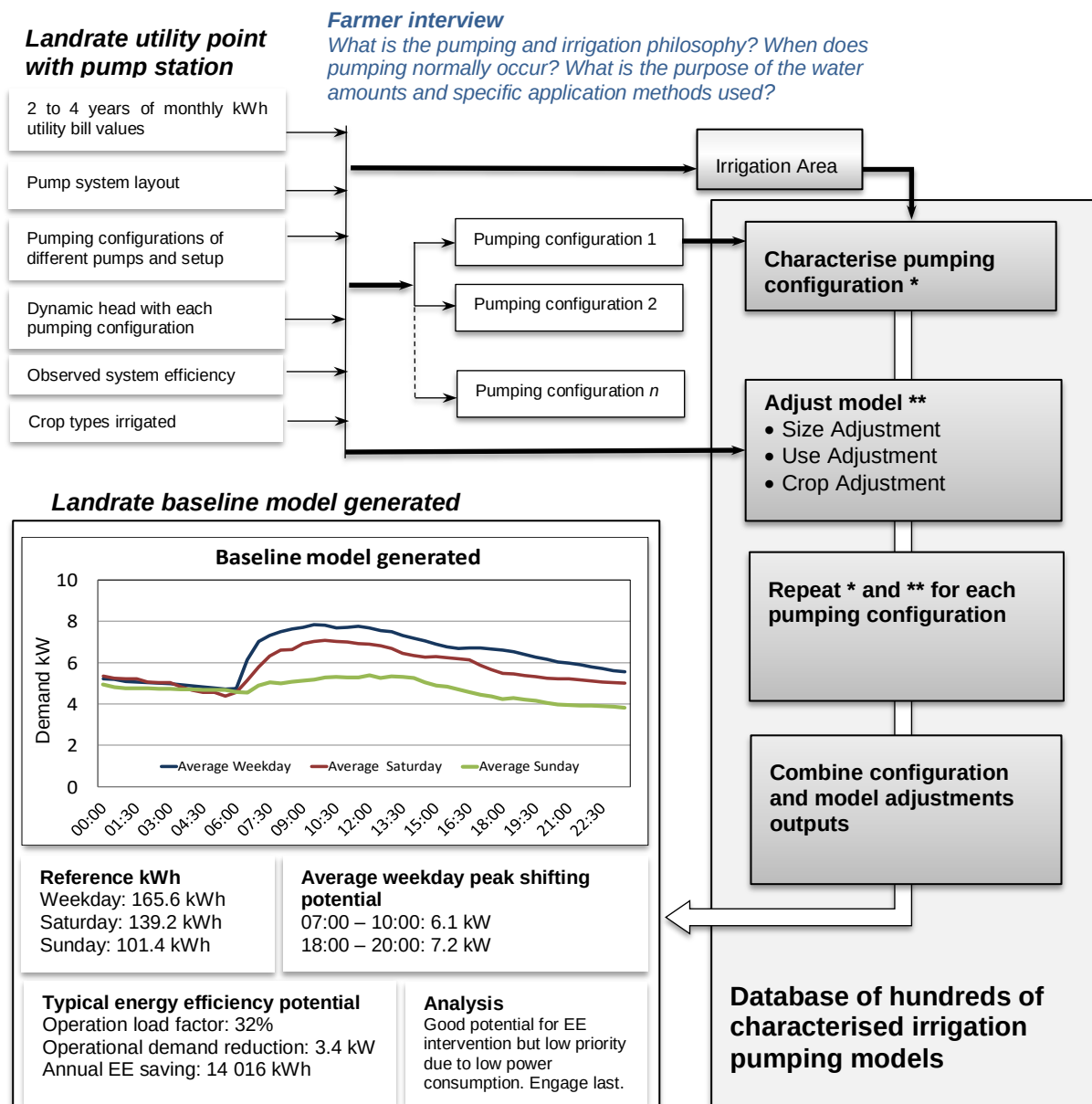


Figure 4-23: Flow chart showing application of the demand profile simulation model.

With the information provided, different pumping configurations can be identified on the irrigation pump(s). This, with other inputs and area information of where the farm is located, are then used for characterization. The characterised model can then be adjusted according to size, use and crop

requirements as shown on the right of Figure 4-23. This should be repeated for each pumping configuration and other pumps in the pump station if applicable. An important aspect here is that the Landrate kWh billing value is the total of all connections (irrigation and non-irrigation) below that point. See the following Section, 4.4.1.6, on how the model is applied on these points. The outputs of each configuration must then be combined to generate the Landrate baseline model output as shown in the block on the bottom left of Figure 4-23. The generated output provides the following information:

- Simulated Landrate average weekday, Saturday and Sunday operational profile baseline model;
- Reference kWh for each day type according to the profiles - the reference kWh is the surface area (energy) under the average demand profile;
- Average weekday peak shifting potential;
- Typical energy efficiency potential; and
- Irrigation point analysis and recommendation. Does the point have a good potential for an energy efficiency intervention and what should its engagement priority be? This can assist project implementers with the focus on the Landrate points with better potential.

4.4.1.6 Application to Landrate points with multiple pumps and non-irrigation loads

The power connections to a Landrate billing point may consist of multiple pumps and even be non-irrigation loads. The question at hand is what amount of the Landrate billing kWh value was used by which load? For irrigation pumps, crop load factors can be used to consumption classify each pump by the crops it irrigates. From these classifications an estimated balance can be developed of what pump used what amount of power. Here inputs from the farmer will be valuable on the typical use of the pumps.

Non-irrigation loads can have several challenges since these may either be fairly constant, like security lighting loads, or totally vary according to season such as packing houses. Depending on the size of the non-irrigation load it may either be ignored or an estimated usage factor should be determined. Here inputs from the farmer will also be valuable on the typical use of the non-irrigation loads. An estimation can be done through handheld measurements and seasonal use approximations. Months with no pumping activities may assist to determine the consumption of non-seasonal loads. Depending on the connected loads, intuitive methods may be required to consumption classify the specific load. With this done, the non-irrigation load can be brought into the Landrate point estimated energy balance of what load consumes what amount of power.

4.4.2 Unique optimal inputs for different application levels

The simulation model discussed in the previous section shows that a large amount of information detail and data inputs is required. Since a simulation model is purely dependant on the type and quality of the information given as inputs, the more information and the better accuracy thereof is of utmost importance. However, information is not always available or may not be very accurate due to different reasons. Such reasons may include among other:

- Shortage of funding to gather the required information;
- Shortage resources or knowledgeable resources to gather the required information;
- Shortage of time to gather information;
- Cooperation from farmers to provide reliable information; and
- Lack of historic information of specific irrigation points.

As an example, the load factor validation analysis discussed in Section 5.3.2 followed the specific approach due to a lack of information available. With all things taken in consideration, that was the best approach to follow and intuitively made the best use of what was available. It is important to notice here again that irrigation projects and programmes may be very challenging and gathering enough relevant information can be exceptionally time consuming and costly.

As mentioned previously, analysis of many irrigation points can reveal that certain pieces of information have a larger contribution to the model and also the accuracy thereof. With project limitations considered, an optimal input model allows variable accuracy with degrees of full, optimal and least data input scenarios. With this, there may be different applications which do not all necessitate high confidence levels. Applications may include the below in typical order of ascending confidence level requirement:

- **Level-1: Area potential scoping study with high-level analysis.** In this scenario a quick high-level analysis of an irrigation area for power load and conservation (energy efficiency and load shifting) possibilities is considered. If an area shows potential from this high-level analysis, deeper investigation can be done. Level-1 may include:
 - A top-down approach using key transmission points mentioned in Section 4.3.4.5 and described in Chapter 5;
 - And/or sample Ruraflex points with data obtained from the utility. Here bullet two of Level-2 may be required;
 - Discussions with Irrigation Boards, equipment suppliers and some farmers to get a feel of the overall irrigation water use and efficiency in that area; and
 - Breakdown from irrigation boards or other resources on the amount of irrigation farmers in the area. A simple Google satellite view as shown in Section 5.2 of Chapter 5 can already reveal much information on the amount of irrigation activities.
- **Level-2: Area potential scoping study with deeper analysis.** This will typically follow Level-1 if the area has shown potential. Here more attention is given and more detail gathered. This is useful to confirm the Level-1 findings and to get a better perspective on the area attainable savings and conservation implementation challenges.
 - Obtain a breakdown from utility or other possible source (local electrician, pumping equipment suppliers, Water Board or Farming Union) of the billing tariff structure in the area. It may be that there are hundreds of small irrigation points and thus very little may be on Ruraflex. This is both good and bad; more Landrate points will most probably result in a larger peak load shifting potential but a small amount of Ruraflex points to develop the simulation model from;
 - Analysis of data from as many possible Ruraflex points obtained from the utility to reveal the overall pumping load and available peak period load;
 - Visits to a sample of farms on Ruraflex to evaluate the energy conservation potential and relate the irrigation activities to the profile data obtained from the utility;
 - Here a sample of Landrate points can also be included to compare the conditions (pumping activities, setup, configuration, crops etc.) of Ruraflex and Landrate points; and
 - During these site visits investigate the barriers and challenges to implement conservation projects and programmes.

- **Level-3: Identification of irrigation point project and programme conservation rollouts.** This follows Level-2 and investigates the possibility and practicality of irrigation point project and programme conservation rollouts. It is important to also have some irrigation point in an area that undergoes project level M&V on conservation projects, especially on Landrate points. This assists in simulation model calibration. See Section 4.4.4. With Level-3 more information is gathered on specific points as listed with Level-2. With this, historical power demand and usage with information from sample Landrate points are gathered to establish the first Landrate simulation models. This can provide further insight on the available loads for ECMs.
- **Level-4: ECM programme rollouts with low confidence levels.** Programme ECM rollouts can be done with limited information but reporting conservatively. Thus, lower knocked-down savings can be claimed. See Section 4.4.3.
- **Level-5: ECM programme rollouts with fair confidence levels.** Programme rollouts with more information than Level-4 but still reporting conservatively. Higher savings can be claimed due to better confidence levels than Level-4.
- **Level-6: ECM programme rollouts with high confidence levels.** Sufficient information and detail are gathered to provide models with high confidence levels. Confidence levels may further be boosted with random sampling to verify savings (can be done through several ECM projects with conventional M&V in the area) and calibrate the models. See Section 4.4.4.
- **Level-7: ECM Projects.** Here full project level M&V (see Chapter 3) can be done on larger ECM irrigation points, sampled points or even wider. Full M&V may provide very high confidence levels and thus maximum claimable savings.

4.4.3 Variable confidence levels and conservative reporting

A proper M&V variable confidence level model (accounting for cost versus accuracy) can align M&V to the most correct and effective approach for a specific irrigation efficiency improvement project or programme. With some ECM projects or programmes, even a low confidence level such as 50% may be appropriate conditional to the conservation reporting objectives and the monetary worth of the reduction achieved (Steyn, 2014).

Consequently, the claimable reduction should be reported conservatively. Thus, from the confidence level, it is certain that at least 50% of the determined saving was achieved allowing only that portion to be claimed. Although this approach may not appear ideal and much attained reductions cannot be claimed, it can provide reliable enough M&V for an incentive mechanism. It enables the quantification of conservation projects which was not possible before due to high M&V costs. Where the importance or monetary worth of a possible reduction justifies higher M&V cost, more detail may be gathered or project level M&V methods providing higher accuracy and better confidence levels can be applied. Applying properly developed M&V methods, may allow a high confidence level with a low error margin on programme ECM rollouts with application Level-6 and even Level-5 (see previous section).

This brings much flexibility with optimal inputs for simulation models and the application levels in programme level M&V. With project level M&V a critical aspect is metering and data gathering equipment. In many cases, the cost of these is so high that it is more than the rebate from the incentive programme. The novel irrigation pumping energy conservation simulation model developed here provides a variable accuracy and confidence level approach, which can provide a cost-effective M&V approach for each type of scenario. Here the South African National Accreditation System (SANAS) TG50-2 document provides valuable guidelines for reporting uncertainty in M&V (SANAS TG50-2, 2017).

4.4.4 Model calibration and model refinement

The approach followed through using Ruraflex irrigation points for model development also realised that continuous monitoring and calibration are done by the simulation model. Since Ruraflex points have billing class utility metering, these inherently have calibrated power metering. Thus, the simulation model can continuously be adjusted against real-world data that is continuously gathered. This continuous stream of input data can also be used to refine the model over time.

Another very useful method for cross verification, model calibration and model refining is to have some Landrate irrigation points in the area to undergo full project M&V (and thus full metering). Here well-developed sampling models can greatly minimise sample sizes, although these will still provide a proper confidence level. See Chapter 2 Section 2.9 for literature and Chapter 7 Section 6.5 on a design method. The simulation model can also be used to simulate the expected baseline profiles and expected saving for the full M&V Landrate points. The effectiveness of the simulation model may thus be directly scrutinised and improved where required.

4.5 CONCLUSIONS AND DISCUSSION

The SPP has very unique M&V requirements, which make normal M&V approaches infeasible. The biggest challenge is the absence of continuous metering, but still having to obtain representative and accurate results. Unfortunately, the associated M&V cost significantly rises with accuracy. With the healthy M&V practice of reporting on conservative savings, an incentive programme can compare M&V accuracy and cost against the additional savings that may be claimed.

A new and unique M&V methodology was required to quantify ECM impacts under the SPP and other similar incentive-based programmes. The chapter therefore focused on the development of a novel M&V methodology for this purpose. Methods and techniques were designed to quickly determine conservative, but representative ECM load reductions without continuous profile measurement. The methodology design was verified by aligning all methods and procedures with international M&V protocols and standards. Further, development was done to assess long-term kWh and average load reduction impacts on irrigation pumps. This was broadened to also address pumps irrigating multiple crop areas and different kinds of crops through crop load factors. For verification, an alternative method was developed and a study was performed to evaluate the crop load factors calculated for a certain area. Also, a regional top-down M&V approach was touched on (this is focussed on in Chapter 5) which can be used to quantify the actual energy efficiency and load reduction on the electricity grid.

The Eskom SPP and the M&V evaluation method focused on determining the annual energy savings. However, there is no indication on when energy is consumed by the pump during the day. Thus, it is not possible to evaluate if the demand reduction achieved occurs over the weekday peak periods. A novel calibrated simulation model was designed for establishing the available DSM peak load for shifting projects. This approach can provide the available load accurately and thus allows load shifting to be added to the SPP and also provides an M&V method to determine the savings from the model. Two very effective components for programme level M&V are the incorporation of variable confidence levels and conservative reporting. This allows for much flexibility and inclusion of projects which under conventional approaches would not be worthwhile due to high M&V costs. Here a project is only eligible to claim reduction corresponding to the confidence level. Thus, project participants are certain that at least the calculated impact was achieved and any monetary reimbursement or rebates would be for true achieved savings. Where the monetary value justifies more accurate M&V in order to achieve a better confidence level, higher conservation impacts can be claimed.

Chapter 5

Regional Level M&V

Chapter 3 focussed on load shifting and energy conservation project level Measurement and Verification (M&V), while Chapter 4 detailed programme level M&V of standardised efficiency rollouts. When large-scale energy conservation programmes or Demand-side Management (DSM) initiatives are implemented, it is very important to see the effect of these on a higher area or regional level. In many cases, the combined M&V results of projects and programmes show considerable impacts. However, the impact reported by this bottom-up approach cannot always be observed at a higher level. Thus, the regional power grid does not experience the same reduction as the project level and/or programme level M&V reports.

This chapter presents a novel regional level M&V methodology which addresses this problem and allows M&V assessments and impact validation at a higher level. A regional level M&V methodology allows for tracking the sustainability of savings over time, long after project or programme level M&V has ceased. Such a top-down approach also has the advantage of being able to provide results much quicker when compared to project level and/or programme level M&V through a bottom-up method.

However, a regional level M&V approach can be very challenging and complicated, requiring intuitive methods to be successfully implemented and executed. This chapter provides a unique case study in which a regional M&V approach was implemented. This case study did not only draw an M&V boundary around a region, but the entire Western Cape province of South Africa. By presenting this case study, the process involved with regional level M&V is demonstrated, the associated pitfalls and challenges are discussed and are solutions provided.

Chapter related publications and conferences

- ❖ Storm, M.E., Gouws, R. and Grobler, L.J. 2018. Novel measurement and verification of irrigation pumping energy conservation under incentive-based programmes. *Journal of Energy in Southern Africa*, 29(3):10-21. ISSN 2413-3051.
- ❖ Storm, M.E., Dalglish, A.Z. and Grobler, L.J. 2007. Methodology Developed to M&V the Total Impact of the Accelerated DSM Initiative Implemented in the Western Cape. *International conference on the Industrial and Commercial Use of Energy conference proceedings, Cape Town*, pp. 61-68. ISBN 0-9584901-7-1.

5.1 INTRODUCTION

A regional level M&V approach is a unique method that can provide several advantages in areas where large-scale conservation programmes or DSM initiatives are implemented. Such an approach is able to evaluate if the impacts achieved by these programmes and initiatives actually make a difference on a higher level on the electrical power grid. Figure 5-1 shows an example irrigation region where DSM initiatives were implemented. In this example, some of the larger farms were engaged with DSM projects first and project level M&V was performed on these. Later a standard energy saving technology retrofit rollout was done over the rest of the farms through a DSM programme. Programme level M&V was performed on these other farms. A regional impact assessment through a bottom-up approach will add the results of the farms with individual project level M&V and the results of all the farms with programme level M&V.

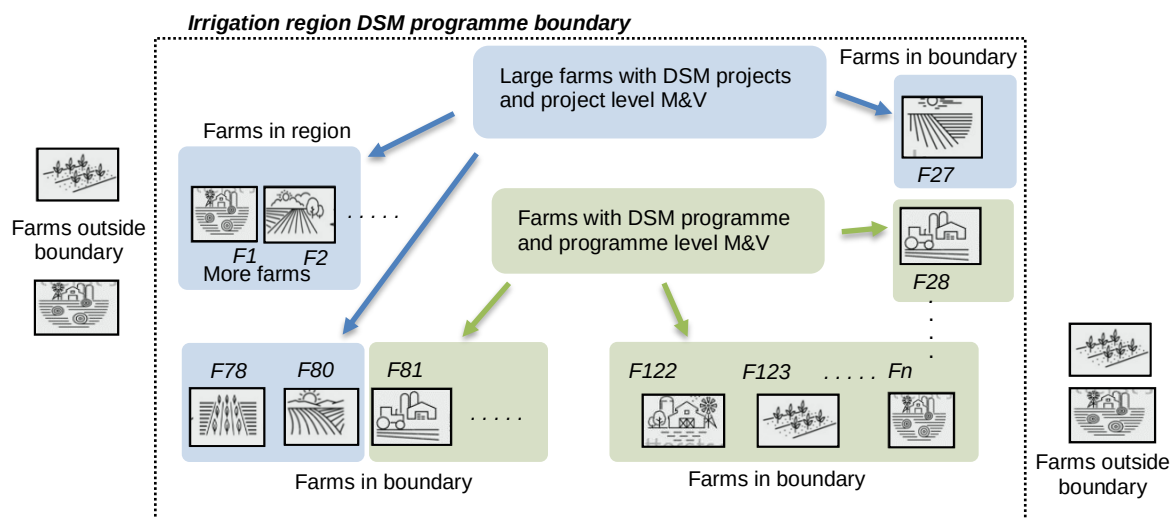


Figure 5-1: DSM programme boundary with project level and programme level M&V performed.

The combined bottom-up M&V project and programme results may show considerable impacts, but this is not always observed at a higher level. This scenario was especially seen with the Eskom DSM programme that was introduced over all the sectors (not only irrigation) in South Africa. Thus, relating again to the Figure 5-1 example, the power lines supplying the irrigation farms in the DSM boundary do not see the same impact as reported by the bottom-up approach. There can be many reasons for this but it normally has to do with the project level and programme level M&V evaluation models used, as well as the sampling approach, the assumptions made and the possible inadequate baseline adjustments which influence the effectiveness of the M&V results.

A regional or area level M&V approach also has the advantage of providing results much quicker when compared to a bottom-up approach. Depending on data availability from the power grid AMR systems, this can allow project stakeholders to rapidly (the day after, or even the same day) monitor the impact of project or programme interventions and be able to swiftly react if impacts are not reached. Power utilities have AMR systems with frequent communication in place on key transmission lines and sometimes at even lower points.

The data from these points are used for Short Term Load Forecasting (STLF) (Yuill *et al.*, 2010; Du Plessis, 2007; Vermaak & Botha, 1998; Delson & Caston, 2012). In South Africa (and in other countries) this is part of the National Control function of balancing electricity demand and supply, according to Du Plessis (2007).

The ready availability of this data and a regional level M&V approach, enables project stakeholders to instantly go back and correct or adjust systems to ensure targets are met onwards. In comparison, because of the vast amount of data and the delay of normal power utility billing point AMR systems (end of the month billing), bottom up results are usually only available two to four weeks after the assessment period ends. Regional or area level M&V also allows cost-effective sustainability tracking of savings over time, long after project or programme level M&V has ceased. Due to STLF type metering points used, there will thus also be historical data in many cases which can be used for baseline development. This historical data can also assist in starting new DSM programme rollouts immediately, without waiting for a baseline metering period to be completed first.

This chapter presents a novel regional level M&V methodology as depicted in the flow chart of Figure 5-2. The approach was uniquely implemented through a case study which did not only draw an M&V boundary around a region, but the entire province of a country. The case study was performed over the whole Western Cape province of South Africa and demonstrates the process involved with regional level M&V. On the right of Figure 5-2 the flow chart shows that the results of the case study are provided and a validation of the results is also given.

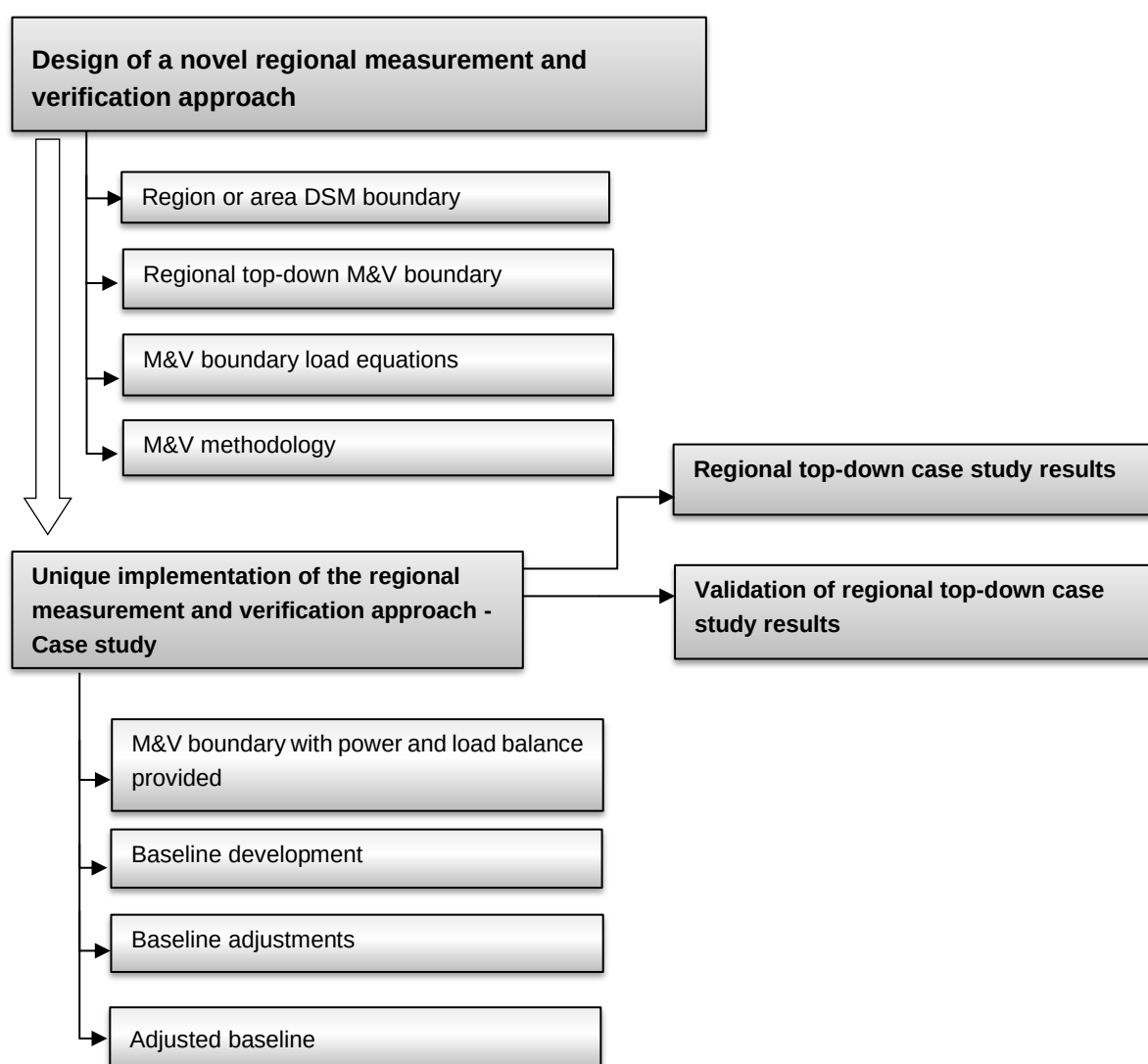


Figure 5-2: Flow chart showing the design of a novel measurement and verification approach with a unique implementation.

5.2 DESIGN OF A REGIONAL M&V METHODOLOGY

The first and most important part of the design is to draw a well investigated and well thought through boundary around the region or area that will be evaluated. Figure 5-3 and Figure 5-4 show two example agricultural irrigation schemes in South Africa with a large number of irrigation farms in one area. Figure 5-3 gives a Google Earth view of the Hartswater Irrigation Scheme in Northern Cape, while Figure 5-4 shows the Loskop Irrigation Scheme in Limpopo Province.

Both irrigation schemes surround towns and other non-irrigation loads. In these two examples, the irrigation farms are very concentrated in the area, and thus can have dedicated distribution power supply lines that in some cases only feed irrigation farms. Other lines may supply a mixture of town and irrigation loads.



Figure 5-3: Google Earth view of the Hartswater Irrigation Scheme (Source: Map data 2018 AfriGIS (Pty) Ltd, Google).

Figure 5-4 indicates towns with industries, and large and smaller settlements between and surrounding the irrigation scheme. There are a number of these which will imply that power lines will have a mixture of residential, commercial, industrial and irrigation loads. The closer view in the bottom of Figure 5-4 shows how irrigation farms are concentrated in the area.

In both Figure 5-3 and Figure 5-4, a typical DSM programme may focus on all irrigation farms and thus the DSM intervention boundary will surround all irrigation farms visible. This is reliant though on the focus of the DSM intervention.

The top-down M&V boundary will be dependent on transmission and distribution metering points available. It should be noted that in many cases, irrigation farms are not as concentrated as in Figure 5-3 and Figure 5-4, but spread wide over a region located between different towns, cities and industries.

In such cases, the DSM boundary is very wide and the top-down M&V boundary becomes very complicated since different types of loads need to be accounted for.

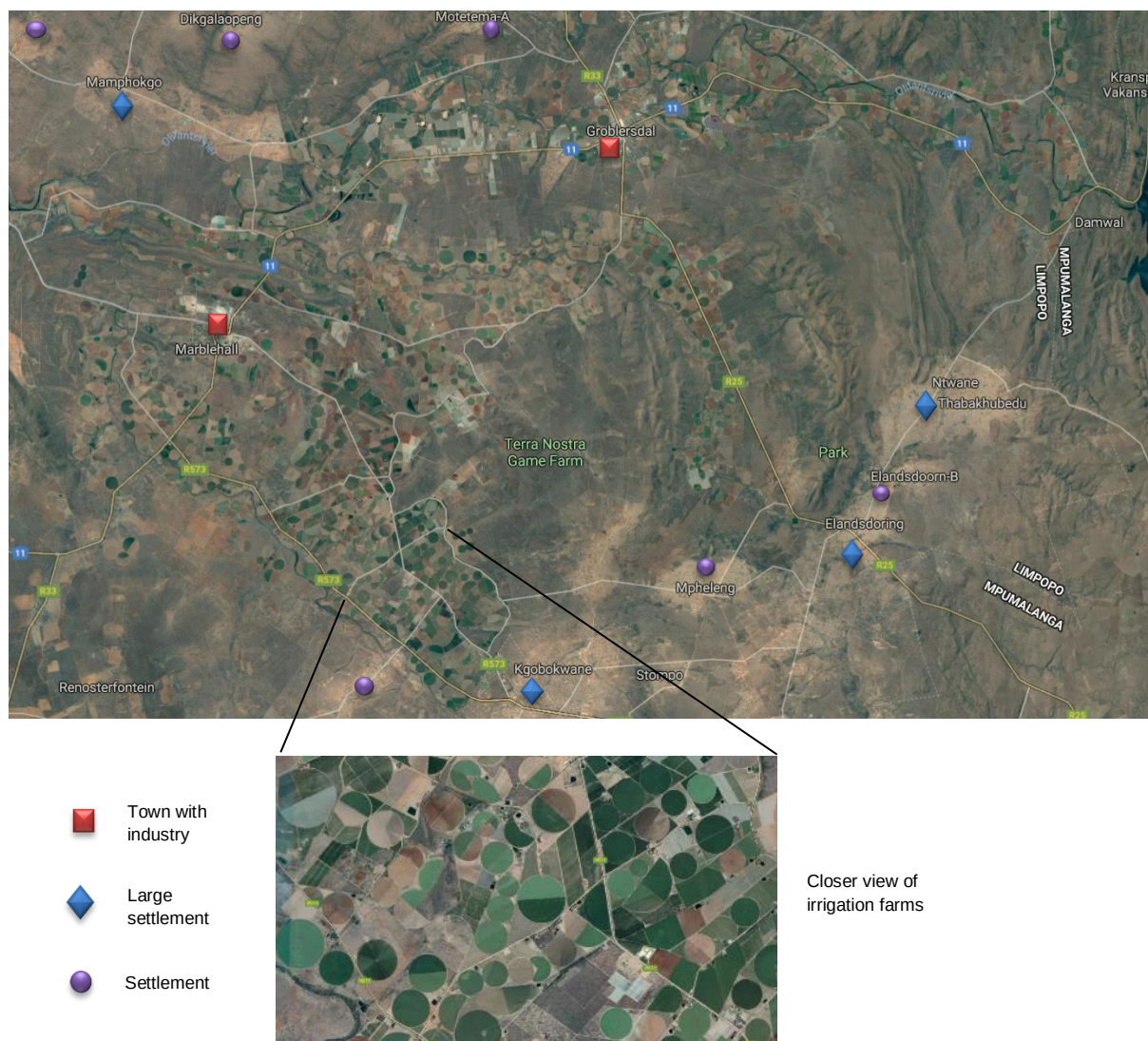


Figure 5-4: Google Earth view of the Loskop Irrigation Scheme (Source: Map data 2018 AfriGIS (Pty) Ltd, Google).

5.2.1 Region or area DSM boundary

In order to establish a regional or area top-down M&V boundary for an irrigation scheme, the M&V boundary should be drawn as close as possible to the irrigation farms. This top-down M&V boundary is dependent on existing power transmission and distribution metering points, the presence of an AMR system, the availability of data and the frequency of data uploads. Here good cooperation from the power utility to supply data and information is key. It would be ideal if a certain power line only supplies irrigation farms, however, this is rarely the case and lines usually have many other loads connected.

Figure 5-5 shows a presentation of a typical complicated network. For the sake of simplicity, a simple line and picture diagram is shown instead of a transmission and distribution line diagram. Thus, no ring feed networks and open points are indicated. This is an important discussion thought later in the chapter since open point shifts can have severe effects on the chosen M&V boundary. In Figure 5-5 irrigation and other farms are scattered over the area with some between the city, town, industry and power stations. The dotted line shows the region in which the irrigation DSM programme will be rolled out. Some of the farms fall out of the DSM boundary as can be seen in the top left and bottom right of Figure 5-5. Since the DSM boundary is so wide, many other loads and power generation points are also

included in the boundary. On the left of Figure 5-5, transmission and distribution lines entering and exiting the region boundary are shown.

The transmission line on the left, $P1_{Trans}In$, carries power from a power station outside the DSM boundary and therefore the amount of power it brings into the region boundary needs to be measured. This should also be done for the wind power generation plant, $WPS_{Gen}In$, on the bottom left of Figure 5-5. On the far right, power lines ($P1_{Trans}Out$, $P2_{Trans}Out$ and $p1_{Dist}Out$) leaving the boundary are shown and the amount of power it takes out of the region should also be quantified. On the top of Figure 5-5, an in-region power generation station ($PS1_{Gen}$) feeding into the network is shown. This can be anything from coal power plants or solar power generation plants. The power supplied by the power station into the network should also be quantified.

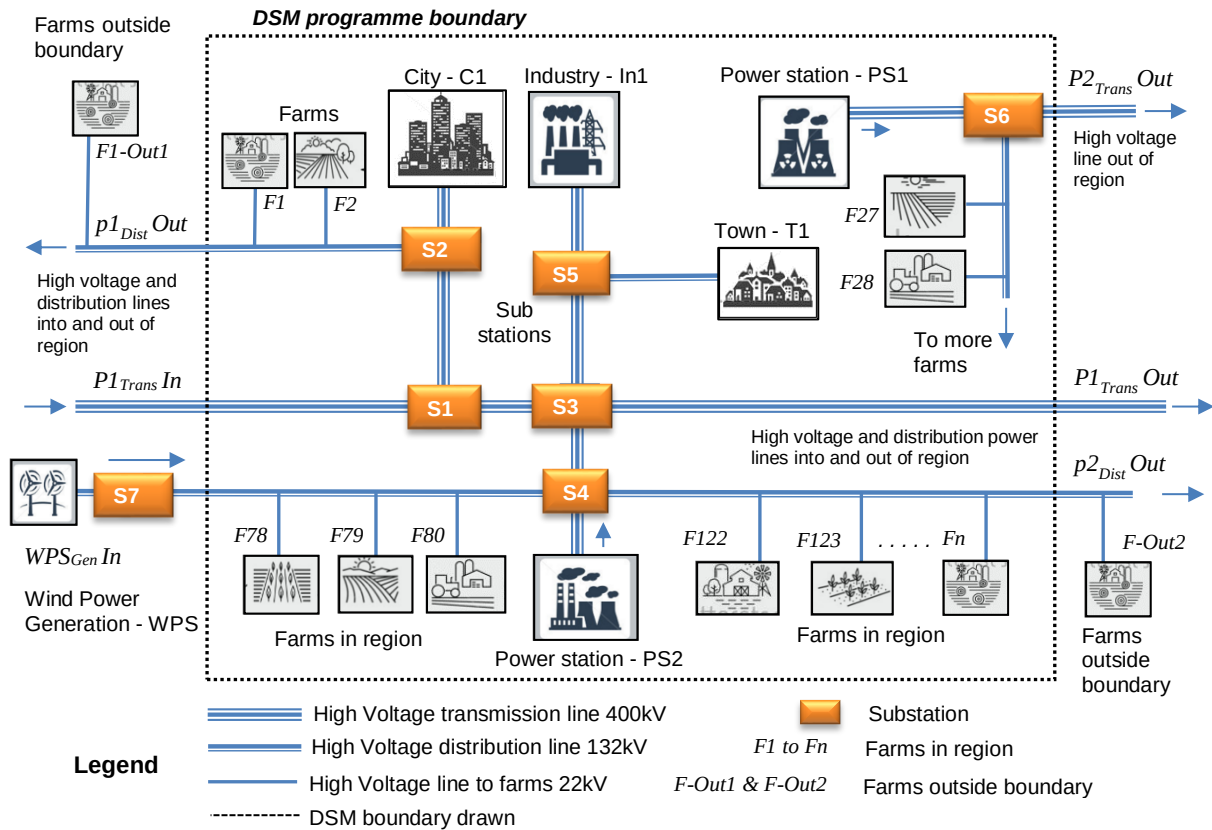


Figure 5-5: Line and picture diagram of DSM programme boundary.

Considering all mentioned, the DSM total boundary power balance equations can be developed. This balance consists of all power lines coming into the boundary, leaving the boundary, power generated within the boundary and all power usage in the boundary; including transmission/distribution losses:

$$P_{DSM\ Boundary} = P_{Boundary}In - P_{Boundary}Out + P_{Boundary}Gen - P_{Boundary}Use \quad \text{Eq. (5-1)}$$

With the variables in Eq. (5-1) defined as:

$$P_{Boundary}In = P1_{Trans}In + WPS_{Gen}In \quad \text{Eq. (5-2)}$$

$$P_{Boundary}Out = P1_{Trans}Out + P2_{Trans}Out + p1_{Dist}Out + p2_{Dist}Out \quad \text{Eq. (5-3)}$$

$$P_{Boundary}Gen = PS1_{Gen} + PS2_{Gen} \quad \text{Eq. (5-4)}$$

$$P_{Boundary}Use = P_{Loads}Use + P_{Losses} \quad \text{Eq. (5-5)}$$

If each of the variables in Eq. (5-1) to Eq. (5-4) could be quantified, the boundary power use (loads and losses) in Eq. (5-5) could easily be determined. However, this is dependent on the availability of metering in the power network. Also, for M&V of the DSM project, not all loads should be captured but only the irrigation farm loads; preferably it should be isolated and then quantified.

5.2.2 Regional top-down M&V boundary

In Figure 5-5 loads such as towns, cities and industries are shown with farms scattered over the area. These loads can have much variation and should as far possible be isolated from the M&V boundary by having these separately quantified. It is better to have the baseline boundaries as close as possible to the DSM irrigation interventions. Considering this, it would be ideal if each farm power supply point on the distribution line would have its own ToU profile meter and AMR with frequent communication.

This would allow the boundary to be moved down and surround only the farm(s) supplied and there will be in such a case no need for the top-down approach. In reality, smaller supply points are only equipped with disc totalising kWh meters and not even ToU meters as discussed in Chapter 3 Section 3.3.4.2 and Chapter 4 Section 4.4.1.2. Also, ToU meters with AMR usually only send data at the end of the billing period and data is only consolidated then.

Therefore, the boundary has to be moved further up to the last level with appropriate metering. Figure 5-6 shows the DSM boundary with all available metering points on the power network. The metering points are differently marked with some indicated with a dot and other as a crossed dot.

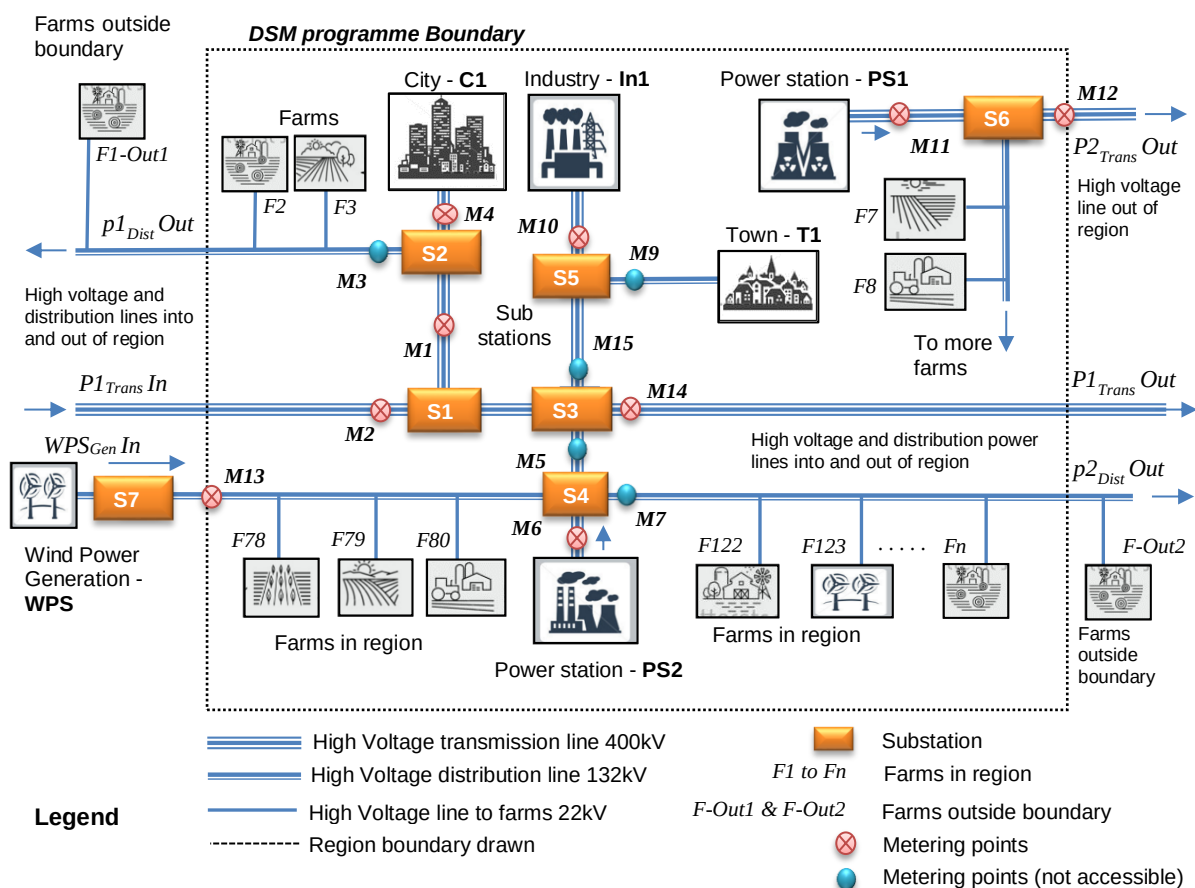


Figure 5-6: Line and picture diagram of DSM programme boundary and metering points.

As given in the legend of Figure 5-6, the dotted metering points are not accessible or operational. This may be a cause of the following:

- The meter point AMR system is not operational due to damage or communication offline;
- The data is only uploaded or consolidated at the end of the billing period and thus not readily or quickly available;
- In some cases, the metering at that point may be damaged and data cannot be obtained from it at all; and
- In many cases there might be no metering at these points at all.

Thus, considering metering points with data available, the best possible approach should be used to isolate the irrigation farms from other loads. In Figure 5-7, three Boundaries, (B-1), (B-2) and (B-3), were created which serve as the overall M&V top-down boundary. The circumstances depicted in Figure 5-7 are not ideal and due to the unavailable metering points, other loads and farms outside the DSM boundary also need to be included. The boundaries drawn involve the following:

- Boundary (B-1): Meter point $M1$ captures all power fed into the boundary. Fortunately, $M4$ is operational and the city load can be excluded from the sector. The distribution line ($p1_{DistOut}$) also supplies farms outside the DSM boundary. Although these will not be part of the DSM programme, the load of these will be part of the M&V boundary.

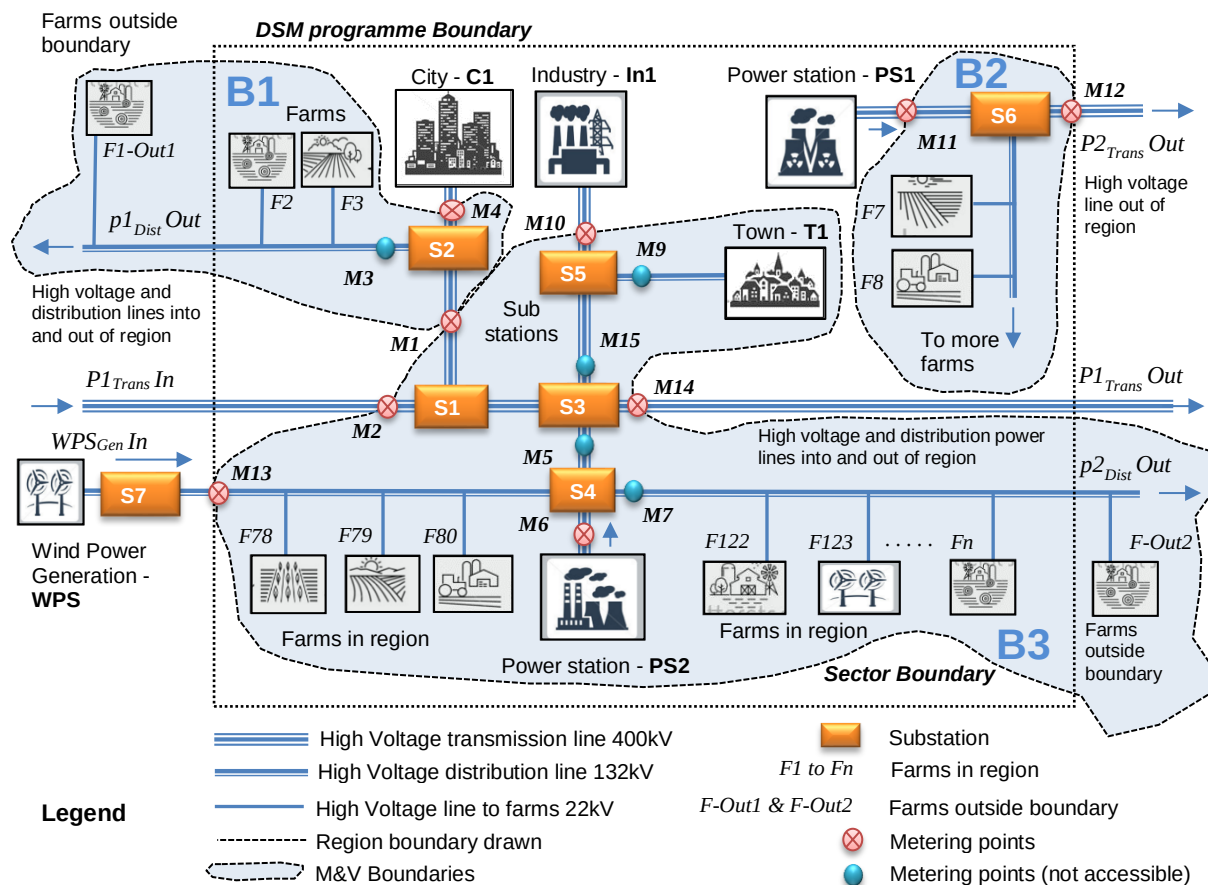


Figure 5-7: Line and picture diagram of DSM programme boundary with M&V boundaries.

- Boundary (B2): Power is generated by power station PS1 and provides power to substation S6 which channels power to DSM region irrigation farms while the rest leaves the DSM boundary through transmission line $P2_{TransOut}$. Since $M12$ is accessible, the irrigation farm load can be isolated by subtracting data of $M12$ from $M11$.

- Boundary (B-3): The unavailability of certain meter points makes this boundary large and it needs to include unwanted loads. The boundary has the wind power station WPS_{GenIn} , power station $PS2_{Gen}$ and power from substation S1 feeding power into the (B-3) network. Since $M9$ is not accessible, the town will be part of the sector load. Fortunately, $M10$ isolates the industry from the boundary. Irrigation farms outside of the DSM boundary also need to be included since $p2_{DistOut}$ also supplies these farms. Since this power line leaves the boundary and there is no meter isolation point, all loads down this line also need to be part of the sector. In this case several irrigation farms and a settlement are further downline supplied.

5.2.3 M&V boundary load equations

With the M&V boundary (B-1) to (B-3) defined, the total top-down M&V boundary load equations can be developed. Eq. (5-6) below gives the total power load of all three boundaries which will be used for M&V analysis, baseline development, impact calculations and reporting. Eq. (5-7) to Eq. (5-9) gives the loads of each of the boundaries.

$$P_{TotalLoad} = P_{Boundary1Load} + P_{Boundary2Load} + P_{Boundary3Load} \quad \text{Eq. (5-6)}$$

Where the boundary loads are described by the equations following. The first is (B-1):

$$P_{Boundary1Load} = P_{Boundary1In} - P_{Boundary1Out} \quad \text{Eq. (5-7)}$$

With variables defined as:

$$P_{Boundary1Out} = M4 \quad \text{and} \quad P_{Boundary1In} = M1$$

Secondly, (B-2) is as follows:

$$P_{Boundary2Load} = P_{Boundary2In} - P_{Boundary2Out} \quad \text{Eq. (5-8)}$$

With variables defined as:

$$P_{Boundary2Out} = M12 \quad \text{and} \quad P_{Boundary2In} = M11$$

And lastly (B-3) is described as:

$$P_{Boundary3Load} = P_{Boundary3In} + P_{Boundary3Gen} - P_{Boundary3Out} \quad \text{Eq. (5-9)}$$

With boundary variables defined as:

$$P_{Boundary3Out} = M1 + M10 + M14$$

$$P_{Boundary3In} = M2$$

$$P_{Boundary3Gen} = M3 + M6$$

5.2.4 M&V methodology

With a proper M&V boundary in place and the power boundary load equations defined, a regional top-down irrigation impact quantification model can be developed. Since it is not possible to simultaneously measure before and after efficiency interventions, the baseline is a calculated prediction of what the electricity demand and consumption would have been in the region if the DSM efficiency interventions were not implemented (IPMVP, 2012). The top-down M&V approach aligns to the whole facticity approach of IMPVP option C and option B of SANS 50010:2018.

The baseline model development essentially consists of the following steps:

- 1) Develop a regional M&V baseline model to predict what the electricity demand would have been in the region without the efficiency interventions. The baseline model consists of demand profiles retrieved for each metering point in Eq. (5-6) to Eq. (5-9) in the previous section. The baseline must consist of an appropriate time period which reflects all seasonal and other key variations.
- 2) After the efficiency interventions were completed, post-implementation, actual demand profiles can again be constructed from the same metering points.
- 3) The baseline must be adjusted to post-implementation conditions according to a baseline adjustment method. The baseline adjustment method is very critical and if it is not diligently developed, the DSM programme impacts will not properly be quantified. The baseline adjustment methods used are dependent on the type of loads captured.
- 4) The difference between the adjusted baseline and actual post-implementation demand profiles gives the achieved efficiency results. Impact results are calculated according to Eq. (5-10):

$$\text{Impact} = \text{Baseline} - \text{Actual} \pm \text{Adjustments} \quad \text{Eq. (5-10)}$$

The Figure 5-10 example gives an indication of what can be expected when developing a regional top-down baseline. However, it can even become more complicated and challenging than Figure 5-10. In such cases very intuitive methods are sometimes required to successfully perform regional M&V. The following section provides an actual case study where a regional boundary approach was implemented.

By presenting this case study, the process involved is demonstrated and the common caveats explained. Although the case study was not focussed specifically on irrigation, the processes followed and the methods used to address non-irrigation type loads are critical for any regional M&V approach.

5.3 IMPLEMENTATION OF A UNIQUE REGIONAL M&V BOUNDARY - CASE STUDY

The unique case study discussed in this section did not only draw a boundary around a region, but an entire province of a country. This study was jointly done with Dalglish *et al.* (2009) with a 2007 conference article published as provided in the abstract at the beginning of this chapter. Dalglish also separately published content as mentioned in Chapter 2 Section 2.7.8. Reference is made to overlapping information. This chapter has a separate focus and takes the case study and results a step further.

As already stated, the case study was not focussed on irrigation, but on the power usage and efficiency of an entire province. During 2006 South Africa's only power utility, Eskom, expected a 400 MW evening peak shortfall in the Western Cape Province due to nuclear power reactor refuelling (DPE, 2006).

The Western Cape is 129,449 square kilometres and the fourth largest of the nine South African provinces (Statistics South Africa, 2009). In comparison, the Western Cape is slightly larger than the state Mississippi in the United States of America (USA), and just more than half the size of the United Kingdom. Thus, it is a very large M&V region that was under evaluation. Figure 5-8 shows a Google Maps view of South Africa indicating the Western Cape province. Eskom initiated an urgent integrated recovery strategy to overcome the 400 MW shortfall consisting of several accelerated DSM initiatives to lessen the overall electricity usage, but more importantly, to reduce the evening peak load (Dalglish *et al.*, 2007). The accelerated DSM initiatives varied from efficient lighting, industrial and commercial efficiency to residential gas cooking and heating with the following targeted demand (MW) impacts:

- Residential efficient lighting (155 MW) – Residential rollout of five million Compact Fluorescent Lamps (CFLs);
- Customer self-generation (50 MW) – Awareness programme, customers visits and promotional campaigns;
- Industrial and commercial efficiency and curtailment 40MW – Rollouts in schools, hotels, malls and office blocks of efficient lighting, dual fuel systems and building management. Retrofits also occurred on Eskom building;
- Energy efficiency campaign (110-160MW) - Promotional and advertising campaigns with specific appeals that included winter pool switch-off, using gas rather than electricity etc.; and
- Gas cooking and heating (50MW) – Campaign to replace electric cooking stoves with gas cooking stoves.



Figure 5-8: Google Maps view of the Western Cape province, South Africa (Source: Map data 2018 AfriGIS (Pty) Ltd, Google).

The urgency of the DSM initiatives and the speed of which these were implemented did not allow sufficient time for an in-depth region load and DSM intervention analysis for thorough M&V baseline development. A method was required through which an M&V approach could be rapidly developed and could also very quickly provide results on DSM impacts achieved.

The impact reports were urgently required by Eskom and stakeholders on the effectiveness of the accelerated DSM programme with regards to the 400 MW shortfall and further planning. The unique approach developed and implemented was the regional level top-down M&V method of the entire Western Cape. The following sections describe the M&V boundary, the baseline model development, the baseline adjustments used, the challenges experienced and the results calculated from the regional level top-down M&V method.

5.3.1 M&V boundary with power and load balance

Considering the project parameters and the rapid development and implementation, the M&V boundary was drawn around the entire Western Cape province. For the M&V boundary equations, as explained in Section 5.2.3, the below key generation and high voltage transmission lines were captured for any power brought into the region and generated inside the region. Some of the loads on the lines measured were outside the Western Cape and also formed part of the analysis. See Figure 5-13 in Section 5.3.3.5.

- Palmiet unit 1 and 2;
- Koeberg unit 1 and 2;
- Droërivier Hydra line 1, 2 and 3;
- Aries Kronos line;
- Acacia Power Station Generator 1, 2 and 3; and
- Power was exported to Namibia, South Africa's neighbouring country, during the project baseline period and assessment period. This was accounted for with a baseline adjustment.

5.3.2 Baseline development

Since the power load of the Western Cape is so diverse, a monthly baseline profile for every day of the week was developed from 2005 data. Eskom control centre data of the key high voltage lines going into and out of the Western Cape were used as listed above. The baseline consisted of integrated 30-minute data of all the key high voltage line measuring points of the province.

Considering the power loads of the Western Cape, power consumption is influenced by temperature due to the use of HVAC (Heating, Ventilation and Air Conditioning). Since temperatures change drastically according to season, the temperature and power demand relation is an important consideration. According to Du Plessis (2007), about 80% of the South African energy demand can be explained by weather. Hourly Cape-Town temperature data was obtained from the South African Weather Services (SA Weather, 2006) and 10-minutely power demand data from Eskom Bellville control centre (Lukhele, 2006). The power demand data was of the key generation and high voltage transmission lines listed in Section 5.3.1.

The developed baseline consisted of the following components (Dalglish *et al.*, 2009):

- Scatter plots relating electricity consumption and temperature;
- Average Monday, Tuesday, Wednesday, Thursday, Friday, Saturday and Sunday demand profiles; and
- Baseline adjustments.

5.3.2.1 Scatter plots

Scatter plots were developed to show the relation between power demand (MW) and temperature (°C) for every 30 minutes for Weekdays, Saturdays and Sundays. Thus, the hourly temperature data and 10-minutely power data were converted to 30-minute interval data. The scatter plots were not done for every weekday (Monday to Friday) separately due to a limited number of points in a month that can be used. For each day type (Weekdays, Saturdays and Sundays) there are 48 scatter plots, thus giving a total of 144 scatter plots per month.

The scatter plots were developed for each month of the period May 2006 to February 2007 using 2005 and 2006 weather and high voltage line data as mentioned in the previous section. Figure 5-9 shows a typical scatter plot of an average weekday at a specific time stamp. For the M&V evaluation that occurred between May 2006 and February 2007, a total of 1440 scatter plots were developed.

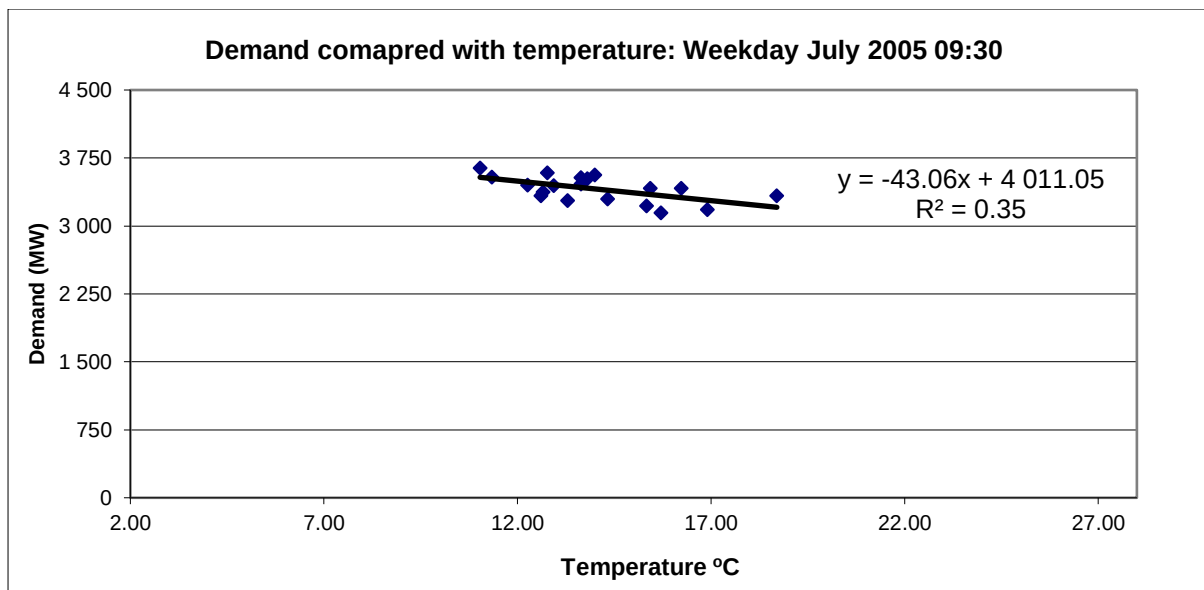


Figure 5-9: Example scatter plot for a July weekday at 09:30.

Linear relations were calculated between demand (MW) and temperature (°C) from the scatter plots. From these relations, the m-values (the slope) were obtained. The m-value shows the relation between energy and temperature for that 30-minute interval. It is also an indication of how temperature sensitive the energy consumption is during that 30-minute period.

5.3.2.2 Average profiles

Average Monday, Tuesday, Wednesday, Thursday, Friday, Saturday and Sunday 30-minute demand profiles were developed from the 2005 power demand profile data. As an example, Figure 5-10 shows a demand profile of an average Monday in July.

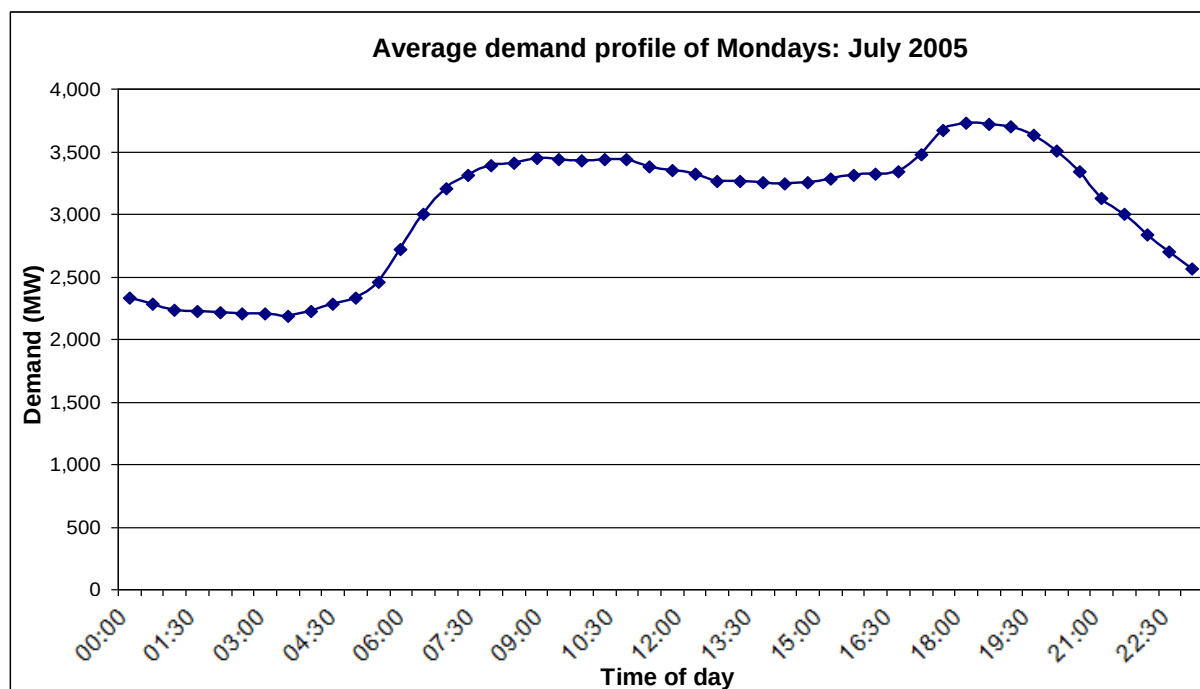


Figure 5-10: Demand profile of an average Monday in July 2005 (Adapted from Dalglish *et al.*, 2009).

The power demand is below 2500 MW from 00:00 till around 05:00 when the load suddenly increases. During the day the load stays below 3500 MW till the evening peak when it reaches a maximum of around 3700 MW.

5.3.3 Baseline adjustments

Baseline adjustments are required to adjust the baseline to post-implementation conditions. Adjustments need to be narrowed to key energy drivers, or energy governing factors, which will influence energy use and demand. This might be due to changing effects over time; seasonal, cyclical or other. If these are not effectively addressed, results may be skewed due to factors not taken into account. The following baseline adjustments were considered and evaluated:

- Temperature adjustments;
- Electricity sales growth;
- Demand Market Participation (DMP);
- Supply losses with only one Koeberg nuclear reactor operating;
- Municipality Curtailment and load shedding;
- Power network operation and open point shifts;
- Leased generation, fuel switching; and
- Export to Namibia (South Africa's neighbouring country).

The investigation of these, model development and the end adjustments made to the baseline are discussed in the following sections. Some of the adjustments were not incorporated from the beginning of the evaluation, but later investigations necessitated these to also be accounted for.

5.3.3.1 Temperature adjustments

Since the temperature differs from year to year, the baselines had to be adjusted to reflect a representative approximation of the expected demand for 2006 and 2007. This adjustment was done through the m-value obtained from the scatter plots in Section 5.3.2.1. As explained, the scatter plots show the relations between power demand (MW) and Temperature (°C) for every 30 minutes for Weekdays, Saturdays and Sundays.

During the post-implementation evaluation period, the actual temperatures of July 2006 were again retrieved from Weather SA. Having this and the scatter plots developed, the Delta temperature between the actual 2006 measured value and the average temperature value for that specific day type were calculated. The temperature differences between 2005 and 2006 were then related to an increase in demand (MW) by using the established m-value as demonstrated in Figure 5-11. Eq. (5-11) below was used to do this adjustment.

$$Delta_{MW} = M_{value} \times Delta_{MW} \quad \text{Eq. (5-11)}$$

This increase (or decrease) in demand was incorporated to adjust the average profiles developed from 2005 data to produce a temperature adjusted baseline. Table 5-1 gives the average weekday temperature differences between the different months for May to December 2005 compared to 2006, and the difference of January to February 2006 compared to 2007.

The top part of Table 5-1 shows the difference in each month between 2005 and 2006. In May 2006 it was on average 0.46 °C colder than May 2005. This resulted in an average weekday increase of 0.71 MW on the baseline as seen in the middle part of Table 5-1. June 2006 was on average 1.86 °C warmer than June 2005 and on average 44.29 MW was subtracted from the baseline.

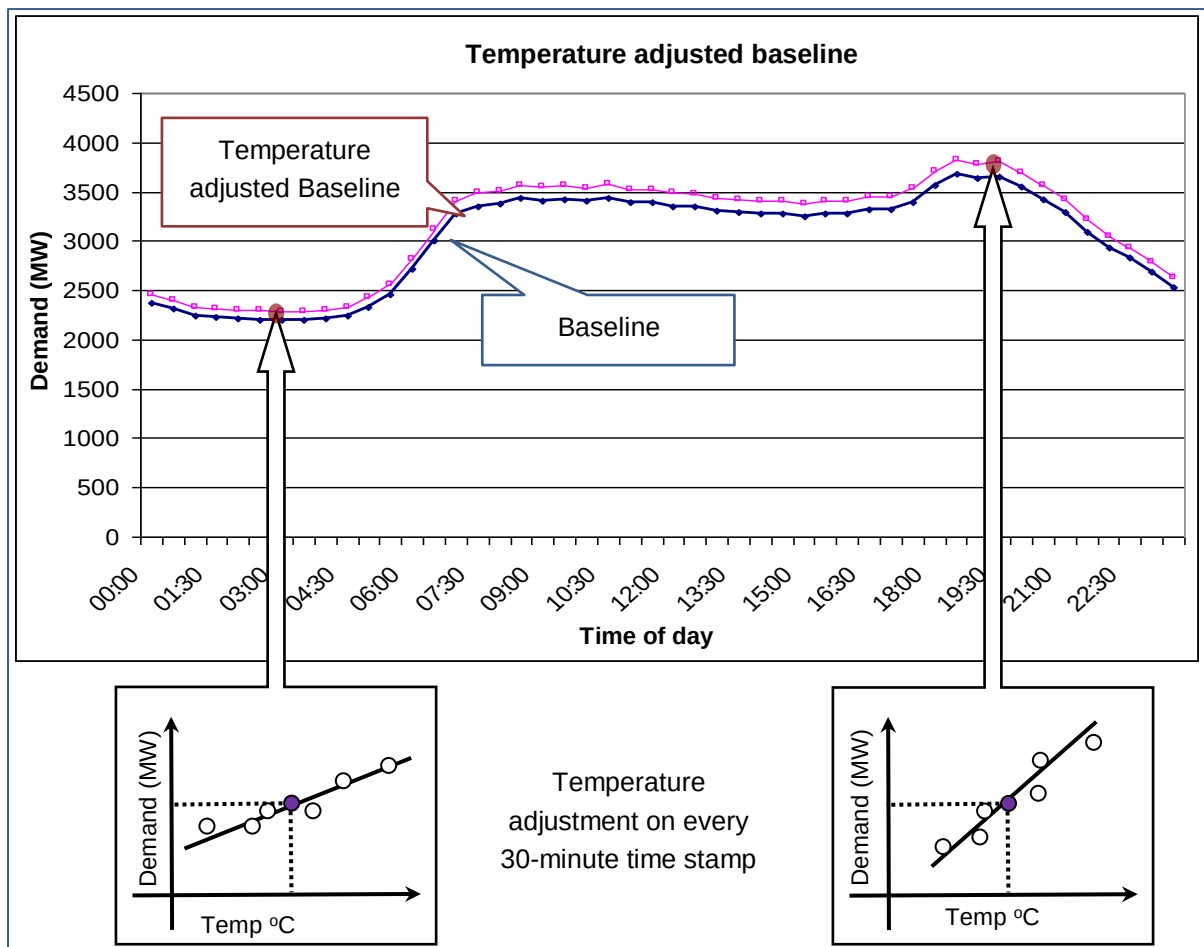


Figure 5-11: Example of baseline temperature adjustment using the scatter plots (Adapted from Dalgleish *et al.*, 2009).

