University of Southern Queensland

Faculty of Health, Engineering & Sciences

DEVELOPMENT OF A PUMP EFFICIENCY MONITOR FOR USE IN COTTON IRRIGATION

A dissertation submitted by

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in fulfilment of the requirements of

ENG 4111/4112 Research Project

towards the degree of

Bachelor of Mechanical Engineering

Submitted: October, 2013

Abstract

Direct energy inputs such as diesel and electricity are major costs incurred on an irrigated cotton farm. They also account for a significant proportion of the total greenhouse gas emissions from cropping systems. As energy costs continue to rise, so too does irrigator interest in assessing ways to improve their energy efficiency. Irrigators want to know how to reduce energy consumption. New techniques and equipment are required to assist irrigators in managing their energy consumption and therefore reduce running costs and meet targets. Cotton farmer's use 60 -70% of their energy during the irrigation process (Ballie & Chen 2008), where large quantities of water are pumped during the irrigation season, and how efficiently this happens depends on the efficiency of the pump stations.

A Pump Efficiency Monitor (PEM) has been developed to identify pump efficiency problems. The PEM enables the continuous measurement of various pump parameters to assess efficiency and monitor energy use during an irrigation season.

The pump efficiency monitor was first trialled during the 2012/13 cotton irrigation season on a farm located at Goondiwindi, Queensland. Data for one pumping event was successfully obtained during the trial. The data was analysed to determine a combined efficiency of the pump and diesel engine. It was identified that reducing engine speed by 250 RPM would improve efficiency. A cost benefit analysis performed on the results indicates that reducing engine speed would reduce running costs for this particular pump station by 44%.

The ability of the PEM to continuously log various pump variables not only provides data to assess pump station efficiency, it also provides accurate information concerning energy use for on-farm energy assessments.

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Limitations of Use

Certification

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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Acknowledgements

This research project was carried out under the supervision of Dr David Buttsworth, I wish to acknowledge his continued support, guidance and patience during the course of the project.

Completion of this project would not have been possible if it weren’t for the love and support of my wife and three children. They have sacrificed many weekends, nights and play dates without their husband / father to harass and play with. “Surfs up kids time to go to the beach.”

I also wish to acknowledge the cooperation and assistance provided by the farm owners, the farm manager and his staff who assisted with this work. Financial support for this project was provided by the Cotton Research and Development Corporation, the National Centre for Engineering in Agriculture and the NSW Department of Primary Industries.

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1.1 Introduction to the Australian Cotton Industry

The versatility of cotton is astounding; cotton can be used as both a food source and fibre crop. The cotton seed that remains after the ginning process, can be used as supplement feed for livestock such as cattle and sheep (Blackwood 2007) as well as being crushed and the oil extracted. The use of cotton seed oil extends from soaps, pharmaceuticals, cosmetics, rubber and plastics with a wider potential use for cotton seed oil including food products such as cooking oil, salad dressings, and sauces. Cotton seed oil was the first type of vegetable oil used in the aforementioned products, other types of vegetable oils started to replace cottonseed oil due to lower production expenses (Morgan 2013). This gave way to a new field of research for the use of cottonseed oil in the production of biodiesel; for use in combustion engines to encourage the offset of greenhouse gas emissions (Fan *et al*. 2011). The cotton fibre can be used to create woven or knitted garments and textile products. The small fibres removed from the cottonseed after ginning, known as linters, are used to produce cotton buds, bank notes, swabs, and bandages (Morgan 2013).

Australia is the fourth largest exporter of cotton and produces some of the highest yielding and finest quality cotton in the world (Cotton Australia 2013a). The total value of the cotton produced in 2011 is $2.87 billon this includes $217 million dollars of cottonseed (Cotton Australia 2013b). The first cottonseeds imported into the nation were on the first fleet in 1788 (Cotton Australia 2013c). In 1830 the first shipment of cotton for export to England consisted of three bags (Cotton Australia 2013c). In 2011 the total bales of cotton produced in Australia consisted of 3,999,600 an 89% increase in production since 1980 (Cotton Australia 2013b). Table 1 indicates the total quantity of cotton grown since 1990 and the bales produced per hectare. Table 1 illustrates the increase in cotton production over the twenty year period (Cotton Australia 2013b). At the turn of the century the cotton industry experienced a ten year period of drought which affected the production output.

Table 1: Australian Cotton Production Statistics (Cotton Australia 2013b)

Year	Total Bales	Bales per ha	Year	Total Bales	Bales per ha
2010/11	3,999,600	6.67	1999/00	3,202,160	6.93
2009/10	1,594,850	8.76	1998/99	3,221,340	6.02
2008/09	1,494,300	9.26	1997/98	3,020,065	6.95
2007/08	601,810	8.77	1996/97	2,710,800	6.96
2006/07	1,199,700	8.93	1995/96	1,712,600	5.97
2005/06	2,618,000	7.85	1994/95	1,365,140	6.55
2004/05	2,904,000	8.98	1993/94	1,411,910	5.12
2003/04	1,531,000	7.79	1992/93	1,559,860	6.06
2002/03	1,630,100	7.39	1991/92	2,018,000	7.16
2001/02	3,072,320	7.60	1990/91	1,804,000	6.58
2000/01	3,441,334	6.73	1989/90	1,287,500	6.00

From the planting of the first cotton crop by the first fleet in 1788, the agricultural production of cotton now extends from Emerald in central Queensland to Griffith in southern New South Wales (Cotton Australia 2013d). This spans a distance of 1500km with varying climate terrain and soil types. Cotton is considered a desert plant and thus suited to the Australian conditions.

The efficiency with which cotton is grown in Australia is three times higher than any other nation (Cotton Australia 2013a). This is due to the technological achievements within the cotton industry. On-farm energy efficiency is becoming increasingly important in the context of rising energy costs and concern over greenhouse gas (GHG) emissions (Cotton Australia 2013a). The rising prices on energy are now one of the major challenges to the agricultural industry in Queensland.

Although the rapidly rising energy prices may have initially been viewed as a temporary phenomenon, many people in the sector now agree that we are entering into an era of high energy prices. A combination of high energy prices and the government's target to reduce the GHG emissions by 25 to 40% by 2020 (Wilson 2013) forces the improvement of on-farm energy efficiency. The fastest, cheapest and easiest way to decrease production expenditure and greenhouse gas emissions is to improve the energy efficiency practices of an enterprise (Ballie & Chen 2008). The agricultural industry is also one of the most severely affected by global warming and climate change (Cline 2008). It is likely that primary producers in Queensland may face either an energy, water or carbon constrained future. Rational and efficient use of energy is essential for sustainable development to ensure the survival of the agricultural industry within Australia. The export of Queensland's agricultural products in 2010-2011 financial year accounts for 12.6% for total state exports (Treasury 2011). Improved energy efficiency will therefore significantly enhance the clean and green image of Queensland and national exports of agricultural products and most importantly improve the enterprises bottom line.

1.2 Irrigation Energy for Cotton

‘This is the way the previous farmer did it so I just carried on with the same practice.’ A common catch cry heard across the agricultural industry and one that was repeated by the grower when asked ‘Why is the engine speed set to 1,800 RPM?’ Unfortunately it is not always the best practice. The Cotton Industry relies heavily on machinery to perform specific tasks; as a result this incurs a high direct energy use on farm. Energy inputs such as diesel and electricity are major costs sustained on an irrigated cotton farm. Ballie and Chen (2008) conducted a series of energy audits on cotton farms and found the energy used varied considerably, ranging between 3.7 and 15.2 GJ/ha, at a cost of $80 to $130/ha depending on the irrigation system and the farming method. By performing energy assessments and/or audits it is possible to identify poor performance and to improve best management practices.

As energy costs continue to rise, so too does irrigator interest in assessing ways to improve their energy efficiency and reduce energy consumption. New techniques and equipment are required to assist irrigators in managing their energy consumption and therefore reduce running costs and increase profit.

On a cotton irrigation farm, water pumping is usually the largest energy use operation at 60 - 70% of total direct energy use (Ballie & Chen 2008). How efficiently this happens depends on the efficiency of the pump stations. A poorly performing pump may affect the entire irrigation system, reducing irrigation efficiency and productivity. Jessen (2008) analysed the results of over 250 pump performance tests conducted in Queensland and found the average measured pump efficiency was around 53%. This indicates that there is scope for improvement as the efficiency of a pump should not be less than 65% for the required duty point (Jessen 2008). Should pump efficiency drop below 65% the pump selection process should be investigated to achieve a better efficiency (Smith 2008). Reynolds *et al*. (2008) has shown that optimising pump performance can provide significant efficiency gains, both economically and from a production perspective.

Another process that requires machinery on cotton irrigated farms includes the harvesting operation which consume 20% of the direct energy input (Ballie & Chen 2008). Modern tractors are highly sophisticated with state of the art technology to provide driver feedback and improve energy efficiency. These technologies incorporate piezoelectric injectors, common rail, engine power management and stop start technology just to name a few (Biggs & Giles 2013). In stark contrast to the technological advancement of tractor efficiency in agriculture, pumping systems are still primitive in design. Current cotton farm pumping systems do not provide the farmer with any computerised feedback to indicate how the pump is performing, although some engines have the computerised capability but the resource is not utilised to its full capacity. In addition the pumping system is required to perform over a range of operating conditions. The operations required by various pump stations include filling storage dams, transfer and distribution of water from various locations on farm or recycling of irrigation runoff. The operation of the pump needs to adjust with changes in river or channel heights which influences the pumping head and consequentially alters the water flow rate through the pump.