The bottom part of Table 5-1 indicates the difference in temperature between the individual months within a certain year. When comparing June 2005 and May 2005 it was observed that June was on average 2.58 °C colder than May.

Table 5-1: Average weekday temperature adjustments

May	T (°C)	June	T (°C)	July	T (°C)	Aug	T (°C)	Sept.	T (°C)
2005	14.53	2005	11.96	2005	13.38	2005	11.51	2005	14.25
2006	14.07	2006	13.81	2006	12.55	2006	12.96	2006	15.62
Temp Diff	-0.46		1.86		-0.84		1.45		1.37
BL Adj. (MW)	0.71		-44.29		17.23		-15.88		-19.97
Oct.	T (°C)	Nov.	T (°C)	Dec.	T (°C)	Jan.	T (°C)	Feb.	T (°C)
2005	14.58	2005	18.59	2005	19.59	2006	22.01	2006	21.63
2006	16.58	2006	18.62	2006	20.23	2007	22.51	2007	21.30
Temp Diff	2.00		0.02		0.64		0.50		-0.33
BL Adj. (MW)	-9.34		-3.08		-25.37		7.84		1.36

5.3.3.2 Electricity sales growth

There is an electrical sales growth on the electrical power network due to new connections every year. Table 5-2 gives the 2005 to 2006 sales growth data. In May a 4.6 % growth can be seen. It was decided by the stakeholders that the growth percentage for each month after May was also fixed on 4.6 % for baseline adjustment. In May 2006 there were already some DSM projects operating and it was assumed that the new connections in May would be the same for June to July. This is a rough adjustment to use, however with the data and information available and the limited time at that stage to investigate better alternatives, the 4.6 % value was sufficient.

Table 5-2: Monthly electricity sales (Redelinghuys, 2006)

	Projections	Actual	Percentage
	2006 consumption (kWh)	2005 consumption (kWh)	Growth
March	1 581 570 943	1 554 331 331	1.72%
April	1 573 638 000	1 507 907 539	4.18%
May	1 626 755 083	1 551 860 277	4.60%
June	1 583 049 854	1 599 282 312	-1.03%
July	1 650 259 074	1 577 406 623	4.41%

The 4.6 % figure would take into consideration new connections (increases in electricity consumption) as well as energy efficiency (decreases in energy consumption). Having this, the baseline for each month can be growth adjusted as shown in Figure 5-12.

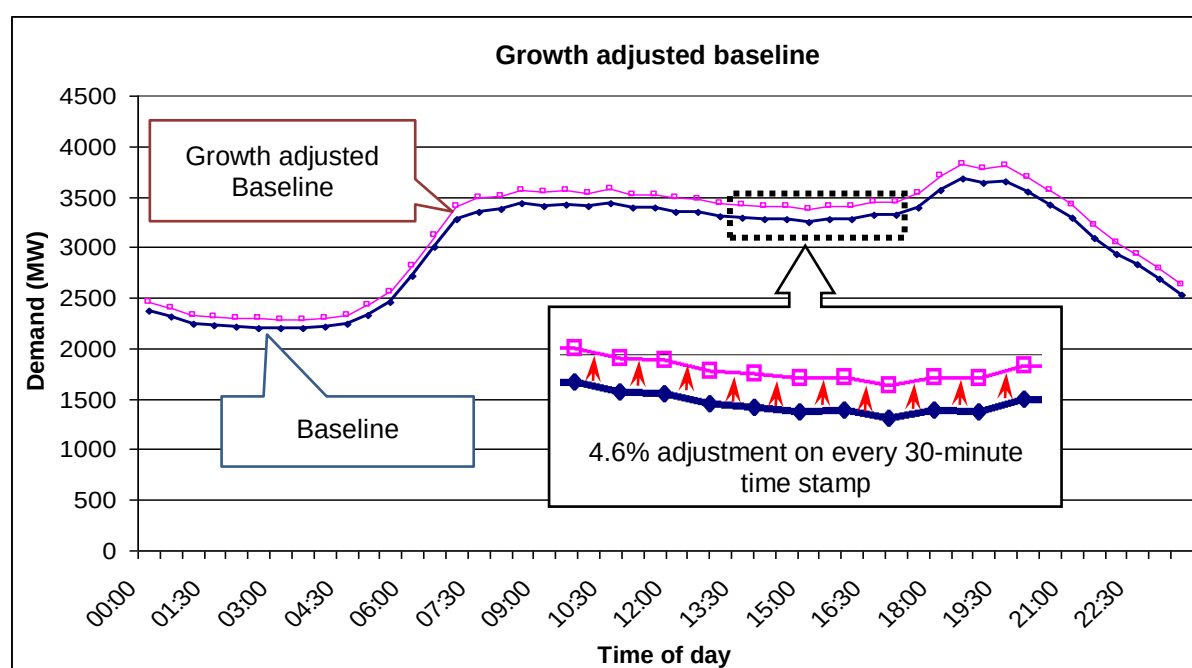


Figure 5-12: Growth adjusted baseline (Adapted from Dalgleish *et al.*, 2009).

Table 5-3 gives the average weekday baseline growth adjustment of each month for May 2006 to February 2007. The growth adjustment for October 2006 was much higher compared to the other months. The demand data of October 2005 was not appropriate to use for a baseline and thus demand data of October 2004 needed to be used. The year to year sales growth of October 2004 to 2005 was added to the 4.6% growth adjustment used. The baseline for February 2007 was also calculated using the data of February 2006 and 2005 by using the 4.6% figure.

Table 5-3: May to August baseline growth contribution.

Month	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan-07	Feb-07
Growth (MW)	133.78	141.73	140.93	146.69	142.06	209.14	142.81	138.23	136.83	148.68

5.3.3.3 Demand Market Participation

Called DMP were events where Eskom requested large industries or other clients to reduce operational load during times when the grid experienced severe strain. Called DMP unfortunately does not mean that the client actually reduced the load by the requested MW, at the requested time and for the requested time period.

Only later the billed DMP data showed the actual load reduction implemented. However, the called data was available quickly while the actual billed DMP data only became available later. Thus, the called data was used for initial impact estimates while the actual billed data was later incorporated. Called and billed data was obtained from Lukhele (2006) and Breed (2006).

5.3.3.4 Supply losses with only one Koeberg operating

Since one of the 800 MW Koeberg units was offline, this power shortage needed to be supplied to the Western Cape from other far-off power stations. This led to an estimated transmission supply loss of 100 MW according to Carolin, (2006). At the stage of the project implementation, a finer model could not be developed which better determine the supply losses according to the time of day as the load on the units varies. Although the estimate was rough, this constant 100 MW loss was used to adjust the baseline.

5.3.3.5 Power network operation and open point shifts

Supply losses can also differ due to power network operation when the load capacity is moved between feeders, or when network open points are shifted. Supply loss differences resulting from this should be accounted for since these might affect calculated saving impacts. During 2006, the loads on the three Hydra-Droërvier lines and the one Hydra-Kronos 400 kV line were close to operational limits.

From March to July 2006, the Aggeneis load was reduced by shifting the open point on the North West network normally situated at Oasis S/S (Taaipit 132 kV feeder) according to Van der Merwe, (2006). Figure 5-13 gives the power network configuration wherein the open point was shifted. The dot far left next to the Oasis S/S indicates the normal position of the open point in the network. The purpose of open point shift was to move the load capacity between feeders within the network. The following shifts were performed and savings achieved according to Eskom (Redelinghuys, 2006):

- In March 2006, the open point was shifted from the Oasis-Taaipit 132 kV feeder to the Renosterkop-Blouputs 132 kV feeder. See Figure 5-14. This resulted in the following:
 - Average savings of 8.7 MVA (over the period 3 March - 12 April 2006);
 - Average savings during peak time of 9.54 MVA; and
 - On certain days, the peak savings were above 10 MVA.
- In April 2006, the open point was shifted from the Renosterkop-Blouputs 132 kV feeder to the Paulputs-Schuitdrift 132 kV feeder which resulted in the following:
 - Average savings of 8.9 MVA (for the period 12 April - 12 July 2006);
 - Average savings during peak time of 11.55 MVA; and
 - On certain days the peak savings were between 16 to 18 MVA.

- In July 2006, the open point was shifted from the Paulputs-Schuitdrift 132 kV feeder to the Oasis-Gordonia 132 kV feeder due to an outage. The network was configured to its normal configuration (open point at Oasis S/S on the Taaipit 132 kV feeder) in August 2006 according to Redelinghuys, (2006).

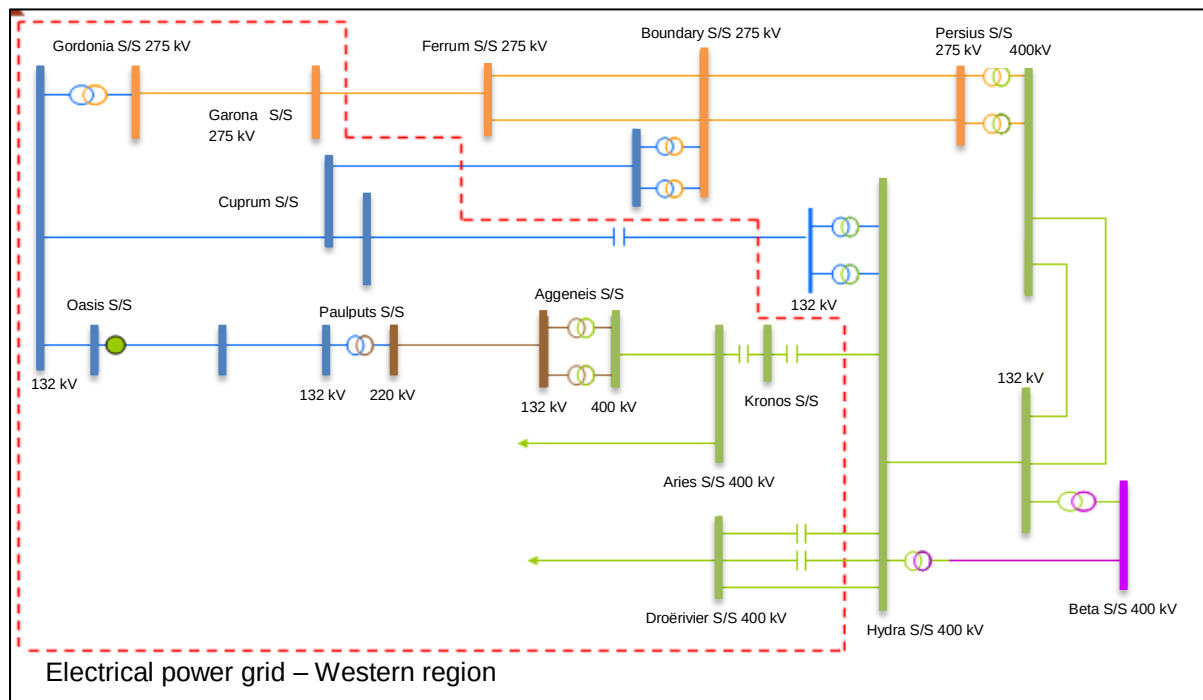


Figure 5-13: Network configuration (Adapted from Van der Merwe, 2006).

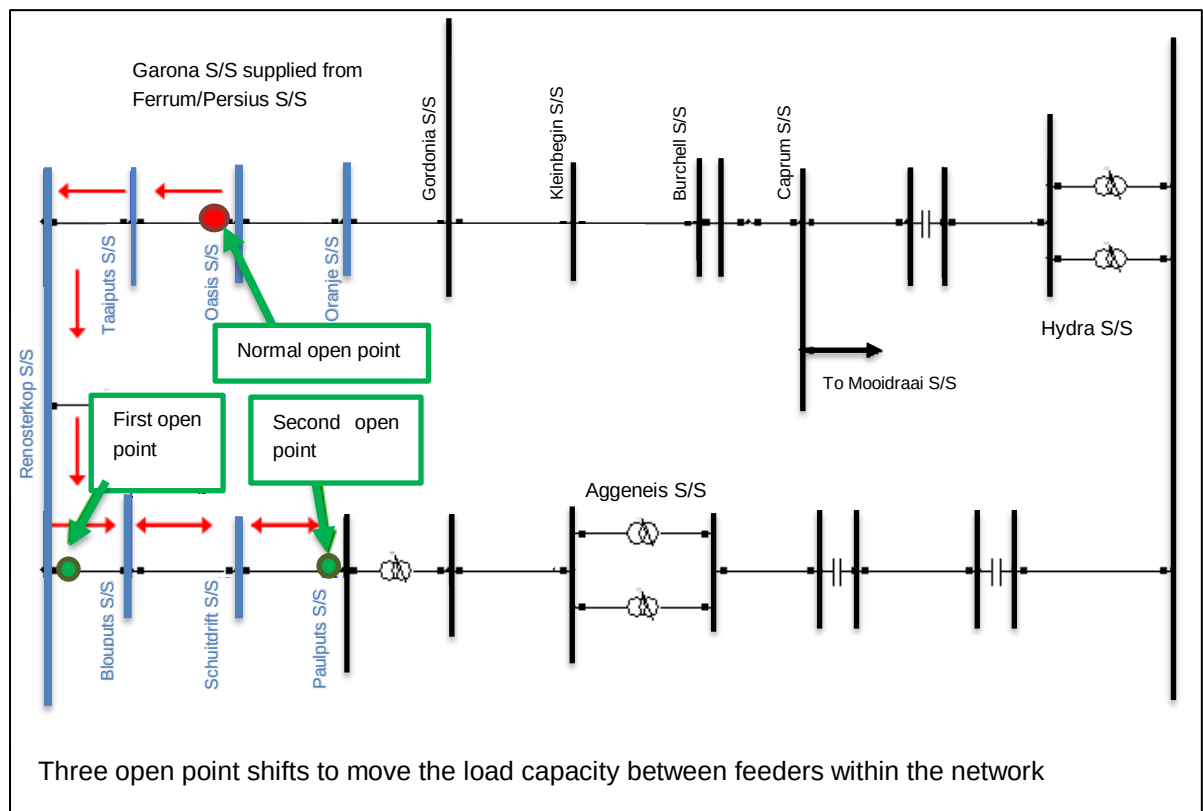


Figure 5-14: Open point shifted in the network (Adapted from Van der Merwe, 2006)

The resulted impacts described were questioned if these could really be classified as savings in the bigger picture. The Western Cape constraints were experienced on the three Hydra-Droërivier 400 kV lines and the Hydra-Kronos 400 kV line. Whenever the loading on these four lines came close to the limit, Western Region had to implement load shedding.

This implied that only a specific amount of power was allowed on these four lines. Through shifting the open point, an average load of 16 MVA was moved from Aggeneis S/S to Oasis S/S. The 16 MW load was supplied during the shift by the Hydra 400/132 kV transformers and the Persius-Boundary 275 kV line. Consequently, the load on the Hydra-Kronos 400 kV line was reduced with 16 MVA.

However, when considering the total Western Cape demand, shifting of the open points did not result in actual savings. However, the 16 MVA reduction on the Hydra-Kronos 400 kV enabled Eskom to supply 16 MVA more to the Western Cape than with the open point in the normal position (Van der Merwe, 2006). The measuring points used for the M&V results already captured the load reduction on Aggeneis S/S since the difference is seen on the Aries-Kronos (Aries-Hydra) line metering point.

Thus, the saving reached through the open point shift was already shown and captured by the Western Cape M&V calculations and impact reports. However, the metering points and M&V approach does not capture the difference in transmission losses due to the open point shift. Though not significant, the open point shift may have had an influence on the Western Cape's DSM impacts during the winter months. It was decided not to further investigate this but to exclude the transmission loss impact at that stage.

However, if the metering points used for M&V were different and the M&V results did not already capture the load reduction, a proper study would have been required. Care should be taken when designing an M&V boundary since open point shifts can have a significant effect on the impact calculation method and the results obtained. In some cases, a shift may result in a metering point not being useful anymore.

5.3.3.6 Municipal curtailing and load shedding

According to the Eskom Western Cape Recovery plan, municipal distributors were allocated monthly demand limits which were proportional to the municipality's energy consumption, recorded in the corresponding period in 2005. Monthly demand limits were adjusted for:

- Load growth;
- System losses;
- Safety margins; and
- Critical and strategic loads.

During the period May 2006 to February 2007 three municipal curtailing events occurred and this must be accounted for in the baseline, otherwise this curtailment would reflect as a DSM saving in the calculations. The proposed mitigating actions of the Eskom Western Cape recovery plan were intended to minimize the impact on customers.

However, the benefits of those mitigating actions did not totally alleviate the requirement for load shedding. Principles to manage planned and emergency load shedding were agreed upon by key stakeholders.

The extent of load shedding is depended on the power supply levels as well as the forecasted level of demand, and any unexpected increases in demand for electricity. Table 5-4 shows the load shedding events that took place between May 2006 and February 2007. As with municipal curtailment, load shedding should be accounted in the baseline.

Table 5-4: May 2006 to February 2007 load shedding events (Lukhele, 2006).

Date	Start Time	End Time	Load Shed		Reason
22-May	17:52	19:26	100.5	MW	Demand to high
01-Jun	18:31	18:44	54	MW	Petro SA could not sync with network
08-Jun	18:00	18:41	422	MW	Koeberg tripped
09-Jun	06:58	17:48	1585	MW	Koeberg tripped
22-Jun	09:15	12:22	312	MW	TX-line tripped
18-Jan	08:00	10:30	220	MW	General shortage of plant Nationally including loss of Koeberg unit 2 at 02:10
	10:00	12:30	233	MW	
	12:00	14:30	190	MW	
	14:00	16:30	100	MW	

5.3.3.7 Leased generation and fuel switching

During the winter months Eskom had a contract with the City of Cape Town for leased generation using the Steenbras and Roggerbaai generators. During this time, the generators' operating data was available and could be incorporated into the baseline (Data received from: Lukhele, 2006). Baseline adjustments were done for the following leased in generators: PetroSA, Roggerbaai, Steenbras, and Acacia Power Station (APS).

Since September 2006 data was not available and the baselines were developed without accounting for the times the generators were used. During the evaluation period EB Steam was the only fuel switching contributor. The contribution of EB Steam was also brought into the baseline adjustment.

5.3.3.8 NamPower export

The power supplied to Namibia in 2005 was used to establish an average weekday baseline for each of the four winter months. The difference of 2006 compared to the NamPower (Namibia's power utility) baseline was taken into account for in the baseline adjustment. Figure 5-15 shows the average electricity imported by NamPower for July 2005 and 2006.

It was observed that for the periods 1 to 10 June, 10 to 14 July and 19 and 21 July 2006, NamPower was importing much less from Eskom compared to what was imported in 2005. Data supplied by: Lukhele (2006) and Sims (2006).

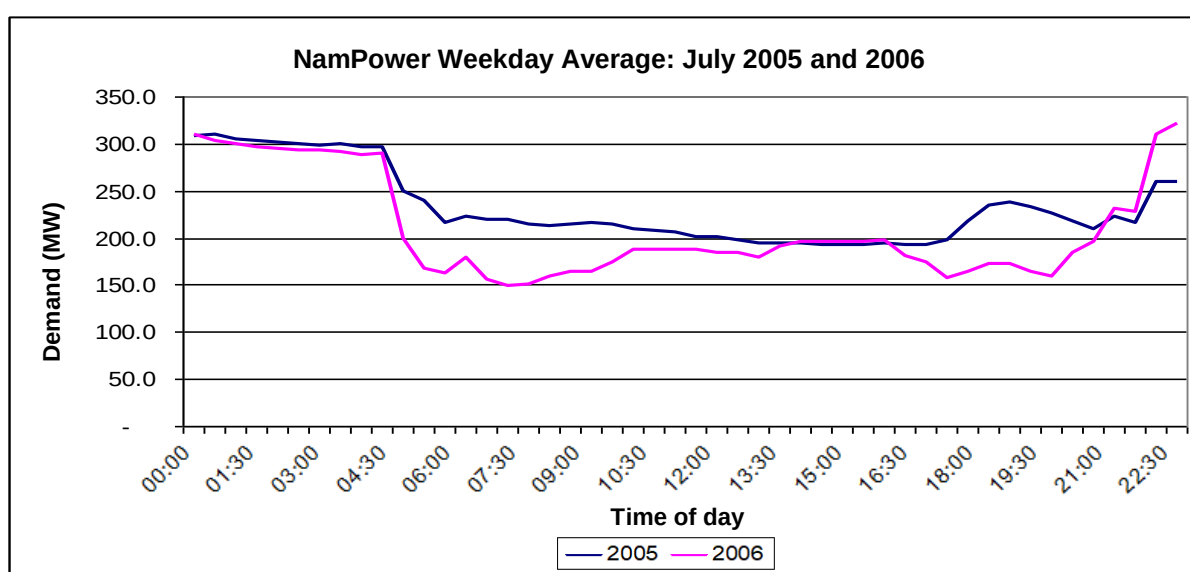


Figure 5-15: July 2005 & 2006 NamPower Weekday Average (Adapted from Dalglish *et al.*, 2009).

5.3.4 Adjusted baseline

All the adjustments discussed in the previous sections were taken into account to obtain the final baseline. As an example, Figure 5-16 shows the final baseline for June 2006. The baseline shows a stacked graph with the different components used in the baseline adjustment. Note that the graph scale on the left does not start at zero but at 2000 MW. The first layer at the bottom shows the average weekday profile of June 2005. On top of this the 4.6% load growth can be seen. Other significant baseline adjustments visible are the Koeberg supply losses, Petro SA, NamPower, the temperature adjustment and Roggerbaai called DMP. With the adjusted baseline completed, the post-implementation results can be calculated.

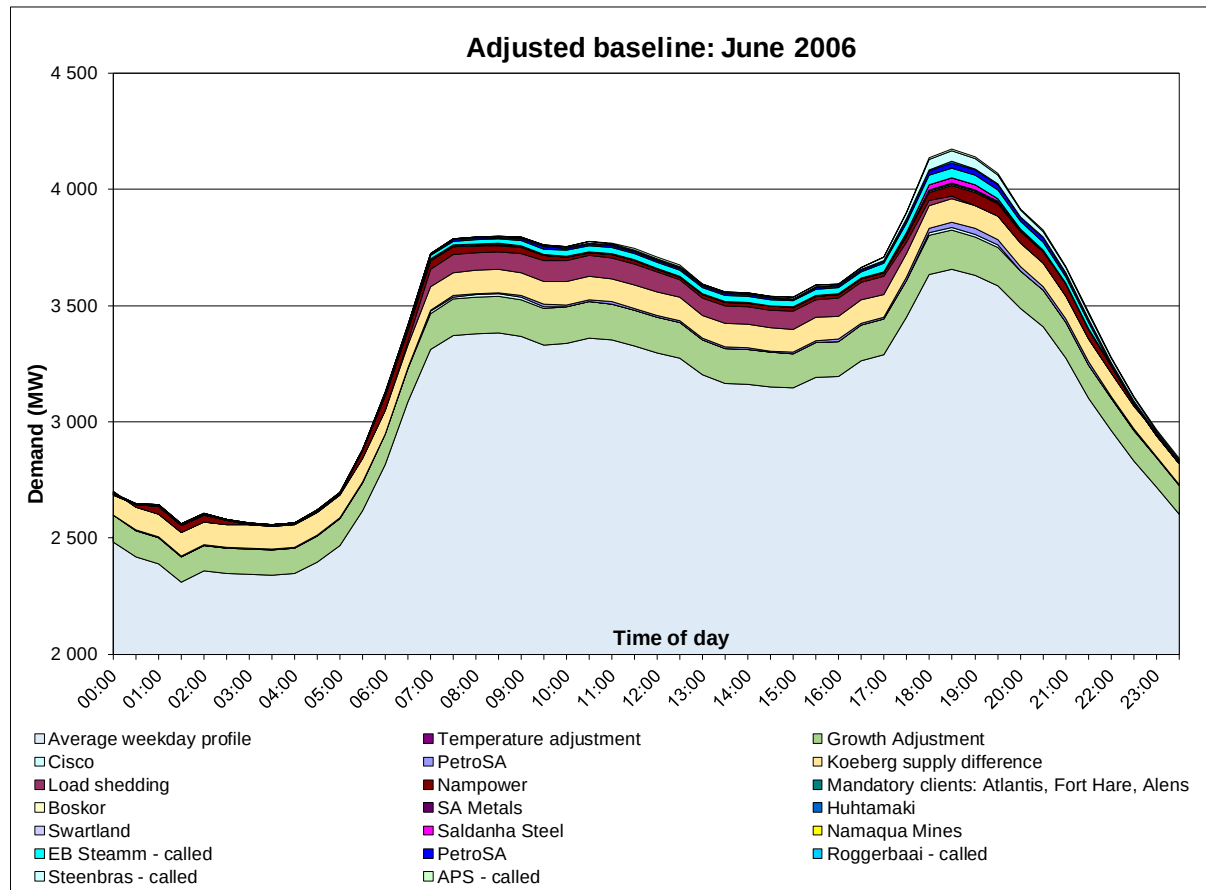


Figure 5-16: The adjusted baseline of June 2006 (Adapted from Dalglish *et al.*, 2009).

5.4 CASE STUDY RESULTS - MONTHLY IMPACTS

The post-implementation evaluation period impacts were calculated for each month using the actual demand profile data and the adjusted baseline for that month. The following section summarise the achieved impacts. Section 5.4.1 provides the impact of the most critical winter month, July 2006. Section 5.4.2 gives a summary of the results achieved in the other months. There were reported on two levels:

- **Total Impact:** Adjusted baseline – actual. This impact includes all measures such as self-generation, leased in generation, DMP, and DSM.
- **DSM impact:** This represents the total impact of all the DSM projects implemented in the Western Cape. The DSM impact was calculated by subtracting the average actual weekday demand from the temperature and growth adjusted baseline. Koeberg and NamPower were added to DSM impacts since the used net effect was reported on.

5.4.1 July 2006 Impact

July was the third assessment month with the highest DSM impacts observed. Figure 5-17 provides the July 2006 average weekday demand and the baseline while Figure 5-18 gives the impacts achieved. Table 5-5 shows the total and DSM impacts in the different time of use periods. An average weekday evening peak of 513 MW was seen in the first two weeks of July (1 to 15 July) while the last two weeks (16 to 31 July) revealed an impact of 278 MW.

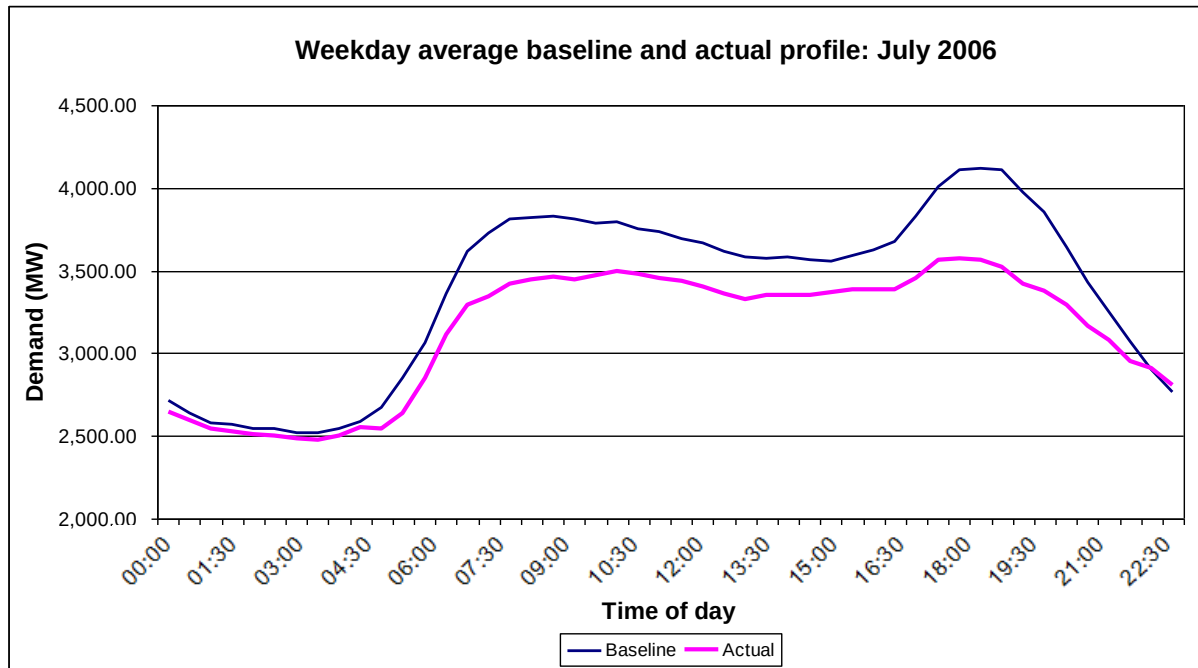


Figure 5-17: Baseline and actual demand of July 2006 (Adapted from Dalgleish *et al.*, 2009).

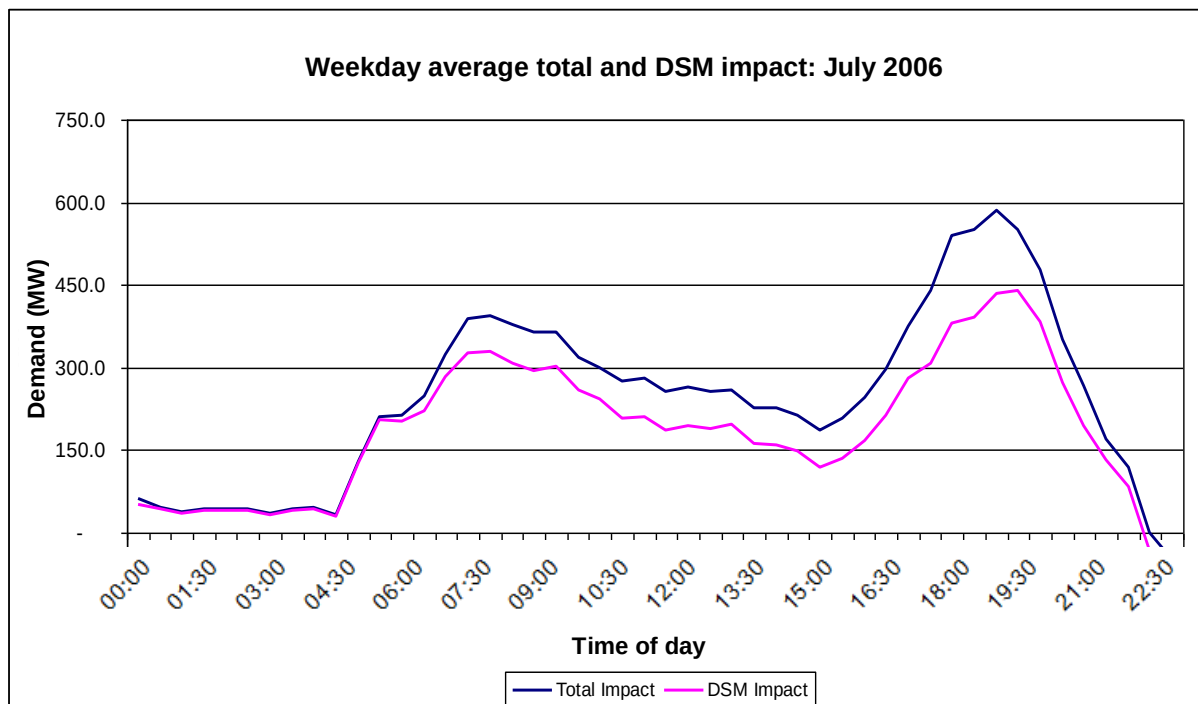


Figure 5-18: Average weekday total and DSM impact of July 2006 (Adapted from Dalgleish *et al.*, 2009).

Table 5-5: July weekday time of use impacts.

Weekdays time of use Impacts: July 2006	Morning	Morning	Morning	Midday	Evening	Evening	Evening
	OffPeak	Standard	Peak	Standard	Peak	Standard	OffPeak
	00:00-	06:00-	07:00-	10:00-	18:00-	21:00-	22:00-
	06:00	07:00	10:00	18:00	21:00	22:00	00:00
Average WD Total Impact	62.82	229.94	367.55	260.94	522.92	308.38	59.23
Average WD DSM Impact	58.93	210.51	306.04	191.03	388.78	233.26	25.95

The decline was a result of the Koeberg unit being back in service from 24 July and certain DSM projects not operating as aggressive from 24 July 2006. The total average weekday evening impact achieved in July was 523 MW. The impact decreased from June to July with 127 MW while the average DSM impact decreased with 108 MW.

5.4.2 Results of September 2006 to February 2007

Figure 5-19 gives a summary of the average weekday DSM impact of May 2006 to February 2007 with adjustments made to October 2006 to February 2007. The average DSM impact, divided into time of use, of May 2006 to February 2007 is shown in the bar chart of Figure 5-20. In August it was seen that the average weekday DSM evening peak impact was 354 MW.

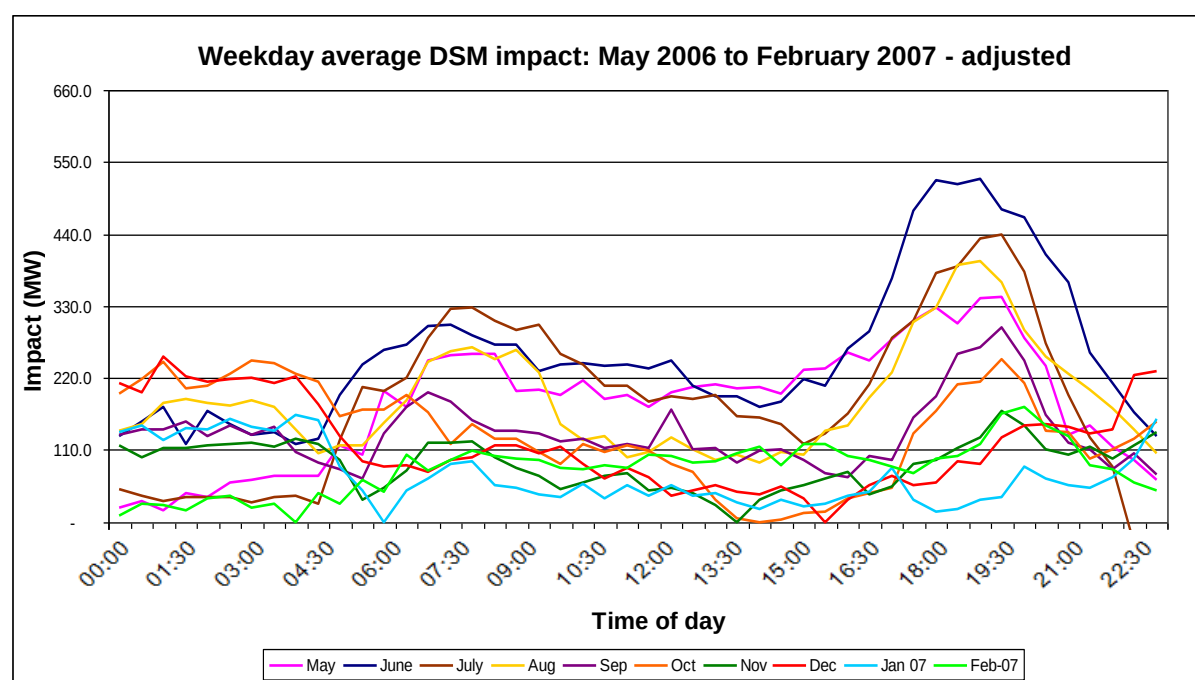


Figure 5-19: Average weekday DSM impact May 2006 to February 2007.

The Figure 5-20 bar chart shows the evening peak DSM impact of August being lower than that of July. It seems that the DSM impact decreased back to a similar impact as achieved in May. The average DSM evening peak impact from May to August was not constant but varied significantly. There was a 180 MW increase in average evening peak DSM impact from May to June, and a 108 MW decline from June to July. The evening peak decline continued in September to an average of 237 MW. The same decline was seen in the following months (after the adjustment) just as expected. The October evening peak average was 198 MW with November following with 124 MW and December with 96 MW. January 2007 impacts further decreased to 38 MW; 470 MW lower than in June.

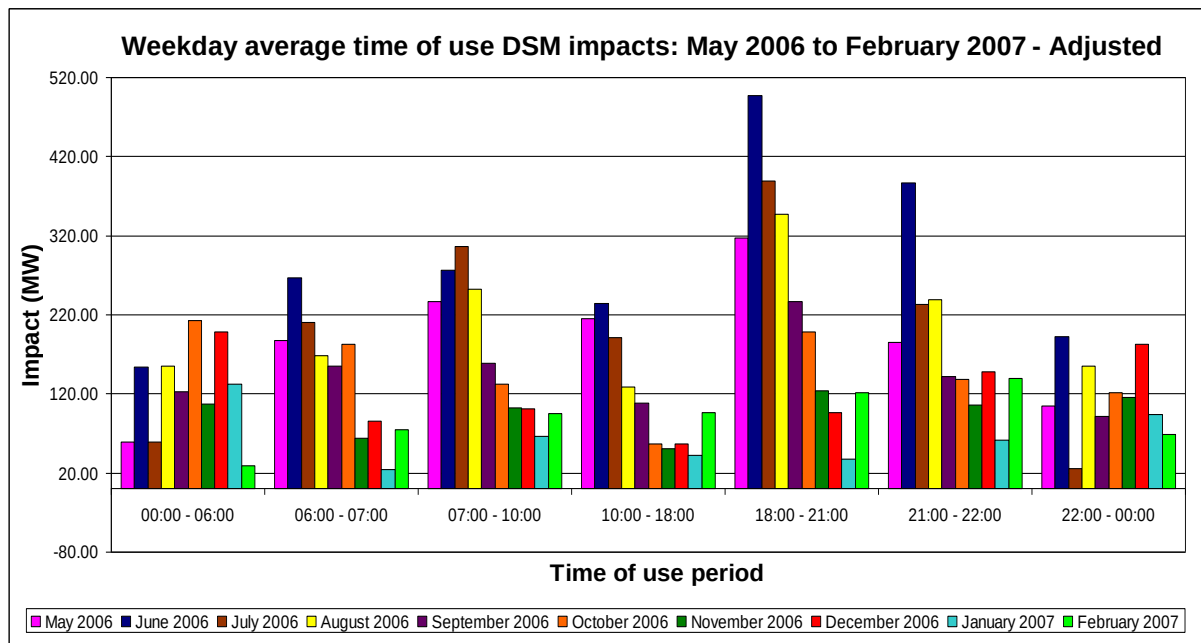


Figure 5-20: Weekday average time of use period impacts.

In February 2007 the evening peak impact was suddenly much higher. This is probably due to the fact that 2005 data was used for the baseline and not 2006 data. During February 2005 there was a much lower demand during the early morning hours than in February 2007. This resulted in the calculated DSM impacts being negative during the early morning hours.

5.5 VALIDATION OF REGIONAL TOP-DOWN RESULTS

With the top-down M&V analysis of the Western Cape accelerated DSM completed, it is important to validate the results obtained by investigating what a bottom-up M&V approach reveals. The bottom up M&V was performed by Botha (2007). Figure 5-21 compares the results obtained from the top-down M&V process with that of the bottom-up M&V process for the period May to September 2006.

The results of May show a difference of 234 MW between the top-down and bottom-up results. This difference increases in June with results of the top-down giving a DSM impact 238 MW higher than the bottom-up results. However, during July, August and September the difference in the results were significantly less. In July the difference was only 36 MW while in August and September the differences were only 17 MW and 60 MW respectively.

From the large difference in May and June between the top-down and bottom-up results it seems that the top-down approach was ineffective. However, the large difference was due to public awareness campaigns and industry voluntary contribution. During May and June there was a big hype in the Western Cape regarding power saving which favoured attention from the public resulting in savings. Part of the awareness campaigns was a very innovative programme, Power Alert, which display on national television the strain on the Western Cape power grid (Dalglish *et al.*, 2007). When the strain was high, residents were requested to switch off certain appliances and lights.

The bottom-up results focus on all the individual projects but do not capture the contributions of public awareness and voluntary contributions. The top-down approach captured the total impact which creates the large difference in the May and June results. This was confirmed by the July to September results, as at the end of July the electricity hype was over since the Koeberg unit was online again.

Suddenly the top-down and bottom-up results were very close. This was expected, since the public and industry stopped with voluntary contribution and returned to normal routine. The close relation in results continued during August and September.

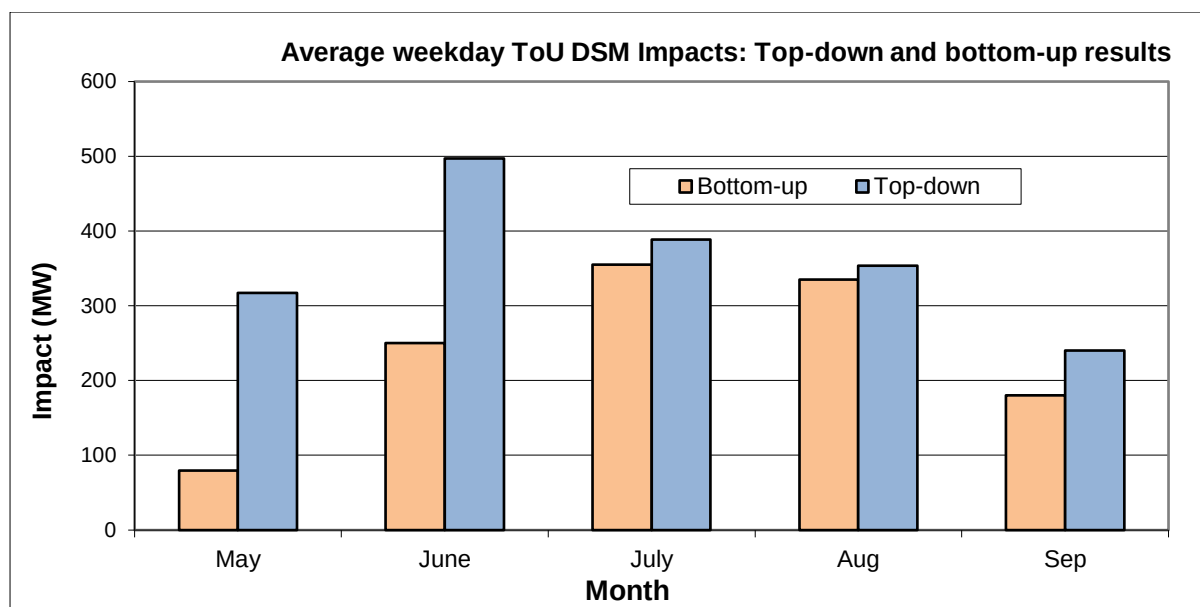


Figure 5-21: Average weekday evening peak DSM impact results of top-down and bottom-up M&V.

5.6 CONCLUSION AND DISCUSSION

This chapter presented the design of a novel regional level M&V approach with a unique implementation case study. A regional level M&V approach can be a very effective method to evaluate impacts of large-scale DSM initiatives. It can also provide results much quicker compared to following a bottom-up project and programme level approach. Here it should be noted that the impacts under assessment need to be significant when compared to the overall measured load. If the impacts are less than 10% of the overall load, it might get lost in profile noise. With the Western Cape case study, the urgent accelerated DSM implementation required rapid M&V which resulted in insufficient time to develop thorough baselines using the conventional M&V approaches. However, the regional top-down M&V methodology followed still provided results that were representative and gave the needed information to the stakeholders.

The results obtained through the M&V of the Western Cape DSM projects, showed that the accelerated DSM initiatives were fruitful and made an evident impact. Overall, the integrated recovery plan that was initiated by Eskom to overcome the electricity shortfall was successful. Only five load shedding events took place through the entire winter season. Although the regional top-down method proved to be very effective, several improvements can be made to provide better and more accurate impact quantification.

With this case study the important challenges and pitfalls were addressed and solutions were provided. A similar approach can be followed when a region with irrigation DSM interventions is under evaluation.

Chapter 6

M&V metering, quality and sampling

The previous chapters considered project level, programme level and regional level Measurement and Verification (M&V) methods. This chapter discusses the fundamental aspects that are used to perform M&V, which include M&V metering, meter data quality and proper meter sampling. Unfortunately, it is regularly observed that the importance of these is underestimated and sometimes neglected. If these fundamental aspects are not appropriately considered and put in place early, it is found that the M&V of incentive-based projects and programmes encounters disastrous shortcomings with incentive requirements.

It was also observed that M&V practitioners, Energy Conservation Measure (ECM) project implementers and other stakeholders often have a significant knowledge gap when it comes to M&V metering. This leads to M&V metering installations not being carried out properly or there is not a clear understanding of what exactly is being measured. This can severely affect the usefulness, correctness and accuracy of the data collected. In addition to this, the implementation of M&V metering itself, especially with irrigation M&V projects, has major challenges and problems. This chapter emphasizes this knowledge gap and provides essential background on M&V metering, Automatic Meter Reading (AMR) systems, data quality and a transparent and auditable data trail. Attention is given to the types of meters that are frequently used with M&V irrigation and related projects. How these function and which pitfalls to look out for are also discussed. From the challenges experienced with M&V metering, an innovative metering and AMR system was designed, developed and commercially implemented that specifically addresses these challenges.

Alongside metering, proper meter sampling methods are sometimes a significant challenge. Large enough sample groups, improper sampling plans and the difficulties that come with sampling load profiles hinder M&V approaches to attain high enough confidence levels and low error margins when it is required. This chapter looks at the conceptual design of an irrigation ECM simplified sampling concept that reduces load profiles to key single value ratios. The value of over sampling practices is also considered.

Chapter related publications and conferences

- ❖ Storm, M.E. Van der Merwe, C.A. Grobler, L.J., (2008b). *M&V of an irrigation pumping project: Case study follow-up.* South African Energy Efficiency Confederation Conference. Johannesburg, Nov 2008.

6.1 INTRODUCTION

Well-designed methodologies with project level, programme level and regional level Measurement and Verification (M&V) as discussed in the previous chapters are of utter importance. Unfortunately, it often happens that the fundamental aspects which are used to perform M&V, are underestimated, neglected or not properly done. M&V metering, meter data quality and appropriate meter sampling form the basis of any proper M&V approach.

It was observed with M&V practitioners, Energy Conservation Measure (ECM) implementers known as Energy Service Companies (ESCOs) and other stakeholders that there is often a severe gap in knowledge on M&V metering. In many cases, M&V practitioners or ESCOs use and install temporary metering themselves to gather baseline data. If installations are not done properly and there is not a clear understanding of what is measured, it can compromise the usefulness, correctness and accuracy of the data collected. It happens that ESCOs also provide metering equipment with the ECM equipment, or in other cases there is already metering installed that can be used for M&V. In these situations, and even if the M&V practitioner or ESCO arrange a meter supplier to perform an installation, the M&V practitioner and ESCO should have the adequate knowledge to assess the correctness of the installation.

Here it is important to note that the installation and implementation of metering and Automatic Meter Reading (AMR) systems can be very challenging. Metering on irrigation ECMs are especially challenging and problematic, and it was found that it often hinders or even prevents successful M&V. The IPMVP guideline and the SANS 50015 and SANS 50010 standards for instance, provide very good guidance on M&V, data transparency, integrity and correctness of project metering data (IPMVP, 2012; SANS 50015, 2015; SANS 50010, 2018). Other standards like the SANS 474 and NRS 057 provide a code of good practice for the installation of electrical metring (SANS 474:2009 and NRS 057:2009). With water flow meters and other M&V metering there also exit specific standards and installation specifications.

However, these do not necessarily provide guidance and solutions to the practical aspects and challenges experienced with metering. In addition, the usefulness of these documents to a non-technical person, or the availability thereof can be a problem. In some cases, it was found that project stakeholders and even M&V practitioners were not aware of the existence of such documents. Here the IPMVP guideline appendixes provide information and standards for different types of meters (IPMVP, 2012).

Asides the significant increase in cost of metering when an AMR system is incorporated, it brings another set of complications. AMR systems are often experienced as a black box where meter data enters and then something can be viewed via an AMR online system. It is not entirely clear to the M&V practitioner if what is measured in the field is actually what is displayed and provided by this system. It may occur that as data passes through this black box, it is introduced to multiplication factors, averaging and other changes without the knowledge of the M&V practitioner. This creates a serious gap and compromises a clear, transparent and auditable data trail.

Considering the above, this chapter will focus on providing value and contribute to the M&V field in the following ways:

- Show the difficulties and challenges that are experienced specifically with irrigation ECM M&V metering (although these challenges are also largely applicable to ECMs in other sectors);
- Explain and demonstrate the basic concept of metering and AMR systems, how these function, what parts are critical and which areas give challenges;
- Identify the areas where a data audit trail can become unclear with metering and AMR systems;

- Provide background on what type of meters are frequently used with irrigation and related type projects, how these function and which caveats to look out for; and
- Through this, provide M&V practitioners and other stakeholders with relevant background and information when sourcing metering and AMR systems suitable for M&V.

The above is done alongside the presentation and explanation of an innovative metering and AMR system, that was designed and development to specifically address M&V meter challenges. Figure 6-1 gives a flow chart of how this is approached. It was aimed, as far possible, to explain metering in laymen's terms and common M&V and energy auditor jargon, and not to engage in technicalities if it is not really relevant.

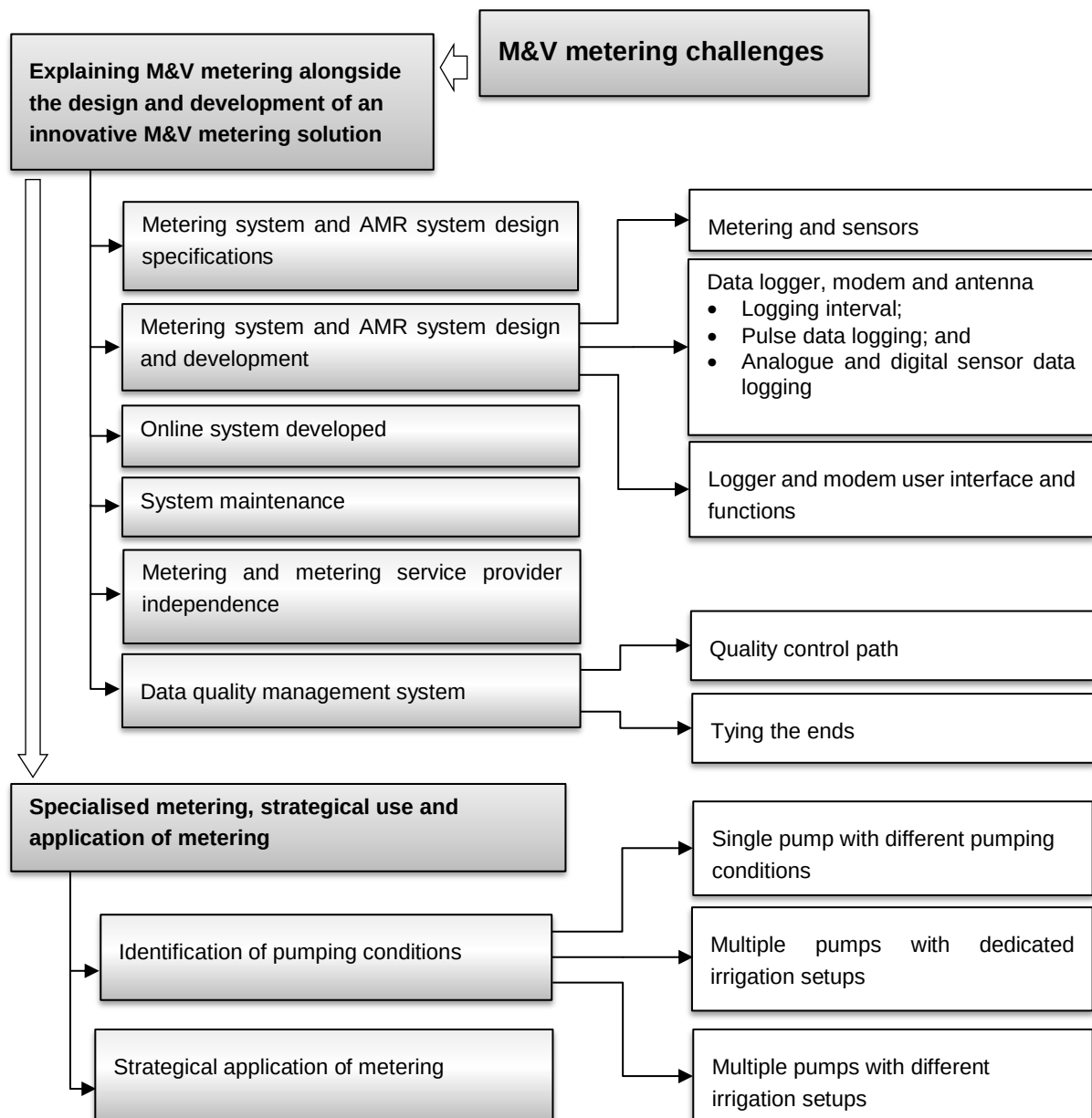


Figure 6-1: Flow chart showing the explanation of M&V metering alongside the design and development of an innovative M&V metering solution.

M&V practitioners, and the normal stakeholders, have a vast difference in technical and non-technical background. They can be for instance chemical, electrical or mechanical engineers, technicians, project

managers, Greenhouse Gas (GHG) experts and even sometimes persons with purely financial and legal background. Certain terms occasionally used in M&V and energy field literature are sometimes not even technically correct but provide a proper means of communication with such a large combination of backgrounds. An example here is the common reference to measuring Amps, where technically, current is measured and its unit is Amp (A).

The metering explanation, design and development topics discussed in Figure 6-1, focus on the aspects related to M&V. Thus, there is not engaged in the technicalities of electronic hardware, firmware, and online system software development. There are however references made in the following sections where more detail on the development can be found in the Appendix. The chapter shows how intuitive design elevates the challenges with M&V metering and quality.

Following the design and development, there is looked at the use of specialised metering as seen on the bottom of Figure 6-1. With this the strategical use and application of standard metering is considered as the need was identified in Chapter 3 Section 3.5.3. Here the use of multiple metering points or intelligent multiple meter approaches replace the necessity for relying on operational level conditions and boundary limits that may be problematic. In many situations, the function of normal metering can be stretched by strategized application which can increase the M&V capability and reach thereof.

Alongside metering, proper sampling methods are a significant challenge M&V practitioners experience. Often large enough sample groups, improper sampling plans and the difficulties that come with sampling load profiles hinder M&V approaches to attain high enough confidence levels with low enough error margins when required. Figure 6-2 provides a flow chart of metering sampling plans and the specific concepts that will be discussed.

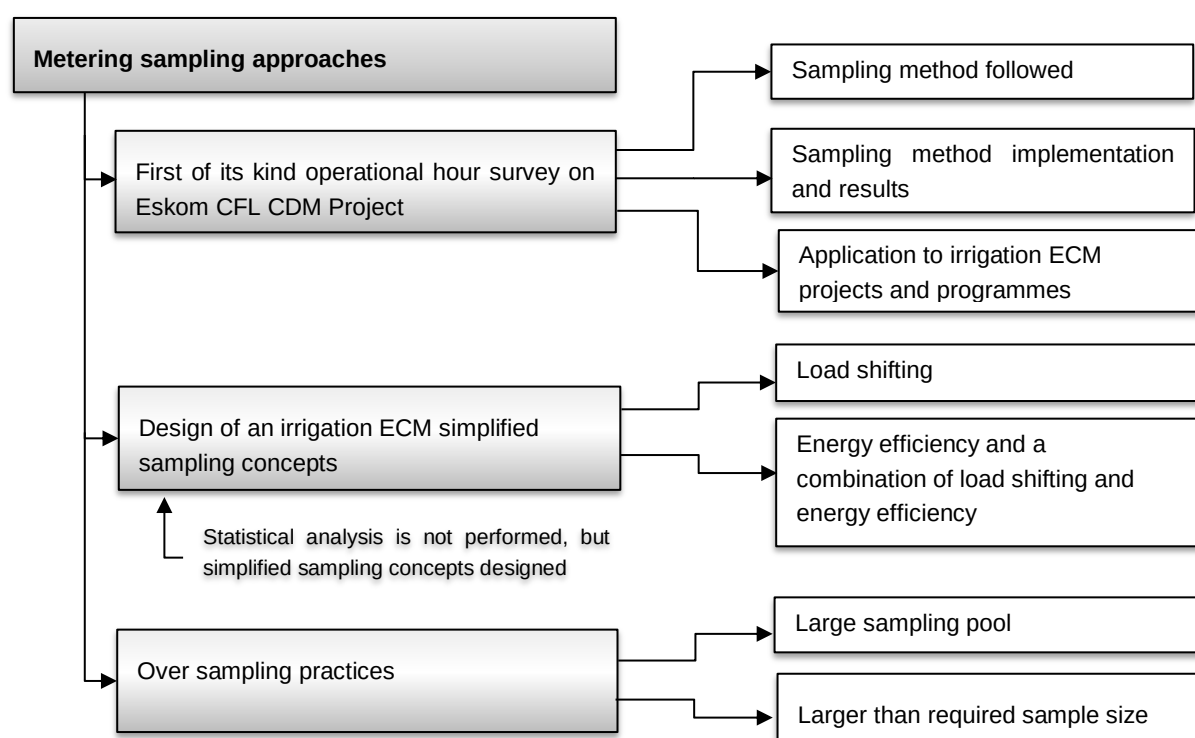


Figure 6-2: Flow chart of metering sampling plans.

This chapter considers how a first of its kind (Clean Development Mechanism) CDM project study sampling approach can be applied to reduce the complexity of load profiles. See the first subheading in Figure 6-2. It also looks at the conceptual design of an irrigation ECM simplified sampling concept that reduces load profiles to key single value ratios. With this there is also looked at the value of over

sampling practices as seen on the bottom of Figure 6-2. There already exist proper and thorough guidelines on sampling and the relevant statistics. Thus, statistical analysis is not performed but focus is placed on providing concepts that can assist with setting up proper sampling plans for irrigation ECM projects and programmes.

6.2 M&V METERING CHALLENGES

The M&V of many irrigation Eskom Demand-Side Management (DSM) projects and the Eskom irrigation Standard Product Programme (SPP) study, identified the need for an application fit metering system. Here can be referred to Sections 2.9 in the Chapter 2 literature survey and Chapter 3 Section 3.5.3 and 3.9.3. This same need was similarly observed in the industrial, commercial and mining sectors. There exist many different metering devices, data loggers, data concentrators and AMR systems within telemetry. These vary in application and implementation complexity, effectiveness and also cost effectiveness.

Normal metering and data loggers are separately not that expensive, but when these are usually combined with remote communication and an AMR system, the cost significantly increases. More cumbersome aspects are metering system installation, setup and commissioning. Several metering systems that were come across with M&V projects are fairly easy to install and set up in a clean commercial building, but it becomes very troublesome in a dirty and muddy irrigation pump station or a tough industrial or mining environment.

Metering with a logger and AMR system regularly requires connection to a laptop for system setup and commissioning. With this, good cell reception with proper and fast data connection is a prerequisite if the facility does not have Wi-Fi. This kind of setup procedure has proved to be very painstakingly, difficult and sometimes impossible. In an irrigation pump station, a laptop needs to be balanced on dirty pump pipes while struggling with laptop software and poor GPRS data connections. Since pump stations are located in rural areas or near rivers, cell and data connections are poor and continually vary.

Experience also showed that these irrigation pump stations are electrically unsafe and are occasionally bee and snake invested. In other extreme cases with pump stations in the South African province Mpumalanga, hippo and other wildlife complicate access installation and maintenance. See Figure 6-3 a) and b). Considering the above, M&V teams and installers normally spend the least possible time necessary in or near some pump stations.



Figure 6-3: a) Pump station next to a holding dam which is the home of a hippopotamus, b) Elephant spotted close to a river irrigation pump station.

Figure 6-4 a) and b) show the inside of two pumps stations where the floor is covered with water. This makes metering installations difficult and also very dangerous. It was commonly found that pump station electrical installations were old and in a poor condition. Maintenance on these is neglected and only the minimum attention is given to have the pumps running again. This frequently involves the farmer only doing a quick Do-It-Yourself (DIY) fix that is not permitted by any electrical and safety regulations. Figure 6-5 shows the inside of two different pump station Distribution Boards (DBs) with dangerous connections and wiring that already overheated.

The setup of metering, the logger and AMR system can be difficult and bring along several complications. It was experienced that after metering system installations, the M&V team was not entirely sure that the system was logging data, logging the correct data and if the data logged was actually being successfully transmitted.

The integration between metering equipment, loggers and communication modems do not always allow proper data cross verification and validation checks. A meter can display that it is measuring data, but it cannot be verified on site if the logger is properly recording the data and that the modem transmits the data. This can usually only be confirmed by the installer checking data online or calling the AMR system office to confirm data uploads and correctness.



Figure 6-4: a) Inside a pump station showing piping, the control DBs and water on the floor, b) Pump station floor covered with water with a metal drum the only dry place to stand.

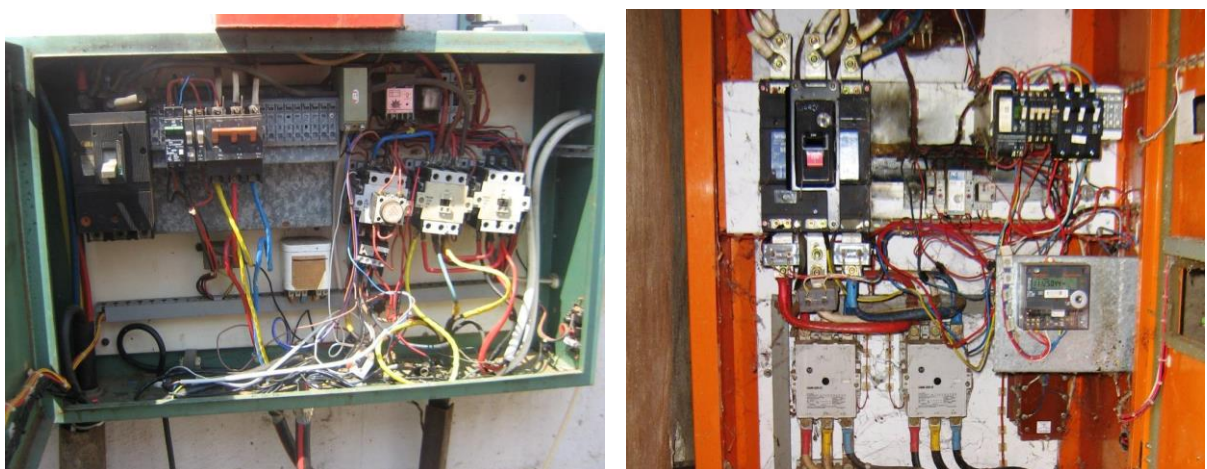


Figure 6-5: a) Inside of a pump station DB with dangerous connections, b) Inside a DB where wiring had already overheated.

Since irrigation pump stations are often far-off with the minimum cellular coverage, this can be a frustrating process. Data can frequently not be viewed online from the pump station, due to poor data communication. Even voice calls to an AMR system office can occasionally be problematic. Some more expensive loggers and modem devices do have a small display or terminal output (to a laptop and later devices have Bluetooth capability to connect to a tablet) through which some logged data information and communication details can be viewed. However, these have limitations and provide much information of one aspect, like logged data, but not of communication.

Issues like these resulted in installers or M&V practitioners leaving the site being unsure of a proper installation; hoping that the system is in order and that the data is successfully communicated. Unfortunately, in many cases the system was not fully operational, requiring costly follow-up site visits.

A further complication that was came across with AMR systems was that the process of data recording, compression, transmission, reception, extraction and data processing seem to be done through a black box. It was found that on the data trail, through this black box, data are introduced to multiplication factors, averaging, interpolation and timestamp changes from backward filling to forward filling. An M&V practitioner is provided access to online data display or a data download without a precise stipulation of what happened to the data. This creates a dangerous gap in the data trail and a troubling question in how the actual data captured by the infield meter correlates to what is seen online.

With M&V projects performed, this has many times resulted into incorrect data used or data with incorrect or shifted time stamps. It was also observed that multiplication factors changed online due to software problems. In one instance time stamps changed due to a MS Windows server system update.

Another aspect that complicates data collection on irrigation pump stations is logger and modem power consumption and dependency on the pump station power supply. It was experienced with the M&V of Eskom irrigation DSM projects that in some areas communication was frequently lost. In certain cases, this was due to reception but in other cases it was due to power cable theft or antenna theft. Farm irrigation pump stations are far-off and isolated, and therefore targeted by copper thieves and cables are torn out of pump stations. When this happens the logger and modem also lose power, and the common backup batteries found also only last a few days. Often the farmer is not aware of it, especially during the low pumping seasons. This is only observed when a meter maintenance team does a site visit. In Figure 6-6 a) one such far-off and isolated pump station is shown that can be easily targeted by copper thieves since it only consists of DBs in the open veldt. Figure 6-6 b) shows the work of cable thieves.



Figure 6-6: Pump station consisting only of DBs in the open veldt, b) Cable theft.

The logger and modem pump station power supply dependency also have the drawback that it consumes power from the point it measures. With a typical pump station, this power consumption of the logger and modem is very small when compared to that of the irrigation pump. However, in other sectors where lower power devices such as lights are measured, this can influence the readings.

Tampering, vandalism and weather conditions require that metering, loggers and modems should be redundant. As shown in Figure 6-6 a), occasionally an irrigation pump station, or rather a power supply point, is in the open veld with DBs exposed to rain and sun. It can happen that even a farmer will tamper with the meter and logger connection to influence measurements. If there is not safeguards and cross check mechanisms in place, this will go unnoticed.

It was observed that the conditions in pump stations even resulted in the catastrophic destruction of M&V metering. Figure 6-7a) shows a power metering installation and Figure 6-7b) shows the remains of it when burnt-out. This was due to a pump station Power Factor (PF) correction capacitor that spectacularly failed next to it and ignited the meter enclosure.



Figure 6-7: a) Three phase power meter installation, b) Meter burnt-out due to failed PF capacitor.

The exceptionally challenging environment of irrigation ECM M&V, and similar problems experienced in the industrial and mining sector, led to the design, development and commercialization of an advanced integrated metering and data gathering system. The development was focussed to provide an M&V application fit but cost-effective solution.

6.3 EXPLAINING M&V METERING ALONGSIDE THE DESIGN AND DEVELOPMENT OF AN INNOVATIVE M&V METERING SOLUTION

From the M&V challenges experienced, a comprehensive list of system specifications was compiled to identify problems, address specific issues and develop methods that can alleviate these problems. The system requirements and specifications grew over time to increase reliability and redundancy.

6.3.1 Metering system and AMR system design specifications

The below 20 bullets list the crucial design considerations that was incorporated with a metering and AMR system that was designed as part of the study.

- **1) Multi-level redundancy** - Data loggers should be robust to harsh environments and have internal data storage redundancy to ensure data protection and security.

- **2) Flexibility and ease of installation** - This system must be flexible, easy to install and easy to implement therefore reducing installation time and pumping shutdown.
- **3) Always on** - The logger and communication modem should not require external power (like 220V supply from the pump station) and only rely on an internal battery. Thus, it draws no power from the pump station and data logging and communication will not be influenced by load shedding or the power supply down due to cable theft.
- **4) Measurement point independence** - Referring to point 3) above, since the logger and modem will not require external power from the pump station, it will not influence power consumption of the point it is measuring. This also isolates the logger and modem from the pump station power preventing it being influenced or damaged by “dirty” power, surges and lightning. Pump electrical switch gear, soft starters and Variable Speed Drives (VSDs) found in a pump station create electromagnetic noise, spikes and harmonics on the power line. In South Africa it is also found that these far-off utility power supply points suffer from voltage dips, flicker and outages.
- **5) Ultra-low power consumption** - The logger and modem should be ultra-low power consumption devices to enable extended time periods (more than three years) of data recording and transmission without battery changes.
- **6) Long-life battery** - The logger and modem require an ultra-long-life battery with high redundancy and high energy density with absolute minimum charge decay over time.
- **7) Integration capability and accommodate a wide range of sensors** - It must be capable of full integration with irrigation ECM metering related equipment such as power meters, flow meters, current transformers, pressure probes etc.
- **8) Redundant against harsh environments** - The logger, modem and battery should also be able to sustain high environmental humidity and high temperatures. The temperature in irrigation pump stations can be significantly higher than ambient departure due to pump operation and heating by the sun. Exposure to water spray and a higher humidity due to water leaks in the pump station should also be considered. With this, exposure to direct sunlight and rain from time to time is also possible.
- **9) Data security and availability** - Important features include:
 - Super capacitor or contingency battery backup layer – This enables the logger to continue recording data (only recording mode, not for communication) for up to an hour, even when the battery is disconnected. This feature is required to ensure no data gaps occur even during a battery exchange;
 - Recorded data on the logger should be protected even when battery power is totally lost, thus data needs to be stored on non-volatile memory;
 - Data logging even with no remote communication – the logger needs to continue logging even if there is no communication for weeks or months;
 - Logger should have internal data storage for a minimum of six months (at 5-minutely recording interval);
 - The logger should be protected with a passcode to prevent tampering or unauthorised persons going into the logger menus and changing settings. The logger should have a data view function whereby data can be viewed while logger settings are not accessible.;
 - Transmitted data needs to be encrypted and protected, and should be viewed securely online;
 - Online data should be hosted on cloud service through a service provided with a proven more than 99% up-time;
 - Frequent database backups; and

- Data export to CSV files from an online system enabling the M&V practitioner to download data to process and store offline.
- **10) Clear and transparent data trail** - Transparent data trail and quality management system on data gathering, transmission, processing and display. This should be SANAS compliant for 12L projects. An ISO9001 quality management plan capturing full installing documentation, cross checks, commissioning and online data verification is recommended.
- **11) True reading** - A true meter and logger display cross verification capability that can identify meter tampering.
- **12) Finer resolution** - Although 30-minute or hourly data is mostly used, a finer resolution enables very accurate interpolation in events that a data point might be missing or corrupted. In contrast, when there is one missing point with 30-minutely data, little data close to this point is available for accurate interpolation.
- **13) Onsite full setup and communication verification without laptop or tablet connection** - The logger and/or communication modem should have its own display that allows the following:
 - Instantaneous readings for correct meter installation verification and comparison with a handheld check meter. This immediately identifies a situation where an installation was not properly done (for instance where a CT on a power meter is installed the wrong way around).
 - On-logger data interpretation. The logger should be able to interpret, process and display data such as pulses, sensors, metering requiring multipliers or scaling factors. The logger should allow on-unit entering of pulse metering constants. Hereby the logger can interpret time lapses between pulses and calculate from this and the pulse constant, a power demand or flow rate value.
 - For power calculations, the instantaneous value can be verified with a handled power meter; and
 - With a flow meter the readings can be verified by checking the meter dial over a short period from which a flow volume and flow rate can be calculated. This can be compared by the logger calculated flow rate.
 - Data logging verification. The installer should be able to check on the display if the data logging is fully active and correctly set up.
 - Remote communication check and data upload verification. The installer should be able to check and verify signal strength and data transmission on the logger or modem display. This can assist the installer to move the modem around to get the optimal reception in the pump station or adding and correctly placing an external high-gain antenna.
- **14) Onsite calibrated system** - Not only the physical meters should be calibrated, but the entire data trail. While the installer is on site, the system should allow reading and data verification for calibration checks. This allows a proper commissioned system with data integrity and confidence that the system is properly set up and operational.
- **15) Remote error reporting and diagnostics** - Daily data and communication checks and error reporting to avoid data loss. The logger itself should be able to receive communication quality information (signal strength etc.) from the modem and save this in an error log which should also be uploaded. This helps with fault diagnostics to identify recurring issues.
- **16) Remote setting changes** - Logger communication, sensor settings and setup options should be over-the-air remotely configurable. This allows post-installation corrections without the need for a site visit.

- **17) Remote firmware updates** - The system must be able to accept and implement remote firmware updates and upgraded to achieve remote maintenance and effectively keep up data collection to reduce costly site visits and routine maintenance.
- **18) Intelligent logger with advanced functions for specialised metering:**
 - The communication interval should be flexible and remotely settable to allow rapid communication during firmware upgrades or intensive monitoring periods. The rest of the time the communication schedule should be kept at a low schedule, such as one to three times per day, to prolong battery life;
 - It should accommodate M&V intelligence to monitor boundary conditions and provide alerts when these are breached. This relates to the operational level boundaries discussed in Chapter 3 Section 3.5.2.4; and
 - It should allow complex pump station multiple meter setups as mentioned in Chapter 3 Section 3.5.3. On this, additional condition sensors can be applied to indicate another pumping condition which further produces accuracy and data reliability.
- **19) Custom upgrades and feature additions** - The logger platform and firmware should allow for custom upgrades and changes to expand its reach to accommodate more sensors and functionality to address market needs.
- **20) Online data access and display** - Includes the following:
 - Online website where basic raw data feed, multiplication constants and processed data can be easily viewed and downloaded;
 - Project interface to enable integration ability to view individual pump stations and multiple pump stations in a project;
 - Meter point instead of logger management;
 - Graphic display of data; and
 - Prompt self-identification diagnostics with display of meter operation or data transmission defects through faulty data feeds.

6.3.2 Metering system and AMR system design and development

This section describes the design and development of an advanced integrated, metering, data gathering and processing system to address the 20 points listed. The aim was to establish a redundant, but cost-effective solution that fits M&V specific requirements and conditions.

With this, the following sections explain the typical metering and metering systems found, provide background on the function of these and identify the caveats found on typical metering and AMR systems.

Figure 6-8 provides a flow chart layout of the designed metering AMR system. This also presents the typical layout of such systems available in the market, although a few concepts, structures and communication protocols may differ between systems.

6.3.2.1 Metering and sensors

On the top left of Figure 6-8 the meter and sensor connections via a connection interface is shown which relays the signals to the data logger. These signals can take on many forms but generally consist of the following:

- **Pulse** - A mechanical flow or power meter has a switch that closes and opens after a specific amount was quantified by the meter. Flow meters typically have impellers that drive gears, and depending on the meter factor, when a gear reaches a specific point a small magnet passes a

small switch that closes. This closing and opening of the switch are seen as a pulse. These switches can also be an electronic transistor that provides the same function. Depending on the size and pulse constant factor, the closing and opening of the switch indicates that for a flow meter a certain amount of the medium has passed. Depending on the size, a flow meter constant can be 0.5, 1, 10, 100, 250, 1000 or even a higher number of litres per pulse. Figure 6-9 shows examples of the pulse readers, pulse switches and different flow meters that are commonly found. Power meters often have a 1000 or 2000 pulses per kWh constant and if not applied correctly, incorrect measurements will be reported. It is very important to notice here that a power meter can either, depending on type and load size, be directly connected or with Current Transformers (CTs). With the last mentioned, the CT ratio should be accounted for in the pulse constant. Section 7.2 elaborates on this.

- **Analogue signal** - Sensors such as CTs and Voltage Transformers (VTs) give a small Alternating Current (AC) analogue signal. These can either be an alternating voltage (0-1V, 0-5V and other) or the sensor can be an alternating current source (0-1, 0-5A and other). Normally the current source is transformed to an alternating voltage for measurement.
- **DC Signal** - Some pressure transducers, pyranometers (for sun radiation), ultrasonic flow meters and many other sensors give a Direct Current (DC) voltage or current. Others receive power and internally regulate the current flow as the measurement of the sensor changes (4-20 mA is very common). Similar sensors are temperature probes such as PT100s, PT1000s and NTC probes which provide a changing resistance with changing temperature. NTC abbreviates Negative Temperature Coefficient, and its internal resistance increases with increase in temperature. PT abbreviates Positive Temperature and lacks the C for Coefficient. A PT temperature probe operates the other way around compared to an NTC.
- **Digital signal** - There are many types of sensor and meter outputs which can be a temperature probe that gives a digital signal, to meters and sensors with RS232, RS485, Modbus, Profibus and several others (RS232; RS485; Modbus; Profibus). There are specific standards for telemetry communication with flow meters, power meters etc.

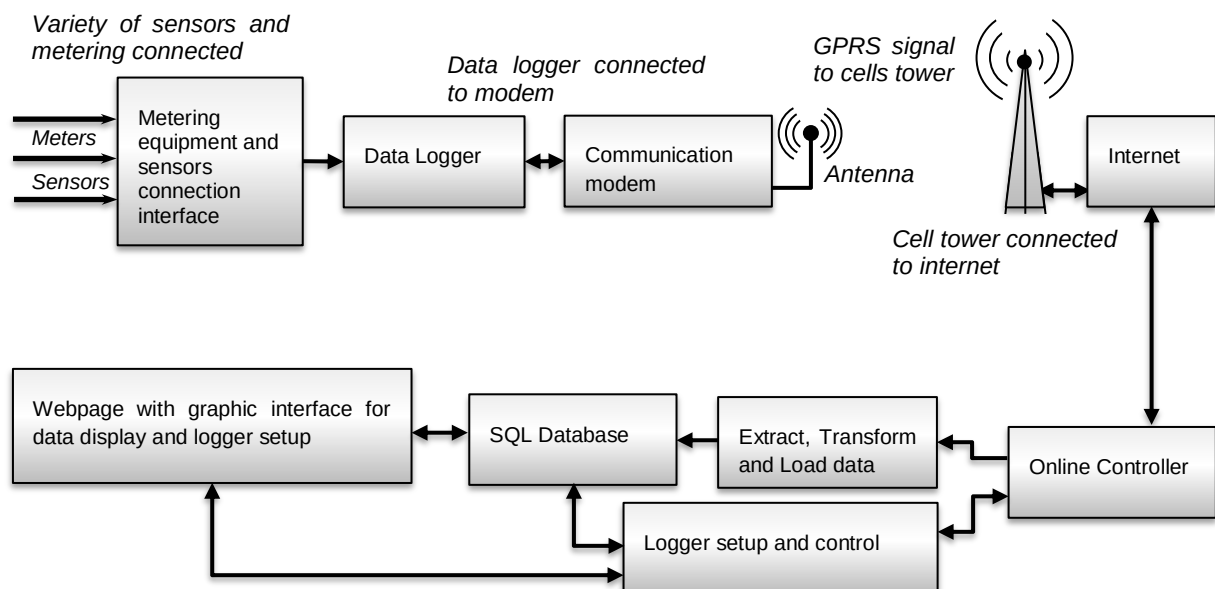


Figure 6-8: Design layout of the metering and AMR system.



Figure 6-9: a) Elster H4000 flow meter with PR7 reader, b) Sensus flow meter with pulser, C) Elster brass type flow meter with a read switch.

6.3.2.2 Data logger, modem and antenna

A special configuration was developed to realise a device that complies with the specification and functionality given in the 20 points of Section 6.3.1 but still being a cost-effective product. This configuration integrates the metering connection interface, data logger, communication modem and antenna into a single unit as shown in Figure 6-10. This single device combining all these parts was named the Integrated Multi-logger (IML).

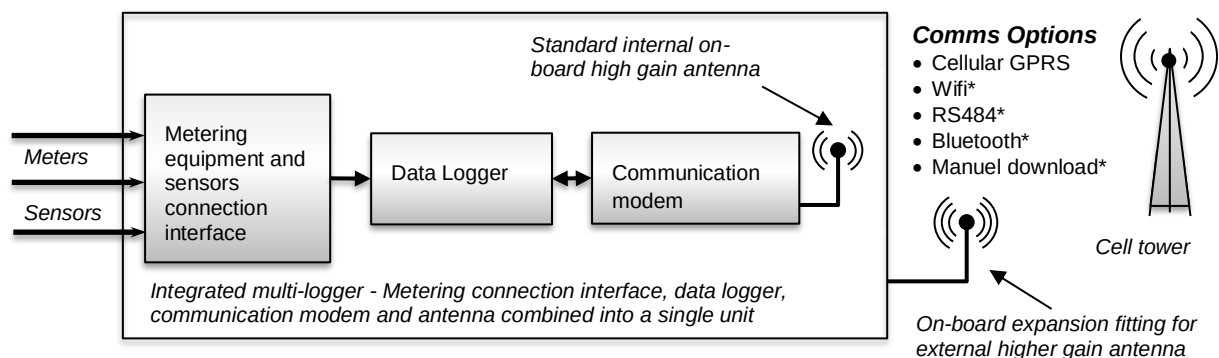


Figure 6-10: Flow diagram of cost-effective design which integrates the metering connection interface, data logger, communication modem and antenna.

The data logger part shown in Figure 6-10 effectively captures, processes and stores signals and information provided by the sensors. This data is stored on reliable non-volatile on-board memory from which the data is uploaded via an integrated GPRS communication modem. The IML device can use its internal Printed Circuit Board (PCB) antenna or an external antenna can be added for areas with very poor reception, as can be seen in Figure 6-10. Other communication methods are also possible but for far-off irrigation pump stations these are not practical.

Figure 6-11 shows the actual integrated device that was developed. Figure 6-11 a) and b) give views of the side and top of the device. On the left side and bottom quick connectors are mounted to allow quick onsite sensor connection for installation or unit replacement. These quick connectors greatly reduce the installation time and complexity, since the sensors and metering cables are custom manufactured beforehand allowing an onsite plug and play solution. This prevents the necessity of cutting and connecting thin wires to in-DB terminal blocks while in a dirty and watery pump station. Figure 6-11 c) gives a close-up of the IML front panel showing the user interface. The user interface is further discussed in Section 6.3.2.3. The IML is build using a standard IP65 enclosure providing protection against dust and water splash. Water proof enclosures are not used since it can easily trap moisture. In severe cases it was seen that moisture enters through the cables itself; between the cable

wire strands and insulation. This happens when the logger enclosure is cool inside and the ambient temperature suddenly rises which creates a lower pressure inside the logger. Thus, outside air and moisture is effectively “sucked” through the wiring. This results in the moisture being trapped inside the unit creating havoc with the electronics. Experience showed it is better that moisture and water should be able to drain out of the enclosure when there was ingress.



Figure 6-11: Designed integrated multi-logger, a) Side view showing quick connect fittings, b) Top and left side view showing both the connectors and front panel, c) Front panel showing user interface.

The IML have undergone several hardware development revisions with the latest remaining fully functional even if the electronics were temporary exposed to direct water. It also stays fully operational in environments with prolonged humidity as high as 98%. The unit has an on-board temperature and internal humidity sensor, a safety precaution, to monitor if the logger device is exposed to high temperature and high humidity. Thus, it will show water and moisture ingress into the device. This data is also logged and uploaded so that the device’s condition can be monitored remotely. Figure 6-12 a) shows the inside of the device enclosure. On the left the device’s PCB motherboard is shown with quick connect data ribbon cables and a quick connect power cable. The ribbons connect to the connector PCBs on the side of the enclosure while the power cable connects to the battery base. The battery baseplate can be expanded to hold up to four high-power density dry-cell batteries.

These batteries are military specification with a 10-year shelf-life making them redundant and safe in harsh environments. Figure 6-12 b) shows the front of the mother board with a Liquid Crystal Display (LCD) and user buttons. On the far right the GPRS module can be seen and below that, the on-PCB antenna. The whole unit was designed to have a cost effective two-layer PCB with easy electronic component pick and place. With this, the modular design with quick connectors enables easy and fast assembly. The device was designed in such a way that all components and sensors are sourced in South Africa.

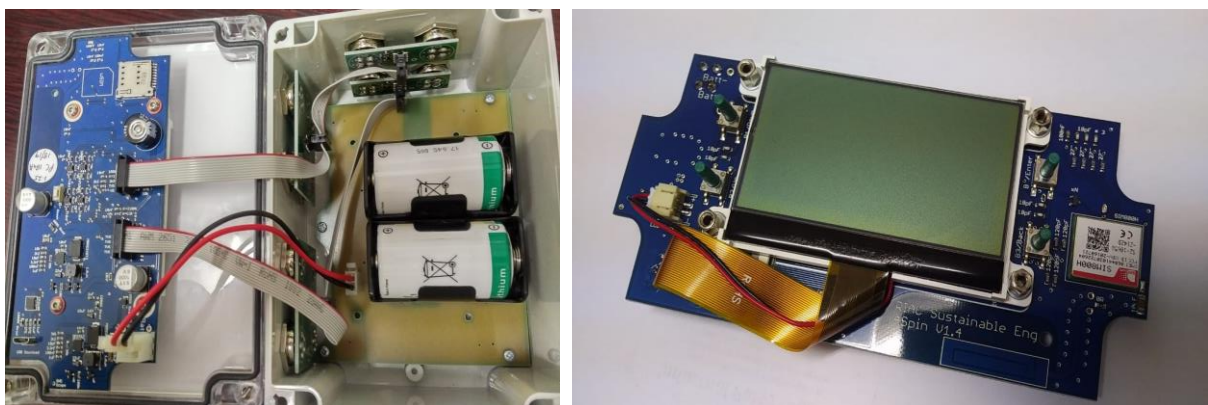


Figure 6-12: a) Inside logger enclosure, b) Integrated PCB with user interface, logger, communication modem and antenna.

With this, the full device manufacturing also occurs in South-Africa making it a proudly South-African product which stimulates the local market. However, only using local components and workforce substantially increased the challenges to still provide a cost-effective product. The following subsections address important logger related aspects of the device.

6.3.2.2.1 Data recoding logging interval

Data loggers found in the market can have a fixed data recording logging interval or some have a configurable logging interval. Intervals can be minutely, five-minutely, every 30 minutes, every hour, bi-daily, daily or longer. Some can provide data at much smaller intervals such as every second or even in milliseconds intervals. The logging interval is dependent on what the measurements are used for. If the start-up current of a motor is measured, a second interval is too long and millisecond or even a smaller interval will be preferred since the start-up peak current is very rapid. It is very important though that every interval has a date and time stamp.

Standard M&V reporting for Eskom DSM projects were done on 30-minute interval demand profile data. A smaller interval of every five minutes is very helpful when interpolation is required with missing time stamps. Minutely data becomes too cumbersome to work with and results in data files being too large. The most common data analysing tool for M&V practitioners is MS Excel. Here minutely data becomes difficult to work with. However, it may be needed in some cases such as accurately determining a demand difference due to equipment switch-on and switch-off. An example of this is an operational capacity test done for residential water heater DSM projects. Here all the geysers (or in batches) are switched off at once late at night and switched on again simultaneously later during the early morning hours, when the geysers cooled down enough so that the thermostat will switch on the element.

The developed IML has therefore user selectable logging intervals. This is also fully remotely changeable and therefore allows the shorter interval measurements to be done for a period. The IML also allows application specific logging interval development. One such application was done on an M&V project to allow variable frequency logging that is activated by an intelligent logger protocol.

In this case the client requested five-minutely data throughout the day, however, when there is flow, one-minutely data for five minutes before and five minutes after the flow event is recorded. This was successfully implemented which demonstrates the flexibility of the custom design environment.

It should be noted here though that this special requirement resulted in the client having data processing challenges later. Although this finer reading was provided, the client at the end used the data to derive an average daily flow rate manually in MS Excel after downloading the data. With constant five-minutely data an average is easy to determine (sum of points divided by amount of points), however, with variable frequency data this simple approach cannot be followed. Summing the points and dividing by the amount of points will give an average, but not a weighted average. Thus, care should be taken when working with variable frequency data such as provided by Supervisory Control And Data Acquisition (SCADA) systems.

6.3.2.2.2 Pulse data logging

With meters providing pulses, a typical data logger will count the amount of pulses in each time period and store the counted value. In some cases, the logger stores an incremented value which is that of the previous interval plus the pulse counted in the current interval. In other cases, a logger may already process the value by incorporating the pulse constant and thus log a consumption or usage rate value. For instance, kW demand or kWh used for power, Litres used or Litre/hour flow rate for liquid mediums. The IML logs the raw accumulated pulse value and has an interactive display to give demand or flow rate values. However, only the raw logged pulse values are uploaded.

6.3.2.2.3 Analogue and digital sensor data logging

With analogue and digital sensors meters, it is vital that integrated (average) values instead of instantaneous values should be used. With instantaneous readings, the logger will log one reading on every five minutes. This reading may thus only represent one second of the five-minute interval and what happened during the other 299 seconds is missed. For some sensors, such as temperatures that measure a system where the variable changes slowly over time, an instantaneous value every five minutes may suffice though.

It is best if a logger takes several samples, say every second, 5 seconds or 15 seconds and uses these to calculate an integrated value. The IML follows this approach and further provides the maximum and minimum value with the integrated value recorded in the interval. This offers additional information on the variations that occurred in every interval.

6.3.2.2.4 Data storage

With far-off irrigation pump stations which cannot always be regularly attended for meter and AMR maintenance, it can happen that months may pass before a metering point can be attended to. See Section 6.3.4 on system maintenance. Therefore, it is imperative from experience that a logger should without communication be able to keep on logging and store data for at least six months.

The IML can store data of more than a year with even 11 variables logged on five-minutely intervals. It is here also very important that recorded data on the logger should be protected even when battery power is totally lost, thus data needs to be stored on non-volatile memory. The IML also has a super capacitor to keep data logging active even during battery changes as described in point 9) of the system specifications in Section 6.3.1.

6.3.2.3 Logger and modem user interface and functions

With the design of the IML it was aimed to establish a very simple but usable user interface whereby the installer:

- Can do full metering and system setup on the device itself;
- Perform full meter reading and logging testing; and
- Verify both the installation and data transmission by only using the IML user interface.

This section describes how the requirements and specifications of Section 6.3.1 were incorporated into the IML. It also aims to provide M&V practitioners and other ECM stakeholders with knowledge on what to look for when sourcing a metering and AMR system. Attention is given to the IML functions and display information to familiarise the reader of what is needed from an M&V fit metering system.

The user interface was designed be easy to use, clear and straightforward. To a large extent it was designed to be self-explanatory, since, experience shows that logger instruction manuals are very rarely used. Figure 6-13 a) shows the design of the logger user interface. There are four buttons, two for entering and exiting menus on the left and two for scrolling up and down on the right. In the centre of the buttons is a digital display which shows the main menu as seen in Figure 6-13 a). Figure 6-13 b) gives a short description of the items listed in the main menu. This is provided on the IML enclosure itself for quick reference.

Figure 6-14 gives a flow chart of the logger menus for settings and functions. The top row shows the menus where instantaneous sensor data is displayed in real time. This is used to verify instantaneous values seen on the IML with instantaneous values measured by a cross check handheld meter. In the first menu on the top left the *Data* option is selected in the *Main Menu*. Then, on the first display on the right labelled 2, the first of three <1/3> data displays are shown with the second and third following:

- Display-2 shows the total number of pulses already counted;
- Display-3 gives the real-time display of the analogue sensors measured – the view gives two Voltage Transformers (VTs) and two Current Transformers (CTs); and
- Display-4 on the far right gives the values of four digital temperatures, the IML internal temperature and internal humidity reading. The last two are safety precautions to monitor the exposure of the logger to high temperature and high humidity. Thus, it will show water and moisture ingress into the logger as described in Section 6.3.2.2.

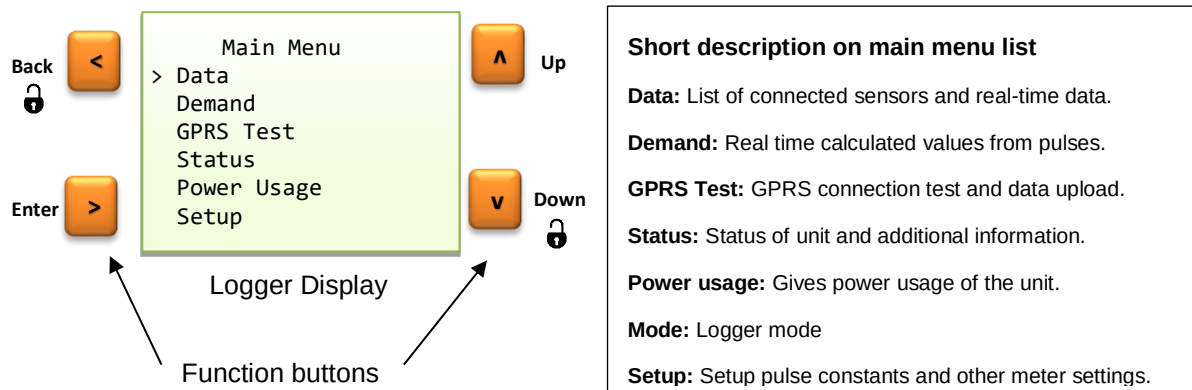


Figure 6-13: Depiction of logger user interface.

The long arrows in Figure 6-14 show progression within a specific menu as seen in the first row. The shorter arrows in the first column and second row indicate that a new menu is selected. Each of the displays are numbered for easy reference. In the second row several menus are described. The first menu selected, display-6, is the real-time pulse *Demand Menu*. Here the demand or flow rate is calculated from the pulse counted and the pulse constant set. This is followed by display-7, the GSM/GPRS test menu, where the remote communication and data upload can be tested. Through this the signal strength and successful data transmission can be very quickly established.

The last display in row two, display-8, gives the *Status* of the last communication, amount of unsent data and logger firmware version. This is very helpful to check communication success when the IML and antenna are installed inside a DB. This happens when the DB door needs to be closed and the GPRS test view cannot be watched to check signal strength and data upload.

The IML also has a test Short Message Service (SMS) function for situations where the unit display cannot be viewed after installation. This typically happens when a logger is installed in a DB with safety lockouts or rooms where power cannot be engaged with persons inside. The logger will send a status SMS to a mobile phone number entered after a selected time delay.

The third row, display-9 to display-12, shows the setup of the pulse connections and pulse constants. The unit of pulse variables measured (Litre, Cube, kW for instance) and the meter pulse constant can be selected. In display-12, the meter display value can be entered. Thus, the physical dial or display accumulation counter reading on the flow or power meter can be entered onto the logger. See Figure 6-15 a) and b) for the display readings of a flow meter and a power meter.

This meter reading will then increment with new pulses according to the pulse constant. Therefore, the logger will always track the meter reading. This value is uploaded and therefore a user can remotely perform a meter reading. This also serves as a tampering cross check; if the meter reading and the logger reading do not match, tampering may have occurred with the logger or the pulse wire. The last row shows display-13 to display-16 where analogue sensors are set up. Display-15 shows the four

analogue sensors selected and Display-16 shows where the type of sensor and its constant are selected. Since the analogue constant is selected here, the sensor constant is applied to the analogue signal received from the sensor providing the appropriate sensor reading.

Figure 6-14 gives only some of most important displays. There are also several other menus for digital sensor setup, hardware configuration, communication schedule and logging interval setup, and setup of the installation test SMS.

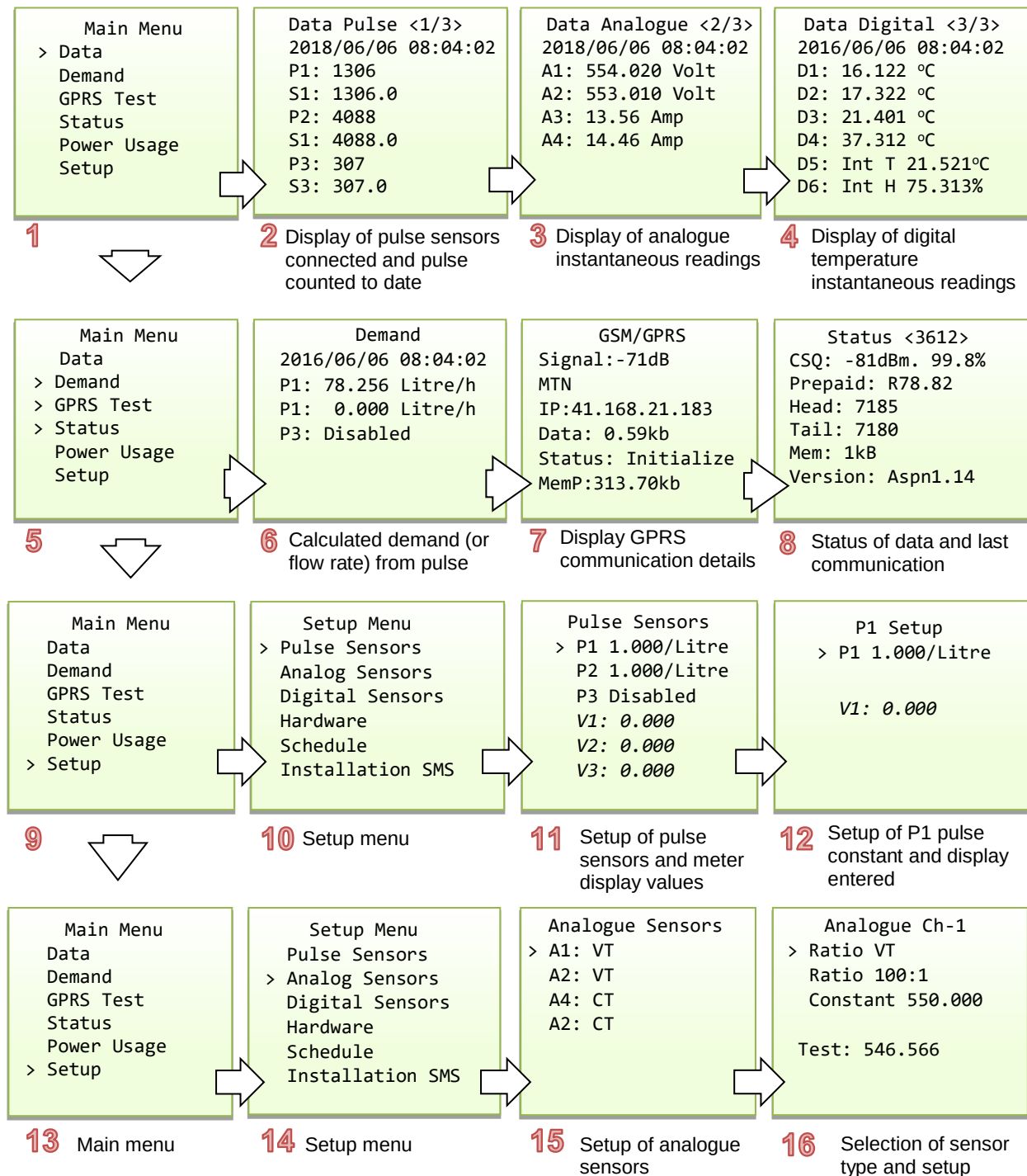


Figure 6-14: Flow chart depicting logger functions and settings.



Figure 6-15: a) Example of a flow meter display reading, b) Example of a power meter display reading.

6.3.3 Online system

The main advantage with an AMR system is that data can be remotely retrieved and viewed online. For this there is an online system required for data handling, processing and online presentation. The data logged with a logger is transmitted with the modem to the cellular towers which is connected to the internet as shown in Figure 6-16. With a typical AMR system there is a controller hosted on a cloud service which interacts with the logger modem, through the internet and through the cellular tower. With the IML, the modem-controller interaction is for authentication, data uploading, remote settings and other functions. From here the data goes through an Extract Transform and Load (ETL) process by which the data string is broken into information that can be loaded into the Structured Query Language (SQL) database. Standard functions and protocols can extract data from the database and display this on a webpage with graphs as shown in Figure 6-16.

An AMR online web interface can vary significantly between service providers, but typically shows graphs of the data and has the option to download the data. Some systems also allow business intelligence on the data with post processing and calculations to show aspects such as system performance and other key information. Provided the functionality, the online system also allows interaction for remote logger setup, although a client does not often have access to this. No matter how advanced an online system may appear, the key important aspect is that it should give a clear, transparent and auditable data trail. An operator should be able to easily and clearly track the process the data undergoes.

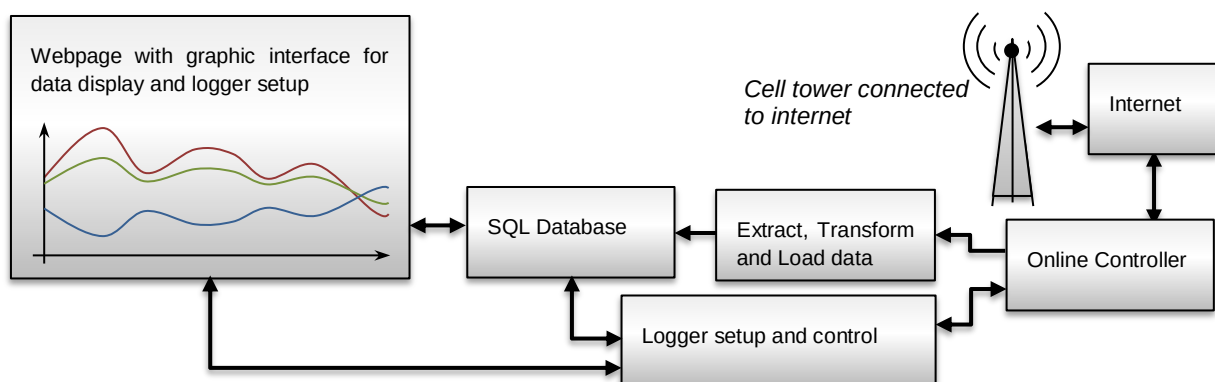


Figure 6-16: Design layout of a typical online AMR system.

An online system was specifically developed for the IML with prime focus placed on this critical design requirement. Figure 6-17 provides a flow chart of the clear data trial that is followed with the IML system. From this a clear data trial, the online display shown in Figure 6-18, was developed. As can be seen in Figure 6-17 and Figure 6-18, the sensors connected, the data type and constants are clearly provided. The first four columns in Figure 6-18 show these parameters with the rest of the columns showing information such as the sensor channel, last data, last upload, process options and lastly the processed data output type. This view provides the client with immediate critical information of what happens with the data.

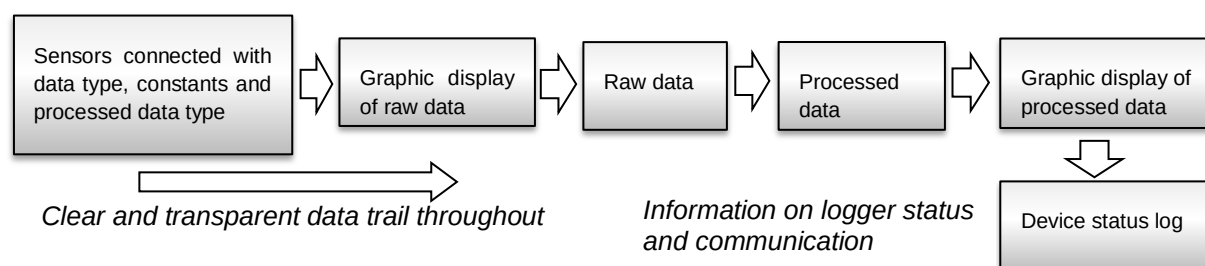


Figure 6-17: Flow chart of the clear data trial.

In the fourth column from right, the user can decide if all or only some of the variables should be processed. In this example, the current (Amps) values were chosen as unimportant (marked as false in the column) and is therefore not processed and displayed with the processed graphs and data.

In the flow chart of Figure 6-17, the sensor information is followed by the graphic display of the raw data which is again followed by the raw data set itself. Thus, the client can progressively first see a graphical interpretation of the raw data set for evaluation as can be seen Figure 6-19. Figure 6-19 gives the raw graphs of several sensors of an example system which includes from the top to bottom:

- Four CTs measuring the current in Amps of four separate system sections;
- Four temperatures; and
- Three pulses.

Sensors Raw Charts Raw Data Processed Charts Processed Data Status Log August 8, 2018 - August 8, 2018											
#	Type	Name	Data Type	Constant	Channel	Last Upload	Last Data	Process	Last Processed Data	Last Execution	Processed Data
1	CT_Current	CT1	A	1	1	2018/08/08 11:00:43	2018/08/08 11:00:00	false			A
2	CT_Current	CT2	A	1	2	2018/08/08 11:00:43	2018/08/08 11:00:00	false			A
3	CT_Current	CT3	A	1	3	2018/08/08 11:00:43	2018/08/08 11:00:00	false			A
4	CT_Current	CT4	A	1	4	2018/08/08 11:00:43	2018/08/08 11:00:00	false			A
5	Temperature	Temp 1	C	1	1	2018/08/08 11:00:43	2018/08/08 11:00:00	true	2018/08/08 11:00:00	2018/08/08 11:07:30	C
6	Temperature	Temp 2	C	1	2	2018/08/08 11:00:43	2018/08/08 11:00:00	true	2018/08/08 11:00:00	2018/08/08 11:07:31	C
7	Temperature	Temp 3	C	1	3	2018/08/08 11:00:43	2018/08/08 11:00:00	true	2018/08/08 11:00:00	2018/08/08 11:07:31	C
8	Temperature	Temp 4	C	1	4	2018/08/08 11:00:43	2018/08/08 11:00:00	true	2018/08/08 11:00:00	2018/08/08 11:07:31	C
9	Temperature	iTemp	C	1	5	2018/08/08 11:00:43	2018/08/08 11:00:00	true	2018/08/08 11:00:00	2018/08/08 11:07:30	C
10	Temperature	iHum	%RH	1	6	2018/08/08 11:00:43	2018/08/08 11:00:00	true	2018/08/08 11:00:00	2018/08/08 11:07:29	%RH
11	Pulse	Pulse 1	L	1	1	2018/08/08 11:00:43	2018/08/08 11:00:00	true	2018/08/08 11:00:00	2018/08/08 11:07:30	L
12	Pulse	Pulse 2	L	1	2	2018/08/08 11:00:43	2018/08/08 11:00:00	true	2018/08/08 11:00:00	2018/08/08 11:07:30	L
13	Pulse	Pulse 3	L	1	3	2018/08/08 11:00:43	2018/08/08 11:00:00	true	2018/08/08 11:00:00	2018/08/08 11:07:30	L
14	Error	Status	Str	1	1	2018/07/31 16:00:50	2018/07/31 14:07:07	false			Str

Figure 6-18: Designed display of the online AMR system sensor and channel setup.

The current and temperature graphs show how the system conditions changes. No constants or scaling factors are added here. The pulse graph at the bottom only shows three ascending lines since these give the raw accumulation of pulse values as directly recorded by the logger.



Figure 6-19: Online graphic display of raw data.

Sensors

Raw Charts

Raw Data

Processed Charts

Processed Data

Status Log

August 6, 2018 - August 8, 2018

Export Data

Records: 709

Errors:

#	Logged On	CT1	CT2	CT3	CT4	Temp 1	Temp 2	Temp 3	Temp 4	iTemp	iHum	Pulse 1	Pulse 2	Pulse 3	Status
1	2018/08/06 00:00:00	0.14016	0.11614	0.29665	0.14714	51.66875	24.15625	58.05	47.70312	12.45711	36.27523	406964	260655	1146468	
2	2018/08/06 00:05:00	0.23159	0.1583	0.33052	0.17625	51.96875	23.99375	58.05938	48.05938	12.64641	36.00135	407010	260687	1146480	
3	2018/08/06 00:10:00	0.14077	0.11823	0.29807	0.14839	51.86562	23.88437	58.15625	48.58437	12.43512	36.03796	407060	260719	1146496	
4	2018/08/06 00:15:00	0.13609	0.11788	0.29523	0.14707	52.18438	23.7625	58.1625	48.5375	12.28819	36.15889	407109	260753	1146511	
5	2018/08/06 00:20:00	0.13827	0.11559	0.2941	0.14546	52.45	23.61875	58.35	48.36875	12.16968	36.19093	407158	260785	1146518	
6	2018/08/06 00:25:00	0.13955	0.11677	0.29594	0.14424	52.39687	23.52813	58.18438	48.41563	12.02596	36.19169	407206	260818	1146527	
7	2018/08/06 00:30:00	0.13974	0.11623	0.29526	0.14634	52.04688	23.38125	58.20312	48.80938	11.91174	36.23061	407255	260850	1146541	
8	2018/08/06 00:35:00	0.13762	0.11558	0.29521	0.14387	51.66875	23.3	58.25	49.17812	11.82808	36.26418	407305	260875	1146562	
9	2018/08/06 00:40:00	0.13663	0.11407	0.29595	0.14396	51.88438	23.175	57.8375	49.4125	11.78411	36.26571	407352	260906	1146576	
10	2018/08/06 00:45:00	0.13908	0.11822	0.29662	0.14484	52.31875	23.04375	58.15313	49.35938	11.69616	36.23595	407401	260939	1146590	
11	2018/08/06 00:50:00	0.13793	0.11826	0.29674	0.1467	52.29375	22.93125	58.24375	49.44688	11.56961	36.23671	407449	260972	1146607	
12	2018/08/06 00:55:00	0.13878	0.11734	0.29724	0.1473	51.70937	22.84063	56.9	49.57188	11.47576	36.27333	407498	261003	1146655	
13	2018/08/06 01:00:00	0.14125	0.12065	0.30199	0.14821	50.54063	22.73125	56.75938	49.27187	11.38299	36.29088	407546	261034	1146693	
14	2018/08/06 01:05:00	0.15728	0.12516	0.302	0.15063	50.97697	22.61184	56.80855	49.12171	11.53856	36.09076	407591	261067	1146733	
15	2018/08/06 01:10:00	0.13994	0.1191	0.29836	0.14711	50.8375	22.53125	57.10625	49.20625	11.35135	36.15126	407641	261101	1146760	
16	2018/08/06 01:15:00	0.13959	0.11596	0.29435	0.14439	51.275	22.41875	57.38125	49.27187	11.23713	36.23481	407689	261133	1146790	
17	2018/08/06 01:20:00	0.13958	0.11626	0.29715	0.14506	51.0375	22.31875	57.36875	49.14062	11.15723	36.27676	407737	261167	1146821	
18	2018/08/06 01:25:00	0.13484	0.11664	0.29443	0.144	51.3625	22.21563	57.675	48.9125	11.0918	36.30079	407789	261201	1146832	
19	2018/08/06 01:30:00	0.14069	0.11759	0.2981	0.14495	52.19062	22.08125	58.44062	48.70312	11.04086	36.31186	407839	261234	1146838	
20	2018/08/06 01:35:00	0.14178	0.1191	0.29656	0.14596	52.51562	21.975	58.49062	48.51562	10.98402	36.30004	407889	261268	1146843	
21	2018/08/06 01:40:00	0.14111	0.1193	0.29711	0.14717	52.34375	21.8375	58.42812	48.65313	10.92181	36.30728	407940	261301	1146853	
22	2018/08/06 01:45:00	0.14156	0.11543	0.29688	0.14662	52.38125	21.73125	58.50938	48.75312	10.87355	36.31147	407989	261334	1146866	
23	2018/08/06 01:50:00	0.14211	0.11966	0.2984	0.14485	51.91875	21.64375	58.18438	48.725	10.82797	36.33284	408039	261366	1146882	
24	2018/08/06 01:55:00	0.13974	0.11765	0.29936	0.14739	51.99688	21.525	58.62812	48.42188	10.80652	36.33627	408087	261399	1146899	
25	2018/08/06 02:00:00	0.14185	0.12138	0.29953	0.14877	51.925	21.45312	58.57188	48.2375	10.79579	36.34009	408136	261433	1146901	
26	2018/08/06 02:05:00	0.18782	0.14132	0.30908	0.16145	52.22813	21.35312	58.86562	48.43125	11.01083	36.12532	408187	261466	1146911	

Figure 6-20: Online raw data set.

The raw data set can be seen in Figure 6-20. The first and second columns in Figure 6-20 show the data entry number and five-minutely timestamp. Columns three to ten provide the current and temperatures recorded. The eleventh and twelfth columns show the device's internal temperature and

humidity. These are followed by the three pulses. Looking at row one and then at row two, the accumulation pulse values can be seen. Thus, any new pulses are added to the last total and stored in that five-minutely interval. On the top right of Figure 6-20, the time period shown can be selected through an interactive and easy to use data selection function. Below this is an export button through which the raw data can be exported and downloaded to an Excel file. Figure 6-21 shows a graph of the processed data while Figure 6-22 provides the processed data set. In Figure 6-21 only the processed pulse values are shown since the current and temperature values have no scaling that needed to be applied.

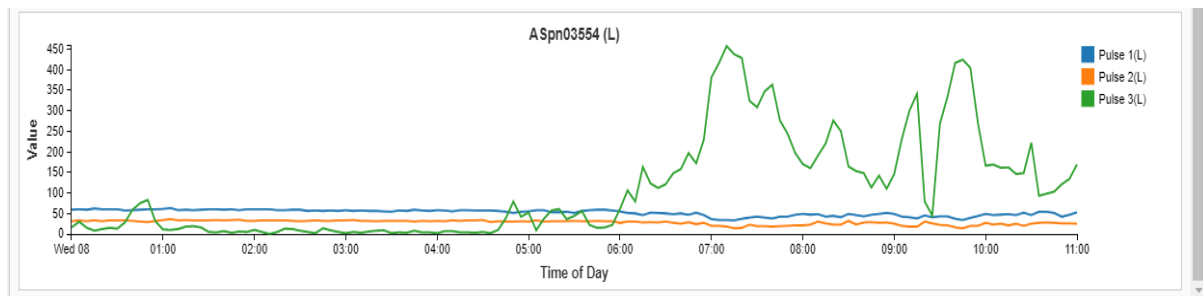


Figure 6-21: Online graphic display of processed data.

As can be seen in Figure 6-18, the constant for all four currents and temperatures is one (1) and needs no conversion. The pulse constant is also one (1), however, the pulse value of each five-minute interval needs to be calculated. These calculated five-minutely Litre (L) values are displayed in the graph of Figure 6-21. In Figure 6-22 processed pulse values can be seen on the right of the temperature data.

On the top right of Figure 6-22 there is also an export button through which the user can download the processed data. Thus, the user can download both the raw and processed data, and directly compare these for data integrity checks.

Sensors Raw Charts Raw Data Processed Charts Processed Data Status Log August 6, 2018 - August 8, 2018										
Records: 697 Errors: 0 Export Data										
#	Logged On	Temp 1	Temp 2	Temp 3	Temp 4	iTemp	iHum	Pulse 1	Pulse 2	Pulse 3
1	2018/08/06 00:00:00	51.66875	24.15625	58.05	47.70312	12.45711	36.27523	49	32	17
2	2018/08/06 00:05:00	51.96875	23.99375	58.05938	48.05938	12.64641	36.00135	46	32	12
3	2018/08/06 00:10:00	51.86562	23.88437	58.15625	48.58437	12.43512	36.03796	50	32	16
4	2018/08/06 00:15:00	52.18438	23.7625	58.1625	48.5375	12.28819	36.15889	49	34	15
5	2018/08/06 00:20:00	52.45	23.61875	58.35	48.36875	12.16968	36.19093	49	32	7
6	2018/08/06 00:25:00	52.39687	23.52813	58.18438	48.41563	12.02596	36.19169	48	33	9
7	2018/08/06 00:30:00	52.04688	23.38125	58.20312	48.80938	11.91174	36.23061	49	32	14
8	2018/08/06 00:35:00	51.66875	23.3	58.25	49.17812	11.82808	36.26418	50	25	21
9	2018/08/06 00:40:00	51.88438	23.175	57.8375	49.4125	11.78411	36.26571	47	31	14
10	2018/08/06 00:45:00	52.31875	23.04375	58.15313	49.35938	11.69616	36.23595	49	33	14
11	2018/08/06 00:50:00	52.29375	22.93125	58.24375	49.44688	11.56961	36.23671	48	33	17
12	2018/08/06 00:55:00	51.70937	22.84063	56.9	49.57188	11.47576	36.27333	49	31	48
13	2018/08/06 01:00:00	50.54063	22.73125	56.75938	49.27187	11.38299	36.29088	48	31	38
14	2018/08/06 01:05:00	50.97697	22.61184	56.60855	49.12171	11.53856	36.09076	45	33	40
15	2018/08/06 01:10:00	50.8375	22.53125	57.10625	49.20625	11.35135	36.15126	50	34	27
16	2018/08/06 01:15:00	51.275	22.41875	57.38125	49.27187	11.23713	36.23481	48	32	30
17	2018/08/06 01:20:00	51.0375	22.31875	57.36875	49.14062	11.15723	36.27676	48	34	31
18	2018/08/06 01:25:00	51.3625	22.21563	57.675	48.9125	11.0918	36.30079	52	34	11
19	2018/08/06 01:30:00	52.19062	22.08125	58.44062	48.70312	11.04086	36.31186	50	33	6
20	2018/08/06 01:35:00	52.51562	21.975	58.49062	48.51562	10.98402	36.30004	50	34	5
21	2018/08/06 01:40:00	52.34375	21.8375	58.42812	48.65313	10.92181	36.30728	51	33	10
22	2018/08/06 01:45:00	52.38125	21.73125	58.50938	48.75312	10.87355	36.31147	49	33	13
23	2018/08/06 01:50:00	51.91875	21.64375	58.18438	48.725	10.82797	36.33284	50	32	16
24	2018/08/06 01:55:00	51.99688	21.525	58.62812	48.42188	10.80652	36.33627	48	33	17
25	2018/08/06 02:00:00	51.925	21.45312	58.57188	48.2375	10.79579	36.34009	49	34	2
26	2018/08/06 02:05:00	52.22813	21.35312	58.86562	48.43125	11.01083	36.12532	51	33	10
27	2018/08/06 02:10:00	52.30312	21.2625	58.99375	48.575	10.90787	36.15355	48	33	1

Figure 6-22: Online processed data set.

In Figure 6-23 the status of the logger during each of the communication events of the selected period is displayed. Information including SIM card prepaid money, device power use, data pointers, mobile network, device firmware version and GSM signal strength are shown.

The head and tail pointers in columns five and six show if there are any data outstanding on the device that was not uploaded yet. In situations where there is poor cell reception and the device has difficulty uploading data, the tail and head pointer value differ after communication.

In such a case, the poor reception will reflect in the GSM signal strength shown in the last column. The -57 shown in the first row indicates a -57db signal strength which is exceptionally good. The signal strength can be interpreted as follow:

- -103dB to -110dB = Very poor;
- -91dB to -102dB = Poor;
- -81dB to -91dB = Good;
- -65 to -81dB = Very good; and
- Below -65dB is exceptional good.

The online system also has dedicated device and sensor setup menus where the device (meter) details can be specified and saved. See bottom right of Figure 6-23. It provides general details about the device, its location and setup of the sensors connected to the device. Here the sensor constants are specified and channel allocations are done.

Sensors Raw Charts Raw Data Processed Charts Processed Data Status Log August 8, 2018 - August 8, 2018								
#	Date/Time	Prepaid Money	Battery Usage	Tail Pointer	Head Pointer	Mobile Network Code	Firmware Version	GSM Signal Str
1	2018/08/08 11:00:45	29.71	5480.399	73196	73196	Vodacom	ASPN3.03	-57
2	2018/08/08 11:00:35	29.71	5479.899	73184	73196	Vodacom	ASPN3.03	-57
3	2018/08/08 10:01:01	29.72	5477.767	73184	73184	Vodacom	ASPN3.03	-57
4	2018/08/08 10:00:42	29.72	5476.816	73172	73184	Vodacom	ASPN3.03	-57
5	2018/08/08 09:00:43	29.73	5474.483	73172	73172	Vodacom	ASPN3.03	-59
6	2018/08/08 09:00:32	29.73	5473.933	73160	73172	Vodacom	ASPN3.03	-59
7	2018/08/08 08:01:10	29.74	5471.95	73160	73160	Vodacom		
8	2018/08/08 08:00:43	29.74	5470.649	73148	73160	Vodacom		
9	2018/08/08 07:00:44	29.75	5468.216	73148	73148	Vodacom		
10	2018/08/08 07:00:33	29.75	5467.616	73136	73148	Vodacom		
11	2018/08/08 06:00:50	29.76	5465.633	73136	73136	Vodacom		
12	2018/08/08 06:00:36	29.76	5464.983	73124	73136	Vodacom		
13	2018/08/08 05:00:35	29.77	5462.899	73124	73124	Vodacom		
14	2018/08/08 05:00:28	29.77	5462.499	73112	73124	Vodacom		
15	2018/08/08 04:00:38	29.78	5460.866	73112	73112	Vodacom		
16	2018/08/08 04:00:31	29.78	5460.516	73100	73112	Vodacom		
17	2018/08/08 03:00:36	29.79	5458.683	73100	73100	Vodacom		
18	2018/08/08 03:00:30	29.79	5458.382	73088	73100	Vodacom		
19	2018/08/08 02:00:57	29.8	5456.55	73088	73088	Vodacom		
20	2018/08/08 02:00:38	29.8	5455.599	73076	73088	Vodacom		

Meter Detail

[General](#)
[Location](#)
[Sensors](#)

Type	Name	Data Type	Constant	Channel	Process	Interpolate
CT_Current	CT1	A	1	1	false	false
CT_Current	CT2	A	1	2	false	false
CT_Current	CT3	A	1	3	false	false
CT_Current	CT4	A	1	4	false	false
Temperature	Temp 1	C	1	1	true	true
Temperature	Temp 2	C	1	2	true	true
Temperature	Temp 3	C	1	3	true	true
Temperature	Temp 4	C	1	4	true	true
Temperature	iTemp	C	1	5	true	true
Temperature	iHum	%RH	1	6	true	true
Error	Status	Str	1	1	false	false
Pulse	Pulse 1	L	1	1	true	true
Pulse	Pulse 2	L	1	2	true	true
Pulse	Pulse 3	L	1	3	true	true

[Edit](#)
[Close](#)

Figure 6-23: Online status view of device and device detail and setup view.

These precise settings are stored and can be accessed at any time, depending on user access levels, to verify the device setup. Figure 6-24 provides an online interface for performing remote settings on the device. A precise log is kept of what settings were loaded when and if these settings were received and acknowledged by the device.

Meter Settings: ASpn03554					
Configure Requests Confirmations					
Type	Created	Sent	Acknowledged	Value	Cancelled
Remote Settings	2018/07/31 16:32:45	2018/07/31 16:00:48	2018/07/31 16:00:49	>2,D3,39.9,70.0,0832697298	☐ Cancel
Remote Settings	2018/07/31 16:32:34			>1,D3,40.0,70.0,0832697298	☒
Remote Settings	2018/07/12 16:12:44	2018/07/12 15:00:37	2018/07/12 15:00:38	LNeLNeLNe,c7ac7ac7a,D1D1D1D1T1H1,N	☐ Cancel
Remote Settings	2018/07/09 15:57:35	2018/07/09 14:00:42	2018/07/09 14:00:47	2,22,4,0;5;15	☐ Cancel
Remote Settings	2018/07/09 12:36:20	2018/07/09 11:00:47	2018/07/09 11:00:47	>2,D3,45.0,70.0,0832697298	☐ Cancel
Remote Settings	2018/07/09 11:16:54	2018/07/09 10:00:35	2018/07/09 10:00:36	>1,D3,45.0,70.0,0832697298	☐ Cancel
Download Firmware	2018/07/06 14:07:14	2018/07/06 14:00:51	2018/07/06 14:00:52	54:ASpinV3.03.hex	☐ Cancel
Communication Schedule	2018/07/06 14:07:06	2018/07/06 14:00:51	2018/07/06 14:00:52	0,22,1;0;5;15	☐ Cancel
Save					Close

Figure 6-24: Online remote settings view.

6.3.4 System maintenance

AMR system maintenance and support are very important aspects to consider when sourcing metering products and service providers. AMR system functionality and maintenance plans are usually related to the metering service agreement option that is put in place with the metering and/or AMR service provider. There are generally different packages available with ones only providing data, some providing remote maintenance and other providing a full remote and onsite maintenance service. Although the last mentioned is very convenient and best to ensure a continuous running system, it is customarily quite costly and makes the total metering and AMR cost too expensive in some cases. In many cases clients or M&V practitioners will opt for a less costly ‘data only’ plan with the onus on themselves to ensure correct installation and onsite maintenance when required.

6.3.5 Metering and metering service provider independence

A central metering issue sometimes overlooked is the independence of the metering services provider. With 12L and related incentive mechanisms there is much attention given to the independence of the M&V practitioner. This practitioner also has the responsibility to investigate the metering and data gathering system to ensure data accuracy, transparency and integrity.

Care should be taken on what metering and AMR system is used in a project. Extra precautions should be put in place if the client’s own metering system is used, or if the ESCO installs or provides a metering system. With Eskom DSM projects it was often found that ECSOs installed, with the ECM, a metering system through which data is collected and relayed to the M&V team. In some cases, this data was already processed. This is very troubling since M&V practitioners should always be provided with the raw data. Here it is of utmost importance to be aware that, especially in this day and age of technology, data provided through a metering and AMR system can be skilfully manipulated. It can further be done in such a way that the system will successfully pass full system calibration and a data audit trail verification. Such skilful manipulation can be used to boost savings in order to increase an incentive payback. A very good example of such skilful manipulation is the Volkswagen scandal where the Environmental Protection Agency (EPA) found that many Volkswagen diesel cars had a “defeat device or software” that could detect when the car is put under testing conditions. When this is detected, the engine performance is changed accordingly to improve carbon dioxide emission level results (BBC,

2015). Such a method can also be used to fool even regular verification checks on metering and AMR systems. The author does not imply here that these types of scandalous practices are often done, but care should be taken towards it. Cross check measures here can include a comparison of periodical AMR reported consumption values with that of an onsite calibrated mechanical dial meter.

6.3.6 Data quality management system

A proper data Quality Management Plan (QMP) to track and evaluate data is a vital requirement. Such a QMP can have a Quality Control Path (QCP) document or protocol which identifies the possible places which can influence data or compromise quality or delivery. This section looks at the quality control of typical systems starting at metering installations, the interaction of installers with logger and equipment during installations, to the online system where data can be viewed and analysed. This QCP identifies possible risk areas and provides key inputs for the QMP. The QMP is based on an ISO9001 Quality Management System (QMS) that was used for M&V purposes. The QMP also aligns with the latest M&V standards surrounding metering and related subjects. This includes the SANS 50015: 2015 and SANS 50010:2018 among other.

6.3.6.1 Quality control path

Figure 6-25 divides Figure 6-10, of Section 6.3.2, into QMP sections for separate evaluation. The following subsection considers important aspects of each component which is vital to form the basis on which to specify the QMP.

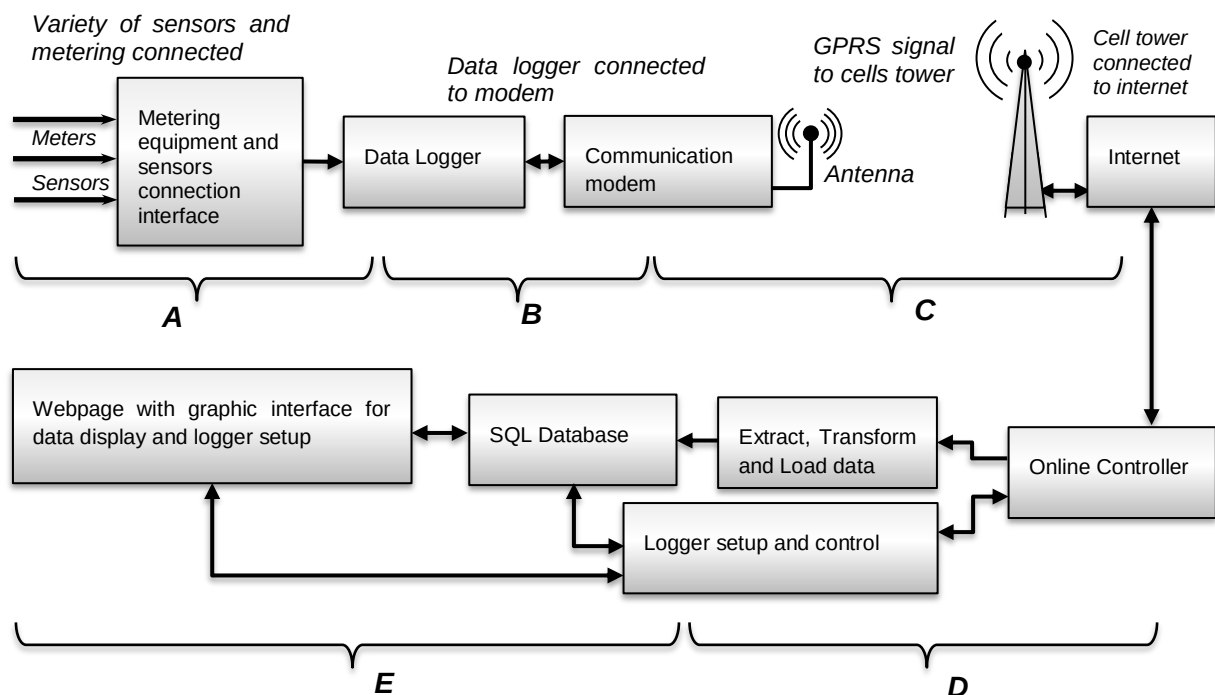


Figure 6-25: Metering and AMR system layout with quality control path sections.

A) Sensor connections and metering interface

Incorrect or improper connections to meters or sensors can influence the quality and consistency of data obtained from the sensors. Sometimes connections deteriorate over time due to exposure to the elements, system vibrations, vandalism or tampering.

It is critical that installers should have a fixed procedure to follow when doing installations. This must contain proper instructions for performing the logger installation and sensor connections. With this a

cross verification and validation procedure must be provided which guides the installer to ensure a proper setup. Considering sensors, the following should be kept in mind:

- **Pulse connections** – With flow meters that have a simple pulse pickup or mechanical power meters with a pulse output, the connection is not polarity sensitive. However, with other types of meters, intelligent pulsers which have a transistor as a switch, correct polarity connection is compulsory. Thus, the correct connection of the wire between the logger and meter is important. Some intelligent meters account for reverse flow, this can be either a separate connection for reverse pulses or the meter provides a net pulse output. For the last mentioned, the meter or meter pulse pickup counts reverse flow and only gives out pulses again after the reverse flow was counted. With pulse connections, the following should always be done:
 - Ensure that pulse wire ends and connector contacts are clean and a good connection is made. When working with connection terminals, make a proper connection so that the wires stay secure. However, do not over fasten connections otherwise the wire conductor itself may weaken and break.
 - Pulse wires should always use twisted pair wires, shielded cable or a combination of these. This prevents that external electromagnetic noise such as electrical switchgear, VSDs or large communication antennas induces 'ghost pulses.' Although loggers may have safeguards against such 'ghost pulses,' these cannot always be distinguished from real pulses. It should be avoided that pulse wires are routed close to electrical wiring or electrical devices. Some loggers do have software filters that can be used to filter certain frequencies to avoid 'ghost pulses.' However, these may not be 100% effective.
 - Ensure that the correct pulse constant is obtained from the meter connected. Flow meters and pulsars have different K factors, with some having two or three K factors to select from. Double check that the desired K factor is used and also verify that the amount of pulses recorded in a certain time, correspond to actual flow that occurred. With power meters it is imperative to account for the CT ratio introduced with the pulse constant.
 - The maximum pulse frequency the logger can accurately count should always be noted. Certain loggers are equipped with pulse speed filters which should be correctly setup. The logger pulse speed filter cut-off limit, or software filter set-point, will block all or most pulses with a frequency higher than the cut-off. As stated, this allows filtering of noise and 'ghost pulses' in areas with high EMP or Radio Frequency (RF). When considering a logger or setting the pulse speed filter, ensure that the maximum pulse speed the meter will give is accounted for. This can be checked by finding the meter's pulse constant (for instance 2000 pulses/kWh for a power meter or 100L/pulse for a flow meter). These nameplate values will be displayed on the meter or pulser, or can be found on a product data sheet. Establish the meter's maximum load/flow rate and calculate the maximum pulses per second it will give. The following bullet points provide examples for a power meter and a flow meter:
 - **Power meter example:** A power meter with a pulse constant of 2000 pulses/kWh is connected. The meter is specified with a maximum load of 100 A. The maximum load value is normally given in Amp. The maximum load in kW can be quickly calculated, assuming a power factor of one (1), by multiplying the maximum current with the rated Voltage (220 V, 380 V or 400 V). For a single-phase meter $100\text{ A} \times 220\text{ V} = 22\text{ kW}$. At full load the meter will give $(22 \times 2000) / 3600 = 12.2\text{ pulses/second}$. Here 3600 is the number of seconds in an hour (60 x 60). For a three-phase meter $100\text{ A} \times 380\text{ V} \times 1.73 = 65740\text{ W} = 65.74\text{ kW}$. At full load the meter will give $(65.74 \times 2000) / 3600 = 18.26\text{ pulses/second}$. With a three-phase meter and CTs, the CT ratio needs to be

compensated for. 100/5 A CTs gives a 20:1 ratio. Therefore, the power meter will give $18.26/20 = 0.91$ pulses/second.

- Flow meter example: An Elster H4000 with a PR7 head which gives one (1) pulse per Litre. The maximum flow rate of this meter is 25 l/s. Therefore, the maximum amount of pulse that will be observed is 25 pulses per second.
- **Analogue, digital and other connections** – With any type of sensor or meter, a clean and proper connection is critical. With this done, the correct sensor and sensor setting should be selected on the logger. For instance, when a 4-20mA WIKA pressure transducer is connected, the pressure range should be correctly selected. If the pressure range is incorrectly selected, the logger will record the wrong pressure readings. When making connections, the following should be kept in mind:
 - With certain sensors, like PT100s for instance, the length of the cable used between the sensor and logger can influence the readings. Some sensors need to be recalibrated when the length of the cable is changed.
 - Sensor cable should preferably be shielded to avoid exposure to external electrical noise. Such noise can leak through into the logger resulting in noise on the measurements and thus also on the data. This noise typically creates spikes or drops on the data sets. This happens since the noise influences the logger reference voltage which is elementary to determine the measurement amplitude.
 - Extra care should be taken when the logger is relying on the pump station electrical power supply as a power source. Since irrigation pump stations are prone to poor power quality and contain motors with switchgear and high start-up currents, electrical noise can leak through the power supply into the logger. This can damage the logger or influence measurements. Proper logger power supplies with filtering can mostly avoid power source noise. However, it was observed in some facilities that power supply electrical noise is so severe that it leaks through isolation transformers and filtering power supplies. In such cases it is better to totally isolate the logger and only make use of batteries to power the logger.
 - Certain loggers have specific modules that are used with each type of sensor. When the module is plugged in, the logger will automatically detect the module and set up the sensor correctly. Here it is important to ensure the right sensor is connected to the right module.