The development of a computerised pump performance monitor will provide user feedback so that farmers may be aware of performance on the run and therefore able to change engine and pump settings to minimise fuel use and optimises pumping operations. This will also lay the platform for automated and/or adaptive control of the pump unit to maximise fuel efficiency in response to changing duty point; something which is now common place on late model release tractors.

Conducting a pump test will verify how the pump is operating at a single point in time. The ability to record an entire pumping event will highlight trends and provide information on how to improve the efficiency of the irrigation process. A Pump Efficiency Monitor (PEM) has been developed to conduct in-depth level three energy audits on cotton irrigator’s river harvest and flood/lift pumps. This project developed a prototype unit and analysed the results of the first stage in the creation of an automated pump efficiency control and monitoring device, as a commercial product, that can be retrofitted to a diesel engine driven pump.

Chapter Two

Literature Review

2.1 Pump Efficiency Vision

A study conduct by Ballie and Chen (2008) identified a heavy reliance on published data in relation to on farm energy efficiency. The report determined that further case studies and on-farm energy audits needed to be performed to establish a benchmark for comparison of future energy use. This comparison is not only relevant for cotton farms but also useful for other industries. Energy audits are a tool used to scrutinise the energy and environment management process. An audit will uncover how energy efficient a process or selected energy consuming items may be and highlight possible improvements or cost savings.

Grundfos (2008) have developed the CR monitor which performs an energy audit and/or monitors pump performance for electrically driven pumps. The CR Monitor records inlet and outlet pressure, water flow rate, liquid temperature, ambient temperature and electrical performance (including current, voltage and efficiency). This lays the foundation for the creation of an automated pumping system, with the ability to record and monitor pump parameters. The Grundfos CR monitor is an excellent system but it is only available for electrical motors. Research indicates that the cotton industry currently lacks appropriate equipment or technology that is able to record and monitor the pump and diesel engine parameters which allow for the calculation of either pump, diesel engine or combined efficiency levels.

The proposal of Mr Ballie and Dr Chen through the seven case studies performed in the article '*Reducing Energy Input Costs and Associated Greenhouse Gas Emissions in Cotton'* has received funding from the Cotton Research and Development Corporation (CRDC) to construct a Pump Efficiency Monitor (PEM) suitable for use in cotton irrigation pumping systems. The proposal to CRDC for the pump efficiency monitor lays the ground work and sets the objectives for this project.

2.2 Principle Function of Pump Station Machinery

2.2.1 Pump Operations

The centrifugal pump was first invented in 1689 by Denis Papin a French physicist, mathematician and inventor (McConnell 2004). The design concept is relatively simple; centrifugal forces induced from the rotating impeller accelerates the fluid from the eye of the impeller towards the outer edge (Mott 2006). Figure 1 provides a simplified schematic of a centrifugal pump. The high speed rotation of the impeller imparts velocity energy on the fluid. Some of this velocity energy is transformed into pressure inside the casing by one of two means, either a volute or stationary diffuser vanes, both of which surround the impeller (Grage 1998). The first stage of pressure increase is formed by the resistance from the pump casing on the fluid; then a reduction in the velocity of the fluid converts the velocity energy into pressure. The resistance to flow in the system (pressure) is then able to be measured on a pressure gauge on the pump discharge (Grage 1998). To allow for a continuous process (fluid flow), the acceleration of the fluid creates a partial vacuum at the eye of the impeller which then draws more fluid into the pump and allows for a continuous pumping system (Grage 1998).

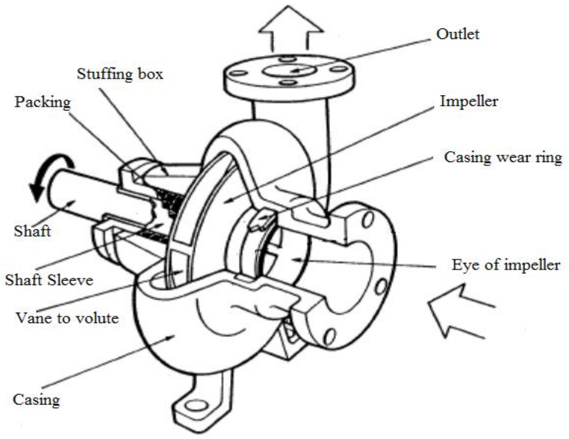


Figure 1: Centrifugal pump components (Pump Fundamentals 2010) .