B) Data logger connected to the communication modem

When sourcing a logger and modem, functional and tested compatibility should be a key requirement. A proper and reliable connection link between the logger and modem is essential, and this setup should be tested in-office before a field installation. It is common that electronic devices do not always have a very accurate and stable internal clock, and a timestamp drift may occur over time. Modern loggers can request the time through the GPRS modem from the cellular network or from the server which ensure that the logger's time does not drift.

C) Communication modem and cell tower connection

Proper communication between the modem and the cell tower is vital. This should be evaluated and confirmed by the installers before the installation commences. If poor cell reception is observed, a Subscriber Identity Module (SIM) card of an alternative cellular service provider can be considered or an external antenna can be added.

D) Online controller and extract, transform and load into the databases

If an AMR service provider's online system was not properly designed and have sufficient checks and balances in place, data can be incorrectly treated and loaded into the database.

Typical issues that may arise here include:

- Time stamp shift - The logger for instance records in local time, Greenwich Mean Time (GMT) +2 hours for South Africa, but the online system interprets the time as GMT. This can result in a two-hour time shift.
- Incorrect sensor allocation - A typical logger and online system use specific channels for certain sensors. If this is not properly set up or managed, a pressure variable can be allocated to a temperature for instance. In most cases such a fault is easily distinguishable but some may appear to be a legitimate reading.
- Multipliers - Unwanted multipliers can be introduced when the system does automatic scaling due to a standard setting. For instance, the system is set to convert all power values from watt (W) to kilowatt (kW). Thus, when the logger already uploads kW values, the online system can introduce an unnecessary 0.001 multiplier.
- Conversion factors - A logger can record flow values in litres, but it is actually desired that flowrate data is provided. With 5-minutely flow values, the litres should be multiplied by 12 (since there are 12 x 5-minutely intervals in an hour) to get a Litre/hour flow rate value. If conversion factors are not properly managed incorrect conversions can easily occur.
- Calculation faults - It may be specified that the online system already calculates certain values from the variables logged. For instance, the online system can already calculate thermal energy from flow and temperature values. In another example, gas volume correction needs to be done for a change in pressure and temperature. In both cases, if the correct formula is not applied it can result in calculation faults.

E) Online logger setup

Smart online systems allow meter point instead of logger management. Here a logger is allocated to a specific metering point as described in Section 6.3.1, specification point 20). Care should be taken that the correct logger is allocated to the correct metering point. Smart online systems also allow easy logger replacements whereby a specific logger is allocated for a specific time period to a metering point. Here great care should be taken in meter replacement management and time period allocation. This can easily lead to the wrong sets of data being allocated to the wrong metering point.

Smart online systems allow full or partial remote settings of loggers. This can entail what type of sensor should be measured at which channel to remote communication schedules and other settings. With this great advantage also comes the danger of remotely changing a logger's settings incorrectly; this in turn can result in incorrect data logging. A proper logger setup management process with cross checks is required. Uninformed, untrained and unauthorised personnel should not be able to get access to such critical settings.

6.3.6.2 Tying the ends

Essentially, in all circumstances an installer must be able to directly relate what is measured in the field at the one end to with what is displayed online on the other end. Here it is critical that an installer captures values observed on the logger, and that on handheld cross check equipment, on an installation sheet (document in paper or electronic form) with the relevant time stamps for every sensor or meter connected. These values should be related to the same values as what are seen online with the same time stamps. A complication here is that handheld cross check equipment or the logger might only display real time instantaneous values.

Online, only the average of the measuring interval may be displayed. With fairly constant loads or flows (or other variables) this is not problematic. However, with much variation in the load or flow, it can be difficult to relate instantaneous values to average values. In such cases, several instantaneous values

can be taken over a few measuring intervals and establish an average over these. The average values can then be compared with the online values. The values seen online and values captured onsite should be noted on the same installation sheet. If these values match, the sheet can be signed off by an authorised person. The same installation sheet can be used to record information such as the logger details, GPRS communication details, relevant information about the site, clear indicators of which site it is and which logger was installed.

6.4 SPECIALISED METERING AND STRATEGICAL USE AND APPLICATION OF METERING

Chapter 3 Section 3.5.3 discussed an approach for using multiple metering points and an intelligent multiple meter approach. Figure 3-26 discussed in Chapter 3 Section 3.5.2.4 is shown again in Figure 6-26 to explain the use of multiple metering points or an intelligent multiple meter approach for specialised metering. This replaces the need for relying on operational level conditions and boundary limits that may not be applicable or have narrow safety margins that may be problematic. A narrow safety margin can be seen towards the top of Figure 6-26 between the operation level-2 and operational level-3 boundaries.

Here the IML discussed in Section 6.3 comes to its full potential. Conventionally, specialised intelligent metering solutions are very expensive; however, the IML was designed to provide an intuitive cost-effective solution for M&V purposes. This aside, there are many metering solutions and providers in the market, thus focus will be placed on the broader requirements of M&V metering. In many situations, the function of normal metering can be stretched by strategized application which can increase the M&V capability thereof. This will be discussed in Section 6.4.2.

6.4.1 Identification of pumping conditions

In explaining the application of an intelligent multiple meter approach, several irrigation pumping setups will be considered that can cause the operation demand profile in Figure 6-26. Within each pumping setup, the possible metering scenarios and options will be discussed. In Figure 6-26 different metering and sensor approaches are listed for pumping conditions identification. These will be discussed in the following sections.

6.4.1.1 Single pump with different pumping conditions

In this scenario, the demand profiles of Figure 6-26 are assumed to be of one single irrigation pump that is irrigating different crop fields. The change in pumping profile is due to the crop fields having each a separate static head and different operational pressures. The variation in level-3 seen in Figure 6-26, is due to centre pivot irrigation on an uneven field and the VSD performs torque control to deliver the same amount of water. In order to establish the different levels on this pump, the following can be considered:

- **VSD frequency measurement** - The VSD can have standard settings which are set up according to each pumping scenario. It therefore adjusts the speed of the motor to achieve the desired flow rate and pressure for the specific irrigation requirement. The VSD accomplishes this by changing the frequency of Alternating Current (AC) power supplied to the pump motor. Here there are two possible options to follow:
 - 1) Use an IML related device that can measure and log the frequency of the power supplied to the motor. This can independently show which pumping condition is currently active.
 - 2) Use a VSD output port, such as MODBUS and RS485 for instance, to retrieve the current frequency setting from the VSD. It should be noted that logger compatibility

with the VSD output port protocol may be a challenge here. Also, this may influence measurement independence as discussed in Section 6.3.5.

- **Pump valve positions** – Here electronic sensors are required to monitor the position of each of the valves that are used to control and direct the flow of water to the different crop fields. The position of the valves will indicate which pumping condition is active and which level is applicable. Here the cost of valve position sensors, installation and upkeep of these sensors can be a challenge. If there is a large distance between the valves and the pump station, RF modules may be required to remotely communicate with the logger.

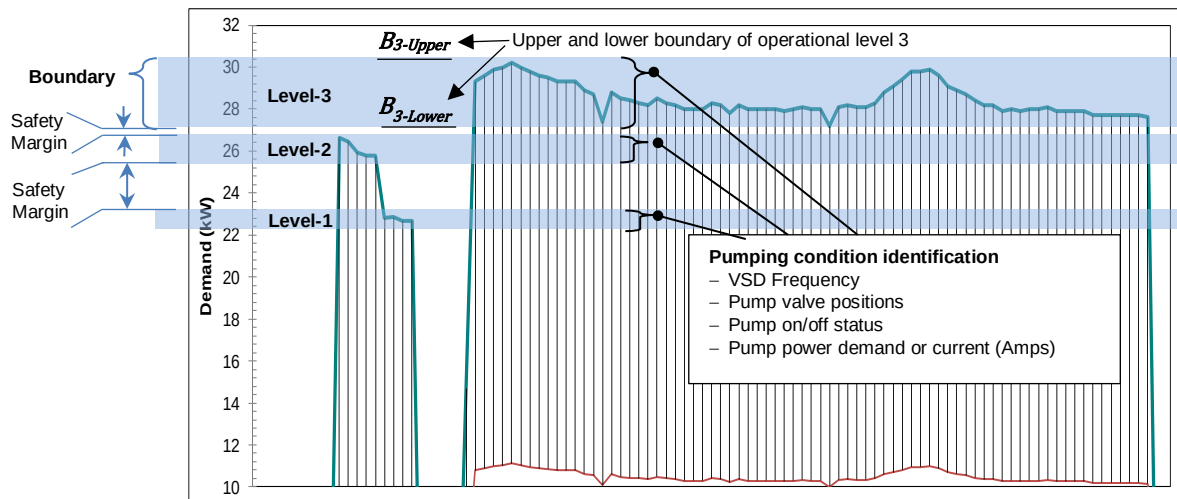


Figure 6-26: Boundary for each operation level taken from Figure 3-26 in Chapter 3 Section 3.5.2.4.

6.4.1.2 Multiple pumps with dedicated irrigation setups

An irrigation pump station may house several pumps which each one irrigating one specific crop field. Thus, there is only one pumping condition present for each pump. In such a scenario, it is definitive that when a certain pump is in operation, a specific pumping condition is active. Therefore, when the on or off status of the pump motor can be determined, this can provide sufficient information. The on or off status can be established using the following:

- **Voltages measurement or applied voltage indication** - In order for the pump motor to operate, an AC voltage is applied to the pump motor windings. This can be observed by a voltage measuring sensor connected to the motor power supply or a voltage sensing sensor that can be placed on the motor wiring;
- **On/off status** - Here a Normally Open (NC) or Normally Closed (NO) switch, on the pump motor switching contactor can be utilised, or a separate relay can be connected to the pump motor power supply in order to activate an NC or NO switch; and
- **Power operational demand or current flow** - Here the motor on/off status can be indicated by the operation demand measured by a power meter or the current drawn by the pump motor by using a CT. The first is an expensive option though for a simple on/off status.

6.4.1.3 Multiple pumps with different irrigation setups

Within this setup, the pump station has different pumps as described in Section 6.4.1.2, but each pump also has different pumping conditions. Some or even all pumps might each irrigate more than one field. A simple on/off status is not sufficient in this case since the operation condition of a pump also needs to be established. The following options can be considered:

- **Single pump options** - Same option as for a single pump as given in Section 6.4.1.1. which is applied to each and every pump in the pump station; and
- **Power meter or CT** - Use a power meter or a CT on each pump to establish operational conditions.

6.4.2 Strategic application of metering

Conventional metering can be strategically applied to extend its use for M&V purposes. Hereby the cost of M&V metering can be significantly reduced. This is especially important for programmatic ECM rollouts where there is very little allowance for metering. Often the cost of metering discourages the use of it, resulting in ECM rollouts with little to no metering which in turn leads to low confidence levels. This in return may result in a knock down of claimable savings due to low confidence levels and large error margins. The following bullets provide some pointers on how the function of metering can be stretched.

- **Use of power meter per phase measurement** - Power meters with registers usually perform per phase measurements instead of only giving the total power. Here each of the three phase inputs of the meter can be connected to one phase of a pump. Thus, the one power meter can be connected to measure three different pumps. Although only one phase is measured, a pump motor is a balanced load and one phase will give a representative value of that pump's operational demand. Phase balance can be confirmed with a handheld power meter. When a difference is overserved, the difference can be noted and incorporated in the total power calculations. Imbalance may be due to motor winding damage or voltage imbalance in the utility power supply. Unfortunately, power meters with registers are in general much more expensive (up to three times more) compared to accumulating pulse output power meters.
- **Use of single-phase power meters** - Single phase power meters cost much less than three phase meters. Thus, a single-phase power meter can be used on one phase of every pump motor. Here balanced phases should also be considered as described in the previous bullet. Single phase meters are usually limited to 45A, 80A or 100A. With a 100A limit, the maximum size pump motor that can be measured is around 55kW. This can be calculated by:

$$(P_{Total} = \sqrt{3} \times V_{line} \times A_{line} \times pf = 1.73 \times 100 \times 380 \times 0.85).$$
- **Use of a CT only** - A CT on one phase of the pump motor can also be used to get a very good representation of the pump motor operational demand. The supply voltage and PF can be measured with a handheld meter and further assumed that these values will stay constant. The voltage and PF may fluctuate somewhat, but current is the key operational performance indicator.
- **Use of on/off status** - On pump motors with a fairly constant load, a simple on/off status as described in the previous section can suffice.
- **Use of VSD output data** - VSDs in general internally measure parameters such as the current drawn per phase etc. If the VSD has an output on which these values can be received, it can be connected to a logger and used instead of M&V meters. However, impartiality and independence should be noted here as discussed in Section 6.3.5.

The points listed above provide options that can significantly reduce the cost of M&V metering by measuring key parameters that can give representative and accurate pump motor operational demand profiles. In some of the options, accuracy is sacrificed to an extent due to the approach followed, but the data gathered will in most cases be relevant and fit for M&V purposes.

6.5 METERING SAMPLING PLANS

Proper metering sampling methods can be a significant challenge for M&V practitioners. Large enough sample groups and proper sampling plans hinder M&V approaches to attain high enough confidence levels when required. It is important to understand that sampling errors arise when only a portion of actual value population is measured and when a biased sampling approach is followed (IPMVP, 2012). It can be difficult to determine an appropriate sampling size since the sampling method needs to be based on some available data that can provide a variance value. When a new project is evaluated, data on which variance can be determined is not always available, leading to several difficulties. With several Eskom DSM projects a simplified approach on larger groups was to take a certain percentage sample size, like 10%. However, with certain projects, even a 10% sample size can still be exceptionally large and will make a project too costly for implementation.

In order to explain how proper designed sampling plans can assist with M&V projects to minimise a sampling size, the next section considers a first of its kind study that was done under the Eskom CDM activities.

6.5.1 First of its kind operational hour survey on Eskom CFL CDM Project

Eskom started a residential efficient lighting initiative in 2004 and since then almost 50 million CFLs (Compact Florescent Lights) were distributed all over South Africa in residential households. In addition to a substantial contribution to the DSM programme, the energy efficiency of these CFLs directly resulted in greenhouse gas reductions. Eskom engaged in trading the emission reductions as CDM Certified Emission Reductions (CERs) and Verified Emission Reductions (VERs) under the Gold Standard. The CDM regulatory body, UNFCCC (United Nations Framework Convention on Climate Change), requires that the Eskom CFL rollout project be registered as a CDM project. The UNFCCC has certain project related methodologies in place under which the project can be registered.

The CDM methodology, AMS.IJ, specifies that a daily average operational hour value of 3.5 should be used as the default value for a CFL. However, previous small sample studies on CFL operational hours in South Africa have shown values of higher than five hours per day. According to the methodology, if the value 3.5 is not chosen, a new value may be established by measuring a sample of households over a period of 90 days with a 90% confidence level and 10% error margin. Since the CFLs were distributed all over South Africa, this 90-day study in essence needed to determine the average operational hours of a CFL in a South African home. From all known sources, such a CFL CDM study has not been done elsewhere in the world in the meanwhile, which makes it first and also the only of its kind.

6.5.1.1 Sampling method followed

According to Statistics South Africa (Census, 2011) there are more than 14.45 million households in the country. Even only a 1% sample size will result in 144 500 houses that need to be surveyed. Although there is such a large number of households in South Africa, following a well-designed statistical sampling method, the amount of lights, and therefore the number of households that need to be measured can be significantly reduced. Under the assumption of an infinite population and a sufficiently large sample, the sample distribution of a sample mean $\bar{x}$ is approximately normal and the finite population correction factor is approximately one (1) and therefore negligible. Under these assumptions the relationship between the margin of error (e) and the sample size (n) of a variable x in a simple random sample design can be derived as follows (Kruger, 2011):

$$P(|\bar{x} - \mu_x| \leq e) = 1 - \alpha \Leftrightarrow P\left(\frac{|\bar{x} - \mu_x|}{s_{\bar{x}}} \leq \frac{e}{s_{\bar{x}}}\right) = 1 - \alpha \quad \text{Eq. (6-1)}$$

But $P\left(Z \leq z_{\frac{\alpha}{2}}\right) = 1 - \alpha$ and $\frac{|\bar{x} - \mu_x|}{s_{\bar{x}}} \sim N(0,1)$

$$\therefore z_{\frac{\alpha}{2}} \cong \frac{e}{s_{\bar{x}}}$$

$$\therefore e \cong z_{\frac{\alpha}{2}} s_{\bar{x}} = z_{\frac{\alpha}{2}} \frac{s_x}{\sqrt{n}}$$

$$\therefore n \cong \frac{z_{\frac{\alpha}{2}}^2 s_x^2}{e^2}$$

Where n denotes the sample size, $\bar{x}$ denotes the sample mean, μ_x denotes the population mean of x , e denotes the margin of error, s_x^2 is the sample variance of the variable x , $s_{\bar{x}}^2$ is the sample variance of the sample mean $\bar{x}$, Z denotes the stochastic variable of a standard normal distribution, $N(0,1)$ - normal distribution with a mean of 0 and a variance of 1, α denotes the specified significance level (i.e. the probability of an error), $z_{\frac{\alpha}{2}}$ is the critical value of a standard normal distribution at significance level $\frac{\alpha}{2}$.

Similar to the above, the relative precision may be expressed as:

$$P\left(\left|\frac{\bar{x} - \mu_x}{\mu_x}\right| \leq e\right) = 1 - \alpha$$

Using the required precision of 0.1 (or 10%), then

$$P\left(\left|\frac{\bar{x} - \mu_x}{\mu_x}\right| \leq 0.1\right) = P(|\bar{x} - \mu_x| \leq 0.1|\mu_x|) = 1 - \alpha$$

If the population mean, μ_x , is then taken to be 5 hours, for example, then

$$P(|\bar{x} - \mu_x| \leq 0.5) = 1 - \alpha$$

This is equivalent to working with a margin error of 30 minutes, in this instance.

A critical point here is to establish the expected variance that can be used for calculations. This is normally a difficult part to determine ahead of time, since the variance of the variables has yet to be measured. The historical sample measurements that were done in the past, as mentioned in the previous section, were here incorporated to establish a variance indicator.

Thus, using the above method with the 90/10 requirement, calculations showed a sample size of only 130 lights was necessary. This is an exceptional low number considering that these lights will present the average usage of a CFL in the houses of an entire nation. Here the importance and power of using a true random sampling approach is highlighted. Within this, any light in any household in South Africa has an equal chance to be part of the sample group. This overcomes the large difference in type and size of households, income level, typography and so many other different factors. Considering this and the high 90/10 requirement, only measuring 130 lamps does not statistically bring any less required value than measuring 144 500 houses that are sampled following a non-random but strategic and planned metering approach which aims to capture and represent all different factors.

6.5.1.2 Sampling method implementation and results

Due to the nature and importance of the project, the minimum amount of information that could be used to determine the variance and the risks involved during the 90-day measuring period, the sample size was significantly increased from the initial estimated 130. Random sampling was done on the Eskom CFL rollout data bases to find houses where operational hour metering could be installed. After much trouble and metering issues, operational hour metering was installed on 536 lights in 115 houses over all nine SA Provinces and measured over a 90-day period. Through this period data was remotely collected from the installed meters. However, several of these meters stopped communicating during the measuring period. Finally, 114 of the 536 measuring points could not be used in the average operational hour calculations. Issues with these points ranged from corrupt meter memory banks to

water damage and meters that overheated. In addition, the data of some meters could not be used since these failed integrity checks in having unrealistic or questionable data. With some meters no data was logged due to incorrect installation or premature failure.

After the completion of the 90-day survey and data collection analysis, the methodology statistical analysis requirement was repeated on the actual data collected. Although it is not a methodology requirement, it was done to evaluate the representativeness of the data collected. With the 90/10 requirement and now the actual measured variance, the necessary sample size increased from 130 to 308 lights to be measured. This revealed much more variance in operation hours than what the sample data showed. The pre-emptive large sample group resulted in the actual used measuring sample of 422, and measured 114 CFLs additionally. Taking this into account, it shows a 90% confidence level with an 8.5% error margin which is 2.5% better than what was actually required. The sampling method detail design and the rest of the 90-day study can be found online at the UNFCCC project repository for the Eskom CFL CDM Programme of Activities (PoA) and Greenfields projects (Eskom CFL CDM, 2012).

6.5.1.3 Application to irrigation ECM projects and programmes

With irrigation pumping ECM projects and ECM programme rollouts there are a multitude of varying factors which influence the measurement parameters. Also, irrigation pumping and operational profiles are much more complex than the operational hours of a simple CFL. This complexity would consequently result in a stratified metering sample approach would need to be followed. Unfortunately, with each level of stratification and variable variation, the sample size grows. If a project or programme ECM requires a 90/10 confidence level and error margin for instance, the sample size with the variation in agricultural irrigation can become too big and costly to measure.

The wonder of the small 90-day metering sample size essentially lies in random sampling and that only one variable was evaluated. The question should be asked here, can the sampling approach of a complex multi-variable irrigation ECM be compacted and simplified in such a way that a high confidence level and low error margin can be reached with a relatively small sample size?

6.5.2 Design of an irrigation ECM with simplified sampling concepts

The IPMVP guideline document (IPMVP, 2012), SANAS Guideline for reporting uncertainty in M&V (SANAS TG 50-2, 2017), the UNFCCC sampling guidelines (UNFCCC sampling guide, 2012) and others provide very proper information on sampling approaches and the relevant statistics to be used. This section does not aim to repeat the information provided in these, but focus on designing concepts that can give simplified methods for irrigation ECMs sampling. The top graph of Figure 6-27 shows the normalised average demand profiles of 60 different Ruraflex irrigation points. As described in Chapter 4 Section 4.4.1, these profiles were derived from four years of historic data of the periods September 2008 to August 2012 as can be observed. There is much variation in the average operation demand profiles of the metering points.

When considering the vast variation in the shape of a different demand profile, it shows the difficulty in doing representative sampling. It will be very challenging to design an appropriate sampling method and it would most probably take a very large sample size to measure enough irrigation points to attain a high enough confidence level and low enough error margin that represent the operational profiles. Considering the average profile seen on the top graph of Figure 6-27, many of operational profiles do not even closely match the average profile. When doing a pump system characterization, as described in Section 4.4.1.1 in Chapter 4, the pumping profiles could be typology categorised which will better group operational profiles. Within these groups the demand profiles will to a large extent better follow the same trends, reducing profile variation.

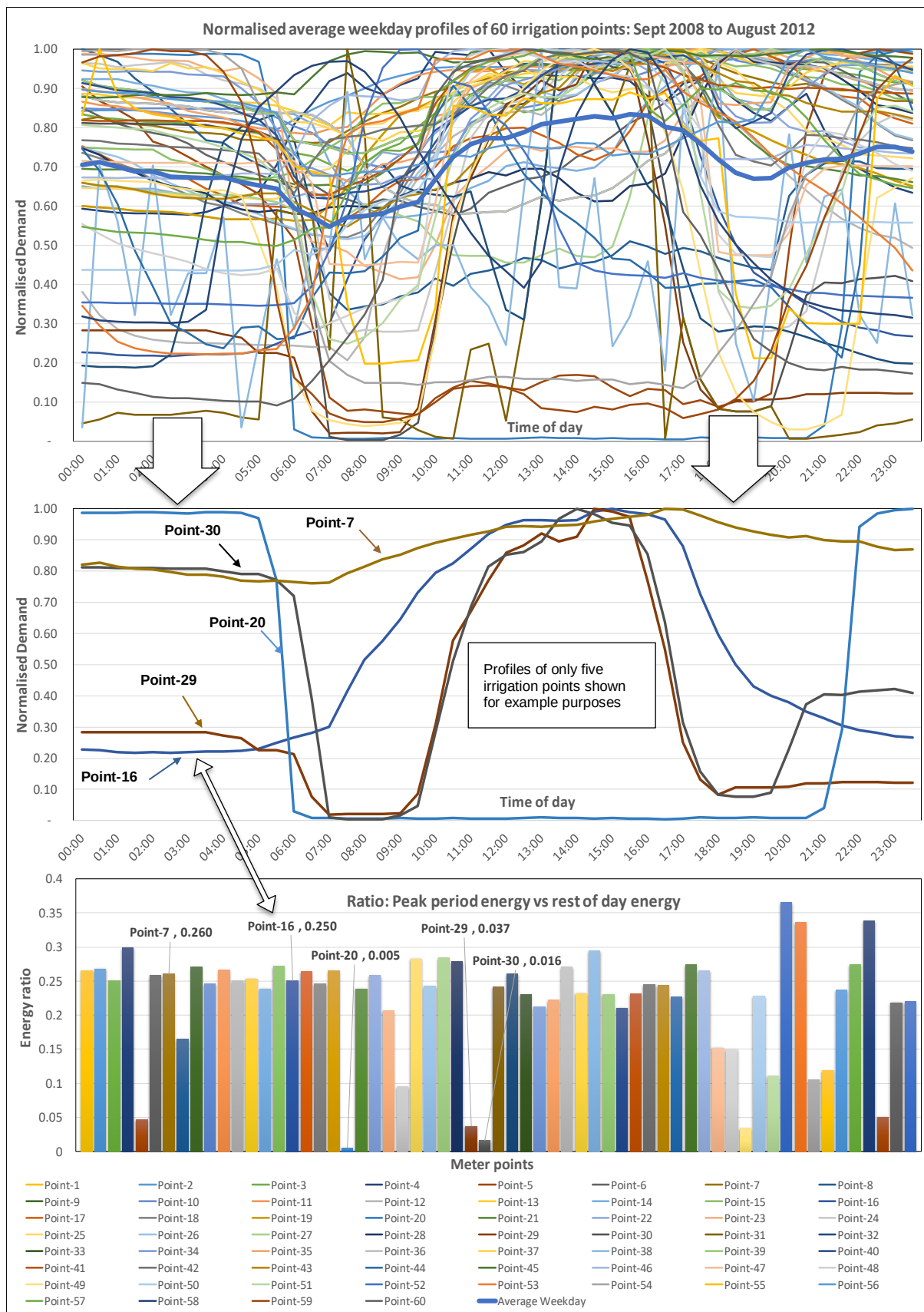


Figure 6-27: Normalised average demand profiles of 60 different irrigation points.

However, this information may not always be available or other project or programme limitations might not allow grouping. The question should be asked here if it is at all necessary to sample for operational profiles. Here it should be considered what exactly will be reported on as part of the M&V objectives, and a sampling approach should be designed around this. The major difference to the profiles in Figure 6-27 and the 90-day operational hour of Section 6.5.1., is that the profiles have 48 points (variables) that can daily vary, while the daily operational hours only have one. The following sections design concepts that can be applied to reduce an operational demand profile to a representative single variable. These include load shifting ECMs, energy efficiency ECMs and a combination of these. Thus, the sampling can rather be done on the variables which greatly simplify the sampling approach.

6.5.2.1 Load shifting

With load shifting projects, the essential M&V reporting requirements are first to establish the baseline available peak load to be shifted, and after project implementation the load actually shifted due to the ECM. As described in Chapter 3 Section 3.3, load shifting only moves the load over the evening peaks to the rest of the weekdays and also to the weekends.

Thus, the same amount of water at the same efficiency will be pumped. Instead of considering the demand profiles, one alternative method is to relate the baseline peak period energy use against that of the rest of the weekdays and weekends. These relations will look as follow:

$$Ratio_{BL\ period} = \frac{\sum Energy\ Use_{Peak\ periods}}{\sum Energy\ Use_{Weekdays\ off\ peak}} \quad Eq. (6-2)$$

$$Ratio_{BL\ period} = \frac{\sum Energy\ Use_{Peak\ periods}}{\sum (Energy\ Use_{Weekdays\ off\ peak} + Energy\ Use_{Weekends})} \quad Eq. (6-3)$$

In Eq. (6-2) and Eq. (6-3) both the morning and evening peak periods are combined. Eq. (6-3) also incorporates the weekend energy. These equations can be adjusted if focus is only required on one specific peak period as was seen with several Eskom DSM irrigation projects where mostly the evening peak was considered. Since Eq. (6-3) already includes weekend energy, the post-ECM ratio calculated will also reflect energy use that moved to weekends. The output of Eq. (6-2) or Eq. (6-3) provides one value that gives a representation of the amount of the energy available for shifting. Having only one value to work with greatly simplifies the sampling approach required.

Depending on the project and the reporting outcome, there may be a specific focus surrounding the peak period demand reduction achieved and how it correlates with the demand preceding and following the peak periods. One method here can consider the energy use of average demand of the periods just preceding and following the peak periods.

Conditional to the logging interval, it can be the time stamp just before and after the peak periods or the average of a few time stamps. With normal 30-minutely data logging, only one time stamp preceding and one time stamp following a peak period will be used. If the logging interval is smaller, like 5-minutely for instance, an average of a few time stamps can be used. Eq. (6-4) below shows the ratio when only considering the evening peak while Eq. (6-5) shows a combination of the evening and morning peaks.

$$Ratio_{BL\ period} = \frac{Average_{Morning\ Peak\ period\ demand}}{Average_{Period\ before\ and\ after\ morning\ peak\ period\ demand}} \quad Eq. (6-4)$$

$$Ratio_{BL\ period} = \frac{Average_{Evening\ Peak\ period\ demand}}{Average_{Period\ before\ and\ after\ evening\ peak\ period\ demand}} \quad Eq. (6-5)$$

Eq. (6-4) and Eq. (6-5) can be expanded to include both the morning and evening peak period as shown in Eq. (6-6) following:

$$Ratio_{BL\ period} = \frac{AverageMorning\ peak\ period\ demand + AverageEvening\ Peak\ period\ demand}{AverageBefore\ and\ after\ evening\ peak\ demand + AverageBefore\ and\ after\ evening\ peak\ demand} \quad Eq. (6-6)$$

These equations only show some of the methods that can be followed. There can be a number of alternative methods that can be considered to better represent the conditions of a specific situation. Also, the methods can be used simultaneously to give a better overall picture of the pumping activities. Some may be used as the key variables on which sampling will be done, while other may be used as additional performance indicators. Here the additional performance indicators can be defined to a specific boundary. When values are observed outside the boundary, it should be investigated and it may require adjustment to the sample size to include the larger variation.

It should be noted that irrigation systems can be very unpredictable and situations very circumstantial. Thus, one model that may work very well in a specific irrigation area may not be applicable to another area. As an example, the weekday peak period energy versus the off-peak energy function in Eq. 6-2 was applied on the demand profiles of Figure 6-27.

In the middle of Figure 6-27, five selected profiles of the top graph are shown separately for explanation purposes. Below these profiles, for direct comparison, a bar chart of the calculated ratio values is shown. Higher values displayed in the bar chart is good news for ECM ESCOs, since it shows a high peak load available for switching. Low values indicate that peak period switching is already performed or the farmer avoids pumping during the day.

The five selected points of the middle graph in Figure 6-27 is correspondently labelled in the bar chart.

- Point-7: Demand profile showing high pumping demand during the day and night with no peak switching. This gives a high ratio of 0.26 since there is a high peak load present.
- Point-16: High working hour (08:00 to 17:00) pumping but low pumping demand during the night, no peak switching. The ratio is 0.25 and close to that of Point-7, however the profile off-peak demand is lower, but also the peak period load.
- Point-20: High evening peak pumping with no pumping from 6:00 to 21:00. This gives a very low value of 0.005 since there is no peak load present.
- Point-29: Peak switching with high working hour pumping but low demand during the night. The low 0.037 value reflects a very little peak load.
- Point-30: Peak switching with high working hour pumping, high early morning pumping from 00:00 but low demand after evening peak. This is lower than Point-29 at 0.016 since there is a high early morning pumping load.

Having all the values displayed in the bar chart, sampling for an ECM can be done and the variance will be determined by the key reporting requirement (in this case load shifting) instead of a load profile.

6.5.2.2 Energy efficiency and a combination of load shifting and energy efficiency

An irrigation pump station energy efficiency improvement as described in Chapter 2 Section 2.3.2 and Section 4.3.1.1 in Chapter 4, will typically also result in an overall operational demand reduction. This demand reduction for a specific pump will only be known after the ECM implementation, and thus cannot be used as a parameter in a sampling approach done before an ECM rollout.

However, in some situations where ECMs were already implemented and the demand reductions are known, it may be used as a parameter. The following points provide potential sampling methods that can be applied. Here it should be noted again that it is circumstantial and the specific conditions and circumstances with each scenario should be considered.

- 1) Energy efficiency ECM sampling before implementation (not time of day dependant). Since the energy use of a specific irrigation point is here the important factor that will be influenced, it would make sense to use the average, say monthly, power consumption of that point as the sampling parameter.

However, there can be a vast difference in the power consumption of different sized irrigation points. This again will result in a large variance which in turn will increase the sample size. It would be better to also establish a ratio of the pump station power consumption to another parameter which will minimise the variation. A good option here will be to use a load factor or operational load factor as explained in Chapter 4 Section 4.3.4.4. The advantage of this approach is that Landrate kWh monthly bill values can be used for sampling instead of load profiles.

- 2) Energy efficiency ECM sampling before implementation (time of day dependant). When one of the outcomes of the ECM is also to know the amount of energy reduction specifically over the peak periods, the focus dramatically shifts. Since the energy reduction over the peak periods, or more specifically the demand reduction, is reported on, focus needs to be placed on the availability of the load over the peak period. In this scenario, the methods in the preceding Section, 6.5.2.1, would be applicable. However, the load factor method described in 1) above can be used as a secondary check parameter.
- 3) Energy efficiency and load shifting ECM sampling before implementation. In such a scenario, an irrigation point can be retrofitted with a VSD for optimising (energy efficiency) and peak period switch gear to prevent peak period pumping. Two things are focussed upon; reducing the operational load while also shifting the peak period loads. Here, both parameters would be important for reporting purposes and may need to be considered in the sampling approach. Here an approach such as in 1) can be determined for energy efficiency while a load shifting sampling method as in Section 6.5.2.1 can be used.

6.5.3 Over sampling practices

With CDM and other incentive-based mechanisms there is often the requirement of a simple random sampling where a certain confidence level and error margin needs to be achieved. Other uses stratified random sampling to allow focus on specific groups and sectors with also a set confidence level and error margin requirement. A very useful tool to allow flexibility and effective metering implementation while still attaining the sampling requirements, is the practice of over sampling. Here oversampling is proposed on two levels. The first has to do with an oversampled pool for effective selection of metering sample sites and the second with a larger sample set.

6.5.3.1 Large sampling pool

When random sampling is done, significantly increasing the sample size to create a sample pool can be very effective. It can happen that an irrigation pump station that is selected for sampling is not fit to be used as a metering sampling site. This can be due to many reasons like:

- The pump station does not provide enough cover and protection for metering against the elements;
- Cellular reception is not proper for remote communication;
- The pump station is in an unsafe area and it would be a risk to install metering there. Here risks can include theft of metering or damage to metering due to flooding;
- The pump station is very difficult to reach; and

- The site is a safety thread to M&V personnel and installers.

When such a pump station is come across, it can be decided not to install there. Another pump station can just be selected from the pool and the metering installation can happen there. When following this method there is always complied with the sampling requirements while ensuring the success of the metering installing and upkeep.

6.5.4 Larger than required sample size

Due to the high cost of metering, project implementers and M&V, practitioners usually make the sample size as small as possible. This unfortunately puts a high risk on the project, since if any of the metering fails on one of the sample sites, the sampling requirement is not met anymore. This situation was experienced with several CDM projects in the past.

This would also have been the case with the Eskom CFL CDM project if proper oversampling practices were not put in place as described in Section 6.5.1.2. Although the cost for M&V metering is higher due to the larger sampling cost, the additional cost may be worthwhile if it ensures that the project is successfully completed within the requirements.

6.6 SUMMARY

The quality and success of any M&V project is greatly dependent on the metering and metering systems that are used. If these are not properly sourced, installed and the installation is not verified, it can result in serious compromising of data quality, correctness and use thereof. It is of utmost importance that metering and automatic meter reading systems should provide a clear, transparent and auditable data trail.

M&V projects, especially irrigation projects, can create severe metering and remote data gathering challenges. The integrated multi-logger was designed and developed to specifically address these challenges through innovative approaches. In addition, the strategic application of normal metering can significantly increase the reach thereof for M&V.

Appropriate sampling methods of M&V metering sites can also create challenges. This becomes an even greater concern when sampling must be done on irrigation load profiles. Designing proper methods that can reduce the variability of load profiles to key reporting factors can assist in sampling and minimizing sample sizes. Also, the use of oversampling methods allows for flexibility and effective metering implementation while still adhering to sampling requirements.

Chapter 7

Integrated enveloping M&V

Significant opportunities to improve on water and energy efficiency exist in the agricultural sector, however, a lack of incentives creates barriers hampering the adoption of irrigation conservation technologies and practices. This chapter focusses on combining incentive mechanisms for water, energy and greenhouse gas to collectively overcome such barriers. An incentive here is broadly defined as a vehicle, that when implemented will enable, motivate or force an irrigator to reduce usage. Such vehicles can be water, energy or greenhouse gas reduction rebates, taxes, or restrictions; or take other forms. A critical requirement of many incentive mechanisms providing monetary assistance is proper quantification of the actual conservation achieved. Water, energy and greenhouse gas have different challenges when it comes to conservation quantification.

With the background of incentive mechanisms provided in Chapter 2; a proper foundation established with original methods developed for Measurement and Verification (M&V) levels in Chapters 3 to 5; and metering, quality and sampling discussed in Chapter 6, this study is concluded with an integrated and enveloping M&V methodology. Here water and greenhouse quantification are defined under project level, programme and regional level, and are integrated with energy conservation M&V to effectively quantify attained reductions. This original approach considers the quantification requirements of certain incentive mechanisms and how these can be met or proposes alternative models that still enable sufficient quantification. The Chapter 5 electrical grid top-down regional quantification methodology is also extended to water. This should be implemented together with water conservation projects and programmes since it is imperative that the actual water conservation in a regional or basin level be determined.

The chapter also investigates the application of the South African section 12L tax incentive (part of the Income Tax Act 58 of 1962) for energy efficient agricultural irrigation. The value and contribution that 12L energy efficiency projects can have on the agricultural sector is evaluated. It shows that if an agricultural electrical demand and usage reduction of only 20% can be achieved through 12L-enabled irrigation projects, this will result in an annual 1.73-billion South African Rand (ZAR) electricity savings for the agricultural sector. The national electrical demand reduction through the electrical savings amounts to almost 250 MW. The cost of building an equal-sized power generation capacity would be around 6.2-billion ZAR. Unfortunately, this chapter shows that 12L is impractical at this stage for the agricultural sector. The biggest hurdle is that the potential irrigation impact is spread over thousands of small projects with impacts too small to justify 12L M&V costs. To unlock the potential of 12L for irrigation, a programme-based impact evaluation approach, utilizing cost-effective M&V, is required while still maintaining a high confidence level with a low error margin.

An expansion of 12L for irrigation energy conservation through an original Agri-M&V approach is proposed. This approach integrates the project level, programme level and regional level M&V concepts of Chapters 3 to 5 to better quantify energy savings by following a deemed savings programme related approach. The framework development and essential concept design are done and a further study is proposed following the Agri-M&V approach which is required to realise 12L for irrigation. Water conservation can be done in conjunction with 12L which will even further increase impacts.

7.1 INTRODUCTION

With a proper foundation established and functional M&V methods developed in Chapters 2 to 6, this chapter focusses on an integrated M&V methodology. Through this the ultimate goal of realising water conservation in the agricultural sector is addressed. With this an integrated approach on the South African section 12L tax rebate (South Africa Government Gazette, 2013) is discussed. It should be clearly and early stated that if conservation projects or programmes are not accompanied with proper governing, accounting mechanisms and policies, attempts will most probably be fruitless or not sustainable. This is especially the case with water. The essential sequence of actions of FAO (2017) for adequate and sustainable water resource as discussed in Chapter 1 Section 1.3.2.5 is critical here. A necessity of the integrated conservation approach of this chapter is that it should not be attempted in isolation. It should be combined with the following to ensure the realisation of conservation in agricultural irrigation:

- Power utility, Water Board, Water Council and government buy-in and support;
- Agri suppliers, ESCO, irrigation advisor etc. buy-in and cooperation;
- Awareness programs and advertisement. Focus on the advantages and emphasise that the programme is there to assist and not oppress the farmer;
- Training programs to farmers and other stakeholders, information sessions and practical workshops on irrigation optimization, efficient irrigation and conservation;
- Conservation agri-advisor visits to farmers;
- Incentive mechanisms made available or the reach of available incentive should be expanded;
- Clarifying, setting and enforcing incentive mechanism rules and regulations, conforming to additionality prerequisites and accounting mechanisms to prevent double dipping and rebound effects (also see Chapter 4 Section 4.3.4.5);
- Strict and proper policies with governing instruments and set limits; and
- Conservation project maintenance to ensure sustainability of savings.

The above list is not part of the focus of this chapter, but is absolutely essential for the success of conservation projects and programmes. If not properly designed, implemented and maintained, savings will not be achieved (or will only be short lived) with no long-term advantage to show from an expensive exercise. As it was shown in this study so far; one of the most important aspects with conservation attempts is proper M&V to quantify actual attained savings. Alongside this, it is fundamental that M&V practitioners or M&V knowledgeable persons be involved as early possible in any planned projects or programmes.

Figure 7-1 illustrates an integrating and enveloping M&V approach for agricultural irrigation energy and water conservation with greenhouse gas mitigation. Item (i) in Figure 7-1 considers probable incentive mechanism and conservation associated benefits with agricultural irrigation. The aim is to incorporate as far possible all available incentives and maximise any other related benefits that results due to the conservation initiative. Building on this, item (ii) in Figure 7-1, gives an incentive and M&V application breakdown on an integrated project level, programme level and regional level. The first box under item (ii) shows an integrated project level M&V application with several sub boxes that are shown to the right. These start with the requirements for the M&V of peak load shifting, Energy Efficiency (EE), water conservation and Greenhouse Gas (GHG) mitigation. Focus is placed on an energy conservation approach and the M&V of impacts. With this, water conservation with practical considerations for M&V is looked at while considering a water balance. As part of this study an investigation was done, similar to that of Chapter 4 Section 4.3.1.1, on water waste and inefficiency on South African farms.

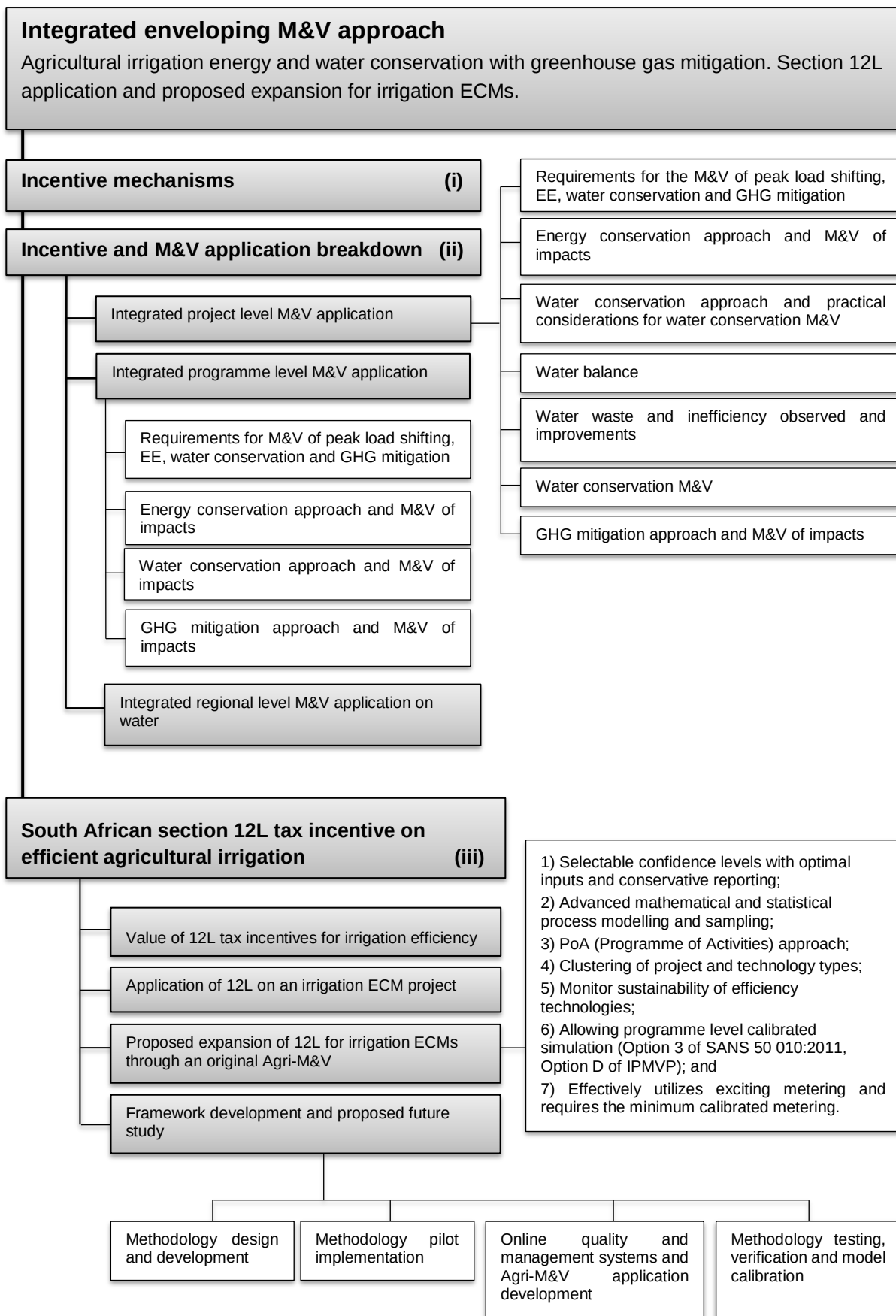


Figure 7-1: Flow chart of the integrated enveloping M&V approach.

The integrated project level M&V application box is concluded by looking the GHG mitigation approach and M&V of impacts with the last listed sub-block on the right of Figure 7-1.

With the integrated project level M&V application forming a proper basis, this is followed by an integrated programme level M&V application and then an important integrated regional level M&V application for water as shown in Figure 7-1. Here the regional level electrical grid analysis of Chapter 5 is applied to realise a regional water conservation M&V concept.

Item (iii) investigates the applicability of efficient agricultural irrigation utilising the South African section 12L tax incentive (part of the Income Tax Act 58 of 1962 with the latest revisions made in 2013). Chapter 2 Section 2.5.2.2 and Section 2.7.7 elaborated on 12L and its requirements. The value of 12L tax incentives for irrigation efficiency is evaluated with the possible application of 12L on irrigation Energy Saving Measure (ECM) projects. From this an expansion of 12L for irrigation ECMs through an original Agri-M&V is proposed. This approach integrates project level, programme and regional level M&V to better quantify energy savings following a programme deemed savings related approach. The framework development and essential concepts are given with a proposed future study. This study is required to realise 12L for irrigation following the Agri-M&V approach.

7.2 INCENTIVE MECHANISMS

There exist several incentive mechanisms (and related advantages) for energy conservation, water conservation and GHG mitigation as given in the literature survey of Chapter 2 in Section 2.5. Figure 7-2 revisits Figure 1-1 in Chapter 1 but provides more information on the specific incentives. As broadly defined in Chapter 1 Section 1.1, an incentive vehicle is defined here as a mechanism that when implemented, will motivate, assist, implore, enable, force or guide an agricultural irrigator to invest in conservation technologies and adopt conservation practices. Such mechanisms can be water, energy or greenhouse gas reduction rebates, taxes, restrictions, penalties, curtailment, cap and trade or other.

Having the correct policies with proper and effective M&V in place (that complies with the requirements and regulations of the available incentive mechanisms), incentives can be combined to realise water conservation uptake under farmers. Much focus is placed in Figure 1-1 on the energy side with other incentives bringing additional benefits where available and applicable. Orange blocks in Figure 1-1 show energy efficiency incentives while maroon blocks provide energy related specific advantages. These include a lower utility bill due to energy efficiency, focus on maximum demand reduction and also taking full advantage of the benefits of Time of Use (ToU) tariff structures. Of course, maximum demand and ToU are only applicable to a utility power supply point that is classified as a ToU point and equipped with ToU metering. Chapter 3 Section 3.3.4.2 provided information on ToU tariff structures and shows Ruraflex which is an agricultural ToU tariff structure. One incentive could be to assist farmers to move to a ToU tariff structure.

All the orange blocks in Figure 1-1, except the one on cap and trade, are specific to incentives available (or that was available) in South Africa. These include the Eskom Energy Services Company (ESCO) funding, Standard Offer Programme (SOP) and the Standard Product Programme (SPP), and section 12L tax incentives. From Chapter 2 Section 2.5.2.1, it should be mentioned here again that most of the Eskom Integrated Demand Management (IDM) funding programmes are not really active at this stage. Thus, currently section 12L is the only real energy efficiency incentive in South Africa. However, the concepts surrounding M&V of Eskom ESCO, SOP and SPP are applicable to any similar type of incentive. The rules, quantification requirements, policies and institutional regulations of incentives might differ from country to country, but the frameworks, concepts and designs are malleable so that these can be aligned to country specific prerequisites and programmes. The right of Figure 1-1 depicts water related incentives and taxes, cleaner development programmes, GHG mitigation incentives and

the advantages associated with optimised pumping and irrigation water efficiency. Here there might also be much variation between countries on incentives, taxation etc. The focus in this chapter is to develop an M&V framework that can incorporate the requirements for as many incentives as possible. It should be noted that incentives may not necessarily be claimed collectively since some may contain additionality clauses and regulations surrounding double dipping. The aim is not to encourage double dipping related practices, but create a platform which can offer a farmer as much possible incentives, benefits, funding and support to invest in irrigation conservation technologies and practices. The following sections consider several related incentive mechanism and the corresponding quantification requirements.

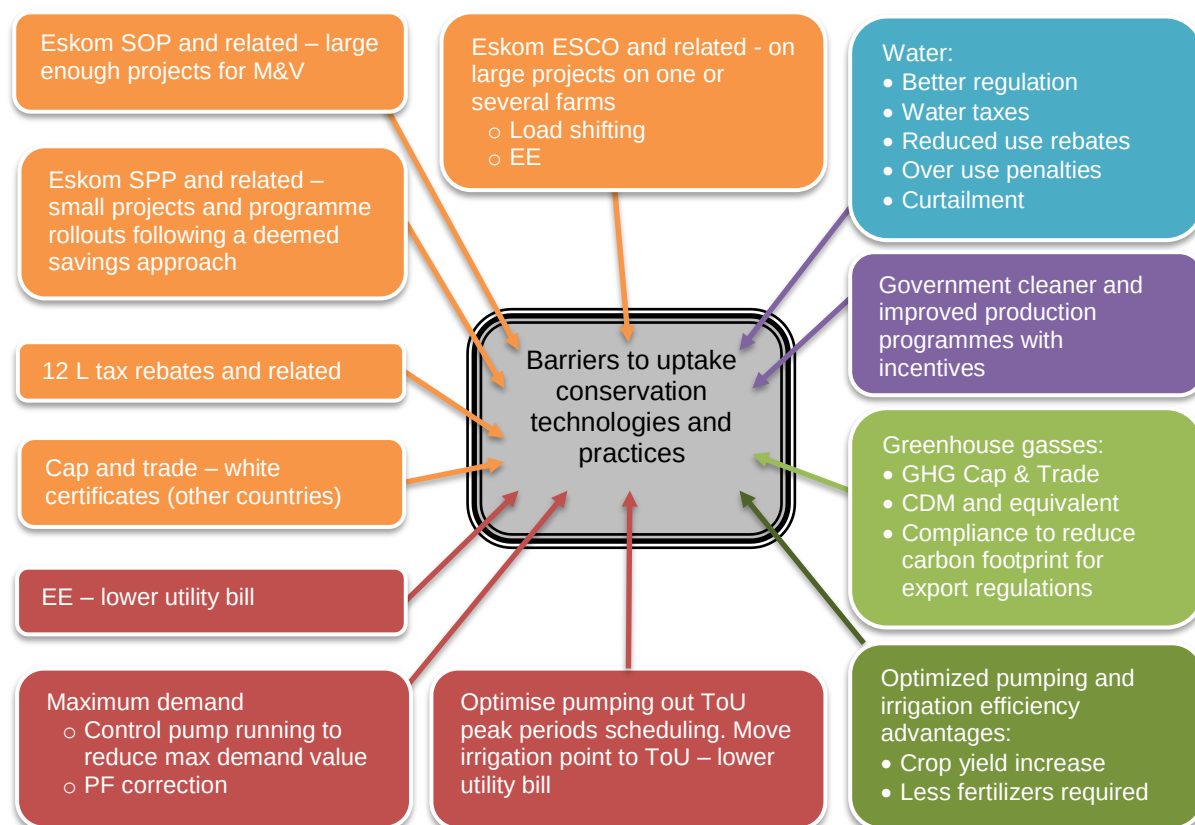


Figure 7-2: Incentive mechanisms to overcome barriers to enable conservation.

7.3 INCENTIVE AND M&V APPLICATION BREAKDOWN

Chapters 3 to 5 focussed respectively on, project level, programme level and regional level M&V. These, with the incentives and conservation benefits of Figure 1-1 and M&V requirements, are examined in this section. It considers the application on each M&V level and considers incentive related rules and regulations while integrating energy and water conservation with GHG mitigation into one framework.

7.3.1 Integrated project level M&V application

In Chapter 3 methods were designed and developed to effectively assess project impacts for different project types and the combinations thereof. These included: load shifting, energy efficiency with an energy governing factor, energy efficiency without energy governing factor, combination of load shifting and energy efficiency, load prevention or clipping and a combination of clipping and energy efficiency. This is essential background for the discussion of this section. Figure 7-3 gives a flow chart of the components included and discussed under project level M&V. On the left of Figure 7-3 the applicable

energy incentives from Figure 1-1 are shown. The energy specific advantages of the maroon blocks in Figure 1-1 are not repeated since these are applicable to all three levels of M&V.

On the right of Figure 7-3 a blue block with water incentives and water use quantification is shown. Except for water quotas, restrictions, limited over use penalties and curtailment, no water conservation incentives currently exist in South Africa. It is also the objective here to avoid incentive vehicles such as water taxes, increased water tariffs or penalties, but rather to target the other Figure 1-1 incentives and benefits through which water conservation can be leveraged. As mentioned in Chapter 1 Section 1.2.1.2 and the literature of Chapter 2 Section 2.5.1, care should be taken with water taxes or other restrictive measures; in South Africa especially, farmers already face high crop input costs and difficult farming conditions. Water restrictions and taxes would increase the current burden on farmers and cut further on already low profit margins.

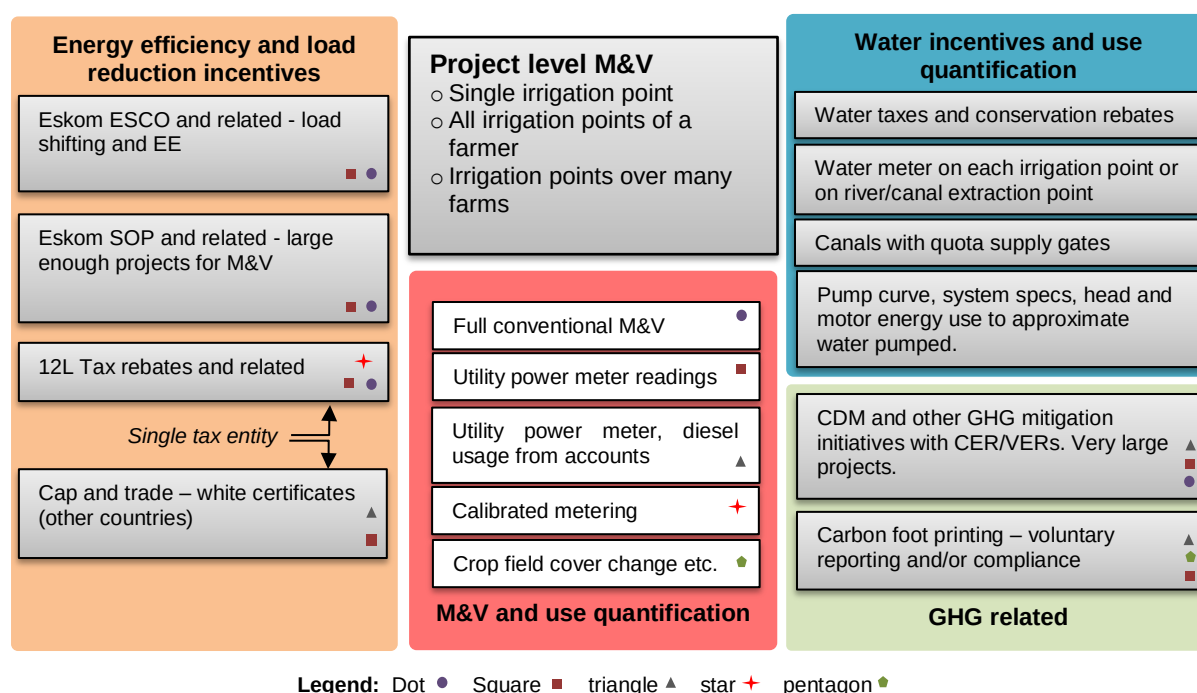


Figure 7-3: Project level M&V with associated incentives and quantification requirements.

The green block on the bottom right of Figure 7-3 shows GHG related incentives. The bottom middle red block indicates M&V and required quantification methods depending on incentive mechanism. Each of the items in the orange, red and green blocks have a dot, square, triangle, star and pentagon legend next to it. These are also shown where applicable in the incentive blocks (except water). For instance, the first item in the energy efficiency block (Eskom ESCO and related) requires full conventional M&V while utility power meter readings may be used. Item three, 12L tax rebates and related, requires full conventional M&V while utility power meter readings and diesel usage from accounts can be used. However, a mandatory requirement with 12L is the use of calibrated metering. It is important to notice that 12L is specifically bound to a single tax entity. This is normally also the case with cap and trade mechanisms in other countries.

As already mentioned, the available incentives in a country may not necessarily be claimable in conjunction with others due to regulations. This section will however, for M&V application explanation purposes, explore all the available options. Here the incentives explained in Chapter 2, project level M&V methods of Chapter 3 and M&V metering of Chapter 6 are fundamental. From the detail provided in Figure 7-3, there will be elaborated on the requirements of each incentive mechanism. Eskom ESCO

projects, Eskom SOP or a related type incentive for irrigation energy conservation can be implemented on one large pump station or multiple pump stations. An ESCO project is though not limited to a single farmer but can encompass many farms. Conservation projects can entail both peak load-shifting and energy efficiency improvements. Here the focus will be also the integration of water conservation and GHG mitigation.

7.3.1.1 M&V requirements for peak load shifting, EE, water conservation and GHG mitigation

With project-level evaluation, the prominent requirement is full M&V on all pumps or a sample of representative irrigation pumps. Since the focus is to incorporate as many possible incentives through which water conservation can ultimately be realised, the following is relevant or a prerequisite:

- With energy measurement and quantification:
 - An electrical power demand profile power meter;
 - Intelligent metering system(s) may be required;
 - Energy Efficiency (EE) with an energy driver (energy governing factor) M&V approach - project type 2 of Chapter 3 Section 3.4; or
 - Combination of load shifting and energy efficiency (with energy driver) M&V approach - project type 4 of Chapter 3 Section 3.6.
- With water extraction quantification:
 - A flow meter on all river and communal dam extraction points and non-quantified canal extraction points - as an energy governing factor.
- With GHG emission and mitigation quantification:
 - Utility electrical bills;
 - Power utility (Eskom) power station emission factors;
 - Power transmission and distribution loss figures;
 - Crop cover change recording; and
 - Certain CDM project methodologies required extensive baseline data.

A load shifting project does not need an energy governing factor but it is a very important consideration for EE projects. In this case, the water pumped will be the key energy governing factor to which energy demand and use reduction can be related. With agricultural irrigation, it is not really possible or accurate to use production output as a governing factor (as can be done for industrial or mining projects). Reason being is that rain, seasonality, crop diseases, hail, floods and a number of other factors can influence crop production.

Unfortunately, the flow meter specification is a sensitive topic since it can significantly increase project cost. However, it is the most important tool towards water conservation. From Chapter 3 Section 3.9.2.2 point 5), it is general practice to install a flow meter on the suction pipe between the river and pump station. Unfortunately, this requires expensive electromagnetic flow meters with no impeller. Normal impeller type flow meters are not suitable in general for river extraction points since impurities will get stuck in the impeller and thus no flow values will be measured.

If impeller type flow meters can be installed after cleaning filters, but importantly before any tap-offs, it can suffice though. Reverse filter cleaning and the related water dumping from the filter assembly will typically be neglected. However, if there are already tap-offs before a suitable place for a flow meter, a flow meter on every tap-off may be required.

Here it is important to refer back to Chapter 3 Section 3.8.1.3 discussing the major interactive effect water extraction flow meters installed on load shifting DSM project had. The water meters were utilised

by the region's Irrigation Board to track each farmer's water usage. Before the DSM project implementation, the Irrigation Board could not track the water usage and check if the farmers stayed within their allocations. Afterwards, the water meters resulted in significant changes in irrigation pump operational demand profiles due to less water pumped. In essence, the water flow meter functioned as a water conservation tool.

With this, a water flow meter is the only real accurate water extraction quantifier that can be utilised. With canal system water, quota allocations are controlled through a Water Board employee manually unlocking and opening a canal gate, letting water run through to the farmers holding dam for set period (Scheepers, 2018). This can be done remotely with servo driven gates but these types of technologies are expensive. The water quota can be an indication of the farmers' water use, but the actual water let through can differ if not exactly controlled.

Incorporating pump curves and pump operation can assist but since most irrigation pump stations irrigate multiple crops with different static heads and crop water application methods, there can be severe variation. However, if intelligent metering is utilised to exactly establish what amount of water went where through detailed pump operation and valve switching monitoring, very representative water pumped numbers can be established. Although, it would here be more in the interest of a Water Board to quantify water than for the farmer through using a complex intelligent metering system. Thus, in conclusion, it is imperative that extraction water flow metering or precise water allocation should be standard practice.

GHG reporting for carbon foot-printing in general may only require power utility electrical bills and emission factors with transmission and distribution loss figures. CDM projects on the other side, depending on the methodology followed, can also require extensive historical baseline data on both power and water use.

7.3.1.2 Energy conservation approach and M&V of impacts

In order to determine an electrical energy use and energy demand reduction due to system optimization, several M&V strategies can be followed. As mentioned, the focus of this chapter is to benefit from all possible incentives and related benefits. With energy conservation, the approach is therefore as follows:

- 1) Shift all possible loads from the peak periods through pump switching automation equipment:
 - o Utilise ESCO or other incentive project funding; and
 - o Optimise and schedule operations as far possible to benefit from lower out of peak power use.
- 2) Optimise the system to lower energy use to shift the same amount of water;
 - o Utilise ESCO or other incentive project funding; and
 - o Benefit from lower power use.
- 3) Also attempt pump scheduling so that large pumps do not operate simultaneously. With this, incorporate power factor correction:
 - o Benefit from a lower maximum demand value on the electricity bill.
- 4) Reduce pumping operations through a no-waste and no-over-irrigation focus (see the following Section for an elaboration on this):
 - o Less pumping leads to less power consumed.

With point 1) and 2) ESCO or related incentive funding can be provided. Any M&V approach would therefore focus on the impact that was made due to the ESCO project intervention. Thus, what are the savings achieved as a direct outcome of the interventions? It is fundamental that there should be

differentiated between a savings that resulted due to the project and a saving that occurred but not as a result of the project. For instance, if the region receives a higher than normal rainfall and the farmer only needs to pump the minimum, much less energy would be used for that period, however, this is not due to the project intervention. The opposite is also true and a very low rainfall period would show increased energy consumption even with the intervention implemented.

Chapter 3 contains novel M&V approaches on the different project types, as mentioned in the beginning of Section 7.3.1, and different setup scenarios and variations. In the situation (load shifting and EE with a flow meter), the options in Sections 3.4 and 3.6.1 can be incorporated.

Point 3) is an additional beneficial option that can be explored while energy saving under point 4) would need to be quantified alongside water irrigated conservation.

7.3.1.3 Water conservation approach and practical considerations for water conservation M&V

Figure 7-4 shows the irrigation pumping setup with flow meters and water balance of two neighbouring irrigation farms. The first farm on top Figure 7-4 is the same one discussed in Section 3.3 of Chapter 3, however appropriately situated impeller type flow meters were added and also an indication of water runoff and deep percolation paths are shown.

The second farm at the bottom is a small holding with only one borehole and a centre pivot. The first farm has three river pumps for extracting water, irrigating crop circles, micro-irrigation blocks and moving water to 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) and is used when maintenance is done on P4. Flow meter 1 was positioned after the line filter which is situated just after where the P3 and P4 pipelines connect.

However, it is placed before the line split to V3 and V4/V5. Since P1 pumps to a holding dam, only a strainer removing impurities (impurities large enough to get the flow meter impeller stuck) from the water was installed before the flow meter. It should be considered that, depending on the situation, a strainer might slightly increase power.

The configuration of the two flow meters avoided that expensive electromagnetic type flow meters needed to be installed on the suction side of the river pumps. Unfortunately, the pumping setups of many irrigation farms do only allow the use of impeller flow meters and thus the electromagnetic type needs to be used.

7.3.1.3.1 Water balance

The two flow meters in Figure 7-4 will accurately quantify the water extracted from the river. With reference to literature in Chapter 2 Section 2.2, Figure 7-5 shows the prime water inflows and outflows for irrigation systems that should be considered (adapted from Burt *et al.*, 1997 and Clemmens *et al.*, 2008):

- 1) Water used by the irrigated crop within the area - beneficial purposes;
- 2) Water consumed in the area under irrigation - but not beneficially;
- 3) Water that leaves the boundary but is recovered and reused - such as the water runoff to the holding dam in Figure 7-4;
- 4) Water that leaves the boundary but is either not recoverable or not reused - runoff to the river and deep percolation in Figure 7-4; and
- 5) Water that is in storage within the boundary.

As a practical explanation of the above with the accompanying literature in Figure 2-2 and Section 2.2.5, the water balance of Farm 1 involves the following:

- Water brought onto the farm or arriving on the farm through rain:
 - Water is extracted from the river and moved to centre pivots and micro irrigation;
 - Water is extracted from the river and pumped into a holding dam from which a centre pivot is irrigated; and
 - Rain water that falls on farm surface.