The two main parts of a centrifugal pump consist of the impeller on a shaft, and the casing surrounding the impeller as identified in Figure 1. Depending on the design of a centrifugal pump they can be divided into three separate categories; radial, axial and mixed flow as illustrated in Figure 2.

Radial flow pumps discharge at 90^{o} to the shaft axis. They predominately produce low flow rates at high total dynamic heads. They come in single or multi stage impeller configurations. Multi stage impellers produce higher head pressures. While at the other end of the spectrum axial flow pumps discharge parallel to the shaft axis; there is no change in the particles radial position. The advantage of an axial flow pump over a radial flow pump is the ability to generate high water flow rates with a low total dynamic head. Axial flow pumps are generally the smallest of the three types. A mixed flow pump is a combination of both radial and axial flow pumps (Potter *et al*. 2011).

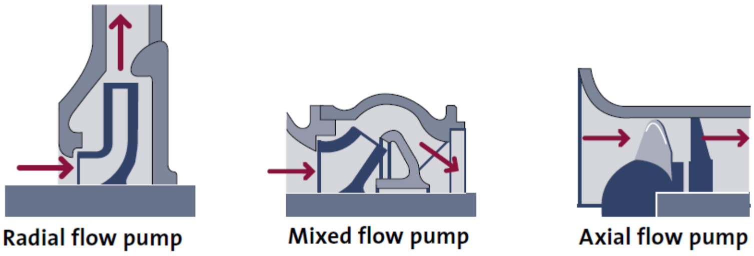


Figure 2: Three categories of centrifugal pumps (Skovgaard & Nielsen 2004).

Sites that have varying installation environments require centrifugal pumps to perform across a wide range of flow rates and head pressures. Many types of pumps exist to cater for an assortment of applications. Suitable pump selection involves identifying theduty point (flow rate and head) to ascertain the correct pump type. Figure 3 overlays the three types of centrifugal pumps to help assist in narrowing the field when selecting a suitable pump for known flow rates and head pressures. Delving further into the specific characteristics of pumps, manufacturers produce pump performance curves to indicate pump operating range for certain parameters. These parameters create a performance curve for head pressure, efficiency, net positive suction head (NPSH) and power, which are displayed as a function of flow rate. In general pump manufacture's create pump performance curves according to ISO 9960 which specifies the tolerances of the performance curves:

- Flow Rate (Q) +/- 9 %
- Head Pressure (H) +/- 7 %
- Power (P) + 9, -0 %
- Efficiency (η) +0, -7 %

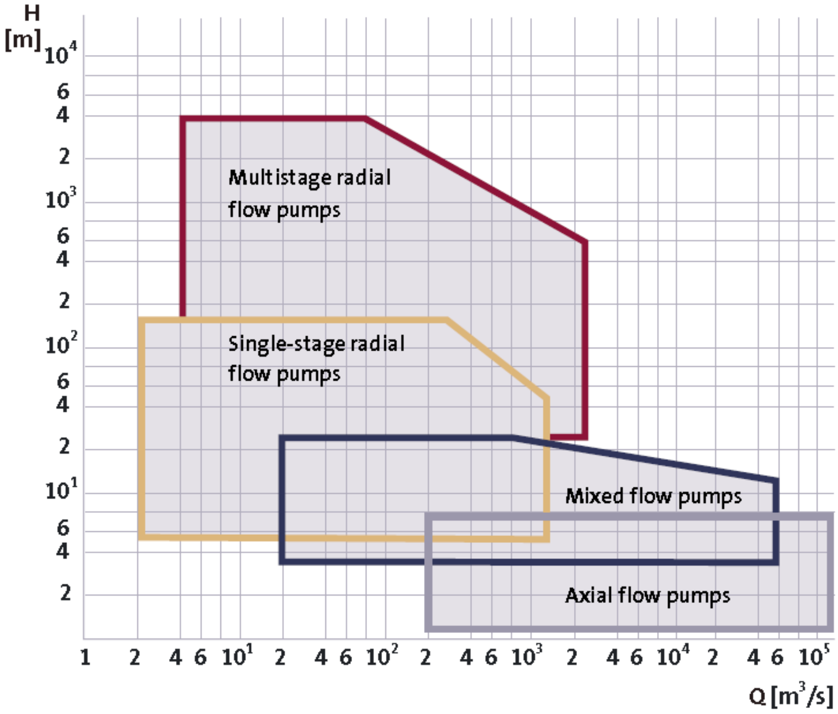


Figure 3: Flow and head compared for the centrifugal pump types (Skovgaard & Nielsen 2004).