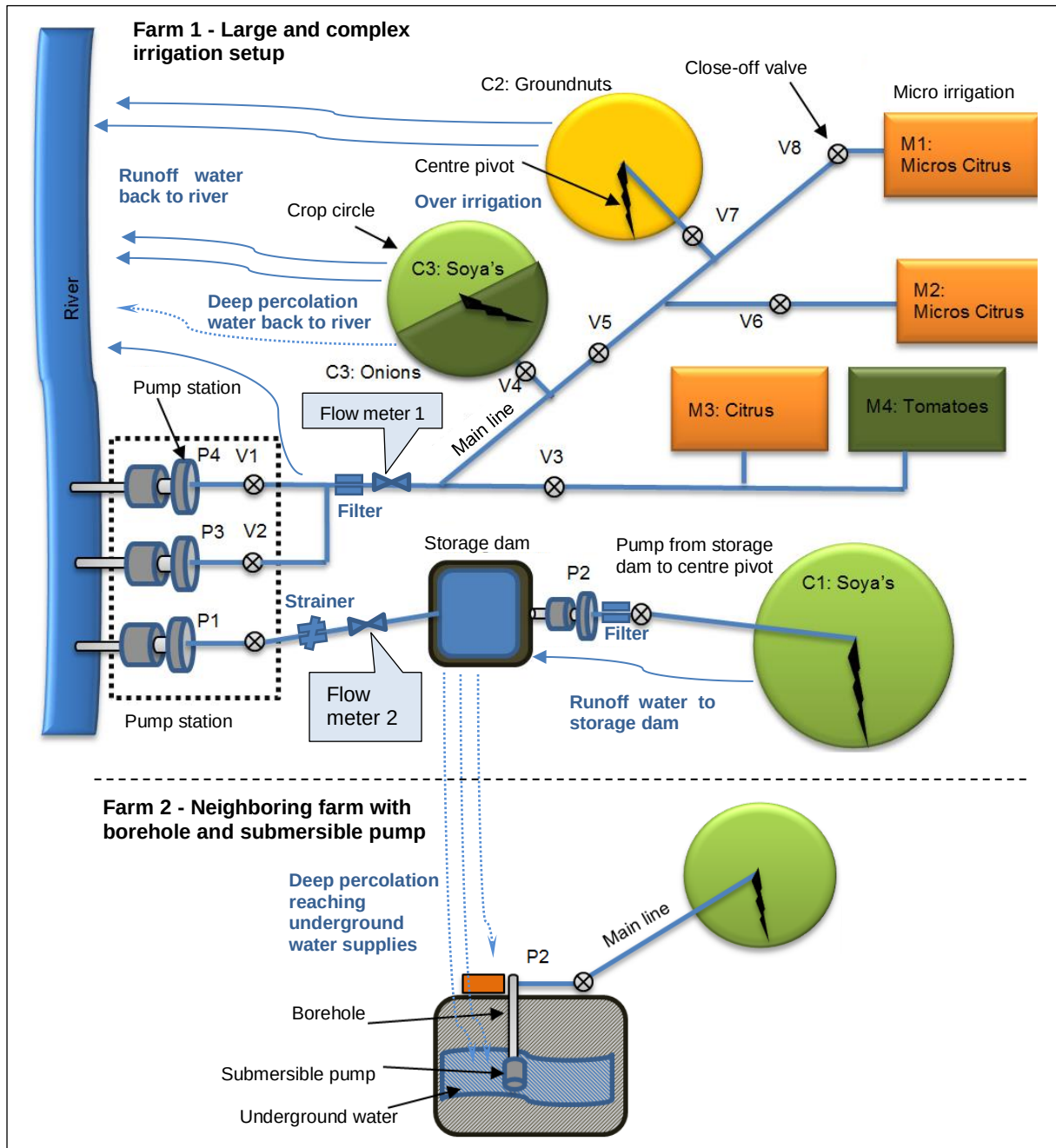


Figure 7-4: Irrigation pumping setup, flow meters and water balance on two neighbouring farms.

- On-farm water destruction, losses on the farm and water moving out of boundary of farm:
 - Water waste due to leaky pump system and main lines creating runoff to the river;
 - Runoff water from crop circle C2 and C3, and leaking system back to river;
 - Deep percolation water ending back in the river;

- Evaporation from the dam, ground infiltration and deep percolation;
- Water caught in plant tissue;
- Evaporation and drift during irrigation, Evapotranspiration; and
- Infiltration and deep percolation.

The water extracted from the river can be exactly quantified but does not represent the actual net water obtained from the river. Unquantifiable water returns back to the river through runoff and deep percolation. Also, deep percolation from the holding dam reaches the underground water supplies of the neighbouring farm. If the water usage of Farm 1 can be reduced by a hypothetical 50% (due to waste prevention, no over irrigation, staying within the quota since flow meter installation, optimised systems and optimum irrigation application), the 50% less extracted is unfortunately not now suddenly available in the river. With optimization, the water runoff and deep percolation return will consequently also reduce. If the farmer would line the dam bed with material to prevent losses (ground infiltration and deep percolation), deep percolation water will not reach the neighbour's underground water supply which can result in the borehole drying earlier in the season. This might in turn require this farmer to also start extracting water from the river.

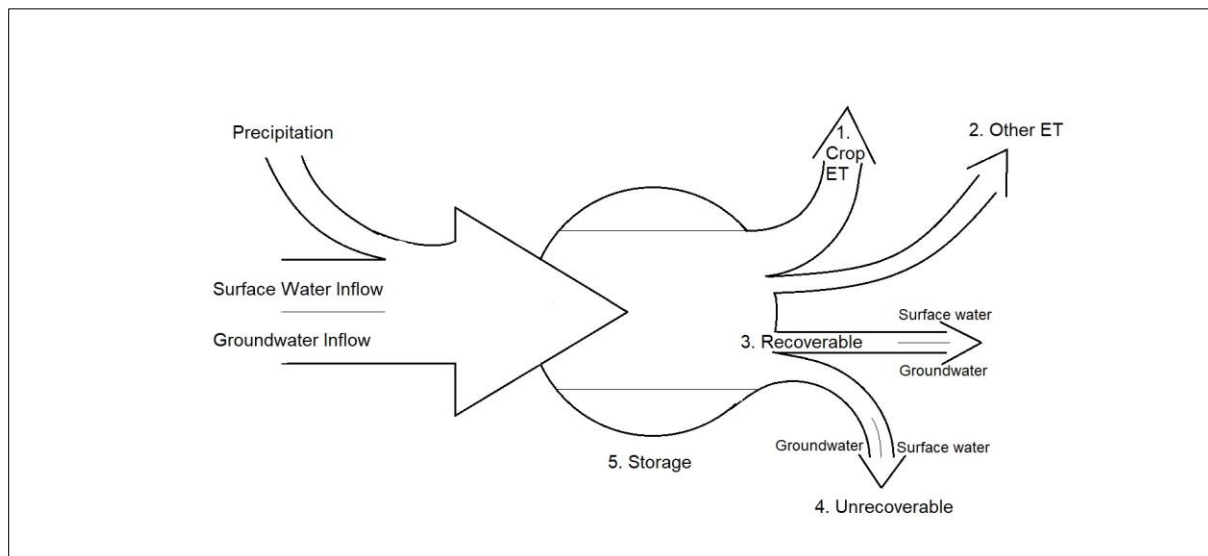


Figure 7-5: Prime irrigation water inflows and outflows (Adapted from Clemmens *et al.*, 2008).

This scenario makes it difficult to exactly determine and define the actual water saving (or the amount of water made available for use downriver) within a river water basin context. This is a critical concept that should be understood before any water conservation rollouts or attempts in an area are initiated. In stark contrast, every kWh of electrical power less used is a direct saving. Of course, this should be in an environment where rebound (electricity saved applied elsewhere later due to farm expansion etc.) is prevented. Thus, a kWh saving cannot necessarily be connected to an equivalent water saving.

Here the more important consideration from a Water Council's perspective would be to achieve a reduction of extraction from the water source. When a farm is engaged for conservation attempts, part of the audit can be to investigate on a high level the possibility of water returning to the source. Trying to accurately quantify this would be a burdensome and difficult exercise that may not bring worthwhile value from the effort. Rather it should be noted with an indicative approach (low, low-medium, medium, medium to high and high) the probability of water returning to the river. This audit notes will be valuable later to analyse and understand the overall water balance of a region from a regional level approach. Section 7.2.3 will elaborate on a regional level M&V method to quantify water conservation.

7.3.1.3.2 Water waste and inefficiency observed with improvements

Only looking at operational efficiency as part of technical efficiency, energy and water use inefficiency and waste is regularly found in the agricultural sector. Chapter 5 considered energy efficiency under the Eskom SPP. The Eskom IDM irrigation energy advisors, Scheepers *et al.* (2013), revealed among other, common water inefficiency and waste culprits listed in Table 4-1.

Table 7-1: Irrigation system energy inefficiency and corrective actions.

Irrigation system	Energy Inefficiency	Corrective action
Pump set	Leaks in: - Leaking seals - Leaking valves	- Change seals - Replace valve seals or valve itself
Main and distribution lines	Leaks in: - Mainlines - Distribution pipes - Delivery pipes and tubes.	- Fix bursts or holes in pipe and repair connections - The same as for mainlines - Repair leaks and replace tubes
Centre pivot and delivery	- Over-pressure at centre pivot nozzles leading to fine mist water delivery and thus much more evaporation (Also see Chapter 4 Section 4.3.1.2.) - Over-irrigation and inefficient water application like flood irrigation are common practice. See Figure 7-8 a). - Incorrect sprayer replacement. Faulty pressure regulators on sprayers are not repaired or replaced as required.	- Optimise pressure - Optimise irrigation through crop water requirements. Change irrigation method where necessary. Add drag lines to a centre pivot. - Use correct sprayers and use correct pressure regulators.

Here system leak repairs and improvements can prevent water waste and increases operational water efficiency. Table 4-1 provides the corrective action in the last column on the right to correct or improve these inefficiencies. Just as with the energy efficiency in Chapter 4 Section 4.3.1.1, this study also independently validated the irrigation energy advisors' observations. Figure 7-6, Figure 7-7 and Figure 7-8 provide examples of the Table 4-1 waste observed. Chapter 2 Section 2.3.2 elaborates on the variety of methods that can be incorporated to improve irrigation water efficiency. These are categorised under Group-1 and Group-2 improvements as given in Section 4.3.1.1 of Chapter 4 and again listed in Section 7.4.4.1. It is important to again emphasise that water conservation as a result of these may not all be seen as water saved in reference to the net water downstream.



Figure 7-6: a) Leaking pump seals, b) Leaking main line, c) Rusted and leaking main line.



Figure 7-7: a) Burst nozzle tube, b) Leaking sprinkler tubes, c) Leaking nozzle.



Figure 7-8: a) Crop over irrigated. b) Centre pivot over irrigating crop.

As described in Section 2.2.4 and 2.6, excessive use of water, like over irrigation, can be identified by using a benchmarking tool such as Data Enveloping Analysis (DEA), by comparing farms in the same region and with identical characteristics with each other. This crop water requirements discussed in Section 2.2.34.3.4.3 and Chapter 4 Section 4.5.6, can play an essential role to establish just the right amount of water needed considering the soil type etc. On top of shifting to more water efficient application methods, decision-making tools could improve economic and water use efficiency.

7.3.1.3.3 Water conservation M&V

Taking everything discussed above in Sections 7.3.1.3.1 and 7.3.1.3.2 into consideration, the only real measurable quantity that can be connected to a water conservation attempt by the farmer, would be the quantity of water extracted. This will be the energy governing factor for energy conservation M&V in Section 7.3.1.2 and from a water conservation M&V perspective, a quantifier of less on-farm usage.

However, water less extracted can also be a result of higher rainfall and not necessarily due to water conservation attempts. Thus, like with energy, a water use governing factor should also be incorporated. Ultimately, the aim would be to M&V the amount of less water used to irrigate a specific crop. Therefore, the amount of water applied per irrigation cycle before and after efficiency improvement can be an indicator. However, this will not show conservation achieved through ceasing over irrigation. On the crop field, water precipitation (water application and rain) meters with data logging capabilities will be able to capture this. Having such data in combination with water application per cycle information and amount of cycle data, can be a feasible approach for quantification. Of course, if the farmer changes from one crop to a next between evaluation periods, as many farmers do, it will severely complicate things. With such a scenario, benchmarking and crop water requirement figures will need to be considered. Although, this will only show the efficiency performance of the farmer but not if there is actually water conserved.

In short there is not an easy and specific method that can be used in all cases. The applicability of methods is circumstantial and will need to be considered case by case. It may be that a certain method can work well in a certain irrigation area and can be applied on all farms there. However, water conservation M&V should always be approached intuitively while considering a wide number of factors that can influence results calculated. Here again the importance of a higher-level quantification method that can evaluate the overall conservation achieved from a regional water balance is critical. Section 7.3.3 elaborates on this.

7.3.1.4 GHG mitigation approach and M&V of impacts

Depending on the country where irrigation water and energy conservation is implemented, the best from available carbon offset markets can be selected. Chapter 2 Sections 2.4 and 2.5.3 and 2.7.2 provide background on GHG mitigation in agricultural irrigation, incentive mechanisms and a discussion on some of the relevant standards. The foremost considerations are the size of projects allowed, the applicable standards and M&V requirements. Through evaluating these, the best applicable GHG incentive can be chosen while also considering how it will align with the energy and water conservation M&V approach.

In South Africa CDM projects were implemented, although none were irrigation conservation related. There is also a carbon tax planned by the South African government with nominal rates, tax free thresholds, maximum additional allowance of trade exposure and additional allowance for process emissions announced (Department of National Treasury South Africa, 2015; Bolt *et al.*, 2014). However, the application is still to be seen and how it will be actually incorporated.

If there is irrigation conservation or active pumping related CDM Programme of Activities (PoA) in a region or country, the best option will be to join these. The low post-2012 carbon price does not allow the registration of new projects. Other voluntary carbon markets can also be considered where available. Many of these also use the UNFCCC CDM guidelines.

7.3.2 Integrated programme level M&V application

The general approach and outcome of conservation programmes is to have an accelerated rollout on many smaller type project sites which cannot justify full project level M&V. Here the focus is standardised, proven and tested conservation methods and approaches that forms part of a fixed package using a saving calculator model. Figure 7-9 shows a diagram of programme level M&V with associated incentives and quantification requirements. On the top right of Figure 7-9 the energy efficiency and load reduction incentives are shown.

Section 2.5.2.1 and Section 2.7.6 in Chapter 2 give the regulations surrounding the Eskom SPP and the associated M&V requirements. Chapter 4 provides an extensive implementation of SPP and the development of novel M&V methods. In other countries there can exist programme type energy conservation rollouts with minimum metering and sampling approach specifications.

A general shortcoming of such programmes is that there is reported on energy savings, but these do not have the means to also report on peak period demand reductions achieved. Section 4.5 designed a unique calibrated simulation model for agricultural irrigation conservation initiatives which can quantify peak reduction achieved. Section 7.4.3.2 and 7.4.3.6 further looks at the application of this.

On the top left of Figure 7-9 water incentives and quantification items are listed. Here the exact same items are given as in Figure 7-3 of project level M&V. The importance of this is elaborated on in the following section. The bottom right of Figure 7-3 gives the GHG related incentives and the middle bottom provides the M&V and use quantification items.

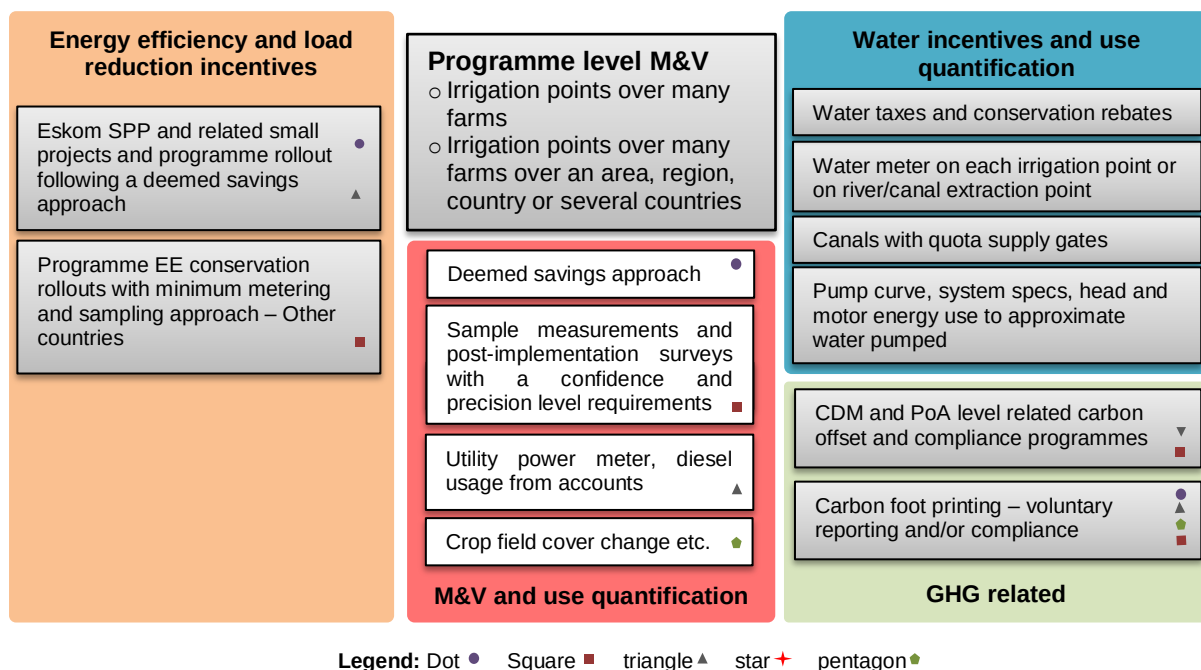


Figure 7-9: Programme level M&V with associated incentives and quantification requirements.

7.3.2.1 M&V requirements for peak load shifting, EE, water conservation and GHG mitigation

With programme level ECM rollouts, a deemed savings M&V approach can be used or full M&V on a minimum number of samples of sites. These are sometimes combined with post-implementation surveys on sample sites. The minimum sample is specified with a certain confidence and precision requirement. As with project level M&V in Section 7.3.1.1, the focus is to incorporate as many possible incentives with programme level M&V through which water conservation can ultimately be realised. The following bullets are relevant to M&V or specific requirements:

- With energy:
 - Deemed saving calculation through a toolkit (such as for the Eskom SPP);
 - Sample measurements; and
 - Measurements can also include in some cases:
 - Utility power meter readings and bills;
 - Diesel usage from accounts (where other energy sources are allowed with electrical power)
- With water:
 - A flow meter on all river and communal dam extraction points and non-quantified canal extraction points - as an energy governing factor.
- With GHG:
 - Utility electrical bills;
 - Power utility (Eskom) power station emission factors;
 - Power transmission and distribution loss figures;
 - Crop cover change recording; and
 - Certain CDM project methodologies – sample measurements.

The requirements surrounding energy significantly differs from Section 7.3.1.1 but with water and GHG it stayed much the same.

7.3.2.2 Energy conservation approach and M&V of impacts

A similar approach can be followed as in Section 7.3.1.2 with project level M&V. Identical items of points 1) to 4) in Section 7.3.1.2 are applicable except that the ESCO funding is exchanged with SPP or related type incentives. The calibrated simulation model of Chapter 4 can bring added benefit to the SSP with providing peak period impacts. All items in point 1) to 4) can also be fully utilised to realise as much possible benefit to the farmer. An option here is to move the applicable irrigation point from a Landrate type tariff structure to the Ruraflex or Nightsave ToU tariff structure. Through this, out-of-peak operational advantages for the farmer and the power utility can be added.

The SPP uses a deemed savings model with savings predetermined and funding provided in the beginning of the project implementation. Thus, no M&V evaluation occurs after the initial project's savings estimation is calculated via the standardised SPP toolkit calculator. SPP related incentive mechanism in other countries may need, on the overall programme, representative sample measurements to be taken. This can entail spot measurements and/or investigating key performance indicators or long-term metering on specific sampled sites. Section 7.4.3.3 elaborates on the value of this for improving confidence in savings and long-term saving tracking and sustainability.

7.3.2.3 Water conservation approach and M&V of impacts

With the ultimate goal of achieving water conservation, the same effort is required with project level M&V for the quantification of water conservation impacts. More importantly again is that all communal water source extraction points should be equipped with flow meters. Reference is made to a communal source since there may be no need to have a flow meter on an isolated dam on the farms that catches rainwater and runoff water. Also, if the farmer has a borehole, it also may not need to be equipped with a flow meter. However, if there is concern on the level of underground aquifers or underground water tables that is also drawn from by other farmers, the boreholes should also have flow meters.

All flow meters should be monitored on usage just as a power utility point. Meter readings may be taken quarterly or bi-annually instead of monthly. This should not be done by a set schedule so that a farmer would not expect when a meter reading will be done. This prevents practices where the farmer bypasses the flow meter manually and removes any bypasses just before the Water Board metering reading site visit nears. Water allocations and quotas can also be considered if not already applicable in an area alongside DEA benchmarking and crop water requirement assessments.

Exactly the same water conservation options for project level M&V are applicable to a project site under a programme. As mentioned in Section 7.3.1.3.3, there is no easy and specific M&V method that can be used in all cases. A similar water conservation standardised toolkit can be developed as for SPP energy conservation. Hereby, if certain standardised system improvements are made, or switched to more efficient water application technologies, the typical saving connected to the irrigation setup and water usage can be calculated. Also see Section 7.4.3 later on the proposed expansion.

During the site assessment and conservation implementation a high-level water return flow audit should also be done and noted. As with project level M&V this is important to give insight on a regional water balance.

7.3.2.4 GHG mitigation approach and M&V of impacts

The same options should be considered and approach followed as with project level GHG M&V in Section 7.3.1.4. The focus though will be solely on active irrigation conservation or pumping related PoAs or low M&V requirement voluntary markets with carbon offsetting. Carbon offsets on a small irrigation point may be trivial and will not bring real benefit for a farmer. However, the combined result of a several hundred irrigation points may be significant.

In addition, carbon offsets can be claimed over a very long period (10 years and longer) depending on the registration type and the presence of savings over the long term. If the carbon offset benefit is not relayed to the farmer, the offset returns can be applied by the Water Board in meter reading cost, system checks, spot audits and maintenance to upkeep savings. Of course, the farmer would need to sign-off carbon reduction rights as part of the initial incentive agreement. Some energy conservation related incentive mechanisms may already make claim of any carbon offsets though.

7.3.3 Integrated regional level M&V application on water

The regional level top-down M&V of electrical energy conservation was thoroughly discussed in Chapter 6. There are no incentives relevant to regional level M&V like for projects and programmes, but it is intended to assess the impact projects and programmes make on the area or regional electrical power grid.

This same approach can and must be extended to water. Just as with electrical energy conservation, it is imperative that the actual water conservation in a regional or on a basin level be assessed. This should be done alongside water conservation projects and programmes that are implemented in specific areas. A regional water top-down M&V method should be made mandatory and used as the key performance indicator of a whole water conservation plan. This can be for an irrigation region, a province (state) or an entire country. As clearly showed in the literature survey, water conservation attempts have failed in many cases considering the net change of water availability. See Chapter 2 Sections 2.2 for more detail on this.

It should be emphasised that any new water conservation attempts will also fail if proper policy, water accounting and governing is not put in place as listed in Section 7.1. Section 2.8 of Chapter 2 examined relevant literature to extend the regional level M&V approach for water conservation impacts. Here water discharge measurement, water resource information with tracking and rainwater catchment measurement methods were investigated.

Similar to a power station being a power source within a regional energy conservation M&V approach, a rain water catchment area or a river entering a region is a water source within a regional water conservation boundary. When compared to the regional electrical M&V boundary of Figure 5.4 in Chapter 5, rivers, streams and canals represent the transmission/distribution electrical lines. Figure 7-10 shows a very simplified water equivalent of Figure 5.4.

From the rivers, streams and canals farms extract water just as from electrical power distribution lines. Also, there can be other users in an irrigation region such as towns, cities and industries that needs to be accounted for as depicted in Figure 7-10. With this, as water flows within the region boundary there is water loss due to evaporation and deep percolation etc., similar to electrical network transmission losses. Then, there can be rivers or streams that also leave the area thus taking water out of the boundary.

It should be emphasised here that the water balance in a region is very complex and more difficult to quantify compared to an electrical network. The aim therefore is not to provide a detailed analysis but merely to propose a high-level framework and concept. It should also be noted that all water extracted by a farm is not used (destroyed as defined in Chapter 2 Section 2.2.5) but some of it can return to the water source through runoff and deep percolation. See Figure 7-4 for an illustration.

In order to establish a regional water conservation M&V boundary, water resource information in combination with existing Water Administration Systems (WAS) and rain catchment area data (with regional climate and other information) can be used as discussed in Chapter 2 Section 2.8. In some countries this may be standard practice with network design approaches enabling enhancement of

statistical streamflow forecasting. Unfortunately, as discussed in Section 2.8.2, hydrometric monitoring networks are declining worldwide due to financial constraints. One of the most important considerations would be to establish a proper but functional area or regional boundary as shown in Figure 7-4. This should be aligned with existing hydrometric discharge measurement points as far possible to prevent additional 'metering' costs.

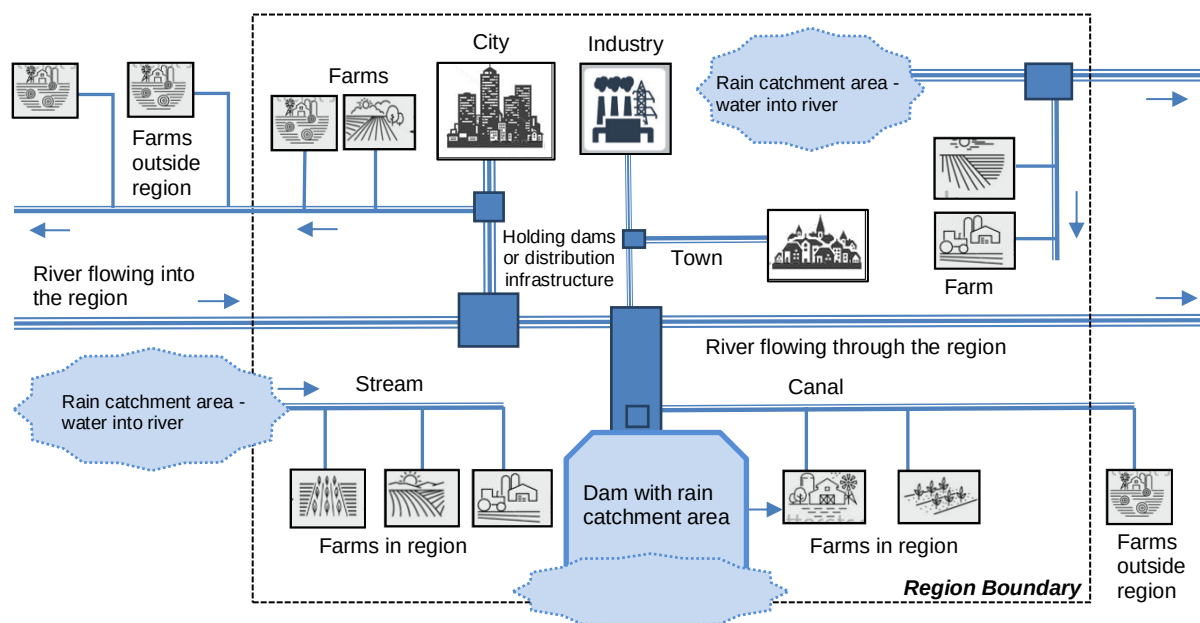


Figure 7-10: Regional level water conservation boundary.

7.4 SOUTH AFRICAN SECTION 12L TAX INCENTIVE ON EFFICIENT AGRICULTURAL IRRIGATION

Currently in South Africa the only real active energy incentive mechanism available is the section 12L tax rebate. Chapter 2 Sections 2.5.2.2 and 2.7.7 elaborate on the regulations of 12L and the specific M&V requirements. The following sections examine how 12L can be applied to agricultural irrigation ECM projects. From all known sources, there has not been a single agricultural irrigation 12L ECM project yet which questions the practicable application of 12L here. From the investigations of Chapter 4, the impact of the majority of typical irrigation efficiency projects is too small to justify normal 12L M&V costs.

The following sections also propose an extension on 12L which can expand the reach of 12L for smaller irrigation points through an original Agri-M&V approach. The approach integrates the project level, programme level, regional-level M&V, metering, quality and sampling concepts of Chapters 3 to 6. This realises a programme-based deemed savings related irrigation pumping methodology, utilizing very cost-effective M&V but which can still provide results with a high confidence level and low error margin. Water conservation can be done in conjunction with 12L which will even further increase impacts.

7.4.1 Value of 12L tax incentives for irrigation efficiency

At this stage every South African Rand (ZAR) spent by the government to sustain the South African power supply unfortunately only does that; sustain the power supply. However, if an expanded 12L tax incentive can be realised for agricultural irrigation, every ZAR spent on this will not only help sustain electrical power supply, but also enables the reduction of irrigation water use, reduces carbon emissions (due to less electricity used and less fertilizer used due to optimum irrigation practices), grows the

economy and enables food security through assisting farmers. Chapter 1 Section 1.3.2.5 lists a few of the additional advantages.

In 2015/2016 as part of this study, a high-level examination was done on the contribution 12L can have for the agricultural sector. At that stage, the South African power generation capacity enlargement cost through building the Kusile power station was estimated to be around 169-billion ZAR (SA News, 2013). With the latest information, the total cost is given as R118.5-billion excluding interest during construction, cost of cover and inflation (Kusile Power Station Project, 2018). The size of Kusile was given as 4800 MW (Kusile Power Station Project, 2018) which relates to more than 24.6-million ZAR per MW generation capacity. Revisiting Figure 1-3 in Chapter 1, the agricultural sector's electrical demand relates to around 1.24 GW average peak load.

For a practical illustration; if only a hypothetical 20% of this demand can be reduced through 12L-enabled irrigation projects, it amounts to almost a 250 MW demand reduction. The cost of building the equal size power generation capacity, when looking at Kusile, would be almost 6.2-billion ZAR. This does not even consider continuous generation costs over time when the power station is operational. For the 2013 to 2015 financial years, the total SA electricity consumption was around 216 TWh or 216000 GWh (Eskom Integrated results, 2015). The 20% demand reduction will consequently also lead to roughly 20% energy reduction which again results in close to 1730 GWh not consumed.

With a typical 1 ZAR / kWh cost (roughly based on the Landrate, Nightsave and Ruraflex tariff structures in 2015/2016) it amounts to 1.73-billion ZAR in annual electricity savings for the SA agricultural sector. On top of this, there are many additional advantages for the farmer, farm employees, Eskom peak period reduction, ECM technology suppliers and the economy. Eskom will lose the 1.73-billion ZAR in electrical sales, however, with the Eskom IDM initiatives; sales were lost in addition to funding (fully or partially) provided for the ECM. The question should be also asked what a 12L tax incentive for irrigation efficiency would cost the South African government? When applying the standard 95c/kWh discount on taxable income to the hypothetical 20% savings scenario used above, a calculation gives: 1730 GWh x 95c/kWh = 1.643-billion ZAR.

This amount will be the hypothetical discount given by SARS to the agricultural irrigation sector. For the sector itself this means about 26.6c/kWh or R460 million less tax to pay that year based on a 28% tax rate (should the full 20% hypothetical savings be realised in one year). However, the 12L tax pay-out can be recovered by the government the following years due to the energy and water savings realised through the 12L projects which again results in improved profit margins in the farming sector.

7.4.2 Application of 12L on an irrigation ECM project

Compared to other industries, the agricultural irrigation brings about several challenges which make 12L applicability more difficult. Section 12L has special requirements and prerequisites as discussed in Chapter 2, Sections 2.5.2.2 and 2.7.7. Yearly weather and rainfall differences, crop changing and other factors can make a significant difference in power (electrical energy) use as discussed in Section 7.3.1. Thus, a proper energy governing factor is essential which will show that less energy is used while irrigating. Thus, system efficiency improvements result in a lower operational demand and therefore also an operation energy use reduction. See Section 7.3.1.1 for an elaboration on this.

It is important to again emphasise that even if the water extraction is measured and historically baseline data show that the period under evaluation have less consumption and thus less energy used, it does not necessarily imply that energy efficiency was achieved. The specific performance period may have had very high rainfall or the farmer may have planted a crop with a much lower water requirement.

Thus, it could be that the following year the previous type of crop is planted again or there is much lower rainfall resulting in the same amount or even more energy being used as in the past. In essence, during

the performance period less power was used and it can be proven both from a calibrated utility point power meter and a calibrated extraction point water meter. It does not prove however, that the less power and water used would not be caught up in the following year. It can be though that the farmer also improved in irrigation practices and thus applied less water to a crop than before. The question here is how can the improvement be proven? This, with the complications mentioned above, makes the application of 12L to agricultural irrigation difficult. Also, the project should be large enough to justify the full M&V 12L requires.

As discussed in Section 2.7.7 of Chapter 2, the cut-off points for 12L viability in 2018 is around 0.5 GWh at 95 cents (ZAR) according to Van der Merwe (2018). The 0.5 GWh cut-off relates to a 57kW demand reduction achieved 24-hours every day over a full year. With an achievable 40% energy efficiency demand and use reduction as shown in Section 4.3.3.3 in Chapter 4, it requires a 142.5kW load running continuously over a year. When considering a high crop load factor of 0.35 (citrus and subtropical fruit) from Table 4-3 in Chapter 4, the 142.5kW load increases to around 407kW to realise a 57kW average annual demand reduction. Here the load does not have to be a single pump motor but can include all pump motors involved under the ECM for the farmer (single tax entity).

A quality (Variable Speed Drive) VSD costs currently around 2000 ZAR per installed and commissioned kW (Scheepers, 2018). The cost significantly reduced from 3500 ZAR that was seen during the SPP testing and implementation phase (2014 to 2016). Here the commissioning entails system setup to optimal pressure and operation conditions to realise savings. Cheap VSD imports allow an installed cost of below 1000 ZAR, however, this is not recommended at all since these VSDs have a severe effect on the power quality of the utility supply lines. Thus, a quality VSD installation (or installations) on a total 407 kW load will be in the order of 814,000 ZAR. Here the 133,000 ZAR of avoided tax is quite low compared to the 814,000 ZAR investment. Also, a SANAS M&V practitioner, M&V metering and other costs should be considered. This is what amounts to the 133,000 ZAR and therefore the 0.5 GWh 12L viability cut-off point.

However, only taking a conservative Landrate flat rate tariff of 1 ZAR per kWh as in Section 7.4.1 preceding, the 0.5 GWh saving relates to a 500,000 ZAR cost saving. Considering this, the cost saving alone should be enough to convince the farmer to invest in VSDs. However, in Chapter 2 Section 2.2.4 the literature survey showed that numbers on paper do not convince farmers necessarily. It should also be noted that these calculations were done on a high crop load factor which significantly increases power use and therefore also higher attainable energy efficiency savings.

For the most practical approach to apply 12L on an irrigation ECM project with 12L compliant attained energy savings, would be to focus on Group-3 (efficient pump system design and setup improvements) ECMs as described in Section 4.3.1.1 of chapter 4 and Section 7.4.4.1 later in this chapter. Thus, by having a power meter and flow meter on the irrigation pump set (or pumps) with a VSD ECM, an energy and water moved relation can be established. Thus, a pre-implementation baseline relation can be developed with a flow and power meter. These meters can then also be used to determine savings post-implementation over the evaluation period. See Section 7.3.1 on project level M&V and Chapter 3 Section 3.4 on the applicable M&V methodology to follow.

This approach will unfortunately not capture energy savings due to improvements made on Group-1 water losses and Group-2 incorrect irrigation practices and over irrigation. These can be incorporated but proving this through a full reliable M&V approach may be too costly since the additional M&V cost may not justify the additional savings quantified. Although, in some cases this may be worthwhile and a careful M&V cost versus additional 12L tax rebate would be the deciding factor. Chapter 4 Section 4.4.3 discusses this with Section 7.4.3.1 also elaborating on this topic.

7.4.3 Proposed expansion of 12L for irrigation ECMs through an original Agri-M&V

As discussed in Section 1.2.1.3 in Chapter 1, most irrigation points in South Africa are small with a typical pump size of only 30 kW which is not nearly viable for 12L. The proposed expansion is an integrated M&V methodology which can address the specific need to realise 12L tax incentives for irrigation in the agricultural sector. This Agri-M&V approach combines people, technology and processes to allow cost effective quantification of irrigation efficiency initiatives. It encompasses all M&V types which include Option 1, 2 and 3 of SANS 50 010:2011 or Option A, B, C and D of the IPMVP (SANS 50 010, 2011; IPMVP, 2012), but primarily applies a programme level measurement, monitoring, evaluation and reporting approach.

It incorporates the concepts of project level, programme level and regional level M&V (Chapter 3, 4 and 5), the Chapter 6 metering, quality and sampling with the content of this chapter to provide a viable M&V approach to effectively quantify savings under a deemed savings type programme. Figure 7-11 illustrates the different aspects incorporated and used as background to realise this 12L expansion. From the top left of Figure 7-11 it includes the concepts of monitoring CDM projects and PoAs, Eskom ESCO, SOP, and SPP irrigation lessons learnt. On the right of Figure 7-11 national electrical grid data, M&V experience, historical data, an online quality management system and advanced predictive modelling are listed.

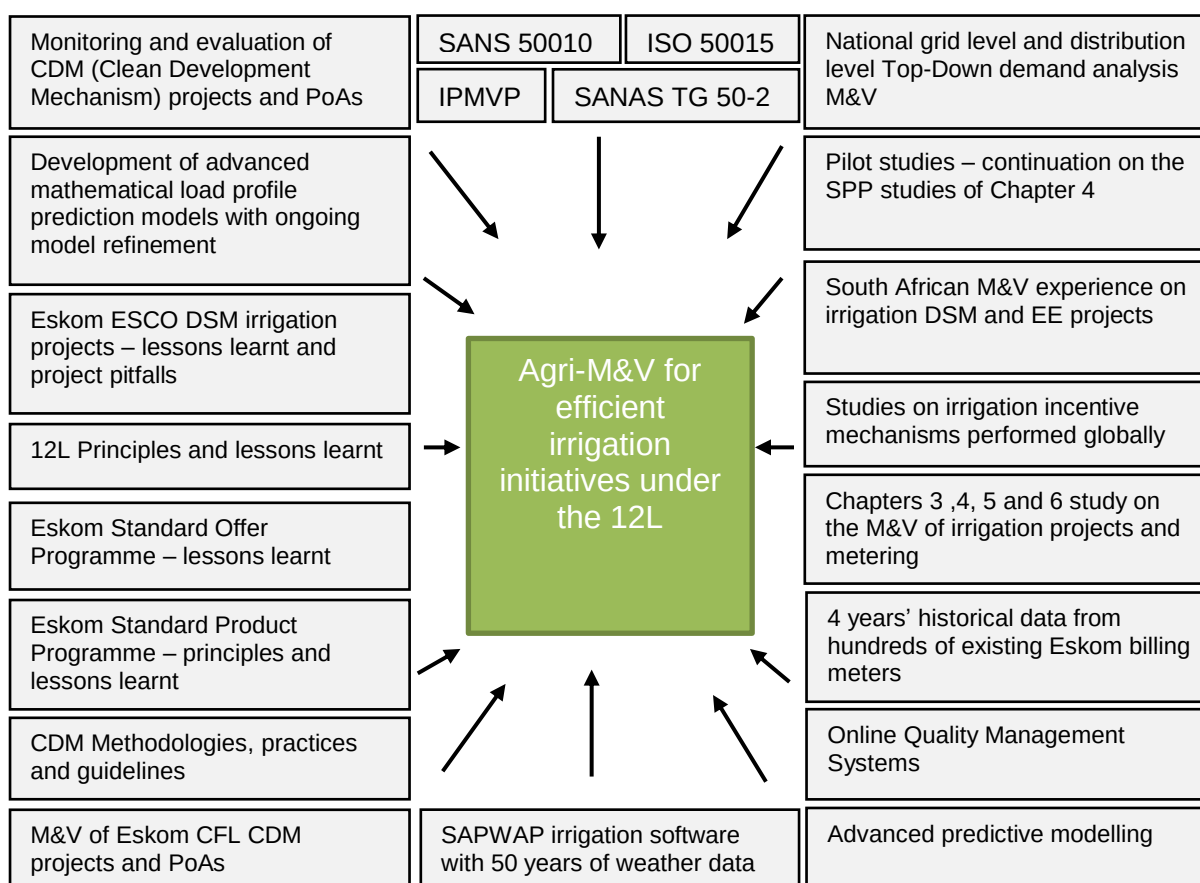


Figure 7-11: Diverse fields of knowledge and expertise incorporated to realise Agri-M&V for efficient irrigation initiatives under the 12L framework.

The methodology allows that M&V on every project (site) can be replaced by programme level M&V with minimum M&V practitioner site visits. The approach can also have focused and strategic rollouts where it is implemented first to address areas where the network and power station are under severe

strain. The calibrated simulation model of Chapter 4 Section 4.5 can also provide Eskom with the actual time of day demand reductions that are achieved for each site. With this it incorporates the regional grid level M&V approach which can assess and quantify the area's actual savings achieved. Policy changes to 12L would be required to realise this approach though. Among other, one such change would involve that savings will not only be applied to one tax year but rather spread over four tax years to ensure sustainability of savings and to reduce the risk of creative savings. It is beyond the scope of this study to engage in the exact policy changes and implications it may have. However, the framework and components required from an M&V viewpoint is examined. Here the key concepts of the Agri-M&V approach as discussed in the following sections include:

- 1) Selectable confidence levels with optimal inputs and conservative reporting;
- 2) Advanced mathematical and statistical process modelling and sampling;
- 3) PoA approach;
- 4) Clustering of project and technology types;
- 5) Monitor sustainability of efficiency technologies;
- 6) Allowing programme level calibrated simulation (Option 3 of SANS 50 010:2011, Option D of IPMVP); and
- 7) Effectively utilizes existing metering and requires the minimum calibrated metering.

7.4.3.1 Selectable confidence levels with optimal inputs and conservative reporting

A proper M&V selectable confidence level model (accounting for cost versus accuracy) can align M&V to the most correct and effective approach for a specific irrigation efficiency improvement project. Section 4.4.3 in Chapter 4 discusses variable confidence levels and conservative reporting, and points out that in some cases even a 50% confidence level may be acceptable, although, the claimed savings will only be a conservative 50% of that what was measured. The SANAS Guideline for reporting uncertainty in M&V also provides valuable insight (SANAS TG 50-2, 2017) on this. Although the approach may not appear ideal since there is a significant knock-down in savings, this approach may provide sufficient M&V for an expansion on the 12L tax incentive.

The uniqueness of a selectable confidence M&V approach is that it will allow appropriate confidence levels and error margins on projects that are evaluated on programme level and not project level. Where higher accuracy is required, methods with high confidence levels can be used if the M&V cost can be justified or if so requested by a client. Here Agri-M&V will also provide the best solutions and most accurate (but cost effective) methods to quantify projects using full M&V. This is done through unique methods designed and presented in Chapter 3.

7.4.3.2 Uses advanced mathematical and statistical process modelling

Agri-M&V incorporates advanced mathematical and statistical process modelling to develop strategic and focussed M&V methods allowing cost efficient quantification of project impacts. Using existing TOU billing meters of Eskom irrigation Ruraflex and Nightsave tariff points, tremendous amounts of data can be gathered through the Eskom MV90 system. The Ruraflex and Nightsave points feeding irrigation systems are then used to create demand profile models from four to five years of data as demonstrated in Chapter 4 Section 4.4 Utilizing these points significantly reduces the large cost of infield M&V metering, meter installation and maintenance. With this Section 4.3.4 shows how area specific weather, crop and soil data are utilised by mathematical processes and irrigation software (such as SAPWAP) to establish energy and water requirements. Combining all the aforementioned with advanced predictive modelling, high accuracy demand and usage profiles can be generated for non-measured irrigation point or a point under the Landrate tariff structure. This allows the quantification of both energy and

demand savings. See Section 4.4.1.4 for the Landrate demand profile mathematical model and Section 4.4.2 on a unique optimal input method for different application levels. For projects requiring full M&V (Option 1 and 2 under SANS 50 010), advanced mathematical pre-emptive baseline models and SLAs (Service Level Adjustments) as developed and discussed in Chapter 3 can be utilised to realise the most accurate but cost-effective M&V approach. Such sites are important also for cross checks and model calibration as discussed in the sections following.

7.4.3.3 Follows a PoA approach with cross check samples

A PoA approach similar to which is used in the CDM environment is incorporated in Agri-M&V. With irrigation projects, a PoA can generally be defined as a set of integrated measures/initiatives (KFW, 2013) to reduce energy and water applied to a designated area defined in a baseline methodology. A PoA is linked to a specific M&V methodology(ies) which is used to evaluate the projects' impacts. Within the PoA, several CPA (Component Programme Activity) clusters are set up.

The major advantage from this is that M&V is done on PoA level and not CPA level which reduces cross check samples. Cross check samples are stratified statistically sampled sites all over the CPAs, which are visited and inspected by M&V practitioners. Within the clusters there are also MV90 and full M&V Landrate sample sites. This statistical site visits and sample sites enable high confidence levels on deemed savings type PoAs. The PoA approach can also have a focused rollout, and can be implemented first to address areas where the Eskom power distribution network and power station are under severe strain, as mentioned at the beginning of Section 7.4.3. Chapter 6 Sections 6.3.2, 6.4 and 6.5 provide concepts on metering systems and sampling approaches that greatly assist with cross check sample sites.

7.4.3.4 Allows clustering of project and technology types

Within the PoA, the CPA clusters consist of bins/baskets of specific efficiency technology types (such as VSDs) or efficiency project types (centre pivots or micro irrigation). On these a generalised M&V methodology (with subset specifications) can be applied which allows for the differences in efficiency technologies and project types.

7.4.3.5 Monitors sustainability on efficiency initiatives

One specific drawback of a deemed savings programme such as SPP is that sustainability of the savings cannot be verified. After the rebate once-off payment there is no guarantee or method to establish later if the savings are sustained. The Agri-M&V approach with PoA cross checks will ensure that the actual sustainability of savings will be tracked and verified over time. This is complemented by the regional level top-down M&V approach which verifies the actual impact seen on the electrical power grid. PoA cross checks together with top-down M&V realises the advantages of full M&V without the high associated cost.

7.4.3.6 Allow programme level calibrated simulations

Calibrated simulations were successfully used with the M&V of the Eskom CFL rollouts and the Eskom RLM (Residential Load Management) geyser ripple control switches (RLM M&V Guideline, 2008; CFL Guideline, 2008; De Canha & Pretorius, 2014). The advanced mathematical model of Chapter 4 Section 4.4 is used to achieve programme level calibrated simulations with proper confidence levels. The PoA cross checks with data from existing Eskom billing meters (see Section 7.4.3.2 preceding) and full M&V projects in the area will allow continues verification and calibration of the mathematical models. These full M&V projects can be sites with large enough savings to justify full M&V or specially selected sample sites which is monitored with full M&V on the long term as discussed in Section 7.4.3.3.

7.4.3.7 Utilization of calibrated metering and incorporation of M&V fit metering systems

A major requirement of 12L is that calibrated metering must be used. Since Eskom billing meters (which should be calibrated) are used to calibrate the model, it inherently assists with compliance to 12L requirements. Section 4.4.4 in Chapter 4 elaborates on this. This combined with the use of only calibrated infield sample site metering and testing will ensure continuous compliance. Also, all water flow meters on water extraction points should be supplied with a calibration certificate. The irrigation M&V fit metering methods discussed and developed in Chapter 6 are key to achieve compliance but still having a cost-effective approach.

7.4.4 Framework development and proposed future study

Realising 12L Agri-M&V for irrigation will require an intensive study spanning a four-year development, implementation, testing, verification, characterisation and model calibration period. However, the study will have a 'hit the road running' approach that establishes practical and almost immediately implementable 12L irrigation projects. The first pilot sites can already start only six months after the study commenced. The proposed Agri-M&V study builds on this study, specifically with regards to the following:

- With consideration of 12L and requirements, intensification on:
 - Agri-M&V on Option 1, 2 (SANS 50 010) – project level;
 - Agri-M&V on Option 3 (SANS 50 010) – programme level; and
 - Top-Down Grid M&V – regional level.
- Policy changes and expansion on section 12L;
- Regional grid analysis of irrigation areas for cluster identification;
- Irrigation energy efficiency initiatives:
 - Efficient technology such as VSDs and the associated pitfalls (poor quality VSDs can have an effect on power quality, thus pump life and therefore savings sustainability); and
 - Pumping and piping system optimization.
- Irrigation water efficiency initiatives;
- Measurement of efficiency initiatives and quantification of water efficiency improvements;
- Agricultural dynamics and efficient farming;
- Rollout mechanisms and awareness campaigns;
- Sociodynamics for acceptance of 12L in the agricultural sector; and
- Online project repository and quality control software design and development.

The study involves a comprehensive scoping study, further literature study and field design study on the specific topics through which the framework can be fine-tuned. From this the methodology and implementation model can be devised. Nearing the end of the first stage, pilot projects (in specific areas) can be engaged, and field and data gathering commence. In concept, the complete four-year study will follow the below steps:

- 1) Methodology design and development;
- 2) Methodology pilot implementation;
- 2) Online quality and management systems and Agri-M&V application development; and
- 4) Methodology testing, verification and model calibration.

Each of these headings are discussed in the following sections with respective flow charts given in Figure 7-12 to Figure 7-14. The four headings are not consecutive or specific to a development year but run in parallel as the project continues.

The study involves a wide field of experts and academia (statistician, mathematician, agricultural, engineering, electrical grid etc.) and requires extensive training and awareness campaigns in targeted pilot areas with the other aspects listed in Section 7.1.

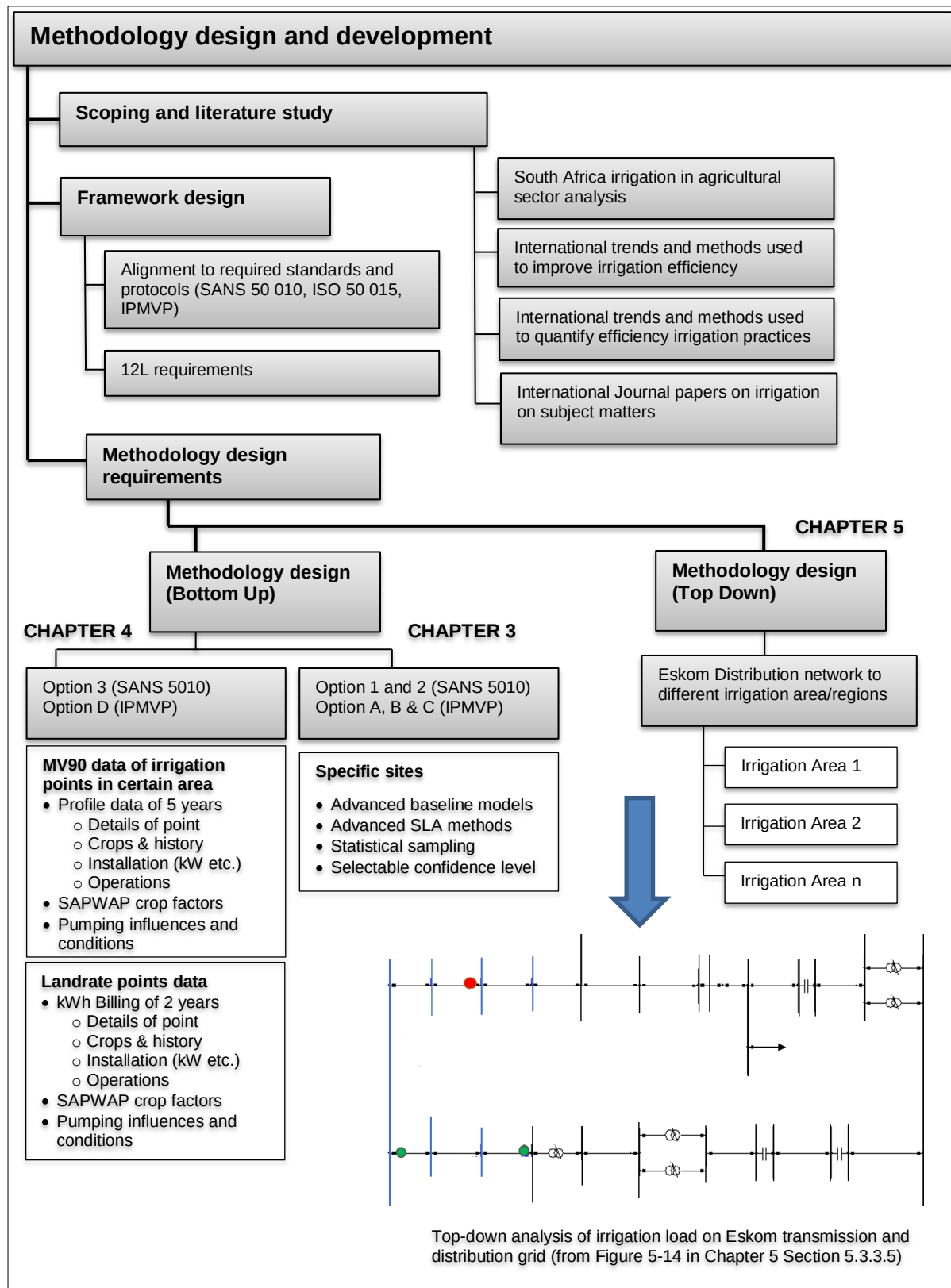


Figure 7-12: Flow chart of methodology design and development.

7.4.4.1 Agri-M&V methodology design and development

The flow chart in Figure 7-12 illustrates the Agri-M&V methodology design and development process. It starts on top Figure 7-12 with a scoping study and comprehensive further literature survey and investigation of irrigation in the South African agricultural sector. This is followed by a methodology framework design and establishment of the exact methodology design requirements. The bottom-up methodology design involves Agri-M&V for irrigation EE initiatives based on Option 1 and 2 of SANS 50 010 within the inefficiency practice Group 1, 2 and 3 as defined in Chapter 4 Section 4.3.1.1 as:

- Group-1: Water losses - leaks and losses in the irrigation system;
- Group-2: Incorrect irrigation practices - over irrigation; and
- Group-3: System design - inefficient pump system design and setup.

The energy conservation M&V side of Group-3 was essentially dealt with in Chapter 3 and Chapter 4 while Section 7.3 of this chapter study also considers Group-1 and Group-2. Further, Agri-M&V also incorporates initiatives under Option 3 within Group-1, -2 and -3 initiatives. The energy side (Group-3) was dealt with in Chapter 3 and Chapter 4 while Section 7.3.3 considered the incorporation of Group-1 and Group-2. Alongside the bottom approach, a top-down analysis on each of the different irrigation pilot areas/regions is done. The Eskom transmission and distribution electrical grid network in the pilot areas will be analysed, and a boundary designed and drawn as described in Chapter 5.

7.4.4.2 Methodology pilot implementation

The methodology pilot implementation is initiated with item (i) on the top of Figure 7-13 by training of M&V personnel, energy advisors and field personnel part of the pilot case studies. This involves providing the M&V practitioners with the proper knowledge on agricultural irrigation systems and M&V audits. The correct M&V requirements and procedures to follow are presented to the involved energy advisors, technology suppliers and installers. Also, field personnel collecting data and engaging pilot sites need to receive proper training.

The Agri-M&V concept needs to be implemented on specific representative pilot areas. Item (ii) in Figure 7-13 shows that, typically, five to ten representative irrigation regions/areas with irrigation schemes should be engaged. In each pilot area farms already on the Ruraflex or Nightsave ToU tariff structures will be targeted since historic 30-minute profile data can be retrieved from Eskom on the MV90 system as discussed in Section 7.4.3.2. If there are no flow meters present, these need to be correctly installed on sample farms as described in Section 7.3.1.3. Information of the irrigation farms in a region can be obtained from the local Irrigation Boards. As mentioned in Section 7.1, cooperation with Water Boards and local stakeholders are very critical. With this representative sample, non-MV90 farms will be statistically selected, site information gathered and equipped with appropriate metering as shown at item (iii) of Figure 7-13. The sampling and over sampling approaches discusses in Chapter 6 Section 6.5.3 can greatly assist here. This data gathering will continue over the full four study period. A baseline period will be required after which the MV90 and non-MV90 irrigation farms can be engaged with specific ECM projects.

After ECM completion, periodic saving reports can be compiled. Item (iv) shows the process involved with profile data analysis and calculations done. With the MV90 irrigation points, historical data, crop load factors and the techniques described in this chapter and the previous chapters can be combined. From the 12L saving reports (and related incentive reports), water extraction reduction reports can also be compiled. Related incentives can be peak period demand reduction for Eskom, for instance, and savings attained for the maroon blocks in Figure 1-1 (lower utility bill and lower maximum demand). The sample non-MV90 points will be fully measured and with this the mathematical model of Chapter 4 Section 4.5 applied. This model is developed from all the MV90 data points with site and area

information and crop load factors. Hereby the mathematical model can be evaluated and compared with the actual savings quantified with full metering. The mathematical model can also be applied to all the MV90 points to verify its effectiveness. From this the model can be adjusted and improved to better simulated available loads and attained savings.

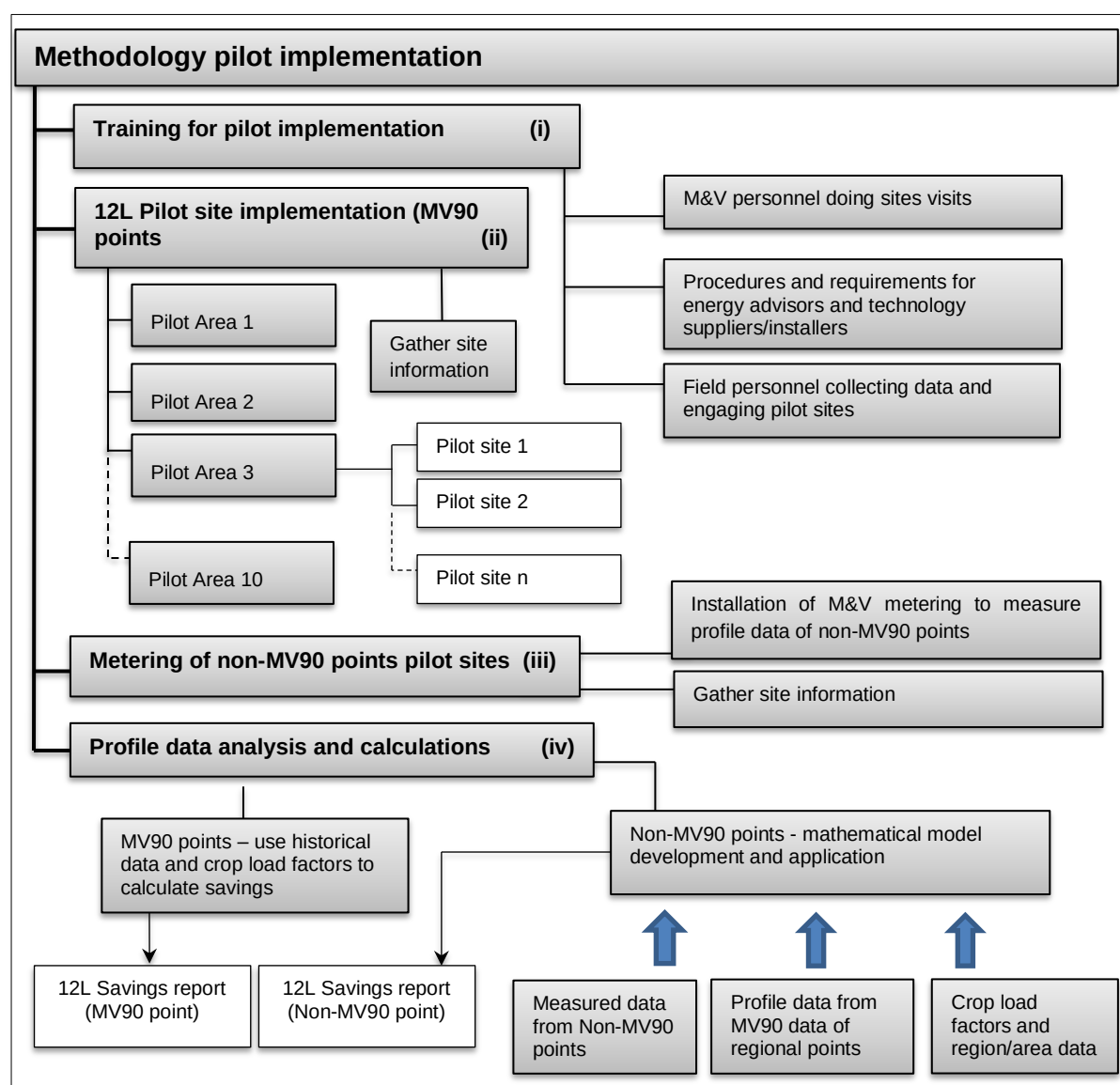


Figure 7-13: Flow chart of methodology pilot implementation.

7.4.4.3 Methodology testing, verification and model calibration

Following the targeted pilot sites in the previous section, ECM pilot area rollouts can commence on all farm irrigation MV90 points that have not been included yet. Also, rollouts on non-MV90 can commence without demand power metering being installed. Flow meters are recommended for all communal water source extraction points as discussed in Section 7.3.2.3. The data of all the MV90 points and full metered sample sites will be used during the full four-year study. During this period the methodology will be tested, verified and the simulation model calibrated as illustrated in Figure 7-14.

Over the four-year period seasonal changes and annual rainfall variations can be evaluated and the impacts of these built into the model. There is also active ongoing monitoring of projects (full M&V) with cross checks to ensure that the calibrated model is robust even with yearly rain and seasonal variations. Information and data will be gathered in the pilot areas on crops planted, SAPWAT data and

analysis used, data of new MV90 points will be incorporated and feedback from M&V cross check site visits analysed. This is uploaded onto the online system described in the next section. Year-1 mainly consists of testing while Year-2 involves testing with the first phase of verification and some calibration. Year-3 have verification and calibration while Year-4 will mainly only do model calibration as depicted on the middle left of Figure 7-14. Alongside this, a top-down M&V grid analysis of each pilot area is done and refined over the four-year period.

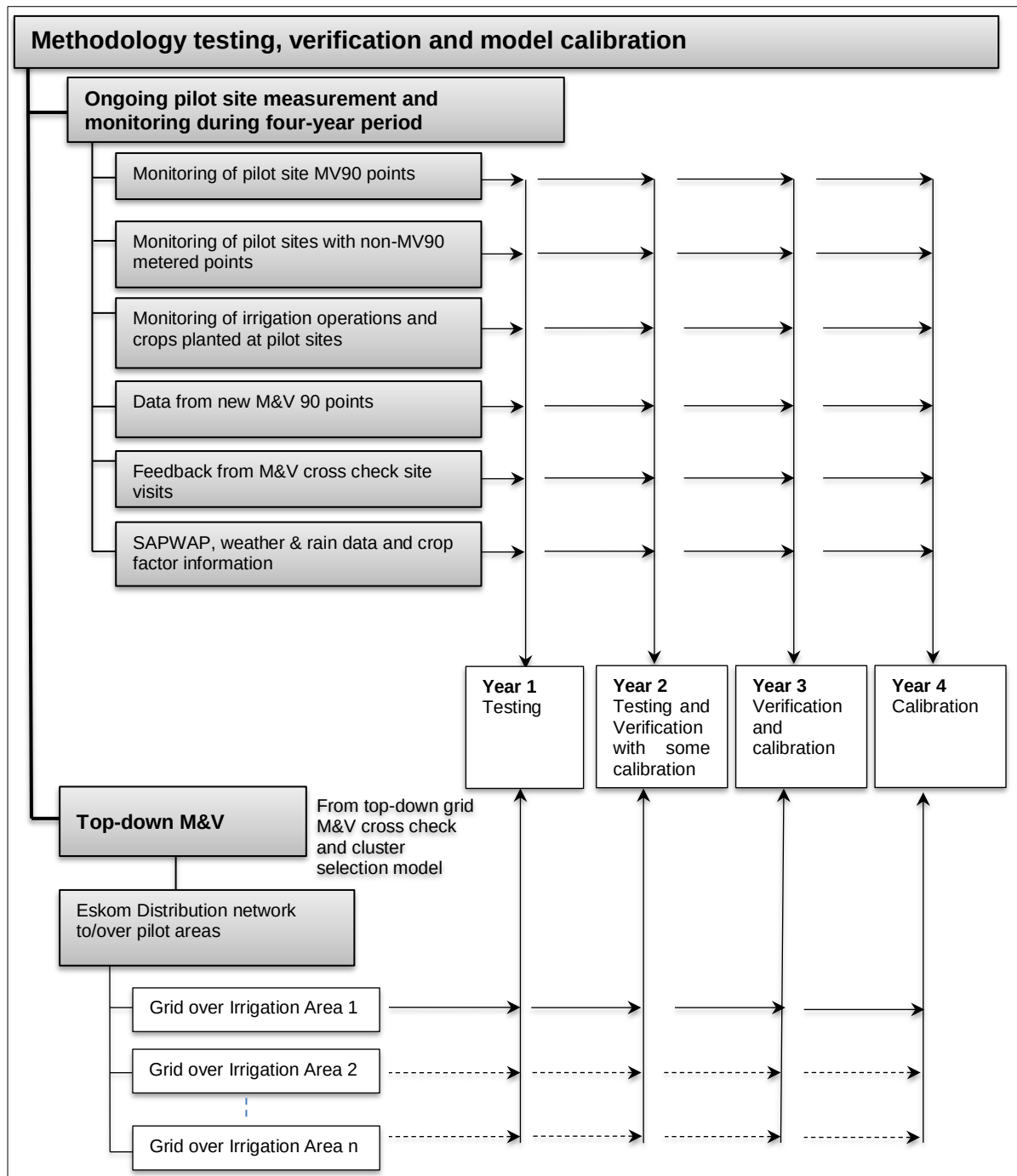


Figure 7-14: Flow chart of methodology testing, verification and model calibration.

Through this the actual ECM reduction impact on the grid can be investigated and the approach improved. Otherwise the grid measurement points can be changed or points added to better quantify the savings. This of course can be done alongside a regional top-down water analysis to quantify the actual water conservation in the area.

7.4.4.4 Online project registry, data submission, quality and management system

Since the aim of the Agri-M&V approach is to extend the reach of 12L to small irrigation points, there will be thousands of possible small ECM projects. Therefore, a proper online project registry, data submission, quality control and management system are required. The online system allows uploading and capturing of projects files, information and data used for cross checking random sampling process and online authorising of a new project. Figure 7-15 outlines the online system components and functionality.