Variable speed pumps operate across a range of pump speeds this allows for a greater range of water flow rate and head combinations. The pump performance curve illustrates the correlation between flow rate (Q) and pressure differential or head (H). Flow rate is normally measured in m^3/h or L/s while head is measured in metres. The benefit in measuring pressure in metres is that it negates the need to consider the specific gravity of the fluid (Mott 2006).

The efficiency of a pump is determined from the relationship between the power supplied to the pump and the effective power in the water delivered by the pump (Mott 2006). The efficiency is dependent upon the duty point of the pump, it is therfore important to select a pump that matches the flow rate and head requirements to ensure the pump is operating at peak efficiency. In some cases pumps may have multiple duty points for various tasks, in these situation, it might be necessary to compromise peak efficiency to achieve an overall efficiency. Fundamentally, the more fluid a pump is required to move, the higher the power requirements.

2.2.1.1 Pump Cavitation

To avoid cavitation within a pump it is imperative to maintain the pressure above the net positive suction head curve (NPSH). This is the minimum absolute pressure that can occur on the suction side. NPSH is dependent on (Pump School 2007):

- The absolute pressure on the surface of the water in the channel,
- The vertical distance from the surface of the water to the pump centreline,
- Friction losses in the suction pipe,
- The velocity head in the suction pipe and
- The absolute vapour pressure of the water at the pumping temperature.

As the velocity of the water increases, the head for friction and velocity increase thus reducing the NPSH allowing cavitation to occur. Should cavitation take place, flow rate and head will dramatically reduce, decreasing the life of the pump by causing varying degrees of damage.

To define pump cavitation it is first important to understand the fluid property, or vapour pressure. The pressure at which small vapour bubbles form within the fluid is known as it's vapour pressure (Cengel & Boles 2007). This is also known as the fluids boiling point. The following is an example of how this occurs naturally. At sea level where the atmospheric pressure is 101.3 kPa the temperature of the water at boiling is 100 ^{o}C. In comparision to the summit of Mt Everest at 8848 metres above sea level (Gamble 2011) where the atmospheric pressure is 32.7 kPa and the water boiling temperature is considerably lower at 71 ^{o}C. Table 2 indicates vapour pressure for the corresponding temperature and density.

Table 2: Vapour pressure of water with corresponding temperature and density (Cengel & Boles 2007).

Temperature (^{o}C)	Density (kg/m^3)	Vapour Pressure (m)
0	1000	0.062
10	1000	0.125
20	998.0	0.238
30	996.0	0.433
40	992.0	0.753
50	988.1	1.26
60	983.3	2.03
70	977.5	3.18
80	971.8	4.83
90	965.3	7.15
100	958.8	10.34

How the vapour pressure relates to cavitation in a pump is important. Once the net positive suction head falls below the vapour pressure (at given temperature of the fluid) vapour bubbles will begin to form. Consider a pump that is required to draw water and exceeds the pumps NPSH by passing through the fluids vapour pressure line as indicated at point A in Figure 4 thus creating vapour bubbles in the fluid. Water enters through the inlet at the centre of a rotating impeller and accelerates the fluid toward the outer edge of the impeller. At point B in Figure 4 the rapid increase in water pressure will cause the vapour bubbles in the fluid to collapse as the pressure increases past the vapour pressure line. The violent collapse of vapour bubbles causes the release of large amounts of energy which can cause severe damage to the pump's impeller and surrounding components such as seals and bearings (Pritchard & Leylegian 2011). Signs of cavitation in a pump include (Mott 2006):

- A loud hammering noise similar to a ball peen hammer hitting sheet metal,
- Vibrations which are transmitted down the transmission line to the engine and
- A reduction in the discharge water flow rate.

Therefore, it is important to reduce the cavitation within a pump to ensure the improvement in the pumps life expectance and efficiency in pumping the required amount of water.

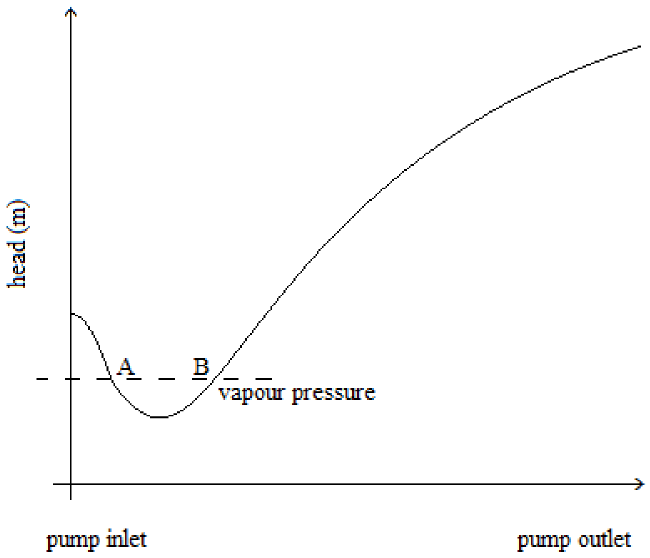


Figure 4: Development of cavitation through a centrifugal pump.