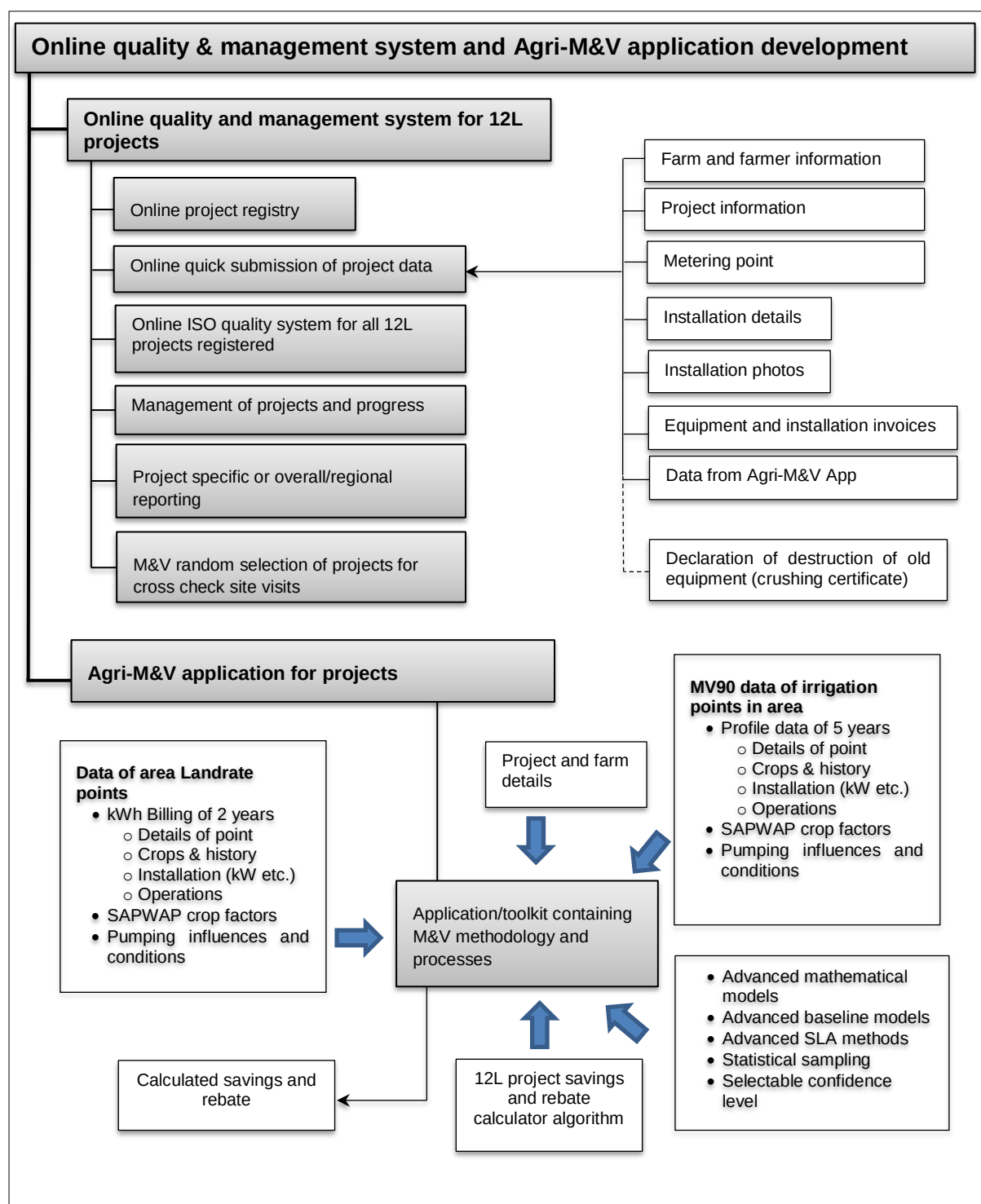


Figure 7-15: Flow chart describing the online quality and management system, and Agri-M&V application development.

The online system can also be used to house the deemed savings tool/application from which saving calculations are calculated. With this it houses the full calibrated simulation model and allows data and information entries of new areas to be imported online. This online system will not be discussed in detail since it is beyond the scope of this study. Figure 7-15 provides the key concepts and can be incorporated alongside the online metering system such as described in Chapter 6 Section 6.3.3.

This allows an online registry and knowledge platform with business intelligence that can identify trends and anomalies. This can complement existing 12L project registries and even improve where certain parts of the current system are ineffective.

7.5 CONCLUSION AND DISCUSSION

This chapter considered the integration of energy and water conservation with greenhouse gas mitigation under project level, programme level and regional level M&V to quantify attained reductions. Through this the ultimate goal of realising water conservation in the agricultural sector is addressed. The approach investigated the quantification requirements of certain incentive mechanisms, the related benefits and how the M&V challenges can be overcome.

Quantifying energy conservation and the associated GHG reduction can have challenges; however, the study provides unique M&V methods to overcome these. When it comes to water, there is not always an easy and specific project level M&V method that can be used in all cases. Also, there is a variety of factors that can influence calculated results with water conservation. The regional electrical grid top-down quantification methodology was applied to water, so as to establish a similar method for quantifying water conservation on a regional level. It should be mentioned again that a regional water balance is very intricate and the M&V of impacts are much more difficult to measure when compared to an electrical network. Such an approach requires a further in-depth study together with field specialists, water boards and water councils.

The application of the South African section 12L tax incentive to agricultural irrigation ECMs was investigated, but it proved to be mostly impractical. The largest potential irrigation impacts are spread over thousands of small projects with a typical irrigation point installed capacity of 30 kW. Even considering a high crop load factor, the operational load must be at least 407 kW to overcome the 0.5 GWh viability cut-off point of 12L. Instead a deemed savings programme-based impact evaluation approach is required through which cost-effective M&V is utilized while still maintaining a high confidence level with a low error margin. The unique 12L Agri-M&V proposed in this chapter can provide an appropriate method ensuring implementable, sustainable and effective delivery of results. Each aspect of the 12L Agri-M&V design is important though, and should be carefully implemented. Otherwise, the functionality of the approach and the correctness of the results obtained may be compromised.

Chapter 8

Conclusion and recommendations

8.1 INTRODUCTION

This study set out to address the ultimate goal of water conservation so that a water crisis looming in many countries can be prevented. Since agriculture is by far the largest water consumer globally compared to other sectors, the study focussed on reducing water usage in agricultural irrigation. From a literature survey and this study done in South Africa, it was shown that water waste, inefficiency and over-irrigation are common practices with significant improvement potential. Although there are substantial water conservation possibilities, reductions are not realised due to a lack of necessary incentives. An incentive was defined in this study as a vehicle to encourage or persuade irrigators to invest in conservation technologies and adopt conservative irrigation practices. In some countries, there are water conservation incentive mechanisms available, though one incentive is not enough to overcome barriers and encourage farmers to invest in irrigation conservation. The study examined available incentive mechanisms in energy conservation, greenhouse gas mitigation and related advantages while also exploring how these can be combined with water incentives to realise conservation.

It was further shown in the study that an essential requirement of incentive mechanisms is proper quantification and accounting of the real attained savings. The different incentive mechanisms investigated require that saving quantification should adhere to strict policy regulation and Measurements and Verification (M&V) rules. The practice of M&V on irrigation conservation was revealed to be very challenging with the cost and complexity thereof often discouraging or preventing conservation projects, even though there are incentives available. The primary focus of this study was therefore to address irrigation conservation M&V challenges by designing and developing original, practical and cost-effective M&V approaches, methodologies and frameworks.

Through these approaches, methodologies and frameworks, novel solutions were created which enables quantification of conservation through M&V on a project level, programme level and regional level. Although water conservation was the overall goal, attention was primarily on electrical energy conservation M&V. The reason for this is that energy, alongside related incentives, can be utilised to realise water conservation. In addition to this, it was highlighted that in most cases water conservation attempts did not achieve conservation but in fact increased water consumption. This further emphasised the necessity of proper quantification methods and accounting to ensure that savings are indeed achieved and also sustained over the long term. With a proper foundation established (and novel methods developed and applied) on the three M&V levels alongside metering, quality and sampling, the study was concluded with an integrated enveloping M&V methodology. This involved integrating the M&V of water conservation and greenhouse gas with that of energy on project, programme and regional level. Through this the goal of realising water conservation in the agricultural sector was focussed on. Furthermore, the applicability of the section 12L tax rebate (Income Tax Act 58 of 1962) to irrigation ECMs was also investigated. From this, increasing the span and reach of section 12L for irrigation was proposed through providing a framework and conceptual design for a unique Agri-M&V approach.

8.2 STUDY ASSESSMENT, CONTRIBUTION AND DISCUSSION

With the study goals completed through original design and development in Chapters 1 to 7, this section specifically considers the contribution the study made while providing a discussion on Chapters 3 to 7.

8.2.1 Project level M&V

The study first gave attention to project level M&V in Chapter 3 which is done through metering of key project parameters over the full contractual life of all project pumps, or a representative sample of pumps. This is only feasible for large projects that can justify the associated high M&V costs, though. The challenges related to the M&V of irrigation pumping Demand-Side Management (DSM) interventions with regard to baseline development and the post-implementation impact assessments were thoroughly discussed. Here the process of baseline development was explained using M&V methods illustrated for different project types. Novel methods were successfully developed for load shifting, energy efficiency with and without an energy governing factor, a combination of load shifting and energy efficiency, load prevention or clipping, and a combination of clipping and energy efficiency.

With some irrigation setups, an intelligent metering system with multiple metering points and sensors is required to capture and identify different pumping scenarios and boundary conditions. This was addressed in Chapter 6 with a specially developed metering system that provides a cost-effective solution with complex metering scenarios. Chapter 3 further presented actual irrigation Energy Conservation Measure (ECM) projects where conventional baseline development methods proved to be ineffective. Here unique alternative Service Level Adjustment (SLA) methods were developed and applied through which the intervention impacts were effectively quantified. Unfortunately, in many cases such problematic situations are only revealed long after the baseline was developed during the post-implementation project assessment phase. Therefore, attention was also given to post-implementation baseline challenges and SLA anomalies that may be encountered by M&V practitioners. Functional advice and intuitive methods were provided to overcome these.

Chapter 3 also gave guidance to project stakeholders whereby they can pre-emptively ensure that the correct mechanisms for a successful DSM project and proper M&V are in place. M&V practitioners are provided with guidance on irrigation pumping M&V while important project aspects were emphasised and hidden pitfalls are discussed. A critical remark is that M&V practitioners, or project stakeholders with a proper M&V background, should be consulted as early on as possible in a new project. It was experienced too many times with Eskom Integrated Demand Management (IDM) DSM projects that M&V practitioners were only involved when the project was already in progress. At that late stage a M&V examination sometimes reveals that the project targets cannot be reached due to incorrect information, the project motivation being based on too little information or wrong assumptions made from the available data. The guidance section at the end of Chapter 3 performed an analysis of an example DSM project and the information and data that are typically provided. Here an M&V scrutiny process was illustrated that displayed the problems that may have been prevented if M&V experience had been incorporated soon enough as part of the DSM project evaluation.

Another problem observed with the M&V of Eskom DSM projects was the general sampling approaches that were followed. The methods used seemed appropriate at the time but resulted in under sampling or a sampling technique that in essence did not represent the entire population. Several reasons gave rise to this which varied from sampling problematic sample sites, sites lost during the post-assessment period and practical implications that prevented specific sites from being measured. In order to address this and related sampling issues, a section on sampling was included in Chapter 6.

8.2.2 Programme level M&V

As described in Chapter 4, programme type irrigation energy conservation rollouts cannot justify full conventional project level M&V, but a programme level M&V method is necessary to quantify impacts. In this study programme level M&V was defined as a method of quantification that does not use continuous metering, but incorporates a calibrated simulation model to establish conservation impacts over the programme's contractual life. One such programme that included irrigation efficiency, the Eskom Standard Product Programme (SPP) in South Africa, was closely investigated in this study. A new and unique M&V methodology was required to quantify ECM impacts under the SPP and other similar incentive-based programmes. Chapter 4 focussed on the development of a novel M&V methodology for this specific purpose. Original methods and techniques were designed to quickly determine conservative, but representative ECM load reduction without continuous profile measurement. Further development was done to assess long-term kWh and average load reduction impacts on irrigation pumps. This was broadened to also address pumps irrigating multiple crop areas and different kinds of crops through crop load factors. For verification, an intuitive method was developed and a study was performed to evaluate the crop load factors calculated for a certain area.

The Eskom SPP and the M&V evaluation method focussed on determining the annual energy savings. However, there was no indication on when energy was consumed by the pump during the day. Thus, it was not possible to evaluate if the demand reduction achieved occurs over the weekday peak periods which was significant to Eskom. An original calibrated simulation model was therefore designed for establishing the available DSM peak load for shifting projects. This new development will be able to simulate the available load accurately and thus allows adding load shifting to SPP while also providing an M&V method to determine the savings from the model. The complete Chapter 4 study forms an essential part of integrated M&V in Chapter 7 and especially provides the M&V building blocks for the proposed expansion on the South African section 12L tax rebate for irrigation ECMs. Section 12L is part of the Income Tax Act 58 of 1962 with the latest revisions made in 2013. The proposed study for realising the 12L expansion in Chapter 7, relates to a large extent to improving and calibrating the mathematical model of Chapter 4.

Two very advantageous and effective components in this model were the incorporation of variable confidence levels and conservative reporting. Simulation models in general are very dependent on the type and quality of the information given as inputs; higher quality input data and more information improves the model output accuracy of the model. However, quality information and data may be scarce and, in some cases, not very accurate due to different reasons. These reasons include shortage of funding, shortage of resources or shortage of knowledgeable resources to gather the required information. There may also be a lack of necessary time to gather information, a lack of historic data and lack of useful information. Further reasons include limited cooperation from farmers to provide reliable information and an absence of specific irrigation points required for the simulation model. Considering such limitations, the optimal input model in Section 4.4.2 allows variable accuracy with degrees of "full", "optimal" and "least" data input scenarios.

This allows for much flexibility and inclusion of projects which under conventional approaches would not be worthwhile due to high M&V costs. In these cases, an ECM is only eligible to claim reductions corresponding to the confidence level, of course. Thus, project participants are certain that at least the calculated impact was achieved and any monetary reimbursement or rebates would be for true achieved savings. Where the monetary value justifies more accurate M&V to achieve a better confidence level, higher conservation impacts may be claimed. Variable confidence levels and conservative reporting set the functional platform to realise selectable confidence levels which are also essential for the proposed section 12L expansion in Chapter 7.

8.2.3 Regional level M&V

Eskom IDM initiated many electrical energy conservation projects and programmes over all the sectors in South Africa. In a given year the combined bottom-up results showed a significant impact, however, this same impact was not observed on the electrical grid. This called into question both the validity of the M&V results and effectiveness of the conservation methods implemented. In order to address this problem, Chapter 5 presented a novel regional level M&V methodology with a unique implementation case study that allowed M&V assessments and impact validation on a regional level. This can be bound to a certain area, a region, an entire province or even a country. A regional level M&V approach is a very practical method to evaluate impacts of large-scale DSM initiatives and can provide results much quicker when compared with a bottom-up project and programme level approach.

Here it should be noted that the impacts under assessment need to be substantial in perspective to the overall measured load. If the impacts are less than 10% of the overall grid load, savings might get lost in profile noise. With the Western Cape case study in South Africa, the urgent accelerated DSM implementation required rapid M&V which resulted in insufficient time to develop thorough baselines using the conventional M&V approaches. However, the regional top-down M&V methodology which followed still provided results that were representative and gave the needed information to the stakeholders. In the case study, problems and pitfalls associated with such an approach were addressed and solutions were also provided. A similar approach was demonstrated in Chapter 5 for when a region with irrigation DSM interventions is under evaluation. This is an essential validation and verification instrument for the proposed section 12L expansion.

8.2.4 M&V metering, data quality and sampling

Chapter 6 gave attention to M&V metering, meter data quality and proper meter sampling which is fundamental to perform M&V. During M&V projects, it was observed many times how the importance of these are underestimated and sometimes neglected. The quality and success of any M&V project is greatly dependent on the metering and metering systems that are used. Often M&V practitioners or ESCOs use and install temporary metering to gather baseline data themselves. If metering and equipment are not properly sourced and installed and the installation is not verified, it can result in serious compromise of data quality, correctness and also the use thereof. It is of utmost importance that metering and Automatic Meter Reading (AMR) systems should provide a clear, transparent and auditable data trail. Considering the importance of metering, the study contributed to the M&V field by showing the difficulties and challenges that are experienced surrounding M&V metering. Much focus was placed specifically on irrigation related metering challenges.

The basic concept of metering and AMR systems were explained. How these functions, which parts are critical and which areas are prone to problems were also addressed. Here the areas where a data audit trail can become unclear within metering and AMR systems were identified. In addition, background was given on what types of meters are frequently used with irrigation and related type projects, how these function and which pitfalls to look out for. The aim was to provide M&V practitioners and other stakeholders with the relevant background and information required when sourcing metering and AMR systems that are suitable for M&V. With this in mind, an innovative integrated multi-logger and metering system was designed, developed and commercialised to effectively address and overcome metering obstacles and complications. Attention was also given to the strategical application of normal metering through which the reach and application thereof in the M&V field can be significantly increased. The metering contribution in Chapter 6 is also essential for the integrated approach of Chapter 7.

Experience with irrigation ECM M&V revealed that appropriate M&V sampling of project sites for metering can also create challenges. This becomes an even greater concern when sampling is to be done on irrigation load profiles. In Chapter 6 focus was also placed on designing proper methods that

can reduce the variability of load profiles to only key reporting factors. These assist with sampling and also minimize the actual sample size needed to reach a specific confidence level and error margin. In addition, the use of oversampling methods which allow for flexibility within projects while ensuring effective metering implementation while adhering to sampling requirements was discussed.

8.2.5 Integrated enveloping M&V

Chapter 7 incorporated the concepts of Chapters 3 to 6 and provided an integrated approach through which it is possible to combine the advantage of several incentive methods. Thus, Chapter 7 examined and analysed the integration of energy and water conservation with greenhouse gas mitigation on a project level, programme level and regional level M&V. Through this, the ultimate study goal of realising and quantifying water conservation in the agricultural sector was addressed. The approach investigated how the M&V challenges can be overcome, as well as the quantification requirements of certain incentive mechanisms and related benefits.

Quantifying energy conservation and the related GHG reduction can have challenges as discussed in Chapters 3 to 6. However, with water there is not always an easy and specific project level M&V method that can be used in all cases, since the practical application is circumstantial and needs to be considered case by case. There are also a wide number of factors that can influence calculated water saving results and therefore an intuitive approach is always required. It is imperative, though, that water extraction flow meters, or precise water allocation, should be standard practice with any water conservation attempt. Although flow meters are a sensitive topic since these can significantly increase project cost, it is the most important tool towards water conservation. Otherwise there is no real method by which water use and conservation can be quantified. Water flow meters that was installed as part of an Eskom irrigation DSM project resulted in significant changes in irrigation pumping operational demand profiles as described in Chapter 3. These changes were due to less water being pumped since the local Irrigation Board could exactly track each farmer's water usage. In essence, the water flow meter unintentionally functioned as a water conservation measure.

Unfortunately, there is currently a very limited number of projects and programmes active under the Eskom Energy Efficiency and Demand-Side Management (EEDSM) programme. Thus, the only real available energy efficiency incentive in South Africa at this stage is the section 12L tax rebate. The application of the South African section 12L tax incentive for energy efficient agricultural irrigation was also investigated in Chapter 7. Unfortunately, 12L was found to be mostly impractical for irrigation in the agricultural sector since the largest potential impact is spread over thousands of small projects. Information provided (see Section 1.2.1.3 in Chapter 1) showed that an irrigation point pump set installed capacity of 30kW is typical in South Africa. Even with a high crop load factor, an operational load should be at least 407kW to surpass the 12L 0.5 GWh viability cut-off point. Instead of the current 12L full project level M&V requirement, a programme-based impact evaluation approach with functional savings is needed. Through this, cost-effective M&V can be utilized to determine ECM impacts while still maintaining a high confidence level with a low error margin. The unique 12L Agri-M&V designed in Chapter 7 can provide an optimised approach ensuring actual, sustainable and effective delivery of results.

8.3 VERIFICATION, VALIDATION AND ASSESSMENT

As stated in Chapter 1 Section 1.6, it is critical that the study content, the methods developed, and the results obtained needed to undergo scrutiny through validation, verification and proper assessments. The study had a wide focus and thus chapters 3 to 7 required separate examination since each of these chapters contain novelty, have a unique application and also contribute to the field in different areas.

Several measures were incorporated and utilised in this examination to ensure authenticity of the methods followed, the approaches developed and the results obtained. Due to the different natures of chapters 3 to 7, scrutiny measures differed between the chapters due to practical considerations.

The first fundamental aspect which was a prerequisite to all chapters was only to use and adhere with accepted and accredited international and South African guidelines and standards. The most relevant of these included the International Performance Measurement and Verification Protocol (IPMVP), South African National Standard (SANS) 50015, SANS 50010 / ISO 50015, SANS 474 and NRS 057, as well as the United Nations Framework Convention on Climate Change (UNFCCC) Clean Development Mechanism (CDM) methodologies and the ISO9001 for quality on M&V processes and metering. Furthermore, data and results underwent cross-verification through performance indicators and a quality management system that required a separate qualified M&V professional to also verify methods and reported results.

This was especially the case with Eskom DSM projects described in Chapter 3. Unfortunately, with situations such as the SLA anomalies and baseline challenges discussed, often only very thorough M&V experience and intuitiveness reveal issues with the methods used and the results obtained.

Chapter 4 Section 4.3 provided a novel M&V methodology for the Eskom SPP which was developed to ensure design verification, and also validation of results. In addition, an intuitive method was developed and incorporated to verify the representativeness and conservativeness of crop load factors that were used to establish savings under the Eskom SPP. The regional top-down method of Chapter 5 was already introduced in Chapter 4 and can be utilized to verify and validate area specific SPP impacts through an electrical transmission and distribution grid assessment. In Chapter 5, the top-down M&V analysis results of the Western Cape accelerated DSM rollouts were validated through a separate bottom-up M&V assessment performed by another independent M&V practitioner organization.

An M&V metering quality control procedure which successfully underwent several ISO 9001:2008 annual audits was developed for and employed on the meter system in Chapter 6. A proper data quality management Plan (QMP) to track and evaluate data was provided as a vital requirement. This QMP has a Quality Control Path (QCP) protocol which identifies areas that can influence data or compromise quality or delivery.

Finally, study content was validated, verified and assessed through independent external field experts that peer reviewed two papers published in international accredited journals. In addition, independent external field experts scrutinized five international conference articles through a similar peer review process.

8.4 KEY RESEARCH QUESTIONS

This section considers the key research questions listed in Chapter 1 Section 1.5 and how these were addressed in the study. The questions below were addressed or touched on in Chapter 2 with some focussed on in the other chapters. The study information and detail are not repeated here but only the sections applicable to each research question are provided. Some of the research questions are also further elaborated on in this Chapter.

- How severe is the water scarcity situation in South Africa and other countries, and what sector is the major water user? (Chapter 2 Section 2.2.1)
- What are the water and energy conservation possibilities in agricultural irrigation and what is the success rate of these? Here it is important to determine what is required to increase the success rate. (Chapter 2 Section 2.3 and also Section 4.3.1 in Chapter 4)

- Are there incentive mechanisms available for agricultural irrigation and how can these be applied to assist with water conservation? (Chapter 2 Section 2.5)
- What are the impact quantification requirements and standards and how should these be applied? The multi-level quantification method was developed from this. (Section 2.7)
- Are there challenges with project level M&V? The specific questions below were addressed in Chapter 2 Section 2.7.3 and Chapter 3:
 - What are the components of a baseline and how is proper baseline development done?
 - What are the pitfalls and solutions required for different type of irrigation DSM project or a combination of different types? These include: load shifting, energy efficiency with an energy driver (energy governing factor), energy efficiency without an energy driver, combination of load shifting and energy efficiency, load prevention or clipping, and a combination of clipping and energy efficiency. What methods and approaches can be developed to overcome challenges with these?
 - How project information is handled and scrutinized by an M&V practitioner?
 - What insight will be valuable for project stakeholders (specifically utility and project investors) on the pitfalls which should be avoided with irrigation project?
 - What evaluation methods are required for new project decisionmakers to quickly evaluate the feasibility of a proposed DSM project at the very start?
 - What guidance can be given to M&V practitioners on what to look out for, what M&V strategy to follow and how to approach baseline development?
- What is programme level M&V and where is it applied? Also:
 - What M&V challenges need to be overcome with the Eskom irrigation Standard Product Programme (SPP) and what methods need to be developed to achieve effective M&V? (Chapter 4 Section 4.3)
 - What method can be developed that will accurately determine how much of the SPP reductions achieved, actually occurred over the Eskom peak period? (Section 4.4)
- What is regional level M&V, where can it be applied and what is the advantage of using such an approach?
 - Are there challenges and pitfalls with regional level M&V and what methods and approaches can be followed or developed to overcome these? (Chapter 5)
 - Are there any case studies of a regional level M&V approach implemented and how were these executed? (Chapter 5 Section 5.3)
- What are the typical challenges with M&V metering and sampling with irrigation ECMs and what can be done to overcome these obstacles? (Chapter 2 Section 2.9 and Chapter 7)
- How can project level, programme level and regional level M&V be integrated to be more applicable to the Eskom SPP and related incentives? (Chapter 4 Section 4.4)
- Is the integration of water conservation quantification and greenhouse gas mitigation quantification possible with that of energy conservation quantification on project, programme, and regional level M&V while satisfying the requirements of current and the most common incentive mechanisms? What shortcomings are there and what can be proposed to overcome these? (Chapter 7 Sections 7.1 to 7.3)
- How can the South African section 12L tax incentive, and similar mechanisms, be applied to irrigation energy conservation and what can be proposed to extend the reach of these? (Chapter 7 Section 7.4)

8.5 FUTURE WORK AND RECOMMENDATIONS

The calibrated simulation model of Chapter 4 was a new development and has not been implemented and tested yet, although the concepts thereof were based on actual field data and M&V studies. However, the effectiveness thereof needs to be evaluated with a proper follow-up study, as proposed for Agri-M&V, through which the model can be verified, improved and calibrated.

With the implementation of the Western Cape regional top-down M&V evaluation of Chapter 5, several lessons were learnt. These are important to consider if any type of regional or area level M&V evaluation is being considered. One of the biggest problems encountered was data availability. The whole M&V process was slowed down due to the difficulty of obtaining data regularly and timeously from the different contributors. Thus, the M&V process can be greatly improved if data, such as Demand Market Participation (DMP) contribution and others, is more regularly and quickly available. This will result in performance assessments being delivered quicker and even shorter assessment intervals could be considered. Another problem leading to time consuming data analysis is the form and format of the data received. This sometimes differed from month to month and the applications developed for the previous data set could not be reused. It is recommended that the data provided by contributors must be in a fixed format for faster processing.

It is critical that the Chapter 7 integrated water and energy conservation programme with GHG mitigation should not be implemented in isolation. It must have the proper buy-in from the power utility, local water boards and regional water councils with government buy-in and support. It should be accompanied with awareness programmes, proper efficient agri-training for farmers and stakeholders with cooperation from agri-suppliers, ESCOs and irrigation advisors. With the involvement of the right authorities and parties, more incentive mechanisms should be made available or the reach of available incentive should be expanded. It is imperative that incentive mechanism policies and regulations should be clear and the proper governing instruments and set limits should be in place to ensure compliance. It is also important that additionality requirements are adhered to and that there are accounting mechanisms to prevent double dipping or rebound effects. A vital component that must be present (this was lacking in Eskom DSM projects), is adequate long-term ECM project maintenance to ensure sustainability of savings.

The electrical grid top-down regional quantification methodology of Chapter 5 was theoretically extended to water in Chapter 7. It should again be highlighted that the water balance in a region is very complex and quantification is more difficult when compared to an electrical network. This requires an in-depth investigation alongside field specialists, water boards and water councils. This investigation needs to form an integral part of future continuation and expansion of this study.

With regard to the proposed expansion of 12L through Agri-M&V, it is critical to view each aspect of the Agri-M&V design as vital and neglecting even one component can severely affect the immediate and long-term success of 12L tax incentives for irrigation. The limited success of CDM projects in SA and the quick deterioration of the Eskom IDM initiated irrigation load shifting projects are testament to this.

Built on this study, the proposed 12L Agri-M&V study will result in a practical and almost immediately implementable approach with major value to the agricultural sector, Eskom, industry and the rest of South Africa. Water conservation initiatives can be realised in conjunction with the 12L energy focus since this will increase the attainable energy savings. Through this it can be rapidly applied to the current water shortage problem in South Africa but can also provide a long-term instrument for preventing the water crisis foreseen in 2030.

8.6 CONCLUSION

This study considered an original approach necessary to address the water shortage threat to South Africa, and also many countries in the world. The study contemplated and critically analysed existing methods and facts through an extensive literature study. Chapter 2 provided this encompassing but relevant literature survey which outlined and highlighted the necessity and novelty of the study. From this, new methods and approaches with mathematical equations were designed, enabling novel development and unique application. The study combined well-researched exiting methods with newly developed methods. Through this, the effort of other researchers and established approaches that are part of international accepted standards were incorporated.

The study was executed by identifying, presenting, formulating and establishing novel design and development on a highly important and original research topic that is relevant to the current water crisis. Chapters 3 to 7 contributed through the design and development of unique methods. These methods were applied and guidance was given to project stakeholders. Both empirical and numerical investigation with assessments were performed on case studies to address the research problem discussed. New insight was gained and applied and this gave rise to other methods with unique applications.

In conclusion, this study successfully achieved the primary aim of developing a novel integrated methodology to measure and verify irrigation pumping energy conservation under incentive-based projects and programmes. This integrated methodology overcame irrigation conservation M&V challenges through providing original, practical and cost-effective M&V approaches, methodologies and frameworks. This established a novel turnkey solution for quantifying irrigation electrical energy conservation on a project level, programme level and regional level. The integrated methodology also provides the necessary building blocks which are essential prerequisites for a platform through which water conservation can ultimately be achieved.

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Appendix A

Peer reviews and publications

Appendix A-1 to A-2 provide the original papers published in international accredited scientific journals while Appendix A-3 to A-7 contain peer reviewed international conference articles. These were also listed in Section 1.7.

A-1 PUBLISHED PAPER - JOURNAL OF ENERGY IN SOUTHERN AFRICA 2018

A-2 PUBLISHED PAPER - JOURNAL OF ENERGY IN SOUTHERN AFRICA 2016

A-3 CONFERENCE ARTICLE - SOUTH AFRICA ENERGY EFFICIENCY CONFERENCE 2013

**A-4 CONFERENCE ARTICLE - INTERNATIONAL CONFERENCE ON THE INDUSTRIAL AND
COMMERCIAL USE OF ENERGY 2013**

A-5 CONFERENCE ARTICLE - SOUTH AFRICA ENERGY EFFICIENCY CONFERENCE 2008

**A-6 CONFERENCE ARTICLE - INTERNATIONAL CONFERENCE ON THE INDUSTRIAL AND
COMMERCIAL USE OF ENERGY 2008**

**A-7 CONFERENCE ARTICLE - INTERNATIONAL CONFERENCE ON THE INDUSTRIAL AND
COMMERCIAL USE OF ENERGY 2007**

Novel measurement and verification of irrigation pumping energy conservation under incentive-based programmes

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Abstract

In most countries the agricultural sector, especially crop irrigation, is a considerable energy consumer. Farm irrigation studies in South Africa showed that energy and water is wasted on a large scale and there is a large potential for improving efficiency. The present study focusses on the measurement and verification (M&V) of irrigation pumping energy conservation measures (ECMs) under the Eskom Standard Product Programme funding mechanism in South Africa. A novel M&V methodology was developed to quantify ECM impacts under the Programme, which has special conditions and unique M&V requirements, which makes normal approaches inapplicable. Methods were designed to effectively determine conservative but representative impacts without continuous power demand profile measurement. The design involved unique methods to quantify operational demand reduction, annual energy consumption and annual average demand reduction impacts. The design was broadened to include pumps irrigating multiple crop areas and different kind of crops. The methodologies and

techniques developed were validated and verified through establishing independent cross-check measures. The paper discusses a regional top-down M&V approach to verify the actual total energy efficiency and load reduction on the electricity grid for a specific region.

Keywords: energy efficiency; demand side management; variable speed drive; load reduction; crop load factors

Highlights

- Irrigation energy conservation measures under incentivised programmes.
- The M&V of irrigation pumping energy efficiency under the Eskom Standard Product Programme.
- Instantaneous and average demand reduction with annual energy consumption reduction.
- Quantify impacts without continuous power demand profile measurement.

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1. Introduction

Most countries use irrigation pumping to increase crop yield, to different extents depending on climate and yearly precipitation. In most of the world about 70% of freshwater demand is for irrigation, and in barren and semiarid regions the value reaches 90% (Molden, 2007). Irrigation in South Africa, compared with other sectors, is by far the biggest water user (Du Plessis, 2009). According to the Department of Water and Sanitation (DWS) 2013–2015 annual strategic overviews of the water sector in South Africa, 62% of South Africa's yearly rainfall water yield was used in those years for agricultural purposes (DWS, 2013; DWS, 2015). On the energy front, the agricultural sector in South Africa contributed 4.7% of electricity sales in 2016, according to Eskom's integrated results (Eskom IDM, 2016). Internationally, Naylor (1996) found irrigation to be the major energy consumer at farm level in other countries. On-farm irrigation pumping is responsible for 23–48% of direct energy consumption allocated for crop production (Hodges *et al.*, 1994; Singh *et al.*, 2002; Lal, 2004), with the figure highly dependent on climatic regions, farming practices, crop type and use of utility power.

The agricultural sector is prone to energy and water wastage through inefficient practices, poor irrigation systems and leaks (Standard Product Programme irrigation supplementary measurement verification and guideline, 2013). Energy and water wastage can be improved or managed by energy conservation measures (ECMs), which can be irrigation energy efficiency (EE) projects or projects which shift the irrigation pumping load away from power utility peak periods. The ECMs can be utility-driven projects or incentivised programmes such as the following:

- government- or utility-funded energy service company projects, such as the Eskom integrated demand management programme (2017);
- the EE rebates or tax rebates like those covered by Section 12L of the South African income tax act (South Africa Government Gazette 2013, 2013);
- the EE trading mechanisms such as white certificate schemes (Tyler *et al.*, 2011) or carbon-trading through schemes like the clean development mechanism (Winkler and Van Es, 2007);
- vertically integrated national appropriate mitigation actions (Dazé *et al.*, 2016); or
- the anticipated South-African carbon tax (Department of National Treasury South Africa, 2015).

Under the Eskom demand side management (DSM) programme, now known as the Eskom integrated demand management (IDM) programme, many load-shifting and EE projects were carried out

in residential, commercial, industrial and mining environments. These included several farming irrigation pumping load-shifting projects (Storm *et al.*, 2008). Projects were mainly interventions that could have a large Eskom peak period demand reduction or a significant EE impact, where some projects implemented both evening peak load-shifting and EE by simultaneous application.

All projects needed to show credibility, and measurement and verification (M&V) had to be applied to evaluate attained impacts (Van der Merwe, 2011), since public funding was provided by the National Energy Regulator of South Africa (NERSA) for the Eskom projects. Intensive M&V on these projects was therefore performed to assess project impacts and report to the stakeholders. The function of M&V is to independently and objectively quantify project impacts and sustainability of impacts over an agreed contractual project life (Den Heijer, 2010). All M&V practices were based on the international performance M&V protocol (IPMVP Committee, 2012). From this, South African M&V practice guidelines (Den Heijer, 2010) were developed, culminating in the establishment of a national standard: SANS 50010:2011 (South African Bureau of Standards (SABS), 2011), recently updated to SANS 50010:2018 (SABS, 2018).

As well as large DSM projects, small-scale EE projects can also add to the national IDM energy use performance improvement and were therefore also implemented to reduce energy consumption for cost saving. The Eskom Standard Product Programme (SPP) was established to provide rebates for these small projects and fast-track implementation and associated performance assessments at a lower overall assessment cost. A project and a programme essentially differ in that a programme is an ongoing roll-out of a fixed technology over many sites, while a project considers a set target defined over certain site(s) (Coetzee *et al.*, 2012) and is not limited to a specific technology. An energy-saving rebate under the SPP is paid to participating parties who replace a standard old, inefficient technology with a standard and proven EE technology. The technologies initially allowed under the SPP included EE lighting, heat pumps, EE shower-heads and solar water heating (Van der Merwe, 2011).

An Eskom IDM energy advisor team (Scheepers *et al.*, 2013) also set out to establish an Eskom programme for irrigation demand reduction and EE. Here, some larger projects fitted under the Eskom Standard Offer Programme (Eskom IDM), which still required conventional M&V (Hibberd, 2011; Den Heijer *et al.*, 2010). The majority of potential projects needed to fit under the SPP, however. According to Van der Merwe (2011) these SPP small-scale projects require a generalised approach that gives acceptable saving impact indication. This

M&V approach recognises a deemed saving rather than a measured saving as with conventional M&V. Several projects could be implemented per site subject to a single project size, each limited to 100 kW average demand reduction during weekdays, and a maximum total of 250 kW impact per site.

Conventional M&V of irrigation projects has already proved to be exceptionally challenging (Storm *et al.*, 2016). It is difficult to determine the efficiency or inefficiency of water usage in irrigated agriculture because it is a 'multiple input – multiple output process' (Malana and Malano, 2006; Rodríguez Díaz *et al.*, 2004). The difficulty of conventional irrigation M&V called for a new and unique M&V methodology to quantify ECM impacts under the SPP and other incentive-based programmes. The focus of this study is therefore M&V on irrigation SPP projects and the novel M&V methods developed to quantify the impacts of these projects.

2. Conventional M&V methods vs SPP M&V requirements

Conventional M&V methods are normally applied on ECM projects with a large demand or EE reduction. This was common practice on large irrigation projects under the Eskom DSM programme, where the ECM intervention cost is high and the total M&V cost involved only a fraction of the total project. The large EE or demand reduction achieved relates to large incentives paid to the ECM project owners. Many implemented demand reduction projects have moved several MW from the evening peak to other times.

It is important for all stakeholders within such an environment to have very accurate M&V results with a high confidence level. Also, the exact project performance must be tracked over the entire project life to ensure that the project targets are met. Here, M&V is critical and the associated cost easily justifiable. The M&V process on these projects require the following critical components and actions (Storm *et al.*, 2008; Van der Merwe, 2011):

- properly define the baseline boundary, which include ECM intervention and all interactive effects;
- define an energy governing factor as;
- proper M&V demand profile metering (billing class in most cases) is required;
- define a functional baseline metering period to capture all project variations and circumstances – anything from a few months to several years;
- baseline model development – the baseline typically consisting of average weekday, Saturday and Sunday demand profiles;
- baseline assumptions made on project parameters and conditions where the baseline is applicable;
- a baseline service level adjustment method to

adjust the baseline relevant to the operation conditions it would have experienced if the ECM was not implemented. This is done by using the referenced energy driver; and

- calculate savings over the project life. This is normally done on a monthly or quarterly year basis. The participating members in the project receive incentives based on the results of the M&V project performance reports.

This conventional M&V method requires extensive baseline development and independent M&V specialists are required throughout the project life to track ongoing savings. Metering and data gathering can be cumbersome and also very expensive.

The SPP M&V approach fundamentally differs from the traditional M&V in the following aspects:

- no profile metered baseline period and no reference energy drivers;
- no ongoing metering is performed on the ECM after implementation;
- no profile baseline development; and
- the incentive is paid to participating parties at the beginning of the project, on a projection of the savings over the following three years. There is, therefore, no ongoing tracking of the project performance.

Considering these, the SPP has unique requirements that make conventional M&V approaches inapplicable. A new M&V methodology was required to assess SPP ECMs and quantify projected impacts without conventional M&V methods, while still having an acceptable confidence level.

3. Novel integrated M&V methodology for the SPP

A novel integrated M&V methodology was developed to conservatively quantify load reduction and energy efficiency resulting from ECMs under the SPP. The scientific approach was developed through a comprehensive study of all SPP requirements, project parameters, system boundaries and approach limitations. The integrated methodology includes the key components displayed in Figure 1. Specific methodology design validation and verification parameters were set as Figure 1(a), (c) and (d).

Figure 1(b) shows the key concepts of the integrated methodology described in the present study. The ECM evaluation looked at how an evaluation criterion can be devised to assess different ECM approaches to ultimately find a sustainable and quantifiable ECM. This then considered how this ECM was applied and how it led to demand reduction and energy saving. The design of assessment/measurement procedures examined the following:

- design a measurement procedure to assess actual attainable impacts through the chosen ECM;

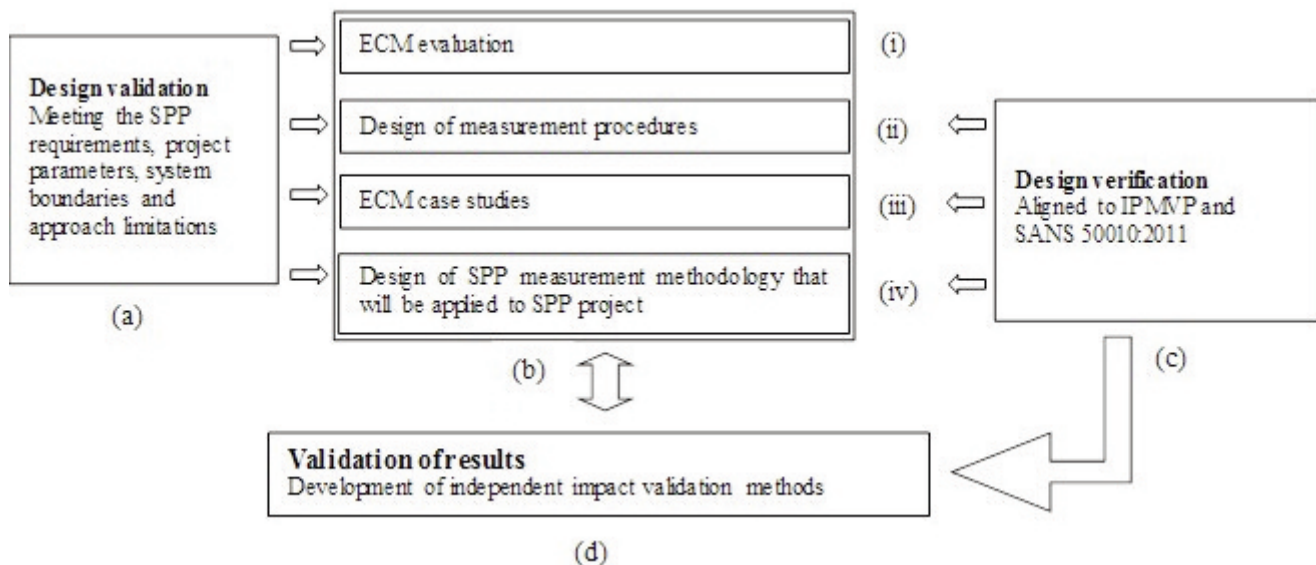


Figure 1: A novel integrated measurement and verification methodology with design validation and verification, with (a) = the design validation; (b) = key concepts of integrated methodology; (c) = the design verification; and (d) = the validation of results.

- design a measurement procedure to accurately apply the aforementioned even when the ECM was already implemented, and no baseline measurements were possible; and
- design a measurement procedure to accurately isolate and quantify the impact of the preferred ECM where other ECMs were also implemented.

Case studies following compartment (iii) of Figure 1(b) were performed to evaluate the actual attainable impacts of the chosen ECMs. Compartment (iv) shows the design of a SPP measurement methodology that includes:

- establish a measurement method to quickly and effectively quantify a conservative but representative load reduction or load shift without profile measurement. Broaden this method for an irrigation pump feeding multiple crop areas and having more than one crop type per centre pivot; and
- establish a functional method to quantify annual conservative but representative energy use impacts of an irrigation pump from the load reduction values. Then broaden the method to an irrigation pump feeding multiple crop areas and having more than one crop type per centre pivot.

Figure 1(a) shows that design validation is done by adhering to the SPP requirements, project parameters, system boundaries and approach limitations. As a design verification in Figure 1(c), all methods and procedures must be aligned with international M&V protocols and standards. Here, the IPMVP and SANS 50010:2011 was applied. Not all

the steps are fully discussed in this study because of the size and complexity of the development. Figure 1(d) gives an independent method to validate the SPP M&V methodology and the actual results obtained from ECMs under the SPP. This is further discussed in Section 8.

4. The ECM evaluation

Compartment (i) in Figure 1(b) presents ECM evaluation as the first key concept of the integrated M&V methodology. This section considers an ECM evaluation by discussing what ECM technologies can be implemented and how these can be applied to lead to demand reduction and energy saving.

4.1 The ECM evaluation criteria

Since no standard tried and proven irrigation EE technology had been found for the SPP, a study on inefficient irrigation practices and possible ECMs was performed (Storm *et al.*, 2008). It considered what ECMs can be implemented to give measurable and sustainable energy saving over the project life with a high confidence level. The study concluded that pump system design and setup system improvements can satisfy these requirements. The technology chosen to best fit the SPP was variable speed drives (VSDs), through which the pumping system can be optimised to achieve demand reduction and energy saving.

4.2 Application of ECM: How it leads to demand and energy saving

It is important to note that a VSD on its own will not necessarily improve EE. The VSD, however, is a 'tool' that enables EE, which is not possible with standard pumping equipment. Figure 2(a) shows a



Figure 2: Irrigation system. (a) pre-implementation conditions with over pressured centre pivot resulting in fine mist; (b) post-implementation conditions showing significantly reduced fine mist (Storm *et al*, 2013).

centre pivot running in pre-ECM implementation conditions. Generally, it is found that centre pivots are over-pressured, resulting in ineffective irrigation.

In these conditions, the sprinklers create a fine mist, which increases evaporation, thus wasting water and subjecting the pump motor to a higher load by the higher system pressure. In South Africa, it is frequently found that irrigation engineers have overdesigned an irrigation system, especially the older ones. The system can be optimised by reducing the motor speed with a VSD so that the choking valves can be completely opened (Scheepers *et al.*, 2013). The water delivery rate is now controlled by the VSD and no more choking is required. The pumping system is further optimised by reducing the centre pivot pressure to an optimum level. Figure 2(b) shows less mist is created since the centre pivot pressure was significantly reduced.

This optimal pressure changes the water mist to larger droplets, which have less 'in flight' evaporation (Morris and Lynne, 2006). Since the pump is not choked anymore and the pressure is lower, a demand reduction as well as EE is realised. The lower pressure also results in less overall water being pumped and less water wasted by evaporation.

5. Design measurement procedures

Compartment (ii) in Figure 1 presents the design of measurement procedures as the next key concept. These design procedures are necessary to quantify the actual attainable impacts through SPP ECMs. The measurement procedures described relate to the conventional M&V methods given in Section 2. Although these methods will not be used in actual SPP M&V project impact projection, they are required in the present study to evaluate what real-world impacts can be achieved. Full M&V is, therefore, used to provide a sampled impact result according to certain project characteristics that can then representatively be applied to other similar projects to ascertain their likely EE impact results.

5.1 Measurement procedure to assess actual attainable impacts

The procedures involved baseline audits through independent validators and proper baseline and post-implementation profile measurements by means of reliable metering, as described below.

Baseline conditions audit

An independent validator is required to visit and assess a pump station and the irrigation system setup before any EE initiatives are considered or discussed with the farmer or any farmers in the region. This can be done through independent audits in an area well before any ECM programme. This is necessary to establish proper baseline conditions without interference. It is important that the baseline conditions may not be influenced for example, any discussion with the farmer might influence him to start operating more efficiently, thus changing the baseline operation. And the moment the typical ECM implementation procedures become available or common knowledge, 'creative savings' may surface through changing the system baseline conditions to run more inefficiently before auditors arrive. It is important during the audit that the exact operational conditions are recorded. This includes different crop areas and circles fed by a specific pump, the valve positions for each pumping scenario, and the operational pressure of each irrigation setting.

Metering installation and verification

Before the ECM is implemented, pump station operational data should be collected, through reliable meters installed on each pump in a station. The correctness of all installations must be verified through calibrated check metering. As an example, a case study of a pump irrigation system with three centre pivots is discussed with the aid of Figure 3, where in Figures 3(b) and (c) the meter installation is verified by using a calibrated handheld and a temporary Fluke power meter.

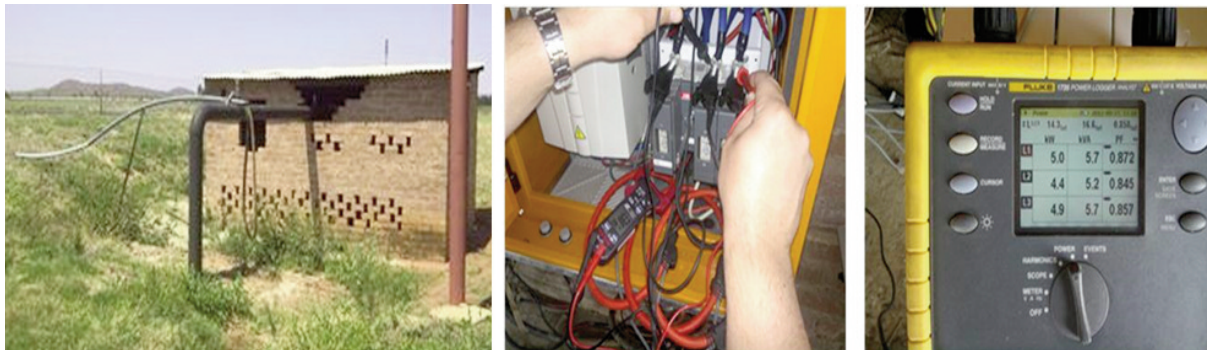


Figure 3: Pump irrigation system: where (a) = case study pump station, (b) = measurements by M&V with a calibrated handheld meter, (c) = fluke power meter measurements compared with M&V meter (Storm *et al.*, 2013).

Baseline measurements

After metering equipment installation verification, full baseline data capturing can be started. For sufficient baseline data, the centre pivots go through the full irrigation cycle. With this, all different pumping scenarios and conditions can be recorded. Figure 4 shows the full cycle pre- and post-implementation demand profiles of one of the case study pump stations. The top line shows a 53-hour full irrigation cycle energy demand profile of the irrigation pump, revealing three distinct operational scenarios: the profile starts at about 37 kW, then drops to about 29 kW for about three hours, and then stabilises to about 36 kW for the rest of the period. These three different demand conditions are caused by the pump irrigating the three different centre pivots. Water supply is moved to specific crops through supply lines by changing valves.

Post-implementation metering

After the ECM was implemented and the system optimised, the same irrigation cycle is repeated with the different pumping scenarios. Figure 4 shows the

post-implementation demand profile as the bottom line on the graph, allowing a clear comparison with pre-implementation demand. For most of the irrigation cycle there was a typical 20 kW difference. The shaded area between the two profiles represents the energy demand reduction achieved over the full irrigation cycle.

5.2 Assessment where baseline measurements were not possible

In cases where it was not possible to install temporary baseline metering before the ECM, an alternative approach was required to quantify the attained impacts. A measurement procedure was established for determining impacts when the ECM was already implemented. In these cases, valid information from a proper baseline audit is required as per Section 5.1. The pumping system can be brought to pre-implementation (baseline) conditions by setting the VSD back to 50 Hz and returning pipeline valves to the pre-chocking settings and system pressures, thus essentially 'eliminating' the presence of the VSD. Now baseline measurements can be done and com-

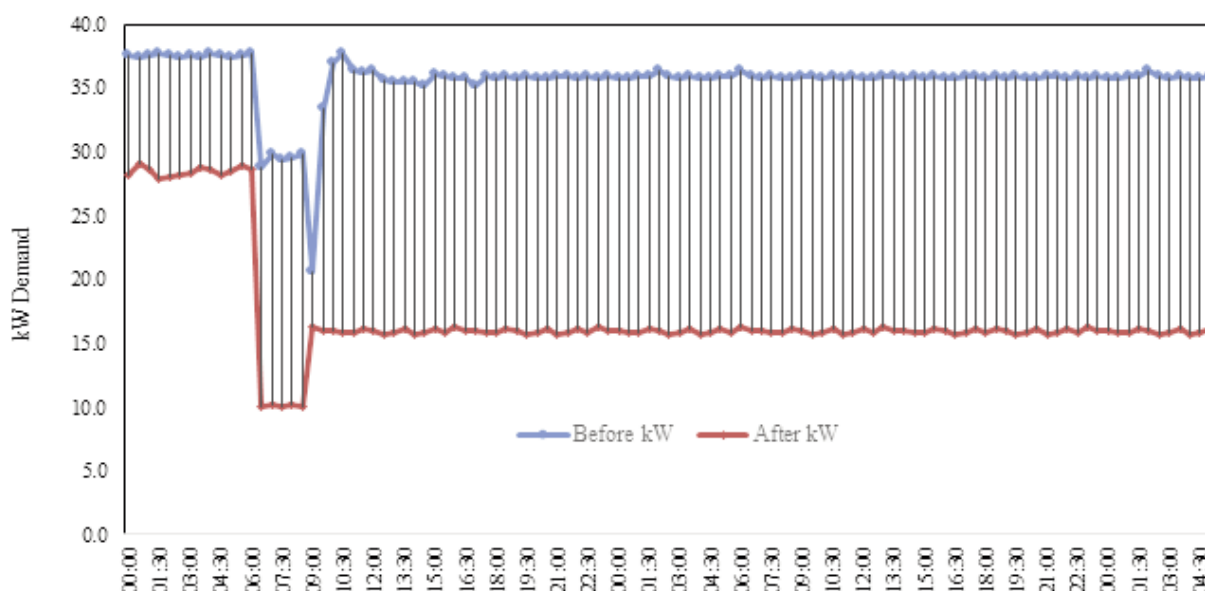


Figure 4: Full cycle pre- and post-implementation electrical demand profiles of the case study pump station (Storm *et al.*, 2013).

pared with post-implementation data to reveal the actual impact. This approach can easily be misused if proper baseline audits were not performed. If baseline audits are not possible, historical data for three months to a year is needed before any ECM implementation is required for suitable M&V. This historical data can be obtained from utility point-of-use profile power metering. From this data, the baseline conditions can be verified. Smaller utility points are, however, not always equipped with profile power meters, but rather with cumulative energy consumption disc meters in kWh. In these situations, additional baseline metering may be required.

5.3 Assessment where other ECMs were also implemented

In the case where other ECMs were implemented with the VSD, a similar approach to that described in Section 5.2 can be followed to accurately isolate and quantify the impact of the VSD. Other ECMs may include an EE pump motor or pipeline efficiency improvements. Comparing the results from proper baseline measurements with the post-implementation results gives the demand reduction due to the VSD and other ECMs. Repeating the method of Section 5.2 and comparing these results with the post-implementation results produces only the impact of the VSD, however. This essentially isolates the VSD impact and excludes the efficiency contribution of other ECMs. With some ECMs, like pipeline efficiency, the exact baseline conditions may not be achieved by applying Section 5.2's method. The pipeline efficiency may result in a lower operational demand with the same baseline valve positions and operational pressure. With both Sections 5.2 and 5.3, it should be noted that M&V is not an exact science and the aim is to quantify representative and conservative savings as prescribed by the IPMVP and SANS 50010:2018.

6. Case studies of actual attainable impact

Case studies were done on 19 VSDs installed on five farms in different areas and provinces. The aim was to quantify the actual attainable demand impacts through metering. The measurement procedures of Section 5, with other newly developed methods, were carried out at several sites to assess and verify demand impacts. Figure 3 shows some of the pump stations assessed during the case study. The line designated 'before' in Figure 4 shows the baseline profile and 'after' the post-implementation profile, where a significant demand reduction can be observed.

6.1 Operational power demand reduction results from case studies

An overall representative electrical demand reduction for the irrigation pump can be calculated from

the profile measurements described in Section 5. This was done to portray a single figure of the attainable demand reduction impact of the 19 case study pumps. The profile measurement method of Section 5 was, however, too costly and impractical to use for all of the case study pumps and an alternative measurement technique was required to obtain demand reduction values for some of them. Section 7.1 describes a simple method that was designed for the irrigation SPP to establish a representative but conservative load reduction value. This technique was used to establish the instantaneous demand values given in Table 1, which summarises the pre- and post-implementation demand measured at each case study site, with the actual demand reduction.

The first column in Table 1 (overleaf) lists the test site, while the second gives the pump station name and the installed capacities of the irrigation pump motors. The next two columns show the before and after ECM instantaneous kW, while the kW and percentage demand reduction are given in the last two columns. The lowest demand reduction, 7.1%, was experienced at Farm 4 and the highest, 71.6%, at pump station P17 on Farm 1. The demand reductions measured were not related to the time of day they occurred (such as during peak periods), as the focus was solely on the attainable demand reduction. Taking all 19 sites into account, the average demand reduction achieved was 42.2%. For all measurements, the pre- and post-implementation conditions were kept the same. This is clear evidence of a definite and significant demand reduction. With project circumstances considered, it can be safely concluded that the implementation of a VSD to optimise the irrigation system can lead to real, tangible and significant demand reductions. The achieved demand reductions will directly result in energy consumption saving and, in most cases, water saving as well, as a result of water usage optimisation.

An important aspect that can be addressed in future studies, however, is to establish a method that can also determine the time of day when demand reduction occurs. This would be valuable, as the contribution the SPP irrigation ECMs demand reduction makes over the Eskom peak usage periods could also be determined.

6.2 Further assessments

The 19 pump stations were not the only pumps engaged by the energy advisors, although these were the only ones independently verified. A total of 46 farms and farm sections formed part of a large testing study over South Africa. With collaboration between M&V and the energy advisors a standard site M&V evaluation criterion, as for the 19 pump stations, was agreed upon to be used for all other farm pump stations. Very similar demand reduc-

Table 1: Achieved operational power demand reductions on 19 pump stations (Scheepers *et al.*, 2013).

Test site	Pump station and installed pump	Instantaneous demand measured			
		kW before	kW after	kW reduction	% reduction
Farm 1	P36 (30 kW)	36	16	20	55.6
	E4 (30 kW)	27.5	11.3	16.2	58.9
	E40 (55 kW)	54	42	12	22.2
	E40 (30kW)	23	13	10	43.5
	P1 (30 kW)	34.4	14.7	19.7	57.3
	P1 (30 kW)	32	16.9	15.1	47.2
	P17 (22 kW)	25.7	7.3	18.4	71.6
	P17 (75 kW)	66.8	30.8	36	53.9
Farm 2	DP (110 kW)	99	53.2	45.8	46.3
Farm 3	75 kW	74.9	50.7	24.2	32.4
	75 kW	62.4	40.8	21.6	34.6
	75 kW	61.7	44.1	17.6	28.5
Farm 4	37 kW	38.1	35.4	2.7	7.1
Farm 5	P1 (30 kW)	46.8	28.8	18	38.5
	P2 (30 kW)	51	25.3	25.7	50.4
	P3 (30 kW)	68.7	33.5	35.2	51.2
	P4 (30 kW)	46.4	31.4	15	32.3
	P5D (30 kW)	45.8	33.7	12.1	26.4
	P6 (30 kW)	44.6	25	19.6	43.9

tions to those found for the 19 pump stations were obtained (Storm *et al.*, 2008).

The savings presented in Table 1, and those of the other 37 pump stations, can only be used as a guide on what can possibly be achieved and not as a national or area-specific representation. The pump stations used did not undergo proper statistical sampling (Carstens *et al.*, 2014; IPMVP Committee, 2012; Xia and Zhang, 2013; UNFCCC CDM Executive Board, 2012) and were assessed as projects were implemented and evaluation sites became available. For a national or area-specific representation a thorough statistical model needs to be developed, one which considers all factors and variables. Therefore, no area representative confidence level and error margin can be tied to the findings.

In order to establish a national or area-specific representation, a proper M&V cost and accuracy model can guide decisions on how to approach this. Unfortunately, with accuracy the associated M&V cost rises significantly. With the healthy M&V practice of always reporting on conservative savings, incentive programmes can compare M&V accuracy and cost with the additional incentives that can be claimed. As with the M&V of normal irrigation projects, in some cases, even a 50% confidence level may be acceptable, depending on the overall reporting objectives and the value of the savings involved, according to Steyn (2014). Here the claimed savings will inevitably only be a conservative 50% of what was measured. Although it may not appear ideal, this approach may provide suffi-

cient M&V for publicly funded incentive programmes, but simultaneously enable projects which may not have been possible before due to high M&V costs. Here the M&V methods described in the present study are ideal. A critical aspect of M&V that requires more attention, on any type of ECM programme, is metering and data-gathering equipment. In many cases, the costs of these are so high that it is often more than the rebate from the incentive programme. An accurate but cost-effective data-gathering system and approach is required for such projects.

7. Design of a SPP measurement methodology

Section 5 described the design of measurement procedures to quantify the actual measured impacts of SPP irrigation ECMs. In Section 6 these procedures were applied to case studies, where the focus was to assess and quantify the real world impacts resulting from the installation of VSDs on irrigation pumps. Here, measurement practices related to conventional M&V methods were applied. However, the SPP cannot financially justify such extensive measurements on all projects and a simplified standardised assessment method is required to establish attainable demand, and therefore energy consumption, reduction.

7.1 Establishing a simplified assessment method for demand reduction

A method needed to be established for the SPP to

measure a conservative, but representative load reduction, without profile measurement. With centre pivots, a conservative approach is to let the centre pivot turn till it reaches the lowest elevation point on the crop circle (Steyn *et al.*, 2013), which requires measurements of a baseline instantaneous demand. This lowest point is the location where the irrigation pump demand is the lowest since the static head is effectively the lowest. These measurements are repeated after the ECM implementation and the results can be compared for the demand reduction. The impact calculated becomes the lowest possible saving that is still attainable. With centre pivots on severely angled crop circles, multiple measurement points may be considered. Crops under micro or sprinkler irrigation have a constant static head and instantaneous measurements can be taken any time after the system stabilised after pump start-up. Irrigation pumps that irrigate multiple crops, as in Figure 4, require a separate assessment for each crop type. A load reduction for each crop is determined.

7.2 Assessment method for annual average demand and energy consumption reduction

Determining the annual energy reduction under the SPP is a difficult study, since the SPP does not allow continuous measurements and the energy consumption saving needs to be determined for a specific crop in a specific area. Without continuous measurement, several other aspects may need to be considered when determining the energy and average demand reduction. These aspects can include:

- location, climatic region and typical annual rainfall;
- crop types: irrigation of summer and/or winter crops, more than one type of crop during a single season;
- irrigation methods and soil type; and
- is water allocation/registration active in the area?

The best approach found was to incorporate crop load factors (Scheepers *et al.*, 2013), through which representative irrigation requirements for a crop were established. Crop water requirement is one of the most important aspects to consider for irrigation efficiency since it is a vital part of agricultural planning (Reddy, 2015). Allen *et al.* (1998) define crop water requirement as: 'the depth of water needed to meet the water loss through evapotranspiration (ET_{Crop}) of a disease-free crop, growing in large fields under non-restricting soil conditions, including soil water and fertility, and achieving full potential under the given growing environment'.

Crop water requirement is a well-studied field and software programmes are available to assist farmers in determining it. An example of this is

CROPWAT (Banik *et al.*, 2014) and the South-African SAPWAT (Heerden *et al.*, 2016), which is based on (Allen *et al.*, 1998) using the CLIMWAT (Tegos *et al.*, 2017) weather database comprising of 3262 weather stations from 144 countries. For the SPP the software program SAPWAT was utilised; among many other aspects, it incorporates 50 years of weather data to calculate a load factor for a specific area and crop type.

From the crop load factor, irrigation system setup and ECM load reduction, the annual energy consumption saving with the annual average demand reduction can be estimated. This can be strategically broadened to an irrigation pump, feeding multiple crop areas and having more than one crop type per centre pivot. However, independent M&V assessment of these crop factors was critical to prevent biased or unrepresentative values. A whole alternative method was developed and a study performed to independently evaluate and verify crop load factors calculated for certain areas (Storm *et al.*, 2013). This study involved determining the real-world crop load factors of hundreds of irrigation pumps stations over a four-year period. This massive undertaking is beyond the scope of the present study, but the results showed that the calculated crop load factors were indeed representative and conservative.

8. Validation of methodology through actual electrical grid impacts

A critical question: what is the actual reduction the electricity grid experiences due to these ECMs? Although ECMs will result in probable short-to-medium term (one to three years) representative reductions, the question is how these impacts will be sustained over longer periods. Also, from other types of EE projects evaluated, it emerged that sometimes re-appropriation effects diminished the real attained savings. An example of this is Eskom residential EE projects and CDM projects (Pandaram, 2006; UNFCCC CDM Executive Board, 2010). Once a homeowner realised that ECMs such as a SWH, geyser switch, geyser blanket or EE lighting reduce the electricity bill, the tendency is often to use more electricity on other household appliances, making up the original electricity cost budget, thus, effectively cancelling any attained savings – though with lifestyle improvements.

Normal M&V models do not actively capture this effect since the measurement boundary is only around the equipment part of the project scope and only direct interactive effects with other technologies are monitored. Here, CDM methodologies have additional methods and calculations to account for re-appropriation effects such as leaking and free riding (United Nations Framework Convention on Climate Change Clean Development Mechanism Executive Board, 2010).

It is imperative that programmes such as the SPP must have regulation to avoid re-appropriation effects. Old, ineffective equipment must be collected and destroyed or they will only be used at another place.

A method is required to quantify what the actual impact of ECMs is on the electrical grid. In 2006, there was a massive implementation of accelerated DSM initiatives in the Western Cape province because of a 400 MW supply shortfall (Storm *et al.*, 2009). A top-down M&V methodology was developed and successfully executed to assess the regional demand impact as seen on the electrical grid. Data was gathered from strategic measurement points on regional transmission and distribution power supply lines. The M&V methodology accounted for the following key aspects:

- average day type demand profiles with temperature adjustments;
- electricity sales growth and demand market participation;
- supply losses, municipality curtailment and load shedding; and
- leased generation, fuel switching, power export and open point shifts in electrical distribution networks.

Strategic measurements were made on the electrical network to isolate key areas effected by ECMs. Measurement data was collected from existing power utility grid meters. Care was taken, since electrical network configuration can change through shifted open points, which in turn may affect measurement data at certain places (Dalglish, 2009). A similar approach can be applied to isolate and assess the impacts of regional irrigation ECMs. Through the distribution networks, key high voltage lines than mainly feed irrigation areas or regions can be identified. Power lines which may tap off and feed industries or towns can also be measured so that these can be subtracted from the totals. The model can be refined through moving down to low voltage customer billing utility meters to remove a farm's loads that are not used for irrigation. This is limited to points with utility profile metering. Data extraction can be done in cooperation with utility grid control centres. From historic data, periodic baselines (monthly for instance) can be developed and baseline adjustments fixed.

9. Conclusions

Eskom's Standard Product Programme (SPP) has unique M&V requirements, which make normal M&V approaches inapplicable. The biggest challenge is the absence of continuous metering while still requiring representative and accurate results. A new and unique M&V methodology was designed to quantify energy conservation method impacts under the SPP and other similar incentive-based

programmes. This new methodology was used on several pilot sites and proved to be functional, giving the required operation electrical demand reduction values required. These values provided clear evidence that the implementation and use of a variable speed drive to optimise the irrigation system can lead to real, tangible and significant demand reductions. By incorporating crop load factors with the demand reduction values established, representative annual energy consumption and annual average demand reduction impacts were also successfully established. These impacts were validated and verified through an independent cross-check measure which showed that the values obtained were indeed representative and conservative.

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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 m³ 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)

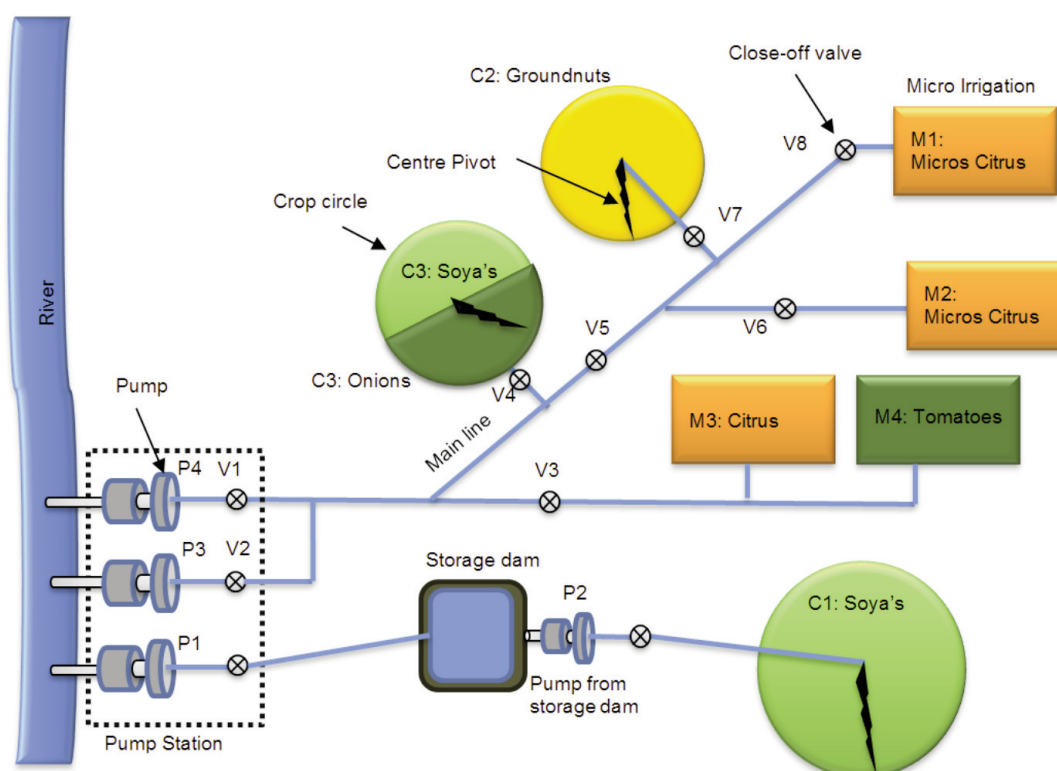


Figure 1: Typical irrigation farm pumping setup (SP programme supplementary M&V guideline, 2013).

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-

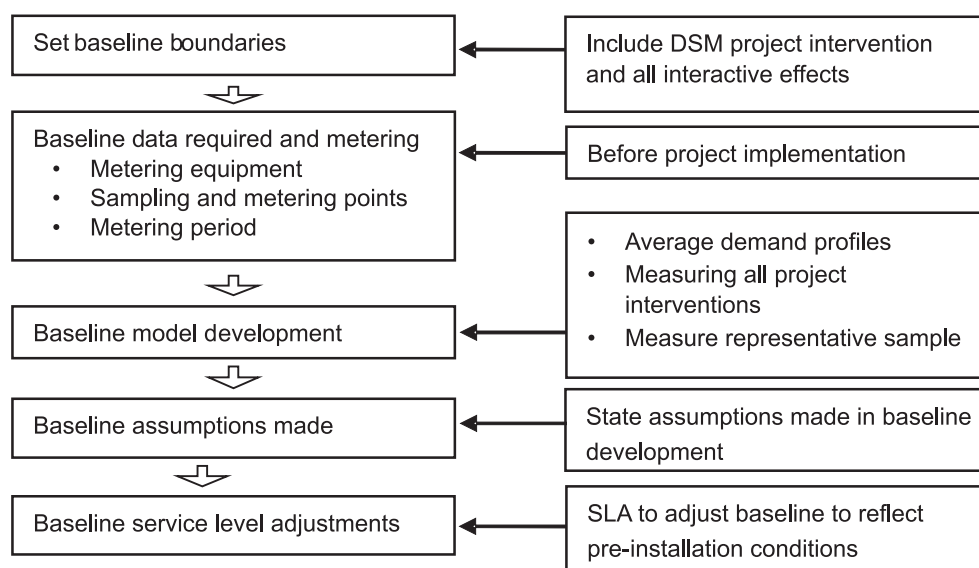


Figure 2: Flow chart of baseline process

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

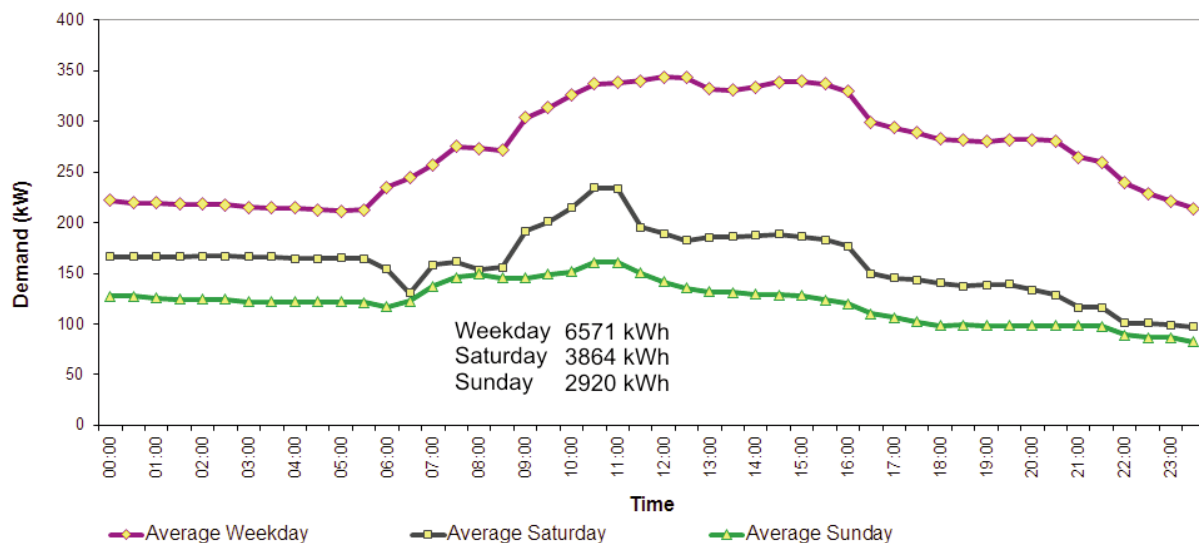


Figure 3: Baseline development process.

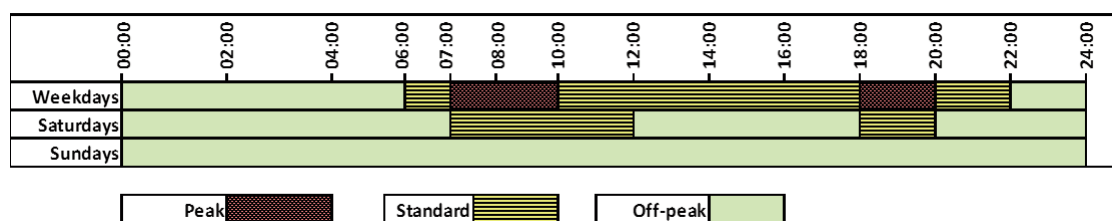


Figure 4: Eskom time of use periods (Eskom tariff and charges booklet, 2014).

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

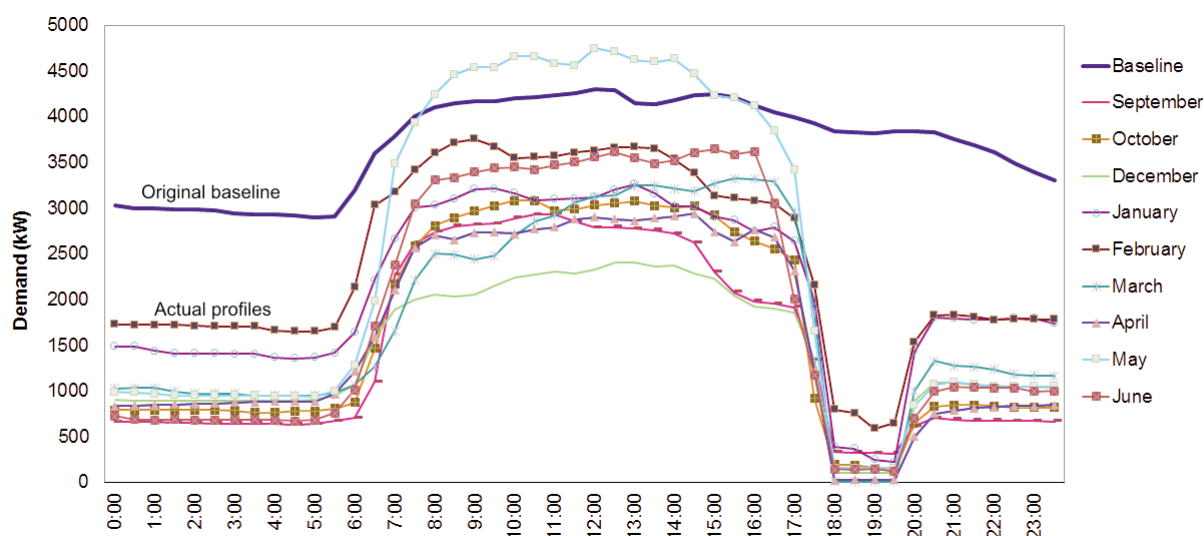


Figure 5: Average weekday baseline compared with actual average weekday PA profiles (Storm et al., 2008b).

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

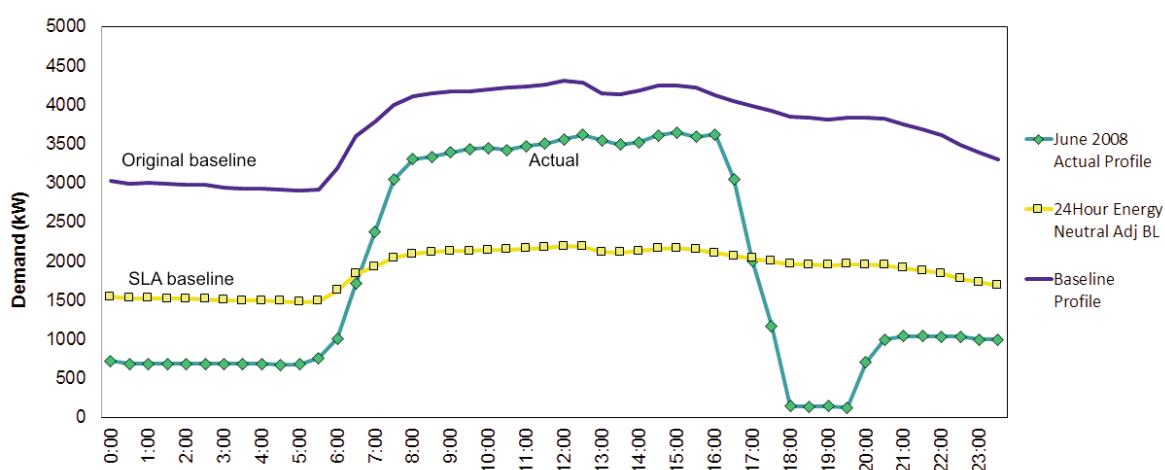


Figure 6: Average weekday developed baseline profile, actual PA profile and 24-hour SLA baseline profile.

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 oper-

ations 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

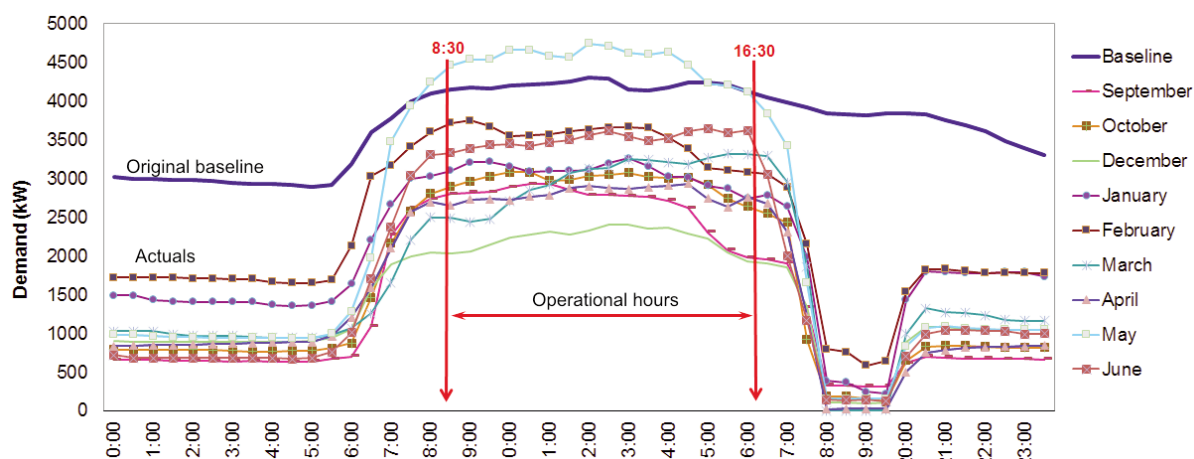


Figure 7: Operational kWh neutral SLA period (Storm et al., 2008b).

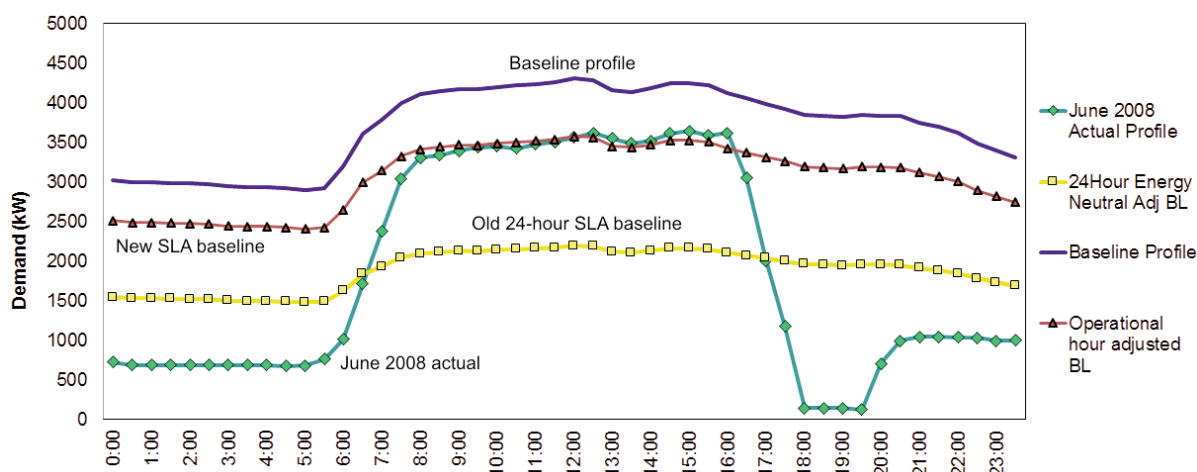


Figure 8: Average weekday developed baseline, Actual, 24-hour SLA baseline and the new operational-hour SLA baseline (Storm et al., 2008b)

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:

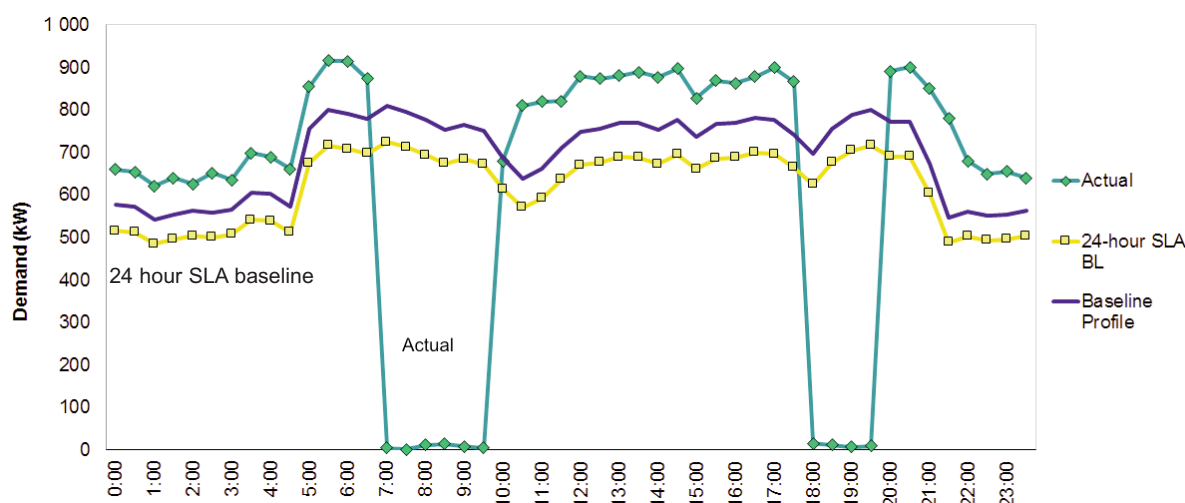


Figure 9: Average weekday developed baseline, actual, 24-hour SLA baseline and the new operational-hour SLA baseline (Storm et al., 2008b).

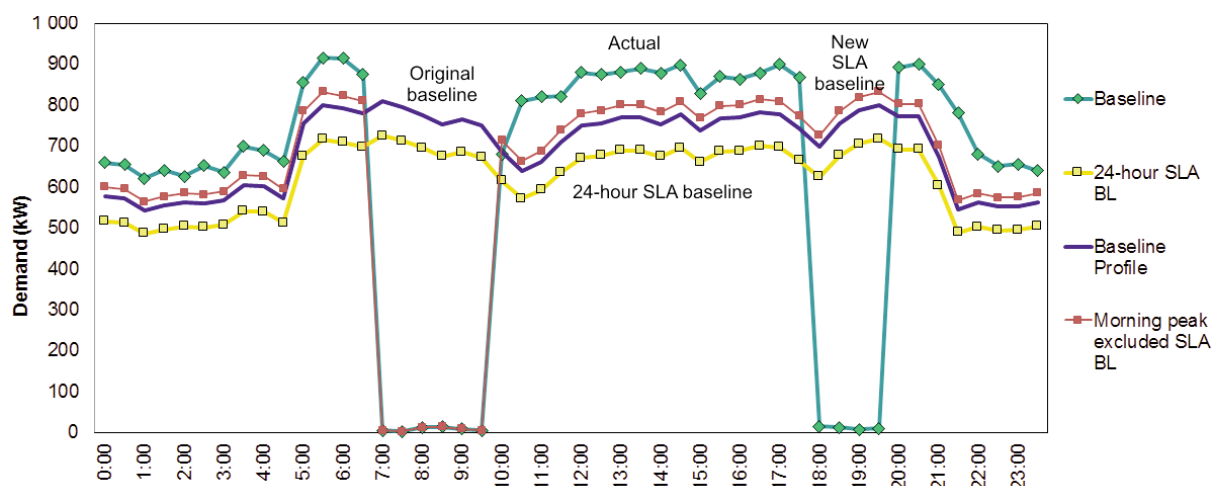


Figure 10: Original baseline, 24-hour neutral SLA baseline and new morning peak excluded SLA baseline and actual profile (Storm et al., 2008b).

- 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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MEASUREMENT & VERIFICATION OF THE ESKOM IRRIGATION PUMPING STANDARD PRODUCT PROGRAMME: EVALUATION OF CROP LOAD FACTORS

SAEEEC 2013

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ABSTRACT

Eskom Integrated Demand Management (IDM) also included irrigation in the Standard Product Programme (SPP) to cater for smaller irrigation Energy Efficient (EE) projects. The irrigation sector is a large energy consumer in South Africa and may have a large EE potential. The unique characteristics of irrigation projects create significant challenges for Measurement and Verification (M&V) under the SPP. Previous M&V studies assessed a large sample of irrigation pumping Variable Speed Drive (VSD) SPP projects. These assessments were conducted to verify project impact availability, project viability and achieved savings credibility. A further study was required to quantify attainable project impacts over the whole project life by incorporating crop Load Factors (LF). This paper focuses specifically on the evaluation and validation of crop LFs as well as its applicability and use in SPP irrigation projects. The evaluation was conducted through a comprehensive crop LF analysis. The aim of this analysis was to determine the typical LF of a large sample of real world pumps and compare these with the Eskom proposed crop LFs.

1 INTRODUCTION

The South African irrigation sector is a significant energy consumer with around 60 000 centre pivots. These may have a large potential for Energy Efficiency (EE), without even considering other irrigation methods such as sprinklers and micros. However, the average irrigation pump is relative small, which makes the attainable EE impacts also small. This makes normal M&V too expensive on such projects. An M&V case study was performed to evaluate the potential and applicability of SPP on the irrigation sector [1].

As part of the case study, the challenges with applying SPP to irrigation sector were investigated. Compared to other SPP technologies like lighting and heat pumps, irrigation projects is difficult and have a multitude of yearly varying variables that will influence the possible savings [1].

In older irrigation projects, the M&V of normal demand shifting already proved to be very difficult and

complicated [2]. Applying SPP takes this complexity even to the next level by implementing EE and not demand shifting [1]. In addition, no continues M&V metering will be done and the savings will be determined using a deemed approach - implying an informed estimated saving will be used for the life of the project. [1,2,3]

An M&V assessment was performed to verify project EE improvement impact availability, project viability and achieved savings credibility assessment on 19 sample sites [1]. From the assessment it was verified that definite and significant demand reductions were achieved with the implementation of VSDs to optimize the irrigation systems. The lowest demand reduction measured was 7.1% and the highest demand reduction measured was 71.6%. From all 19 case study sample pumps measured, the average demand reduction was 42.2%. [1]

With potential demand reduction impacts verified, the next step was to establish what the yearly average impact will be. The demand reduction results captured shows the attainable impact when the pump is running. However, the question now is how much that pump is operational during the year? This can be determined through crop LFs.

2 CROP LOAD FACTORS

The Eskom Irrigation Energy Advisor team [4] considered several methods to establish a representative LF for an irrigation pump. The troubling issue is the many factors and variables influencing the LF of an irrigation pump.

Considering an ideal situation with a single irrigation pump with one type of crop for a three year period, among other the following needs to be considered:

- Soil type (Sand soil requires much more water for instance);
- Climatic region;
- Typical rainfall for the specific farm (this is essential since it is commonly found that irrigation farms, only a few kilometres apart, can have significant average rainfall differences) – ‘barbwire phenomenon’ ;
- Irrigation practices of the farmer - this differs between farmers;

- Issues such as water restrictions; certain areas sometime experience green draughts although there is sufficient irrigation water available, but irrigation control boards still restrict water allocations; and
- Crop variants may also influence the amount irrigation water required; for instance certain sunflower variants are much more resistant to draughts than other variant types.

By considering the above only for a single pump and a single crop already stages a daunting task to establish the pump load factor. Typical irrigation setups are far from ideal with one pump irrigation several different crops with the switch of valves. Some irrigation lands are also planted with two types of crops in a year. With this, crop rotation practices are critical for healthy crop lands.

A specific method researched and tested by an Eskom Energy Advisor [5] was to use crop load factors. Through a specialised irrigation software programme SAPWAT incorporating 50 years the typical water requirements for a specific crop in a specific area and soil type can be calculated.

Calculations are done on comprehensive crop data and are used as an irrigation guidance tool by farmers across South Africa. Having the crop load factor and the irrigation system setup and characteristics for that crop, the load factor, typical power use and average demand required for that crop can be calculated.

Now, even if a single pump irrigates multiple crops, the overall (yearly average) LF of the pump can be calculated by combining the crop LF of each crop. This also allows for multiple crops on one irrigation land in a single year.

Apart from irrigation system characterisation, it was required from M&V to independently verify the application of crop LFs. M&V normally does verification by doing representative period measurements on a system establishing a typical baseline. Also, crop load factors can only be really tested when measuring the LF of a pump over several years.

In this case, it was out of the question. Even more so, SPP allows no measurements over the project life. An intuitive way is needed to evaluate the calculated crop load factors for an area without installing expensive metering.

3 EVALUTION OF CROP LOAD FACTORS

The evaluation was done through a comprehensive crop LF and pump LF analysis. The aim of this analysis was to determine the typical LF of a large sample of actual irrigation pumps and compare these with the Eskom proposed crop LFs.

The critical outcome of the analysis was to verify if the Eskom crop load factors are representative and conservative.

3.1 SAMPLE PUMPS AND DATA USED

It was a significant challenge to obtain the required kW demand profile data of enough sample pumps. Data (30min, kW profile data) was collected from M&V meters on old irrigation projects and Ruraflex points through the Eskom MV90 system.

Through much effort from the Eskom personnel [6,7], more than enough data was collected. The period used for the analysis is Sep 2008 till August 2012.

The period was respectively broken into the following four data year sets:

- Aug 2008 till Sep 2009;
- Sep 2009 till Aug 2010;
- Sep 2010 till Aug 2011; and
- Sep 2011 till Aug 2012.

Data in Mpumalanga and the Eskom Eastern region (KZN) were collected.

3.1.1 Mpumalanga Data

In Mpumalanga, M&V are involved with various irrigation projects since 2005. Of these projects the required info and kW profile data have been collected for more than four years. The irrigation projects included river pumps alongside the Crocodile River spanning from Machadodorp to Komatipoort and pump stations alongside the Lomati and Komati River. A few borehole pumps were also included in the total of 65 pumps/pump-stations that formed part of the study.

3.1.2 KZN Region Data

In Eastern Region (KZN) only data of Ruraflex points were available. From all the data collected, M&V was able to use 104 MV90 metering points for the LF analysis. The points included pumps stations in amongst other the following areas: Pietermaritzburg, Kokstad, Pongola, Greytown, Estcourt, Bergville, Colenso, Eshowe, Marina Beach, Harding, Underberg; Ixopo, Newcastle, Paulpietersburg, Ingagane, Nottingham Road, Empangeni and Margate.

3.2 DATA PROCESSING

Data was consisted of four year 30min demand profiles in Microsoft Excel files and text documents. The vast amount of data sets were scrutinised to check for faults and missing timestamps. Data credibility with sanity checks were also done, since data sets are in some cases corrupted due to metering faults. In cases where data were questionable, some periods or the complete measured points were discarded. [8,9]

The four year data of each point was processed in order to deliver average weekday, Saturday and Sunday daily profiles. The daily profiles were generated for each calendar month and each calendar month was accordingly allocated to the four data year sets. [8,9]

The daily data were also used to determine the weekday, Saturday and Sunday LF for each calendar month. From the three day types, the weighted average LF was determined. Having the LFs per day type, the farmer's pumping tendencies can also be evaluated. For instance, some farmers tend to only pump over weekends part of the year to benefit from the lower weekend tariffs on Ruraflex and Nightsave. Although not immediately relevant, the results from the daily LFs can be used to evaluate the typical available demand during the weekdays.

An important aspect to note is that instead of the installed capacity, the maximum operational capacity (utilization capacity) was used to calculate the LFs - thus the maximum demand of a pump station. Therefore, the study boundary was set around the power measured by the metering point since:

- In many cases the installed capacity information was not available or unreliable. Information of some pumps stated it to be a specific size (kW) although it was observed from the measured data to have a maximum demand of twice the installed capacity. Motors are often run above 100% of the nameplate installed capacity;
- Resistance is often experienced from the farmers on the supply of data and information of pump stations;
- Most of the MV90 point captures a whole pump-station and not individual pumps. These pump-stations frequently contain backup pumps and other less used maintenance pumps. Adding the installed capacities of these much less used pumps to the total installed capacity of the pump station will result in an inaccurate LF for the pumps that are actually used; and
- Details of changes to the pump stations over the four year period are not always available. The farmer may have changed the installed pump with another pump being a different size or expanded the station to contain more pumps.

The maximum operation capacity of a pump (or pump-station) was calculated on a monthly basis, yearly basis and for the whole four years. From this, changes in the operational capacity of each pump (or pump station) can be easily observed.

The final LF calculations were based on the yearly maximum operational capacity. Where installed capacities of individual measured pumps were available and reliable, the LFs were also calculated on the installed capacities.

4 MPUMALANGA LF AND CROP LF ANALYSIS

The first area considered for evaluation was Mpumalanga, specifically the Lowveld where several old Eskom DSM load shifting projects were implemented. The Mpumalanga evaluation was later followed by the Eastern region (KZN) analysis. The following sections give the results for Mpumalanga.

4.1 MPUMALANGA LF ANALYSIS RESULTS

Table 1 provides the results of the LF analysis performed on the 65 points over the four year period. A breakdown was made to distinguish between the results of Ruraflex and non-Ruraflex points (Landrate and Nightsave). It is important to note that only 16 non-Ruraflex points were measured and therefore not statically representative of all Mpumalanga non-Ruraflex points. However, it does give an indication of the typical LF that can be expected. On the Ruraflex points an average LF (based on maximum demand) of 0.248 (24.83%) for the whole period September 2008 to August 2012 was calculated. The LF (also based on maximum demand) of the non-Ruraflex points were considerably lower at 0.155 (15.5%). The weighted averages of all the points were 0.227 (22.65%).

Table 1: Mpumalanga yearly LFs calculated

Period	Ruraflex	Non-Ruraflex	All
Sep 2008 to Aug 2009	0.260	0.150	0.231
Sep 2009 to Aug 2010	0.257	0.137	0.228
Sep 2010 to Aug 2011	0.233	0.142	0.211
Sep 2011 to Aug 2012	0.267	0.200	0.251
Whole Period	0.249	0.155	0.226

Here it is important to note that due to the large sample of pump stations evaluated; statistically the variety of crops irrigated in the area is probably addressed through random pump selection. The next steps are to treat the Eskom proposed LFs and the calculated pump station LFs as comparable commodities.

This can be done by dividing LFs found into a scale. This scale is divided into 0.1LF increments. For instance if a LF of 0.03 was found, it was divided into the 0 to 0.1 increment. All LFs above 0.6 were allocated to one increment. Figure 1 to Figure 4 gives bar charts, visually displaying in which LF increment the amount of calculated LFs (of the different points) fall. Figure 1 shows that 8.3% of all the measured LFs are in the range 0 to 0.1 and 36.7% is in the range between 0.1 and 0.2. In the 0.2 to 0.3 range 36.7% of the pumps LFs are seen.

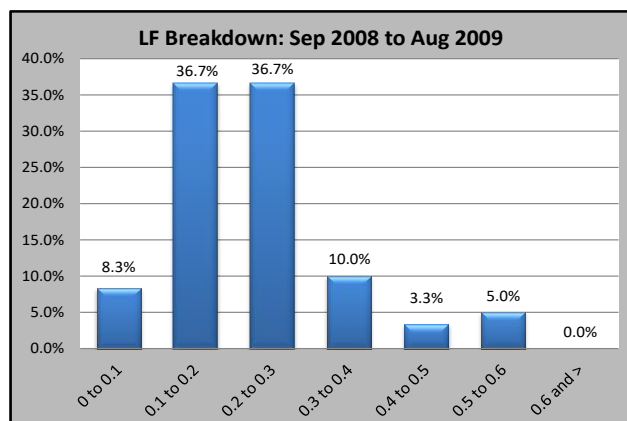


Figure 1: LF breakdown for Sep 2008 to Aug 2009

In the year Sept 2008 to Aug 2009 no LFs above 60% was seen. Figure 2 to Figure 4 gives the results of the three other year sets while Figure 5 provides a summary of the whole four year period.

From Figure 5 it can be seen that for the whole four year period, 34% of the pump LF's fell in the range 0.1 to 0.2 and 32% in the range 0.2 to 0.3. Only 11% of the LFs were below 0.1, while 23% were above 0.3. Less than 1% on average was above 0.6.

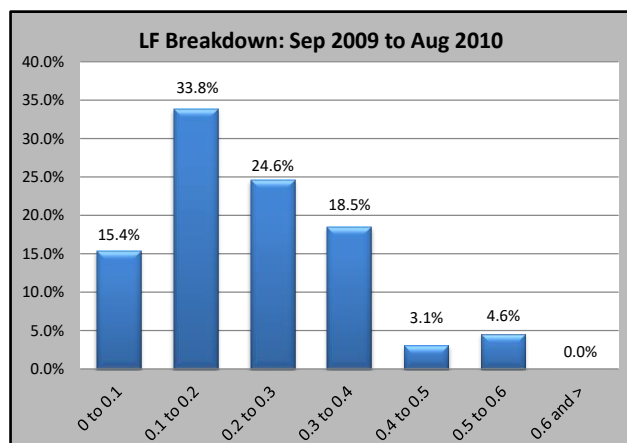


Figure 2: LF breakdown for Sep 2009 to Aug 2010

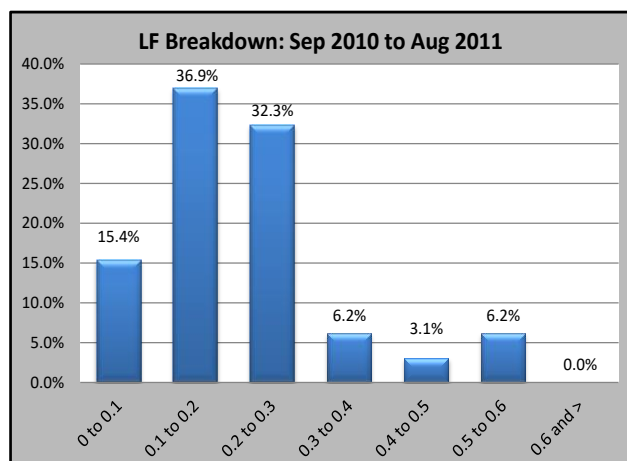


Figure 3: LF breakdown for Sep 2010 to Aug 2011

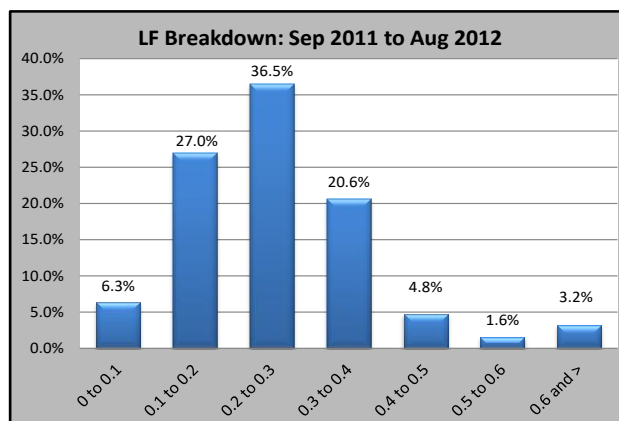


Figure 4: LF breakdown for Sep 2011 to Aug 2012

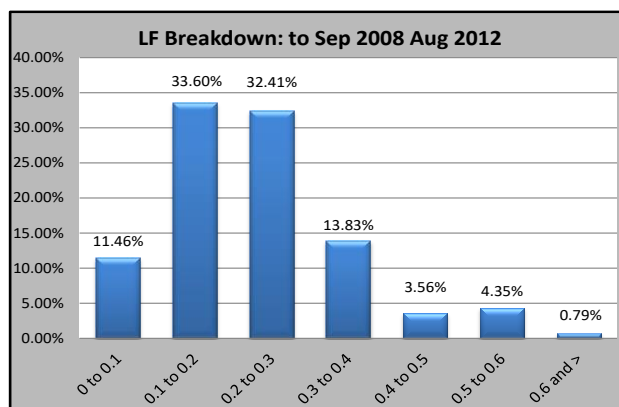


Figure 5: LF breakdown for Sep 2008 to Aug 2012

4.2 ESKOM PROPOSED CROP LOAD FACTORS

Table 2 list the Eskom proposed crop LFs for different type of crop planted in Mpumalanga. Figure 6 shows an analysis of the percentage of crop LFs that falls in the different 10% increments. This bar chart also compares the Eskom proposed crop LFs and the measured MV90 LFs. Evaluating the bar chart, it is seen that 50% of the proposed crop load factors conservatively fall within the 0.1 to 0.2 range.

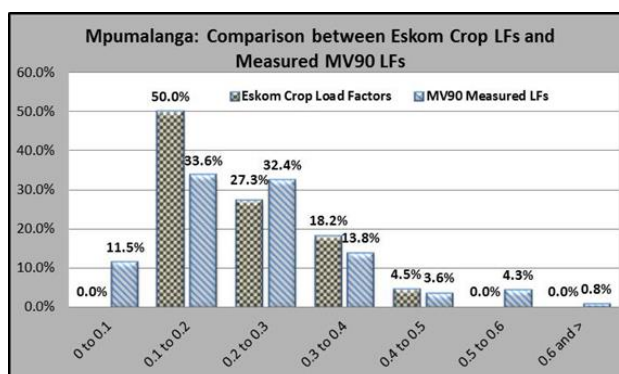


Figure 6: Mpumalanga Eskom Crop LFs and MV90 LFs

Further, 27% fall within the 0.2 to 0.3 range and only 23% is above 0.3. The biggest proposed LF, according to Figure 6, is 0.4 for tomatoes. Overall, the results show that the proposed Eskom LFs are representative, but

conservative of the typical LF (according to max demand) seen in the field. The overall weighted average measured LF in Mpumalanga is 0.231, while the overall proposed Eskom crop LF is 0.226.

Table 2: Eskom crop load factors for Mpumalanga

CROP LOAD FACTORS - MPUMALANGA	
Crop	Annual Load factor with rain
Beans	0.18
Cabbage Crops (Summer)	0.13
Cabbage Crops (Winter)	0.13
Citrus & Subtropical Fruit	0.35
Cotton	0.19
Grapes	0.25
Green Peas	0.13
Groundnuts	0.20
Lucern	0.28
Maize	0.18
Nuts - Almonds	0.21
Nuts - Pecan	0.15
Onions	0.21
Planted Grazing (Perennial)	0.22
Planted Grazing (Seasonal)	0.28
Potatoes	0.31
Soft Fruit (Ave)	0.35
Soya Beans	0.16
Tendrils crops	0.11
Tomatoes	0.40
Vegetables	0.36
Wheat	0.18

5 KZN LF AND CROP LF ANALYSIS

Similar to Mpumalanga, a LF analysis was also conducted for the KZN province.

5.1 KZN LF ANALYSIS RESULTS

Table 3 provides the results of the LF analysis performed on the 104 point over the four year period. Unlike the Mpumalanga analysis, only data from Ruraflex points were available. Therefore no analysis was performed on Landrate points. Of all the Ruraflex points an average LF (based on max demand) of 0.213 (21.29%) for the whole period September 2008 to August 2012 was calculated.

Table 3: KZN yearly LFs calculated

Period	Ruraflex
Sep 2008 to Aug 2009	0.223
Sep 2009 to Aug 2010	0.228
Sep 2010 to Aug 2011	0.183
Sep 2011 to Aug 2012	0.234
Whole Period	0.213

5.2 ESKOM PROPOSED CROP LOAD FACTORS

Table 4 lists the Eskom proposed crop LFs for different types of crops planted in KZN. Just as for Mpumalanga,

Figure 7 shows a bar chart breakdown of the measured MV90 percentage crop LFs compared with the Eskom proposed crop LFs. Only looking at the MV90 LFs, it can be seen that 8% is in the 0 to 0.1 range and 59% of the proposed crop load factors conservatively fall within the 0.1 to 0.2 range. Further 33% fall within the 0.2 to 0.3 range and no LFs above 0.3.

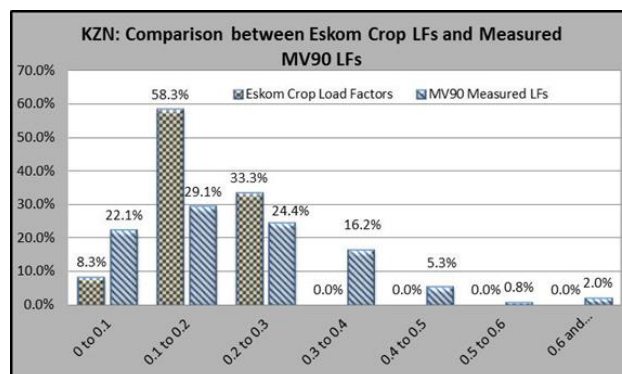


Figure 7: Bar-chart comparing Eskom Crop LFs and measured LFs

The biggest proposed LFs according to Table 4 are 0.27 for cassava and potatoes. The overall average measured LF in Mpumalanga is 0.213, while the overall proposed Eskom crop LF is only 0.174.

Table 4: Eskom crop load factors for KZN

CROP LOAD FACTORS - Eastern Region	
Crop	Annual Load factor with rain
Beans	0.17
Cabbage Crops (Summer)	0.08
Cabbage Crops (Winter)	0.12
Cassava	0.27
Citrus & Subtropical Fruit	0.23
Cotton	0.15
Grapes	0.17
Green Peas	0.11
Groundnuts	0.15
Lucern	0.21
Maize	0.15
Nuts - Almonds	0.17
Nuts - Pecan	0.06
Planted Grazing (Perennial)	0.19
Planted Grazing (Seasonal)	0.23
Potatoes	0.27
Soft Fruit	0.22
Soya Beans	0.15
Sugar Beet	0.19
Sugar cane	0.21
Tendrils crops	0.12
Tomatoes	0.15
Vegetables	0.24
Wheat	0.15

By comparing the Eskom crop LFs and the MV90 measured LFs, overall the results show that the proposed Eskom LFs are representative but conservative. The Eastern region Proposed LFs is more conservative than Mpumalanga proposed LFs.

6 CONCLUSION

The South African irrigation sector is a significant energy consumer which may have a large potential for Energy Efficiency (EE). However, these are all small EE impacts making normal M&V too expensive for these projects. Therefore an M&V case study was performed to evaluate the potential and applicability of SPP on the irrigation sector and the M&V thereof. An M&V assessment on 19 irrigation sample sites verified that definite and significant demand reductions can be achieved with the implementation of VSDs. The next step was to determine how much a pump is operational during the year?

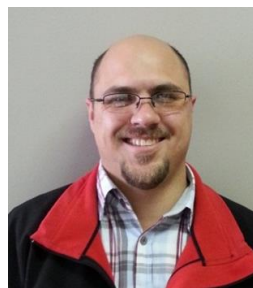
A specific method researched and tested by an Eskom Energy Advisor was to use crop LFs through a specialised irrigation software programme called SAPWAT. It was required from M&V to independently verify the application of crop LFs to SPP. Normal M&V measurements was not an option and an intuitive way needed to be found, to evaluate the calculated crop load factors for a specific area. This evaluation was done through a crop LF and pump LF analysis determining the typical LF of a large sample of actual irrigation pumps and comparing these with the Eskom proposed crop LFs. The critical outcome of the analysis was to verify if the Eskom crop load factors are representative and conservative.

In Mpumalanga a total of 65 pumps and in KZN a total of 104 pumps and or pump-stations formed part of a LF study. A total of four years data of each point was processed in order to determine the weekday, Saturday and Sunday average LF for each calendar month. Comparing the Eskom crop LFs and the MV90 measured LFs, the results show that the proposed Eskom LFs are indeed representative, but conservative. The overall average measured LF in Mpumalanga is 0.213, while the overall proposed Eskom crop LF is only 0.174. The KZN proposed LFs is more conservative than Mpumalanga proposed LFs.

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Presenter: The paper is presented by Markus Storm

MEASUREMENT & VERIFICATION OF THE ESKOM IRRIGATION PUMPING STANDARD PRODUCT PROGRAMME

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ABSTRACT

Eskom Integrated Demand Management (IDM) initiated a funding mechanism termed the Standard Product Programme (SPP) to cater for smaller Energy Efficient (EE) projects. The impacts of these projects also need to be assessed though the Measurement and Verification (M&V) role has reduced to a mere verification and assurance function. The irrigation sector is a large energy consumer and in South Africa there is around 60 000 centre pivots alone. Not even considering other irrigation methods such as sprinklers and micros, there may be a large potential for energy efficiency. However, the average irrigation pump is relatively small which makes normal M&V too expensive for the possible attained savings. Therefore these small irrigation pumps also need to be engaged under SPP. M&V performed on normal load shifting irrigation projects with full M&V already proved to be a challenge in the past. Moving to EE irrigation projects the M&V process is further complicated. Having irrigation EE projects under the SPP topology, is a very daunting challenge. Before Eskom can start with the Standard Product Irrigation Programme (SPIP), it is first necessary for M&V to assess the practicability of irrigation energy efficiency projects under the SPP. Therefore a significant sample of irrigation pumping projects were assessed with case studies in order to verify project impact availability, project viability, achieved savings credibility and also long term sustainability.

1. INTRODUCTION

The Eskom SPP technologies are limited to lighting, heat pumps and efficient shower heads with the irrigation pumping sector now under investigation. The rules of this funding mechanism dictate that a certain incentive is paid to participating parties based on using standard EE technologies to replace standard old technologies and the resulting energy savings achieved. These projects are limited to a daily saving size of 250 kW or less [1]. Since all public funding mechanisms need to show credibility in such spending activities M&V have to be applied to projects making use of this funding mechanism. Since the impacts are too small to warrant the normal M&V cost, the role of M&V has reduced to a mere verification and assurance function; establishing credibility in the results as presented in the SPP toolkit. Eskom [2] developed this Toolkit as a clear guiding tool to assess and calculate savings for SPP projects. This toolkit was also scrutinised by the NWU M&V team to assess its credibility. Applying the SPP to projects like EE lighting replacement in a building is fairly easy and accurate. There are only two key variables to

consider, the kW reduction of each light replaced and the lighting operational hours (which are relatively fixed). From this, a very good and representative estimation can be calculated to establish a deemed savings value.

However, when considering irrigation projects, there are a multitude of yearly varying variables that will influence the possible savings. The M&V of normal demand shifting irrigation projects under IDM already proved to be very difficult and complicated in the past [3]. Now the planned SPIP takes this even to the next difficulty level by implementing EE and not demand shifting. Accurate EE M&V requires the measurement of continuous kW demand profiling with an energy driver such as flow. The biggest hurdle for SPIP is that no continuous M&V metering will be done to evaluate project performance over the project life. The savings will be done following a deemed approach – implying an informed estimated saving will be used for the life of the project.

It was the task of the NWU M&V team with the assistance of the Eskom Irrigation Energy Advisor (EIEA) team [4] to find a way to implement SPP on the irrigation sector, but still having credible and accurate M&V results. It was the priority of M&V though to independently establish the following:

- If there are indeed irrigation energy inefficiency practices present on South African farms;
- What EE initiatives can be implemented and which are sustainable over the project life (three year period). What are the potential impacts if these inefficiency practices are improved;
- What M&V approach can be followed to evaluate these EE initiatives - What are the variables and drivers which will influence energy use and what method can be followed to determine the M&V savings over the project life.

These points are required to verify project impact availability, project viability, achieved savings credibility and also long term sustainability of project impacts.

2. IMPACT AVAILABILITY

The EIEA team are busy for the past two years attempting to establish an Eskom programme for irrigation demand reduction and EE. From their involvement and analysis performed, several areas were unveiled to initiate possible energy savings. Figure 1 and Figure 2 shows examples of irrigation inefficiency found by the EIEAs:

- Pump motor - Under or oversized motor leading to poor Power Factor (PF). Motors are old and inefficient with motor bearings worn.
- Pump set - Inefficient pumps with flow restrictive manifolds and leaking pump seals and valves. Pump choking practices and cavitation. Incorrect suction pipes and layouts with wrong pump line-up or orientation. Incorrect eccentric couplings or damaged couplings.
- Mainline and distribution pipes - Diameters of main lines are too small. Leaking mainlines. Unnecessary friction due to poor design.
- Centre pivot - Leaking pipes, nozzles and drain valves. System pressure too high. Faulty sprayers are replaced with incorrect sprayers and faulty sprayer pressure regulators are not replaced. Over irrigation.



Figure 1: (a) Leaking pump seals. (b) Leaking sprinkler tubes. [4]

Considering these and other information gathered by the EIEAs, it appears that there are many possibilities for improving EE on irrigation systems. It was the responsibility of M&V independently to assess the viability of EE improvements, project impact availability and project credibility.



Figure 2: (a) Restrictive manifold. (b) Over Irrigation. [4]

3. AVAILABILITY AND VIABILITY ASSESSMENT

The best way to verify EE project availability and viability is to perform site visits on a sample of repressive farms. During these site visits the M&V team performed audits on the farms with putting emphasis on the five points listed in Section 2. Meetings were held with the farm owners or farm managers so that M&V can directly discuss the farm's irrigation operations. Through this a high level assessment was performed on the farmer's general pumping efficiency awareness. After the meetings several pump stations were visited during which M&V could investigate the pumping

equipment and irrigation system to assess EE project availability and also the viability of such a project. Several farms (part of a sample) were visited in the following areas and provinces:

- Bergville, Empangeni and Estcourt - (KZN);
- Malalane, Shoemanskloof, Komatipoort and Middelburg - (Mpumalanga); and
- Groblersdal, Marble-hall and Thabazimbi - (Limpopo).

From these site visits, pumping operation audits and meetings with the farmers it was confirmed that energy is indeed wasted at a large scale in the irrigation sector. Now considering the amount of pivots (around 60 000) in South Africa, a large EE impact can be made by the irrigation sector [5]. Although the above list will each lead to energy savings (water savings also directly leads to energy savings) it is very difficult to establish the exact energy savings. This is especially the case where multiple EE initiatives will be implemented or where irrigation operation methods are improved.

4. ENERGY EFFICIENT METHODS THAT CAN BE IMPLEMENTED

The number of areas to improve EE on a single irrigation system complicates the M&V process necessary to quantify the savings. The inefficiency practices listed in section 2 can be divided into the three groups:

- Group 1: Water losses - Leaks in irrigation system.
- Group 2: Incorrect irrigation practices - Over irrigation.
- Group 3: System design – inefficient pump system design and setup.

The question at hand was what EE initiative can be implemented on which group for the SPP that will lead to measurable and sustainable energy savings over the project life with a high confidence level. Since M&V only report on conservative savings a lower confidence level will directly results on lower savings reported.

Considering Group 1, water leaks can be fixed to prevent water losses. However, there is no guarantee that the system will be maintained and that new leaks will be attended to by the farmer. When considering Group 2; even if the farmer is introduced to more effective irrigation methods and provided the technology; there is no easy measurable guarantee that the farmer will keep using the efficient practices.

Considering Group 3; system design improvements can lead to measurable savings and a considerable confidence level. With these improvements the farmer will save energy when the pump is used for all normal pumping practices. A combination of the groups further increases the initial savings assessment complexity and should be avoided at this stage. It was therefore decided between the Eskom energy advisors and M&V that the current irrigation SPP will only focus on Group 2 EE improvements. More specifically the main focus will be to implement Variable Speed Drives (VSDs) through which the pumping system can be optimised and energy savings can be achieved.

Following this decision several test was engaged by the energy advisors and VSDs where installed by ABB [4] for evaluation purposes. With this the credibility of savings achieved with a VSD needed to be investigated and assessed by M&V. This was done by evaluating case studies on 19 VSDs that were implemented on farms.

5. CREDIBILITY ASSESSMENT OF PROJECT IMPACTS - CASE STUDIES

It is important to note that a VSD on its own will not necessarily improve EE. The VSD however is the 'tool' enabling EE which is not possible with standard pumping equipment. The case studies assessed the before EE project demand availability and the demand reduction results obtained through the VSD EE intervention. This was done on farms in the areas listed in section 3. During the assessments, the type of farming activities and crops planted were also investigated. With this the irrigation water supply (in order to consider water restrictions etc.) and type of irrigation systems were noted. Measurements included the before and after implementation instantaneous demand with a full irrigation cycle demand profile. The following section describes and discusses one of the case studies performed. Farm details were omitted to lessen detail provided in this article.

5.2 CASE STUDY 1 – GROBLERSDAL AREA

The farm is located in the Groblersdal area and farming activities include the cultivation and irrigation of summer and winter crops namely citrus, tobacco, maize; winter wheat and pastures. Irrigation water is drawn from balancing dams fed from a canal forming part of the Loskop Dam irrigation scheme. The scheme is controlled by the Loskop Irrigation Board and pre-approved water quotas are delivered to their end users annually [6]. Figure 3 shows a Google Earth satellite view of the farm layout with the different centre pivots and pump stations. Notations on Figure 3 denote: P - centre pivots, B - citrus and other crop under micro irrigation in blocks, and E - pump stations.

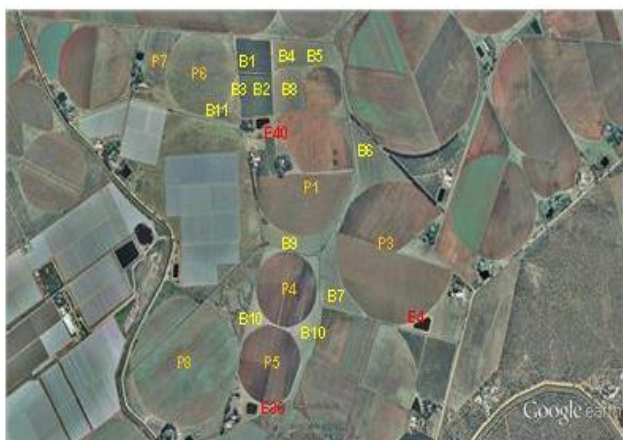


Figure 3: Google Earth satellite view Groblersdal farm

Data was gathered by a EIEA [6] before and after the project implementation. The M&V Team performed a pre-implementation site visit and a post-implementation

credibility site visit to do measurements and verify all information collected.

The M&V team also had private discussions with the farmers during which the pre-installation pumping conditions were discussed. This case study investigates three pump stations on the farm. The first pump station is discussed in more detail to show what the M&V assessment involved and what tests was performed. The assessments of the other two stations are only summarised. Although not only VSD EE indicatives were done at the pump stations, the focus of the case study was only evaluating the impact the VSDs enabled. At all three pump stations an Elster 1140 meter was installed for M&V measurements. Tests were performed on these meters to check the installation and if the data gathered by the meter can be used for M&V purposes.

5.2.1 Pump station E36

Within pump station E36 the existing old 30 kW motor was replaced with a new EE motor. Also the Star-Delta starter was replaced with a VSD. Figure 4 shows the outside of pump station E36. The EIEA collected information and data before and after the installation with the Elster meter and a temporary Fluke power logger. The first M&V credibility assessment was performed to verify the data collected and information. The Elster meter Fluke power logger was verified with a calibrated M&V handheld meter as shown Figure 5.



Figure 4: Pump station E36

After verification of the data and meter installation credibility, the pre and post implementation conditions could be measured. Although the VSD was already installed, it is possible to bring the system back to pre-implementation conditions. This is done by bringing the motor operation back to baseline conditions by setting the VSD on 50Hz and returning the valves to the original chocking settings with the original system pressures. Following this approach excludes the demand reduction due to the new EE motor installed and only shows the improvement the VSD enables. In Figure 6 the centre pivot is shown running on baseline type conditions. In Figure 6 the centre pivot is shown running on baseline type conditions.



Figure 5: (a) Measurements done by M&V with a calibrated handheld meter. (b) Fluke power meter-measurements compared with M&V meter.

As commonly found, the centre pivot is over-pressured resulting in the sprinklers creating a fine mist. This fine mist is very inefficient since it increases the amount of water that evaporates and the pump motor has a higher load. It was observed that irrigation engineers normally overdesign a system (especially the case with older systems) and in most cases also over-spec the pressure required at the centre pivot.



Figure 6: Before conditions - Centre pivot over pressured resulting in fine mist

Operational values gathered are listed in Table 1. During test two the system was set to an optimised condition by reducing the motor speed with the VSD so that valves can be opened 100%. The VSD now controls water delivery, thus no more chocking of the pump. Also the pumping system is optimised for effective but efficient irrigation by reducing centre pivot pressure to an optimum level. In Figure 7 the centre pivot pressure was significantly reduced to an optimum level changing the water mist to larger droplets. These larger droplets have less 'in flight' evaporating compared with the mist. The lower pressure and thus less water irrigated results in direct demand reduction. The VSD operated on 37 Hz which is a 26% reduction in the motor speed.

The demand profiles gathered by the metering needed to be analysed and compared with the instantaneous demand readings. Figure 8 show a 53 hour full cycle before and after demand profile over an irrigation period wherein all the different pumping conditions/cycles were captured. Since the pumping before and after cycle lengths are identical, the two demand profiles were put onto one graph for comparison. The lined area between the profiles indicates the difference.



Figure 7: After conditions - Centre pivot correctly pressured, fine mist significantly reduced

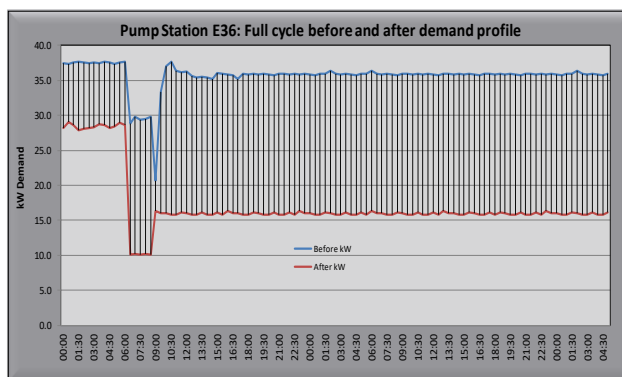


Figure 8: Full cycle before and after demand profile

The before demand profile starts at around 37 kW then for a while drop to around 29 kW and then for the rest of the period stays around 36 kW. The three different demands observed are the pump irrigating three different crops. A significant demand reduction is observed over the full irrigation cycle. Instantaneous values of the before and after measurements are listed in Table 1.

5.2.2 Pump station E4

Similar to pump station E36 the motor was replaced and the Star-Delta starter was replaced with VSD. Figure 9(a) shows a distant view of pump station E4 visited by the M&V team while Figure 9(b) gives a closer view showing the VSD enclosure, new pump motor and Elster meter.



Figure 9: (a) Pump Station E4 visited by M&V Team. (b) VSD enclosure, new pump motor and Elster meter.

From the site similar energy saving opportunities as with pump station E36 was seen. Just as with the with centre pivot, the micro irrigation system was also over-pressured before the EE intervention. The VSD was used to fully open all valves and optimise the water pressure to an effective

level. Figure 10 shows a full irrigation cycle before and after demand profile of the pump. Demand profiles were also measured before the installation and after the installation long enough to capture the full irrigation cycles for pump station E4.

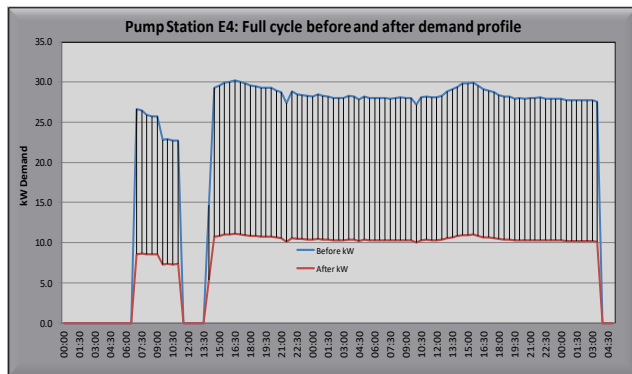


Figure 10: Pump Station E4 full cycle before and after demand profile.

Since the pumping cycle lengths was also identical, the demand profiles of a before and after cycle was put onto one graph for comparison. Different pumping scenarios are observed since the pump also irrigates different crops. Variation is also observed in the demand a specific crop requires. This is a result of the centre pivot irrigation areas in the crop circle that is more elevated. See Table 1 for the before and after conditions instantaneous values kW values measured.

5.2.2 Pump station E40

Pumps station E40 houses two pumps. The old 30kW motor was kept in place while the Star-Delta starter was replaced with a VSD. The 55 kW motor was replaced with a new motor and the Star-Delta starter replaced with a VSD.

With this, a new pump was installed and changes in the irrigation pipe work were done. Figure 11 and Figure 12 respectively show a full irrigation cycle for the before and after demand profile of the two pumps. Table 1 also list the instantaneous before and after kW values measured.

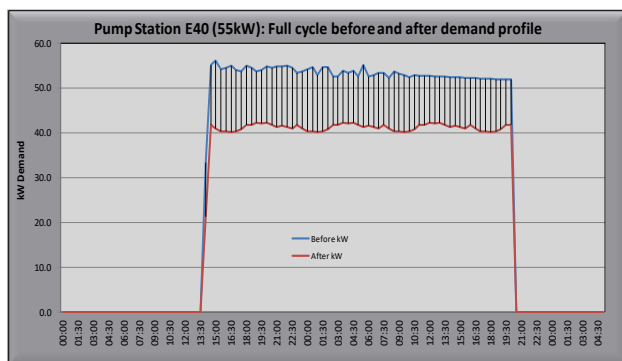


Figure 11: Pump Station E40 full cycle before and after demand profile – 55 kW pump

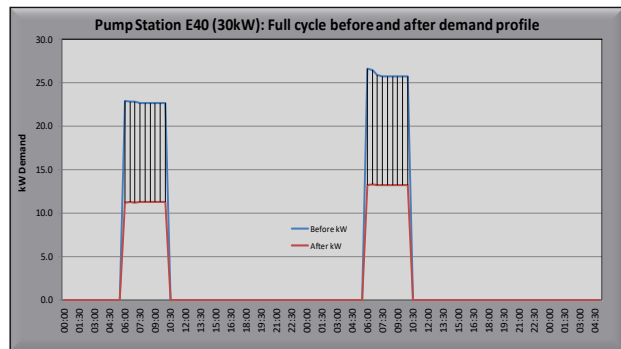


Figure 12: Pump station E40 full cycle before and after demand profile – 30 kW pump

6. CREDIBILITY ASSESSMENT RESULTS

The EE improvements, project viability, data and results proved to be credible after the M&V assessment on the 19 sample sites. M&V was satisfied with the measurements taken and verified the accuracy of the measurement equipment used by the energy advisors. There is a definite and significant demand reduction achieved with the implementation of a VSD to optimization the irrigation system. Similar evaluations and tests as in section 5 were done on all 19 pumps assessed during the case studies. The measurements taken during the entire credibility assessment are summarised in Table 1.

Table 1: Pump station E36 details

Area & Province	Pump station and installed pumps	kW Before	kW After	Hz (Frequency)	Instantaneous demand reduction	
					(kW)	(%)
Groblersdal, Limpopo	P36 (30 kW)	36	16	37	20	55.6%
	E4 (30 kW)	27.5	11.3		16.2	58.9%
	E40 (55 kW)	54	42		12	22.2%
	E40 (30kW)	23	13		10	43.5%
	P1 (30 kW)	34.4	14.7	36.7	19.7	57.3%
	P1 (30kW)	32	16.9	41	15.1	47.2%
	P17 (22 kW)	25.7	7.3	35	18.4	71.6%
Middelburg (Mpumalanga)	P17 (75 kW)	66.8	30.8	38	36	53.9%
	Dam pump (110 kW)	99	53.2	39.9	45.8	46.3%
Colenso (KZN)	75 kW	74.9	50.7		24.2	32.4%
	75 kW	62.4	40.8		21.6	34.6%
	75 kW	61.7	44.1		17.6	28.5%
Mooirivier (KZN)	37 kW	38.1	35.4		2.7	7.1%
Thabazimbi (Limpopo)	P1 (30 kW)	46.8	28.8	41.7	18	38.5%
	P2 (30 kW)	51	25.3	37.1	25.7	50.4%
	P3 (30 kW)	68.7	33.5	42.7	35.2	51.2%
	P4 (30 kW)	46.4	31.4	37.1	15	32.3%
	P5 D(30 kW)	45.8	33.7	39.7	12.1	26.4%
	P6 (30 kW)	44.6	25	37.5	19.6	43.9%

The before and after EE intervention instantaneous kW readings are listed since in not all cases profiles were available. The frequency to which the VSD was set is listed in the fifth column. The two last columns in Table 1 give the kW impact and also the percentage demand reduction. The lowest demand reduction was seen at a Mooirivier pump (7.1%) and the highest demand reduction was seen at P17 Groblersdal area (71.6%). On average there was a 42.2% demand reduction measured over all 19 pumps.

7. SUSTAINABILITY ANALYSIS

Part of the case study credibility assessment the long term sustainability of the VSD irrigation EE initiatives was also analysed. The M&V team had discussions with the farmers on their historic farming activities and also what they plan to cultivate in following years.

It is important to investigate if the savings achieved will be maintained. In addition to this several sample pump stations will be evaluated for the life of the SP project to verify through actual measurements if savings still achieved.

8. CONCLUSION

From the M&V Credibility site visits, pumping operation audits and meetings with the farmers it was confirmed that energy is wasted at a large scale. This was observed in areas ranging from pump motor and pump set inefficiency to centre pivot and irrigation operation inefficiency. Different M&V credibility assessments was performed with the first verifying the data collected by the Eskom Energy Advisor. The permanently installed onsite Elster meters and temporary installed Fluke power logger were verified with a calibrated M&V handheld meter. The readings of the Fluke and Elster meters exactly correlated to that of the M&V meter.

With this next credibility check was to compare the instantaneous M&V demand readings of the baseline conditions with the demand profile gathered by the Eskom energy advisor. These compared very well and the small variations found may be the result of the centre pivot being in another position. The post implementation M&V measurements also compared very well with the data gathered by the Eskom energy advisors.

The proposed EE improvements, project viability, data and results proved to be credible after the M&V assessment on the sample sites. There is a definite and significant demand reduction achieved with the implementation of the VSD and system optimization via the VSD. The lowest demand reduction was measured was 7.1% and the highest demand reduction measured was 71.6%. From the 19 case study sample pumps measured average demand reduction was 42.2%.

The credibility assessment determined that there are definite demand reductions and therefore energy savings when the pump is operational.

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Currently he is involved in M&V projects varying from irrigation pumping to CDM CFL projects and measurement system development



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as a senior lecturer specialising in energy engineering, electrical machines and control at the North-West University. The Engineering Council of South Africa (ECSA) registered him as a Professional Engineer and the SAEE certified him as CMVP.

Co-author: LJ Grobler holds Ph.D. degree in a mechanical engineering and is a professor at the School for mechanical and materials engineering, and also the North-West University engineering faculty Dean. He specialises in M&V and in energy management and process energy optimisation. He is certified by the SAEE as a Certified Energy Manager (CEM) and a CMVP.

Presenter: The paper is presented by Markus Storm.

MEASUREMENT AND VERIFICATION OF AN IRRIGATION PUMPING PROJECT: CASE STUDY FOLLOW-UP

ME. Storm, C.A. van der Merwe and Prof LJ Grobler
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ABSTRACT

This paper takes the reader through the M&V process and its various challenges experienced by the NWU M&V Team while performing the M&V activities on a DSM irrigation pumping load management project. The objective of the DSM project was to implement load control systems to shift the irrigation pumping load of a farming community. This was done so that all pumping activities are operated outside the Eskom evening peak periods from Monday to Friday.

1. INTRODUCTION

The Measurement and Verification (M&V) of Demand Side Management (DSM) projects have typical challenges and problems that complicate, and even sometimes hamper the M&V process. This is also the case with irrigation pumping DSM projects. However, the M&V team experienced an exceptionally difficult time to perform M&V on a specific project.

The project is distributed over a large rural area and includes more than 300 pumps. M&V was faced with problems from finding or reaching pumps stations to cable theft, various metering problems and even snake and hippo infested pump stations. The following sections describe the M&V process and the challenges experienced by the NWU M&V Team while performing the M&V activities on this project.

2. DSM PROJECT BACKGROUND

The objective of this Demand Side Management project was to implement load control systems to shift the pumping load so that all pumping activities are operated outside the Eskom evening peak periods from Monday to Friday. These impacts needed to be assessed in order to verify the DSM impacts and savings for the client, the ESCO and Eskom.

The project was implemented in a region with over 120 farms with a total of 314 pumps. The pumps are spread over a large rural area of approximately 13 000 Ha and are used to pump water from numerous boreholes, canals and rivers. See Figure 1 for a partial satellite view of the project region. The project region is much wider than the part shown in Figure 1.