A situation arises in which the noise generated from the diesel engine running in close proximity to the pump makes it difficult to detect cavitation. Research has been conducted and a product manufactured that has the ability to detect cavitation (Klubnik 2007). The violent collapse of the vapour bubbles generates a particular vibration pattern or high frequency energy. Through the analysis of this energy it is possible to identify whether the frequency is increasing or decreasing and thus recognise the state of cavitation (Klubnik 2007). Automated monitoring devices already exist which are capable of collecting and analysing vibration data and informing the operator on how to alter the system to reduce cavitation (Reeves 2007). The four most common reasons for pump failure include: insufficient lubrication on bearings, fatigue due to overloading unbalanced or misaligned pumps, improper installation of pump components and finally contamination through seals (Meggitt 2008). Meggitt (2008) claims vibration detection equipment will detect all of the listed common pump failures.

2.3 Critical Factors in System Efficiency

2.3.1 Pump Efficiency Degradation

Due to the large number of pump types for various applications this section will focus on the main problems associated with large irrigation pumps used on cotton farms. Large pump casings are generally made from cast iron which has a rough cast finish. Manufacture’s will apply a coat of paint to reduce corrosion while the pump is in storage before sale. Once the pump is in service and high volumes of water are passing over the casing erosion corrosion will start to occur and rapidly remove the coat of paint. Erosion corrosion is caused by the movement of a fluid over a metal surface, removing parts of the metal surface (Askeland & Phule 2006). The carbon dissolves from the solution in the cast iron and leaves a porous surface, this results in tuberculation on the pump volute surface and reduces efficiency by 25% (Welke 2012).

Tuberculation is the formation of localized corrosion products spread over the surface of the cast iron which forms knob-like mounds (Rothwell 1979). Figure 5 depicts tuberculation in pump casings. The corrosion mounds increase the roughness inside the pipe which increases the resistance to water flow (Rothwell 1979). Aftermarket products can be applied to construct an extremely slippery surface within the pump casing which will improve pump efficiency and reduce energy inputs (Belzona 2013).

Figure 5: Pump internal with severe tuberculation (Verosky *et al*. 2008).

The impeller of a centrifugal pump is designed to move the water from the centre or eye to the outer edge. This is achieved by the centrifugal forces created by the rotating impeller. The energy supplied to the impeller from the diesel engine is transferred to the water through the impeller volute surface. The very nature of this energy transfer causes high amounts of friction on the impeller volute surface and encourages erosion corrosion. Applying a surface coating will reduce friction and improve pump efficiency. In 2008 a Lowara pump was independently tested with a coating of *'Super Metal Glide'* and the results from the test indicate a 7% reduction in power consumption when the pump was run at its peak efficiency point (Maillard 2008).

The seal between the pump impeller and casing must be of good quality to stop any water recirculation. Welke (2012) highlighted that the gap between the impeller and seal is typically 0.4mm, generally on low quality pumps this seal is machined straight into the cast iron casing. The cast iron casing erodes very quickly which in turn will increase the size of the gap and reduce pump efficiency. In which case it not only increases the amount of energy required but also significantly reduces the water flow rate through the pump. To combat the problem a replaceable seal ring constructed from a material with a high resistance to abrasion can be installed. Materials suitable for this application are stainless steel rings and ceramic coatings (Welke 2012).

2.3.2 Power Efficiency Transfer

The output shaft on the diesel engine drives the pump in one of three common ways, belts chains, gears and direct drive. Belts and gear driven systems have associated energy transmission losses, while an engine with a direct drive system incurs no losses. The disadvantage of a direct drive system is that there is no means of reducing the output speed of the engine. The speed of the engine must match the operating speed of the pump for correct operation.

A gear mechanism transfers the rotary motion from one shaft to another by the interface of toothed members; and by altering the diameter of the gears this will alter the ratio at which the output shaft operates providing a means to increase or decrease shaft speed. From the various means of transmitting power such as gears belts and chains, gears are generally considered the most hard-wearing and robust (Juvinall & Marshek 2006). The efficiency of a gear driven system is dependent upon the surface roughness between the gears and the type of lubrication system utilised together with the arrangement of the gear teeth whether it’s a spur, bevel or helical gear (Kahraman et al. 2008). Efficiency losses occur from the sliding frictional element between the opposing gears mesh and the hydrodynamic rolling element. Hydrodynamic rolling energy losses are compression of the lubricating oil between the teeth (Anderson & Loewenthal 1980). The efficiency of power transmission in a gear system is as high as 98% (Juvinall & Marshek 2006).

Belts and chains are flexible components. A belt system allows for greater distance between the drive shaft and driven shaft allowing greater flexibility in design and is relatively quiet during operation. The flexibility within a belt reduces the transmission of vibration and shock between the components. Some common types of belts are flat belts, V-belts and toothed belts. The energy losses in belts tend to be higher than gears. The efficiency of a V-belt configuration when first installed is about 97%. After the run-in period the belt stretches and loses tension which causes slippage within the sheaves ultimately reducing efficiency to approximately 94% (Francis 2000). Energy loss occurs from the friction caused by the slippage of the belt and the sheave generating heat within the belt. This not only reduces efficiency but also shortens the life of the belt. To maintain maximum efficiency in a belt, system alignment and tension should be continuously checked and adjusted by the grower to ensure that the belt is operating at or near the rated load capacity. By the grower scarficing a little time to continually re-tension belts that are in good condition, they can ensure the pump's efficency can increase by about 3-4% thus saving the grower money in the long run (Francis 2000).

2.4 Energy Audits

The purpose of conducting an energy audit is to provide the energy user with information to establish consumption rates from the various energy inputs and recommendations to improve energy efficiency (Australian Standards 2000). The energy audit will provide a benchmark that can be used to compare the site to other energy users and display whether energy consumption is high, at a reasonable level or running efficient. This will also establish if further investigations need to be conducted. Essentially there are three levels associated with an energy audit each subsequent level requires further investigation into the energy consumed on site.

2.4.1 Level One Energy Audit

A level 1 energy audit, also known as an 'Overview', accounts for all the energy consumed on site. This will create an initial benchmark for comparison in later years to identify any significant changes or improvements from the initial level. The audit generally does not require a site visit and can be completed as a desktop study. The auditor will require the quantity of the several types of energy (electricity, diesel, petrol, gas, coal etc.) consumed on site for the previous 24-months. From the supplied energy data, consumption can be broken down into monthly or seasonal variations. Rough savings and costs can be determined from the identification of any potential reduction in energy consumption. The accuracy of the figures from a level 1 energy audit should be within ±40% (Australian Standards 2000).

2.4.2 Level Two Energy Audit

A level 2 energy audit should be carried out every 3-5 years. The audit begins with the same process as a level 1 audit with the addition of a site visit. During the site visit a record of all power ratings for each electrical item and fuel consumption for machinery must be compiled. Through discussion with the site manager or the appropriate personnel an accurate assumption for equipment annual run times are collected. A combination of rated input energy and annual run times will provide an estimate of the annual total energy consumed for each item for an annual year. According to the

Australian Standard 3598:2000 the accuracy of the gathered data will generally be within ±20%. The collation of data will provide greater detail of analysis and therefore further recommendations for potential energy and cost savings.

2.4.3 Level Three Energy Audit

Level 3 energy audits should only be performed after a level 1 and/or 2 audits have been conducted and individual high energy consuming items have been identified. A level 3 energy audit will provide further detail into energy consumption for individual items over time. Not all sites will require a level 3 audit. High energy consuming areas identified in either level 1 or 2 audits will benefit from a level 3 audit before any investment into equipment or process upgrades are considered to improve energy efficiency. The installation of energy meters and logging equipment onto individual items or sections will enhance the quality of the data gathered. This will provide further information into possible energy savings. In addition a cost benefit analysis of any potential infrastructure upgrades will determine how much energy will be saved plus the payback period for the infrastructure. The accuracy for the data gathered from a level 3 energy audit should be within +10%for costs and -10% for benefits (Australian Standards 2000).

2.5 Efficiency Improvements from Pump Station Layout

The turn of the century witnessed the redesign of cotton irrigated pump stations. Before the redesign *'Irrigators frequently complained that they could not keep the water up to the cotton fields'* (Reynolds et al. 2008). The original installation design from the mid 1980's incorporated the Macquarie 26HBC-40 mixed flow pump driven by a diesel engine. However this was considered less than ideal, once the irrigators realised the pumps were not deliveing their rated capacity. The cause was identified as the pump installation being too high above the source and discharge pan, resulting in the water being siphoned from the pump. Figure 6 illustrates the discharge outlet below the mid-point of pump; as a result there was nothing for the pump to push against due to the negative discharge pressure. This caused severe cavitation within the pump, which also resulted in a 40% reduction in flow rate from the required 100ML/day, for cotton requirements, to only 60ML/day (Reynolds *et al*. 2008). The pump was exceeding its rated suction head and with no discharge pressure irrigators found that increasing the pump speed only exacerbated the problem of insufficient flow rate. A full redevelopment of the pump station was necessary for cotton irrigators to supply the vital water needed in the cotton fields.