The water allocation for the farmers in the region is controlled by an Irrigation Board. The Board allocates more than 85 000 000 m³ water per year. Each consumer has water rights allocated which may be

pumped during scheduled periods for irrigation purposes.



Figure 1: Partial satellite view of the project region

The pump stations are often situated in inaccessible rural areas. Many pump stations are located near the river or next to holding dams. Figure 2 and Figure 3 shows two such pump stations.



Figure 2: Pump station next to a holding dam (home to a hippopotamus)

It is dangerous to visit a large number of the pump stations since snakes, bees and other hazardous creatures and elements are regularly found.

The holding dam in Figure 2 for instance houses a hippopotamus and the pump station in Figure 3 can only be reached with difficulty over slippery rocks. These and other circumstances complicated the M&V process and required a unique M&V strategy.



Figure 3: Pump station at the river

3. M&V STRATEGY

The project was analysed and classified according to the guidelines set out in the M&V Framework [1]. Only the irrigation pumps are affected by the DSM Project, therefore the M&V project boundary only included the pumps and their motors.

This project had the following classification:

The "Post" Requirement may be used for the baseline implying that the same amount of water still has to be pumped after implementation than before implementation. This may be done because the measures implemented are considered to have no impact (do not change in anyway) the Requirement of the system.

It was consequently accepted that any variation in Requirement occurring after the implementation of the DSM measure would have occurred anyway. In addition to the abovementioned characteristic, this project is also characterised by the following:

1. The "Post" Operating Hours may NOT be used for the baseline.
2. The implementation of the DSM measure has resulted in a change in system efficiencies.

This implies that the measures implemented are considered to have impacted (changed) the Operating Hours of the system. It is consequently necessary to determine a baseline for the Operating Hours.

Therefore, this M&V plan focused its efforts in the following areas:

- Determining a baseline for the Operating Hours of the system -- pre implementation.
- Determining the Operating Hours of the system -- post implementation.
- Determining the Load/Requirement of the system -- post implementation.

4. BASELINE DEVELOPMENT

4.1 BOUNDARIES OF THE BASELINE MODEL

The boundaries of this project include the electricity use and consumption of the pump stations. The selected sample of pump stations represents the total electricity demand and consumption of all the pumps in the region.

4.2 BASELINE DEVELOPMENT

A baseline represents what the electricity usage would have been without the DSM project intervention. To develop the baseline and calculate the project impacts for this project, it is necessary to quantify the following variables:

- The actual operating hours of all the pumps prior to implementation, and
- The actual operating capacity of all the pumps prior to implementation.

4.3 PRE-IMPLEMENTATION METERING EQUIPMENT USED AND DATA ACQUIRED

The pump stations captured in the project are hard to reach by using rough dirt roads. It is very difficult and would be too expensive to measure each pump included in the project. In addition, the conditions of much of the pump stations are not suitable to house M&V metering. Some pump stations consist of only a metal plate suspended with four droppers in the open veldt. See Figure 4.



Figure 4: Pump station in the open veldt

There were two metering attempts performed on the project. However, the first proved to be a costly, time consuming and unsuccessful exercise.

4.4 ATTEMPT 1 – ON/OFF LOGGERS

The first attempt to measure the operating profiles of the pumps was by installing event (on/off) loggers on about 50% of the pumps.

These loggers were installed strategically to affectively capture and represent the operating profiles of most of the project pumps. However, this attempt was not successful. Several of the loggers were lost due to floods, many were stolen and other loggers were simply removed.

4.5 FIXED SAMPLE METERING

An alternative was to install fixed metering in a secure manner at a sample of pump houses. Only a selected sample representing all the other pumps was chosen to be measured.

Since there is such a large variety of pump sizes to be measured, 1.2 to 110kW, and due to the conditions of the project it was not feasible to develop a baseline for each pump size. Therefore, the pumps included in the project were divided into four groups according to motor nameplate installed capacities:

- 1.2-11kW
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- 30-70kW
- 70-110kW

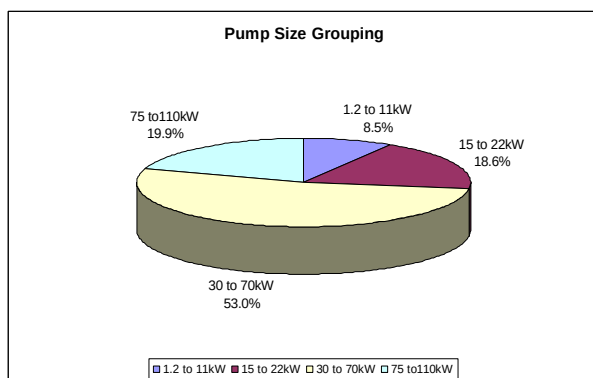


Figure 5: Pie chart of pump groups

Figure 5 gives a pie chart showing the percentage each pump size groups contributes to the total amount of pumps in project. 53% of the total amount consists of the 30 to 70kW pumps.

Within these groups a sample was chosen in such a way that the measured pump stations will appropriately represent the specific group. Typographically the location of the measured pump stations was chosen so that it is spread over the whole project capturing different farms in the region. However, the sample could only be selected from pump stations satisfying the following criteria for the M&V meters:

- The meters must be remotely downloadable, thus good GSM cell phone signal strength is required in the pump station,
- The meters are expensive, thus the pumps station should protect the meter from the environment,
- There is regular flooding in the region, thus the pump station must be located above the flood line,
- There is also frequent theft of the farmers pumping equipment and cables, thus the pump station should be lockable and preferably near

the farmer's house or in a safe area.

These criteria complicated the sample selection process and made it hard to find appropriate pumps stations to represent the groups. It was especially difficult to find sample stations for the 1.2 to 11 kW size pump, since these are not usually located in a pump station but stationed in the open veldt.

A total of 35 remotely downloadable electricity billing class meters were installed at the selected sites. More than 10% of all the pumps in the project were measured. Although this was not a trouble free solution, the M&V Team was able to develop baselines and perform post implementation assessments with the metering. The difficulties encountered with this metering method are described in Section 7.

4.6 BASELINE MODEL DEVELOPMENT

The data required to calculate the baselines was half-hourly electricity demand profiles in kW of the measured pump motors.

Using the data downloaded from the meters a sample baseline was developed for each of the different groups. This sample baseline consists of the measured demand profiles of the sample pumps as shown in Figure 6, bottom profile. This profile was then adjusted to the installed capacity of the sample pumps, second line from the bottom, according to the scaling ratio.

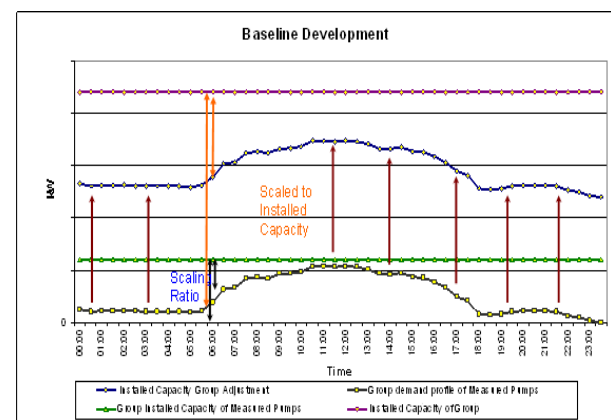


Figure 6: Baseline development

The top line gives the total installed capacity of all the project pumps within the group. The sample adjusted baseline, second line from the bottom, was then scaled according to the top line. This results in the projects baseline for the group, second line from the top in Figure 6. This process was used to develop baselines for each of the groups that represent the average Weekday, Saturday and Sunday demand profiles.

Each of these baseline demand profiles have referenced daily energy consumption in kWh that represents the average daily service level. The baseline demand profile can be adjusted on a daily basis to represent the daily service level.

5. BASELINE ASSUMPTIONS MADE

The following assumptions were made during the baseline development process:

- The sample group reflects the whole group's operations.
- Average pumping system resistance stays the same after implementation.

6. DETERMINING THE BASELINE AND ACTUAL POWER DEMAND PROFILES AFTER PROJECT INSTALLATION

The baseline demand profile will be scaled up or down according to the 24-hour SLA_{factor} (Service Level Adjustment Factor) so that the daily baseline kWh is equal to the actual post-implementation daily kWh. However, scaling can only be done until the maximum operating capacity of the pumping systems is reached.

Then the "additional" energy will be added to the back of the average baseline power demand profiles so that the average daily $kWh_{baseline} = kWh_{actual}$. Using the data downloaded from the meters during the post implementation phase a sample actual demand profile can be developed for each of the different groups. This sample actual demand profile consists of the measured demand profiles of the sample pumps as shown in Figure 6, bottom profile. As with the baseline development, this profile must be adjusted in

accordance with the installed capacity of the sample pumps according to the scaling ratio. Second line from the bottom in Figure 6.

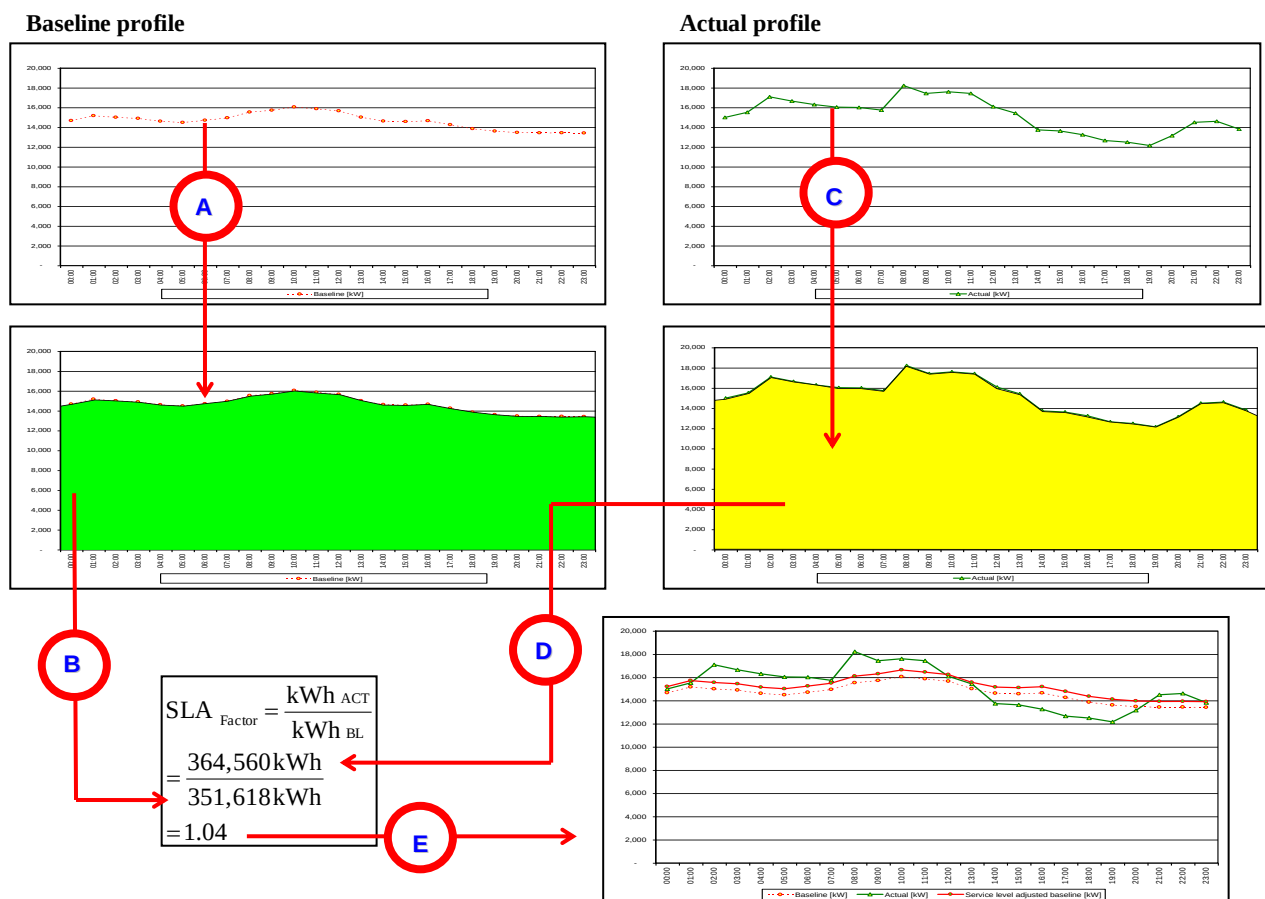
The top line in Figure 6 gives the total installed capacity of all the region's pumps within the group. The sample adjusted actual demand profile, second line from the bottom, must then be scaled according to the top line. This results in the project's actual demand profile for the group, second line from the top in Figure 6. This process must be used to develop actual demand profiles for each of the groups.

This can then be represented as average Weekday, Saturday and Sunday actual demand profiles. Each of these actual demand profiles has referenced daily energy consumption in kWh that represents the average daily service level.

Now the baseline demand profile can be scaled up or down so that the daily baseline kWh is equal to the actual post-implementation daily kWh on a day-to-day basis. Scaling can only be done until the maximum operating capacity of the pumping system is reached.

By comparing the baseline and actual demand profiles the energy and demand impact of the project can be calculated.

Figure 7 illustrates the service level adjustment. In step



A and B the referenced kWh of the baseline is determined from the baseline demand profile. The same process is used in step C and D to find the kWh of the actual demand profile.

From this the SLA_{factor} is calculated and the baseline is accordingly scaled as shown in step E. By doing this daily adjustment, water demand growth is automatically taken into account.

7. PROBLEMS ENCOUNTERED DURING POST IMPLEMENTATION

7.1 DATA DOWNLOADING

The remotely downloadable meters were chosen to reduce the effort to attain data for the baseline development and post implementation phase.

Although there was strict criteria for the choice of pump stations regarding conditions and signal strength to install metering at, major problems still surfaced. The following sections describe the different problems encountered.

(a) Signal strength and Network trouble

There were frequently problems experienced regarding GSM cell signal strength. Sometimes the meters could not be reached at all and other times the meters are only accessible for short periods.

In addition, when the cell phone network becomes busy, the GSM data signal is simply dropped. There were attempts to switch over to GPRS modems; however, there is not a GPRS signal available at all the project sites.

The only way to get data was to download early in the morning before the cell network gets busy. In certain cases, a whole month's data was downloaded in day sections; since the varying signal strength does not allow larger data sets.

(b) Cable theft and load shedding

During the data downloading process it often happens that the one day a meter is accessible and the next day it is not. With these instances, the cause is normally one of the following:

- Cable theft,
- Pump station maintenance,
- Regional supply faults and interruption,
- Scheduled load shedding.

Figure 8 shows the damage caused by cable thieves who regularly visit the pump stations in the region. The farmers have to bury the cable beneath half a meter concrete and rock to prevent cable theft. Pump station maintenance and regional supply further complicate the data downloading process.

The M&V team is normally not aware of the situation at the pump station and it is difficult to telephonically reach the farmers where the 35 meters are installed. The only alternative usually is to routinely check if the meter can be accessed.



Figure 8: Cable theft

Fortunately, there are schedules available for the National load shedding activities, so M&V can plan when to reach and download the data.

However, any supply interruptions cause the metering to lose timestamps. These lost timestamps have to be manually found and corrected by the M&V team through a time-consuming process.

7.2 SIM RECYCLING

Lately it occurred that some of the meters could not be read at all. When investigated, no supply or any other type of problem was found at the pump station. On further investigation it surfaced that the modem SIM-cards cell numbers of the meters was recycled by the cell service provider.

Apparently, if there is no phone call made from a number within a specified period, the SIM cell number is recycled and issued to a new customer.

7.3 METER BURN OUT

As if the bizarre pump station conditions of bees, snakes and hippos was not enough M&V had another surprise coming. One of the meters installed in a pump station was totally burnt.

Figure 9 shows the meter before the burn-out (second box from the left). Figure 10 and Figure 11 shows the marks and remains of the incident. In Figure 11 one can see that the only remains of the meter and box.

Since the burn-out was so severe, the exact cause of the fire could not be determined. The most probable causes are faulty or ineffective surge protection or a blown power factor correction capacitor.

This capacitor was located next to the meter. Fortunately, no other pump station equipment or metering was damaged in the fire.



Figure 9: Meter before burn-out



Figure 10: Wall burnt where meters was located



Figure 11: Meter leftovers

8. LOAD REDUCTION ANALYSIS

During the Performance Assessment period it was observed that the planned evening peak DSM targets were not met. On average the project underperformed

close to 50% although the required switching occurred as planned. This underperformance was investigated and all the possible causes therefore evaluated.

8.1 BASELINE AND PERFORMANCE ASSESSMENT PROFILES

Figure 12 shows a graph comparing the developed average Weekday baseline profile with the actual average Weekday profiles of the Performance Assessment (PA) months.

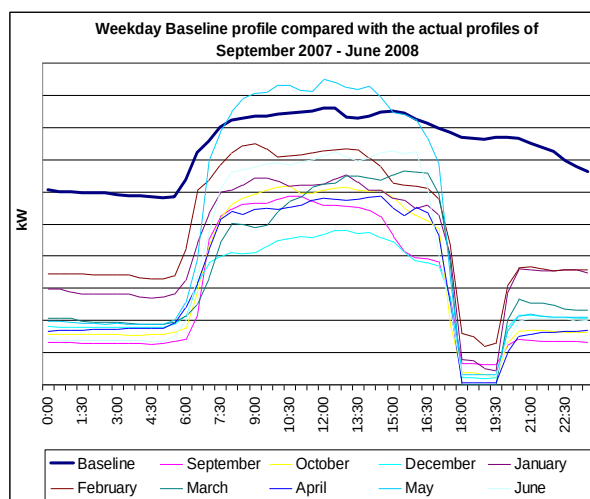


Figure 12: Graph of average Weekday Baseline profile compared with actual average weekday profiles of the PA months

The Baseline profile is the top thick line while the PA profiles are the bottom thinner lines in Figure 12. In addition, the same occurrence can be seen late evenings (20:00 - 00:00) after the Eskom evening peak.

During the morning hours from 00:00 - 06:00 it is clear that the pumping load significantly reduced throughout the PA months when compared to the baseline period.

From 7:30 in the morning and onwards the pumping load increases drastically as the farmers start to irrigate the lands. At 18:00-20:00 the pumps are switched off again for the evening peak period.

8.2 EFFECTS OF PUMPING LOAD REDUCTION ON DSM PROJECT IMPACTS

Examining the actual profiles in Figure 12 it seems that the evening peak switching made a large evening DSM impact.

However, when studying Figure 13 we see that the 24-hour energy neutral SLA adjustment described in Section 6 lowers 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) in Figure 13. This significantly reduces the available DSM evening peak impact although large switching did occur as is evident from the switch-off drop in the actual profile.

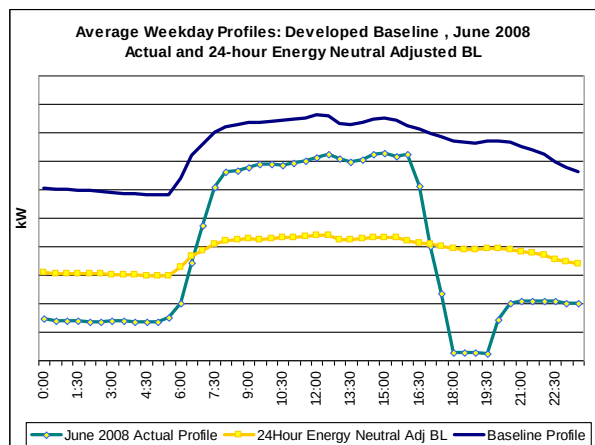


Figure 13: Graph showing the average weekday developed baseline profile, PA profile and 24-hour service level adjusted profile

8.3 CAUSES OF LOAD REDUCTION

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

- Higher rainfall during PA period than during the baseline period – this will cause the farmers to reduce their pumping activities.
- Change in operation conditions and pumping schedules as side effect of the DSM project implementation.

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

On further investigation the actual cause of the load reduction was found to be an unforeseen side effect of the DSM project itself. Along with the switching gear and valves needed to automate the pumps for the evening peak switching there were also water meters installed.

These water meters are utilised by the regions' irrigation board to track each farmer's water usage, since every farmer has a certain water allocation.

Before the DSM project implementation, the irrigation board could not track the water usage and check if the farmers stay within their allocations. The consequence was that the farmers could actually pump as they pleased.

This resulted in the farmers leaving the pumps running through the night as seen from the baseline profile. Afterwards, during the PA period, they had to comply with the water allocations and therefore adjusted their pumping schedules to occur during the day time.

8.4 POSSIBLE SLA ALTERATION

The desired pump switching and evening peak load reduction occurred as was planned for the DSM project. However, the unforeseen early morning and late evening load reduction have a negative effect on the calculated DSM impacts as discussed in Section 8.2.

This implies that the 24-hour SLA methodology developed during the baseline period does not accurately incorporate the operational conditions prevailing during the PA period.

A possible alternative approach that will more accurately portray the DSM impacts is to use an operational-hour SLA. This implies that only the part of the day the pumps are normally operating is used to determine the SLA factor. In Figure 14 it can be seen that between 8:30 and 16:30 the pumps are operational as it was during the baseline period. This time of the day can therefore be used as the kWh neutral time period.

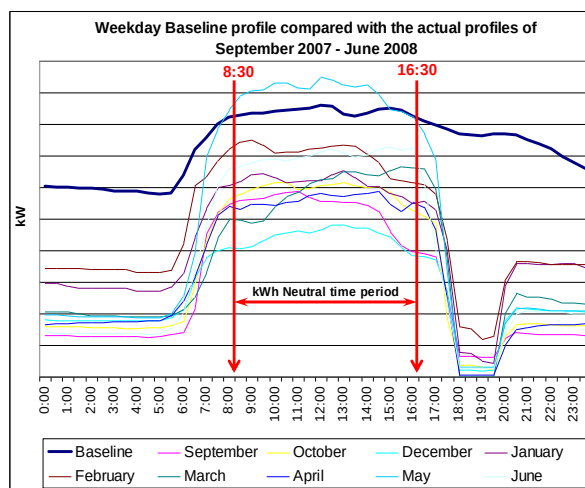


Figure 14: Operational kWh neutral SLA

The SLA factor calculation procedure as shown in Figure 7 will still be applicable as shown below;

$$\text{SLA}_{\text{FactorOperational}} = \frac{\text{kWh}_{\text{ACT}_{\text{Operational}}}}{\text{kWh}_{\text{BL}_{\text{Operational}}}}$$

$$= \frac{364,560 \text{ kWh}}{351,618 \text{ kWh}}$$

$$= 1.04$$

However, the kWh of the actual PA profile is divided by the kWh of the baseline profile for the periods between 8:30 and 16:30 to obtain the operational-hour SLA factor.

Finally, as described in Section 8.2, this SLA factor is applied over the whole 24-hour baseline profile (multiplied with each 30min baseline profile point). This then yields the new service level adjusted baseline.

Figure 15 shows the original baseline profile, a PA month profile, the old 24-hour SLA baseline and the new operational-hour SLA baseline. The baseline SLA baseline is not lowered so drastically anymore and yields a larger available DSM impact.

This method will more accurately portray the DSM switching impacts and will not be influenced by the morning and evening additional and unforeseen load reduction due to water allocations.

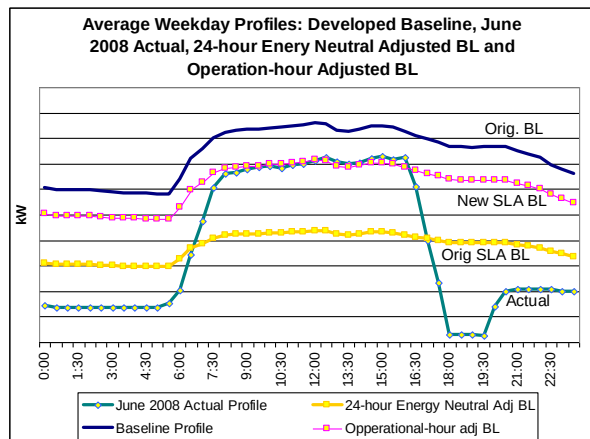


Figure 15: Graph showing the average weekday developed baseline profile, PA profile, 24hour SLA baseline and the new operational-hours SLA baseline

9. SUMMARY

This DSM project involved a large rural area with difficult to reach and sometimes dangerous pump stations. The area and nature of the project sites complicated the M&V process. M&V was faced with problems ranging from finding or reaching pumps stations to cable theft, various metering problems and even snake and hippo infested pump stations.

An M&V methodology was developed and metering process and plans specified. However, only a second metering attempt was successful and the data thereof could be used to develop the baselines and determine the post implementation DSM impacts. This metering alternative was unfortunately also not trouble free and M&V was again hampered.

Problems included cable theft, load shedding, data downloading problems, SIM recycling and even a meter burn-out. Although these problems were encountered and new problems regularly surfaced, NWU M&V was able to effectively keep up the M&V process and each month determine the attained DSM impacts.

During the PA period it was observed that the intended evening peak DSM targets were not met. Although the required switching occurred as planned the project underperformed on average close to 50%.

This effect was investigated and all the possible reasons for such an occurrence evaluated. On inspection it was

found that the actual cause of the load reduction was an unforeseen side effect of the DSM project itself.

A probable alternative SLA methodology was developed that will more accurately capture the DSM switching impacts. This approach will not be influenced by the morning and evening load reduction due to water allocations.

10. REFERENCES

[1]. Willem den Heijer, LJ Grobler, The Measurement and Verification Guideline for Demand-Side Projects (v5r3), 2006.

11. AUTHORS

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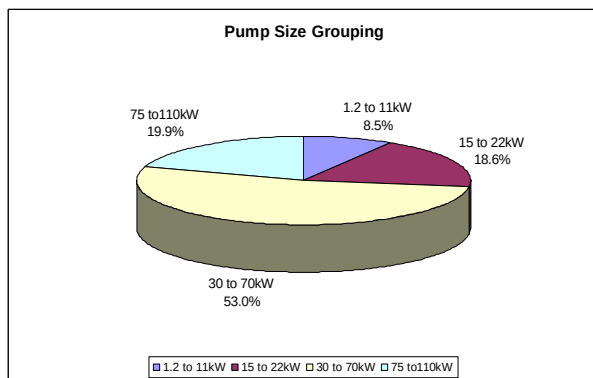


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- There is regular flooding in the region, thus the pump station must be located above the flood line,
- There is also frequent theft of the farmers pumping equipment and cables, thus the pumps

station should be lockable and preferably near the farmer's house or in a safe area.

These criteria made it hard to find appropriate pumps stations to represent the groups. It was especially difficult to find samples for the 1.2 to 11 kW pump stations, since these are not usually located in a pump station but is stationed in the open veldt.

A total of 35 remotely downloadable electricity billing class meters were installed at the selected sites. More than 10% of all the pumps in the project were measured. Although this was not a trouble free solution, M&V was able to develop baselines and perform post implementation assessments with the metering. The difficulties encountered with this metering are described in Section 7.

4.6 BASELINE MODEL DEVELOPMENT

The data needed for the project to calculate the baselines was the half-hourly electricity demand profiles in kW of the measured pump motors.

Using the data downloaded from the measured pumps a sample baseline was developed for each of the different groups. This sample baseline consists of the measured demand profiles of the sample pumps as shown in Figure 6, bottom profile. This profile was then adjusted to the installed capacity of the sample pumps, second line from the bottom, according to the scaling ratio.

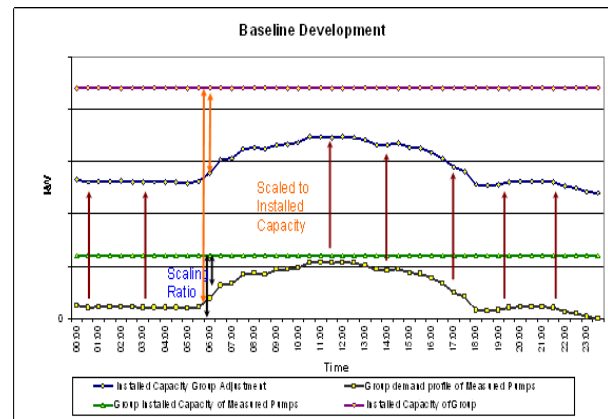


Figure 6: Baseline development

The top line gives the total installed capacity of all the project pumps within the group. The sample adjusted baseline, second line from the bottom, was then scaled according to the top line. This results in the projects baseline for the group, second line from the top in Figure 6. This process was used to develop baselines for each of the groups that represent the average Weekday, Saturday and Sunday demand profiles.

Each of these baseline demand profiles have referenced daily energy consumption in kWh that represents the average daily service level. The baseline demand profile can be adjusted on a daily basis to represent the daily service level.

5. BASELINE ASSUMPTIONS MADE

The following assumptions were made during the baseline development process:

- The sample group reflects the whole group's operations.
- Average pumping system resistance stays the same after implementation.

6. DETERMINING THE BASELINE AND ACTUAL POWER DEMAND PROFILES AFTER PROJECT INSTALLATION

The baseline demand profile will be scaled up or down according to the SLA_{factor} (Service Level Adjustment Factor) so that the daily baseline kWh is equal to the actual post-implementation daily kWh. However, scaling can only be done until the maximum operating capacity of the pumping systems is reached.

Then the "additional" energy will be added to the back of the average baseline power demand profiles so that the average daily $kWh_{baseline} = kWh_{actual}$. Using the data downloaded from the measured pumps during the post implementation phase a sample actual demand profile can be developed for each of the different groups. This sample actual demand profile consists of the measured demand profiles of the sample pumps as shown in Figure 6, bottom profile. As with the baseline development, this profile must be adjusted to the

installed capacity of the sample pumps according to the scaling ratio. Second line from the bottom in Figure 6.

The top line gives the total installed capacity of all the region's pumps within the group. The sample adjusted actual demand profile, second line from the bottom, must then be scaled according to the top line. This results in the project's actual demand profile for the group, second line from the top in Figure 6. This process must be used to develop actual demand profiles for each of the groups.

This can then be represented as average Weekday, Saturday and Sunday actual demand profiles. Each of these actual demand profiles has referenced daily energy consumption in kWh that represents the average daily service level.

Now the baseline demand profile can be scaled up or down so that the daily baseline kWh is equal to the actual post-implementation daily kWh on a day-to-day basis. Scaling can only be done until the maximum operating capacity of the pumping system is reached.

By comparing the baseline and actual demand profiles the energy and demand impact of the project can be calculated.

Figure 7 gives an illustration of the service level adjustment. In step A and B the referenced kWh of the

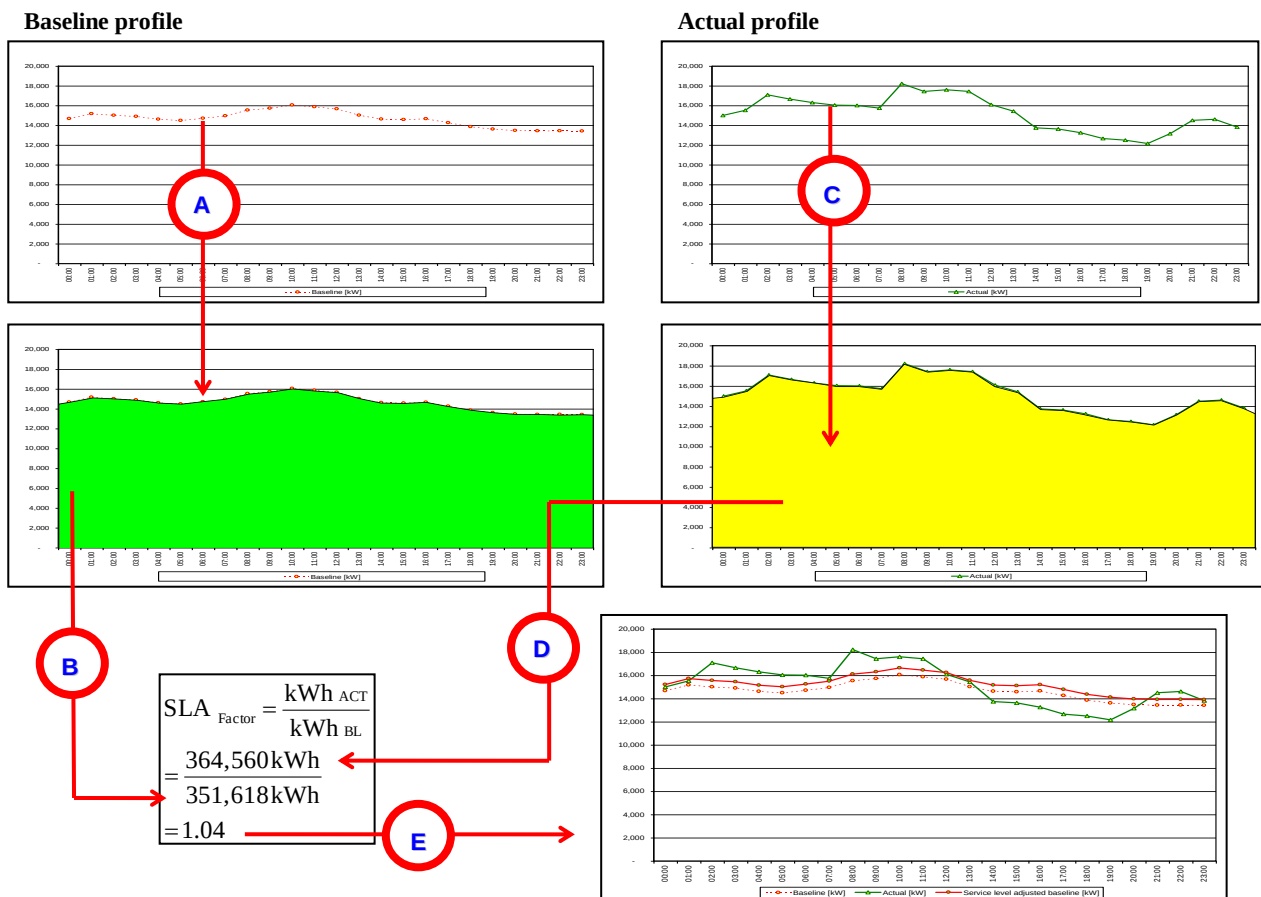


Figure 7: Service Level Adjustment for the baseline

baseline is determined from the baseline demand profile. The same process is used in step C and D to find the kWh of the actual demand profile.

From this the SLA_{factor} is calculated and the baseline is accordingly scaled as shown in step E. By doing this daily adjustment, water demand growth is automatically taken into account.

7. PROBLEMS ENCOUNTERED DURING POST IMPLEMENTATION

7.1 DATA DOWNLOADING

The remotely downloadable meters were chosen to reduce the effort to attain data for the baseline development and post implementation phase.

Although there was strict criteria for the choice of pump stations regarding conditions and signal strength to install metering at, major problems still surfaced. The following sections describe the different problems encountered.

(a) Signal strength and Network trouble

There were frequently problems experienced regarding cell signal strength. Sometimes the meters could not be reached at all and other times the meters are only accessible for short periods.

In addition, when the cell network becomes busy, the GSM data signal is simply dropped. There were attempts to switch over to GPRS modems; however there is not a GPRS signal available at all the project sites.

The only way to get data was to download early in the morning before the cell network gets busy. In certain cases, a whole month's data was downloaded in day sections since the varying signal strength does not allow larger data sets.

(b) Cable theft and load shedding

During the data downloading process it often happens that the one day a meter is accessible and the next day it is not. With these instances, the cause is normally one of the following:

- Cable theft,
- Pump station maintenance,
- Regional supply faults and interruption,
- Scheduled load shedding.

Figure 8 shows the effect of cable thieves who regularly visit the pump stations in the region. The farmers have to bury the cable beneath half a meter concrete and rock to prevent cable theft.

Pump station maintenance and regional supply problems complicate the data downloading process.

The M&V team is normally not aware of the situation at the pump station and it is difficult to telephonically reach the farmers where the 35 meters are installed. The only alternative usually is to routinely check if the meter can be accessed.



Figure 8: Cable theft

Fortunately there are schedules available for the National load shedding activities, so M&V can plan when to reach and download the data. However, any supply interruptions cause the metering to lose timestamps. These lost timestamps have to be manually searched and corrected by the M&V team through a time consuming process.

7.2 SIM RECYCLING

Lately it occurred that some of the meters could not be read at all. When investigated, no supply or any other type of problem was found at the pump station. On further investigation it surfaced that the SIM-cards cell numbers of the meters was recycled by the cell service provider.

Apparently, if there is no phone call made from a number within a specified period, the SIM cell number is recycled and issued to someone else.

7.3 METER BURN OUT

As if the bizarre pump station conditions of bees, snakes and hippos was not enough M&V had another surprise coming. One of the meters installed in a pump station was totally burnt.

Figure 9 shows the meter before the burn-out (second box from the left). Figure 10 and Figure 11 shows the marks and remains of the incident. In Figure 11 one can see that the only remains of the meter and box.

Since the burn-out was so severe, the exact cause of the fire could not be determined. The most probable causes are faulty or ineffective surge protection or a blown power factor correction capacitor.



Figure 9: Meter before burn-out



Figure 10: Wall burnt where meters was located

This capacitor was located next to the meter. Fortunately no other pump station equipment or metering was damaged through the fire.



Figure 11: Meter leftovers

8. SUMMARY

This DSM project involved a large rural area with difficult to reach and sometimes dangerous pump stations. The area and nature of the project sites complicated the M&V process. M&V was faced with problems from finding or reaching pumps stations to cable theft, various metering problems and even snake and hippo infested pump stations.

An M&V methodology was developed and metering process and plans specified. However, only a second metering attempt was successful and the data thereof could be used to develop the baselines and determine the post implementation DSM impacts. This metering alternative was unfortunately also not trouble free and M&V was again hampered.

Problems included cable theft, load shedding, data downloading problems, SIM recycling and even a meter burn-out. Although these problems were encountered and new problems regularly surface, NWU M&V was able to effectively keep up the M&V process and each month determine the attained DSM impacts.

9. REFERENCES

[1]. Willem den Heijer, LJ Grobler, The Measurement and Verification Guideline for Demand-Side Projects (v5r3), 2006.

10. AUTHORS



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Presenter:

This paper is presented by Markus Storm.

METHODOLOGY DEVELOPED TO MEASURE AND VERIFY THE TOTAL IMPACT OF THE ACCELERATED DSM INITIATIVES IMPLEMENTED IN THE WESTERN CAPE

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ABSTRACT

Eskom expected a supply shortfall of 400 MW during the 2006 winter months in the Western Cape. The main reason for this was due to the refuelling of one of the two Koeberg units.

An integrated recovery plan was initiated by Eskom for the Western Cape to overcome this shortfall. The recovery plan included various accelerated Demand-side Management (DSM) initiatives to reduce the amount of electricity consumed as well as to reduce the peak load.

The North-West University M&V team was requested to do the measurement and verification of the accelerated DSM programme for the whole of the Western Cape. A top-down M&V methodology combined with the conventional M&V was used to M&V the impact of these initiatives.

In May the average weekday evening peak DSM impact calculated with the top-down approach was 317 MW, 497 MW in June, 389 MW in July, 354 MW in August and in September the DSM impact was 237 MW.

This paper describes the methodology and procedures that were followed for the M&V process used to calculate the DSM impacts obtained during the winters months in the Western Cape.

Keywords / -phrases:

M&V, Measurement and Verification, CFL, Compact Fluorescent Light, DSM, Demand-Side management, Koeberg supply losses, DMP, Demand Market Participation, Leased Generation, Fuel switching.

1 INTRODUCTION

During the winter months of 2006 Eskom expected a supply shortfall of 400 MW in the Western Cape. Refuelling of one of the two Koeberg units was the main reason for this shortfall.

Eskom started an integrated recovery for the Western Cape to overcome the shortfall of 400 MW. This recovery plan included different accelerated Demand-side Management (DSM) initiatives to reduce the electricity consumption and reduce the peak load. Table 1 shows some of the main focus areas of the

accelerated DSM programme for the Western Cape. The North-West University M&V team was requested to perform the M&V (Measurement and Verification) of the accelerated DSM programme for the entire Western Cape during the winter months.

The conventional M&V approach is to define the M&V boundaries as close as possible to the intervention to eliminate or reduce the influence of external factors that are not related to the DSM project. The general rule is that if the impact of the intervention is less than 10 % of the total energy consumed the boundaries have been set too wide and need to be brought closer to the intervention. See 3.1.

Table 1: Accelerated DSM programme implemented in the Western Cape

Program	MW	Notes
Efficient lighting	155	Residential retrofits, subsidy programmes and promotion campaign – 320 000 units installed in 2 weeks. Final roll out of 2 million Compact Fluorescent Lights (CFLs).
Customer self generation	50	Awareness programme. Customer visits. Promotional campaign.
Industrial and commercial efficiency and curtailment	40	Including schools, hotels, malls, office blocks Lighting, dual fuel systems, building management. Eskom buildings retrofit.
Energy efficiency campaign	110 - 160	Promotional and advertising campaign. Specific appeals: Pool pump switch off in winter, gas rather than electricity. Look at alternatives such as geysers etc.
Gas cooking & Heating	50	
TOTAL	400	

The M&V process of most of the accelerated DSM programmes had the following problems:

- It was not possible to draw the M&V boundaries close enough to the DSM intervention so that the impact of the measure was more than 10% of the total energy consumed.
- Due to the urgent nature to implement these DSM initiatives, M&V did not have sufficient time to

develop the baselines using the conventional M&V approaches.

A top-down M&V methodology in combination with the conventional M&V process was therefore used to M&V the impact of the accelerated DSM initiatives in the Western Cape.

The total DSM impact using the top-down M&V methodology was determined as follows:

- Baseline models were developed for the Western Cape to predict what the electricity demand would have been without DSM. These models were developed using 2005 electricity data, growth and temperature data.
- The total demand profile for the Western Cape was measured from 1 May 2006.
- The differences between the total baseline and actual demand for the Western Cape gave the total impact of all the DSM initiatives.

The following points are addressed in this paper:

- Demand-side management and demand market participation in the Western Cape.
- The methodology followed to develop the baselines used in the Cape top-down M&V campaign.
- Adjustments made to the baseline to incorporate initiatives such as DMP, leased generation, fuel switching, supply losses.
- The monthly impacts achieved by the DSM programmes in the Western Cape from May to September 2006.
- A critical evaluation of the accelerated DSM programme.
- Lessons learned.

2 DEMAND SIDE MANAGEMENT (DSM) AND DEMAND MARKET PARTICIPATION (DMP)

2.1 DEMAND-SIDE MANAGEMENT

Demand Side Management (DSM) broadly refers to the planning and implementation of activities designed specifically to influence the time, pattern and amount of electricity usage. DSM in the Western Cape included energy efficiency, load shifting, and load shedding. Energy efficiency influenced the demand profile throughout the day while load shifting influenced the demand profile during peak periods.

Load shedding influenced the demand profile when the electricity supply network was under extreme strain and the security of the network was jeopardised.

Table 1 shows a summarised plan for the extensive demand-side management programme implemented in the Cape. Eskom identified potential areas of efficiency and peak shifting to categorise electricity users as being residential, commercial or industrial.

On the industrial and commercial side efforts were focused on customer self generation, energy efficiency, and load shedding. In the residential sector, most efforts were focused on energy efficiency such as distribution of CFLs, fuel switching as well as through extensive energy efficiency campaigns.

2.2 DEMAND MARKET PARTICIPATION

Certain industrial customers within the Western Cape have signed DMP contracts with Eskom until end of July 2006. When strain was experienced on the electricity supply network, Eskom asked those DMP clients to reduce the load by their contracted MW for a specified number of hours per day.

3 BASELINE DEVELOPMENT AND BASELINE ADJUSTMENTS

3.1 TOP-DOWN M&V METHODOLOGY

Figure 1 describes the proposed top-down M&V methodology. The total DSM impact was determined as follows:

- Baseline models were developed for the Western Cape to predict what the electricity demand would have been without DSM. These models were developed using 2005 electricity data, growth and temperature data.
- The total demand profile for the Western Cape was measured and is illustrated by the second line from the top in Figure 1. This was done from 1 May 2006.

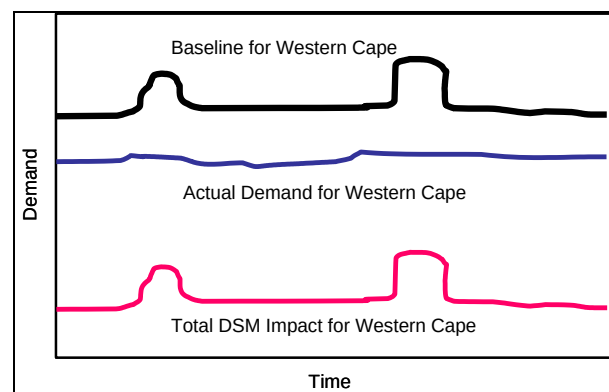


Figure 1: Method to determine Total DSM Impact

- The differences between the total baseline and actual demand for the Western Cape will give the total impact of all the DSM initiatives. The impact is illustrated by the bottom line in Figure 1.

3.2 BASELINE DEVELOPMENT

The baseline is a prediction of what the electricity consumption would have been in the Western Cape without any DSM intervention. The baseline was used to do impact calculations according to the following formula:

$$\text{Impact} = \text{Baseline} - \text{Actual} \pm \text{Adjustments} \quad 3-1$$

The developed baseline consisted of the following components:

- Scatter plots relating electricity consumption and temperature.
- Average Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, and Sunday demand profiles.

Adjustments made to the developed baseline included the following:

- Temperature adjustments,
- Electricity sales growth,
- Demand Market Participation (DMP),
- Koeberg supply losses,
- Municipality Curtailment,
- Load shedding,
- Leased generation,
- Fuel switching and,
- NamPower.

Development and adjustments to and of the baseline is discussed in the following paragraphs.

3.2.1 Scatter plots

The scatter plots show relations between MW and Temperature for every 30 minutes for Weekdays, Saturdays, and Sundays. For each day type (Weekdays, Saturdays, and Sundays) there are 48 scatter plots; a total of 144 scatter plots per month. The scatter plots were developed for each month of the period May to September 2006 using 2005 data.

Figure 2 shows a typical scatter plot of an average weekday at a specific time stamp. For the M&V campaign between May and September 2006 a total of 720 scatter plots were developed. Linear relations were calculated between MW and Temperature from the scatter plots. From these relations the m-values (the slope) were obtained. The m-value shows the relation between energy and temperature for that 30-minute interval of a specific day type (Weekdays, Saturdays, and Sundays) of a specific month.

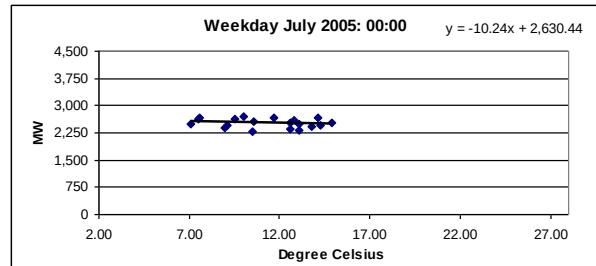


Figure 2: Scatter plot for an average weekday at 00:00

It is also an indication of how temperature sensitive the energy consumption during a 30-minute period is. Hourly temperature data of Cape Town weather station was obtained from WeatherSA. Ten minutely energy data was obtained from Bellville control centre [1]. The data received contained the following:

- Palmiet unit 1 and 2.
- Koeberg unit 1 and 2.
- Droërivier Hydra line 1, 2 and 3.
- Aries Kronos line.
- Acacia Power Station Generator 1, 2 and 3.

3.2.2 Average profiles

Average Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, and Sunday 30-minute demand profiles were developed from 2005 data.

These profiles were developed relating to the average temperature measured during the specific month. Figure 3 shows a demand profile of an average Monday in July in July.

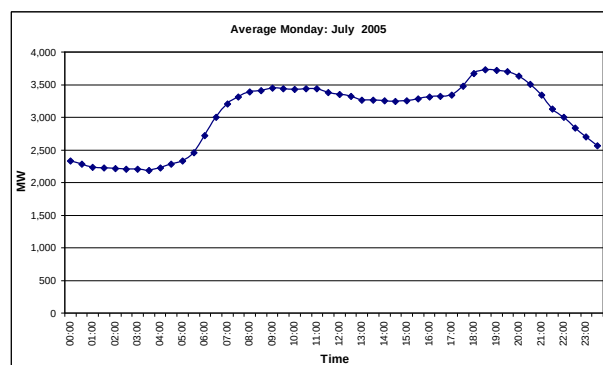


Figure 3: Demand profile of an average Monday in July 2005

3.3 BASELINE ADJUSTMENTS

3.3.1 Temperature adjustments

Since the temperature and growth differs from year to year, the baselines had to be adjusted to reflect an accurate approximation of the expected demand for

2006. This adjustment was done using the m-value described in section 3.2.1.

The average temperature of each specific day type (Monday, Tuesday, Wednesday, etc) was calculated from July 2005 data. Having these values the Delta Temperature between the actual 2006 measured value and the average temperature value for that specific day type was calculated.

The temperature differences between 2005 and 2006 were then related to an increase in demand (MW) by using the established m-value. Equation 3-2 was used to do this adjustment.

$$\Delta_{MW} = M_{value} \times \Delta_{T} \quad 3-2$$

This increase (or decrease) in demand was finally taken into account to adjust the average profiles developed from 2005 data to produce a temperature adjusted baseline as shown in Figure 4.

The average weekday temperature differences between the different months for May to September 2005 and 2006 was calculated. In May 2006 it was on average 0.46 °C colder than May 2005.

This resulted in an average weekday increase of 0.71 MW on the baseline. June 2006 was on average 1.86 °C warmer than June 2005 and on average 44.29 MW was subtracted from the baseline.

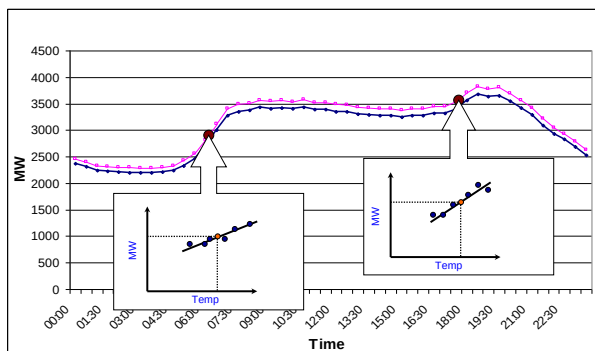


Figure 4: Baseline temperature adjustment using the scatter plots

When comparing June 2005 and May 2005 it was observed that June was on average 2.58 °C colder than May.

3.3.2 Electricity sales growth

Figure 5 shows the growth adjusted baseline. According to the sales data given in Table 2, there was a 4.6 % year to year sales growth in May. The growth percentage for each month was also fixed on 4.6 % for the June to September 2006 baselines.

In May there was already some DSM projects operating and it was assumed that the new connections in May would be the same for June to July.

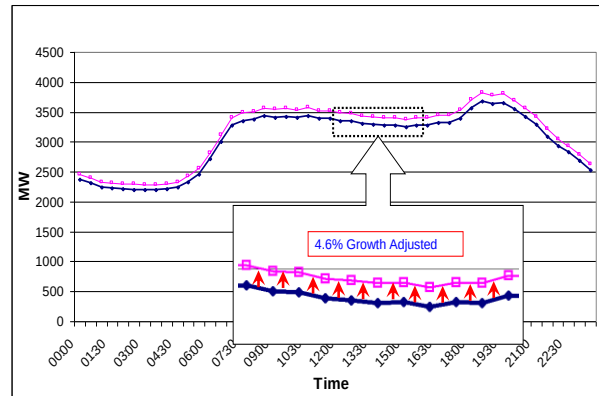


Figure 5: Growth adjusted baseline

Table 2: Monthly electricity sales

		Total Tariffs		
		SACS July Projections	CM Actual	Percentage
		2006	2005	Growth
March	SAP Total Consumption (kWh)	1,581,570,943	1,554,331,331	1.72%
April	SAP Total Consumption (kWh)	1,573,638,000	1,507,907,539	4.18%
May	SAP Total Consumption (kWh)	1,626,755,083	1,551,860,277	4.60%
June	SAP Total Consumption (kWh)	1,583,049,854	1,599,282,312	-1.03%
July	SAP Total Consumption (kWh)	1,650,259,074	1,577,406,623	4.41%

4.6 % might be a conservative growth figure to use since the figure takes into consideration new connection (increases in electricity consumption) as well as energy efficiency (decreases in energy consumption).

Figure 5 illustrates how the growth adjustment was made to a baseline. Table 3 gives the average weekday baseline growth adjustment of each month for May to September 2006.

Table 3: May to September 2006 baseline growth contribution

May	June	July	Aug	Sep
MW	MW	MW	MW	MW
133.78	141.73	140.93	146.69	142.064

3.3.3 Demand Market Participation

Called and Billed DMP data was obtained by the M&V team. Called DMP data included requests from Eskom to a client to reduce load. It does not mean that the client actually reduced the load by the requested MW or for the requested time. Billed DMP data includes data that were used to bill the clients for their actual load reduction.

3.3.4 Supply losses with one Koeberg operating

We were informed by Eskom that there were more supply losses with one Koeberg unit operating instead of two Koeberg units. According to Eskom personnel the supply losses with one unit running is 100 MW [1]. These losses were taken into account by adjusting the baseline. The Western Cape should have saved 100 MW for those losses to be overcome.

3.3.5 Municipality curtailing

According to the Eskom Western Cape Recovery plan distributors were allocated monthly demand limits which were proportional to their energy consumption recorded in the corresponding period in 2005. Monthly demand limits were adjusted for load growth, system losses, safety margins and critical/strategic loads.

However during the period May to September 2006 only 2 Municipality curtailing events took place.

3.3.6 Load shedding

The proposed mitigating actions of the Eskom Western Cape recovery plan were intended to minimize the impact on customers. However, the benefits of those mitigating actions did not totally alleviate the requirement for load shedding.

Principles to manage planned and emergency load shedding was agreed by key stakeholders. The extent of load shedding required depended on the power supply levels as well as the forecasted level of demand and any unexpected increases in demand for electricity.

3.3.7 Leased generation

Also included in the baseline adjustments were the following leased in generators:

- PetroSA
- Roggerbaai,
- Steenbras, and
- Acacia Power Station (APS).

During the winter months Eskom had a contract with City of Cape Town for leased generation using the Steenbras and Roggerbaai generators. During this time, the generators operating data was available and could be incorporated into the baselines.

Since September the data was not available and the baseline of September was developed without accounting for the times the generators was used.

3.3.8 Fuel switching

EB Steam was the only Fuel switching contributor.

3.3.9 NamPower

The power supplied to Namibia in 2005 was used to form an average weekday baseline for each of the four months. The impact of 2006 compared to the NamPower baseline was taken into account for this baseline adjustment.

It was observed that for the periods 1 to 10 June, 10 to 14 July, 19 and 21 July 2006, NamPower was importing much less from Eskom compared to what were

imported in 2005. It was observed that NamPower did import less electricity when requested to do so.

3.3.10 Adjusted baseline

All the adjustments discussed in the previous paragraphs were taken into account to obtain the final baseline. Figure 6 shows the final baseline for June 2006 as well as all the different components used in the baseline adjustment.

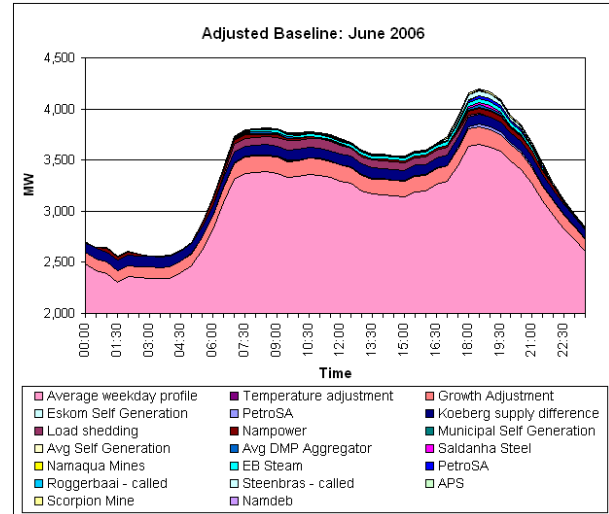


Figure 6: The adjusted baseline of June 2007

4 BASELINE VERIFICATION

The developed baselines were calibrated according to IPMVP (International Performance Measurement and Verification Protocol) standards. Firstly the percentage MBE (Mean Bias Error) was calculated by subtracting the actual half hourly 2005 data from the adjusted baseline. The differences are summed and divided with the sum of the actual values of the whole month. The MBE is expressed as [2]:

$$MBE(\%) = \frac{\sum_{month} (S - M)_{30min}}{\sum_{month} M_{30min}} \times 100 \quad (4-1)$$

S indicates the kWh baseline and M the actual measured kWh values. The MBE indicates how well the demand profile is predicted by the baseline when compared by actual data. However, it is subjected to cancellation errors, where the combination of positive and negative values for (Baseline - Actual) serves to reduce MBE. To account for cancellation errors, the CV(RMSE) (Coefficient of Variation of Root Mean Square Error) was also needed [2]:

$$RMSE_{month} = \sqrt{\frac{\sum_{month} (S - M)_{30min}^2}{N_{30min}}} \times 100 \quad (4-2)$$

$$CV(RMSE_{month}) = \frac{RMSE_{month}}{Average_{month}} \times 100 \quad (4-3)$$

The CV(RMSE) is a normalized measure of variability between two sets of data. For calibrated simulation purposes, it is obtained by squaring the difference between paired hourly data points, summing the squared differences over the month, and then dividing by the number of points, which yields the mean squared error.

The square root of this quantity yields the root mean squared error. The CV(RMSE) is obtained by dividing the RMSE by the mean of the measured data for the month. The combination of MBE and CV(RMSE) represents how well a model fits the data: the closer to zero, the better the calibration [2].

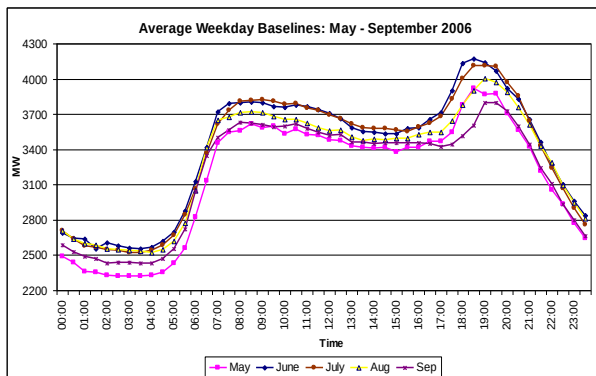


Figure 7: Adjusted Baselines of May September 2006

The baselines were verified by the using the actual demand and temperature values of the relevant month in 2005 to test the baselines developed from the same data. The adjusted baselines developed for each month May to September 2006 is shown in Figure 7.

5 MONTHLY IMPACTS

The average monthly impacts achieved during weekdays were calculated by using the adjusted baselines. This section summarises the achieved impacts of each of the months May to September. The following components are illustrated in Figure 8 and Figure 9:

- **Total Impact:** Adjusted baseline – actual. This impact includes all measures such as self generation, leased in generation, DMP, and DSM.
- **DSM impact:** This represents the total impact of all the DSM projects implemented in the Western Cape. The DSM impact was calculated by subtracting the average actual weekday demand from the temperature and growth adjusted baseline. Koeberg and NamPower (since we used the net effect) were added to DSM impacts.

The total and DSM impacts is also given Table 4; average over the TOU (Time-of-Use) periods.

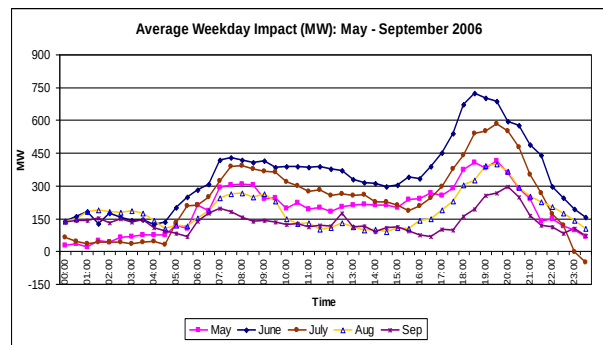


Figure 8: Average weekday total impact of May September 2006

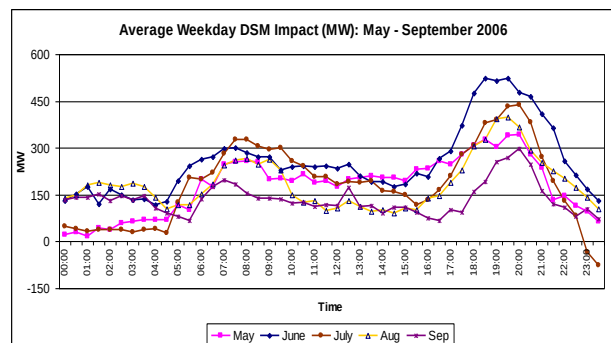


Figure 9: Average weekday DSM impact of May to September 2006

5.1 MAY IMPACT

The total average weekday evening impact achieved in May was 370 MW. DSM contributed 317 MW to the total impact. Figure 8 and 9 shows the average total and DSM impact achieved in May compared with the other months.

5.2 JUNE IMPACT

The DSM impact increased to 497 MW from May to June. The total average weekday evening impact achieved in June was 650 MW. DSM contributed 497 MW to the total impact. The average total impact increased from May to June with 280 MW while the average DSM impact increased with 180 MW.

5.3 JULY IMPACT

The total average weekday evening impact achieved in July was 523 MW. DSM contributed 389 MW to the total impact. The average total impact decreased from June to July with 127 MW while the average DSM impact decreased with 108 MW.

5.4 AUGUST IMPACT

The total average weekday evening impact achieved in August was 354 MW. However, the total and DSM impact of August is equal as seen in Table 4. The reason was that all DMP contracts expired on 31 July and both Koeberg units were operating again.

The average total impact decreased from July to August with 169 MW while the average DSM impact decreased with 35 MW.

5.5 SEPTEMBER IMPACT

In September the average weekday total and DSM impacts was again the same, just as with August. The total impact decreased with 117 MW from August to 237 MW in September.

6 BOTTOM-UP RESULTS

Figure 10 compares the results obtained from the top-down M&V process with that of the bottom-up M&V process [3]. The results of May show a difference of 234 MW between the top-down and bottom-up results.

This difference increases in June with results of the top-down giving a DSM impact 238 MW higher than the bottom-up results. However, during July, August and September the difference in the results were significantly less.

In July the difference was only 36 MW while in August and September the difference was only 17 MW and 60 MW respectively.

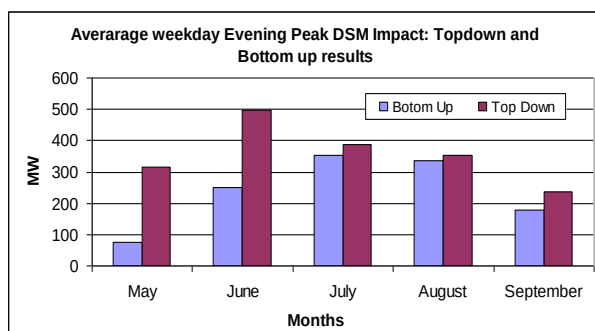


Figure 10: Average weekday evening peak DSM impact results of top-down and bottom-up M&V

The large difference between the results during May and June is a result of public awareness and industry

voluntary contribution. During the May and June there was a large hype in the Western Cape regarding power saving which favoured attention from the public resulting in savings.

The bottom-up results focuses on all the individual projects but does not capture the contributions of public awareness and voluntary contributions. The top-down approach captured the total impact which creates the large difference in the May and June results.

This was confirmed by the July to September results. At the end of July the electricity hype was over since the Koeberg unit was online again. Suddenly the top-down and bottom-up results was very close.

This was expected, since the public and industry stopped with voluntary contribution and returned to normal routine. The close relation in results continued during August and September.

7 LESSONS LEARNT

One of the biggest problems encountered during the measurement and verification of the Western Cape DSM impacts was data availability. The whole process was slowed down due to difficulty of obtaining data from the different contributors.

This M&V process can be improved if data, such as DMP contribution, will be more regularly and quickly available. This will result that the monthly performance assessments will be sooner delivered.

Another problem leading to time consuming data analysis is the form and format of the data received. This differed for some months and the applications developed for the previous set of data could not be used. It is recommended that the data delivered to the M&V team must be in a fixed format for faster processing.

The M&V process can also be improved by incorporating more inputs from outside parties. Their

Table 4: Average weekday total and DSM TOU period impacts

Weekdays TOU Impacts: May to September 2006	Morning OffPeak	Morning Standard	Morning Peak	Midday Standard	Evening Peak	Evening Standard	Evening OffPeak
	00:00-06:00	06:00-07:00	07:00-10:00	10:00-18:00	18:00-21:00	21:00-22:00	22:00-00:00
May							
Average WD Total Impact	62.04	198.38	281.07	221.50	370.14	189.04	108.17
Average WD DSM Impact	58.97	188.14	236.43	215.20	317.27	185.25	105.11
June							
Average WD Total Impact	160.15	293.99	399.66	368.58	649.85	462.63	221.57
Average WD DSM Impact	154.22	267.37	275.93	234.37	496.86	387.26	192.74
July							
Average WD Total Impact	62.82	229.94	367.55	260.94	522.92	308.38	59.23
Average WD DSM Impact	58.93	210.51	306.04	191.03	388.78	233.26	25.95
August							
Average WD Total Impact	151.30	187.45	260.59	153.83	353.75	276.45	149.97
Average WD DSM Impact	151.30	187.45	260.59	153.83	353.75	276.45	149.97
September							
Average WD Total Impact	122.51	155.37	158.32	108.42	236.66	141.58	91.82
Average WD DSM Impact	122.51	155.37	158.32	108.42	236.66	141.58	91.82

perspective and views might result in more accurate handling of the different components.

From the results that was delivered and what happened during the winter months in the Western Cape indicates that the top down approach did work. The 400 MW Eskom had to shift via DSM to avoid load shedding was reached as shown by the top down M&V.

This can be confirmed by the few load shedding events seen in the Western Cape during June and July. Also the M&V results of July to September compares well with that of the bottom-up M&V results.

8 CONCLUSIONS

The M&V team did not have sufficient time to develop credible baselines using the conventional M&V approaches. This was a result of the urgent need to implement the accelerated DSM initiatives.

It however was felt that the top-down M&V methodology combined with the conventional M&V used to M&V the total impact of the accelerated DSM initiatives in the Western Cape, represented a feasible approximation. The developed baselines were also verified using IPMVP standard verification techniques.

The results obtained through the measurement and verification of the Western Cape DSM projects showed that the accelerated DSM initiatives made an evident impact. The highest average DSM impact (497 MW) was observed in June during the evening peak. The average impact declined to 389 MW in July and 354 MW in August.

Only five load shedding events took place. All of the shedding events that occurred were caused by supply problems. The major load shedding event was on 8 and 9 June when the Koeberg unit tripped.

In conclusion, the M&V of the integrated recovery plan that was initiated by Eskom for the Western Cape to overcome the electricity shortfall was successful. During June the required 400 MW were saved by the DSM projects as shown by the top down M&V results. The viability of the top down M&V was confirmed since most of the power cuts expected through the winter months of 2006 were avoided.

9 REFERENCES

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