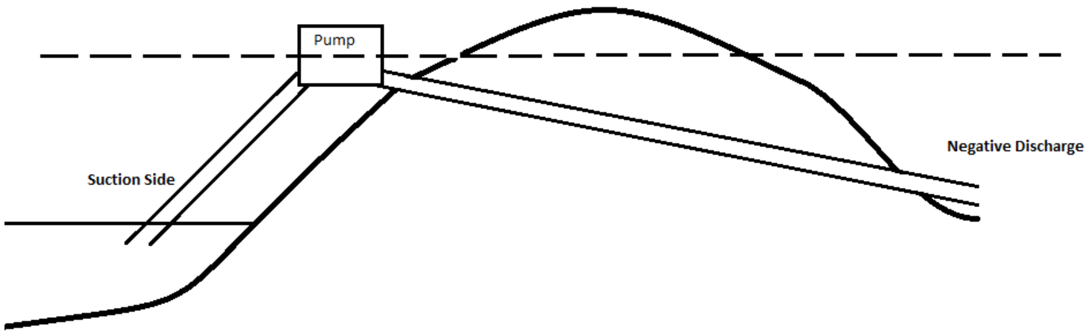


Figure 6: Original layout for diesel engine pump station typically used up to late 90's.

A case study site at "Topbox" was recognised and redeveloped at a cost of $49,650. This included $4,600 to incorporate a foot valve and shed plus $40,500 for a new John Deere 60814 engine and gearbox. The pump demands were 125 horse power to move 100 ML of water a day rotating at 520 RPM. The original engine was producing 200 horse power at 1,800 RPM exceeding requirments and resulting in glazing on the cylinders from a rich mixture creating unburnt fuel in the exhaust. Additionally $4,550 was spent on labour, an excavator and concrete to reposition the pump station two metres below the original site and install a distribution tank that elevated the discharge level to create a positive discharge pressure as represented in Figure 7 (Reynolds *et al.* 2008). This gave the pump a lower suction head and a higher discharge head, water flow rate was increased to 90ML/day and fuel consumption was improved by over 20% (Reynolds *et al*. 2008). The original system took 12 days to water 350 hectares. The redevelopment reduced water time to approximately 5 days. The operating cost for the pump station saw a dramatic reduction from $285/Ha to $101/Ha, this is equivalent to a 64.5% improvement in efficiency. The payback period for the redevelopment costs of $49,650 equates to 9 months.

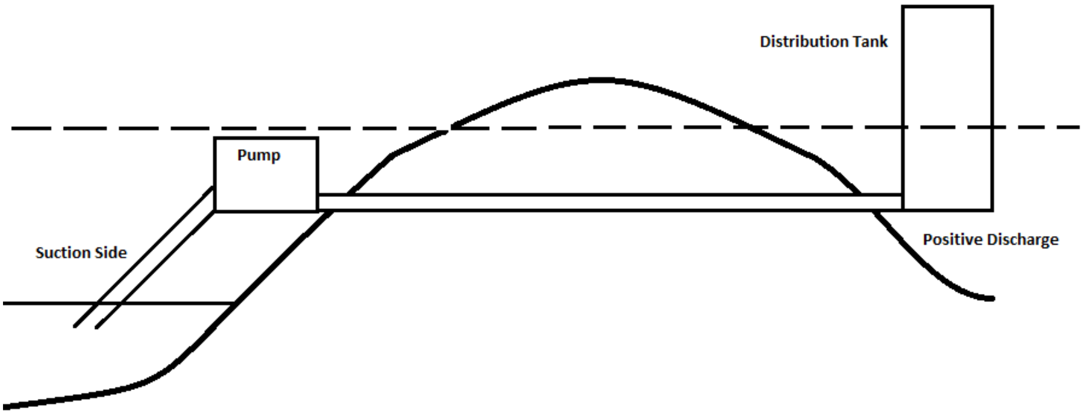


Figure 7: Redeveloped pump station to reduce cavitation and increase water delivery.

2.6 Conclusions from Literature Review

The literature review identifies efficiency issues for cotton irrigation pump stations. There is between 60-70% of energy consumption on cotton irrigation farms in the pumping operation. The efficiency issues have ranged from cavitation, inefficient power transfer and poor installation design. Problems such as tuberculation occur over time and may go unnoticed for many years, while the efficiency of the pump station steadily decreases. Altering the task required of a pump station may unknowingly induce cavitation, thus reducing efficiency. The highlighted problems expose a gap in the current management tools of cotton irrigation pumps and the need to create a pump efficiency monitor. The pump efficiency monitor will provide another tool to support cotton growers to reduce energy consumption and meet greenhouse gas emission targets within irrigation practises.

Chapter Three

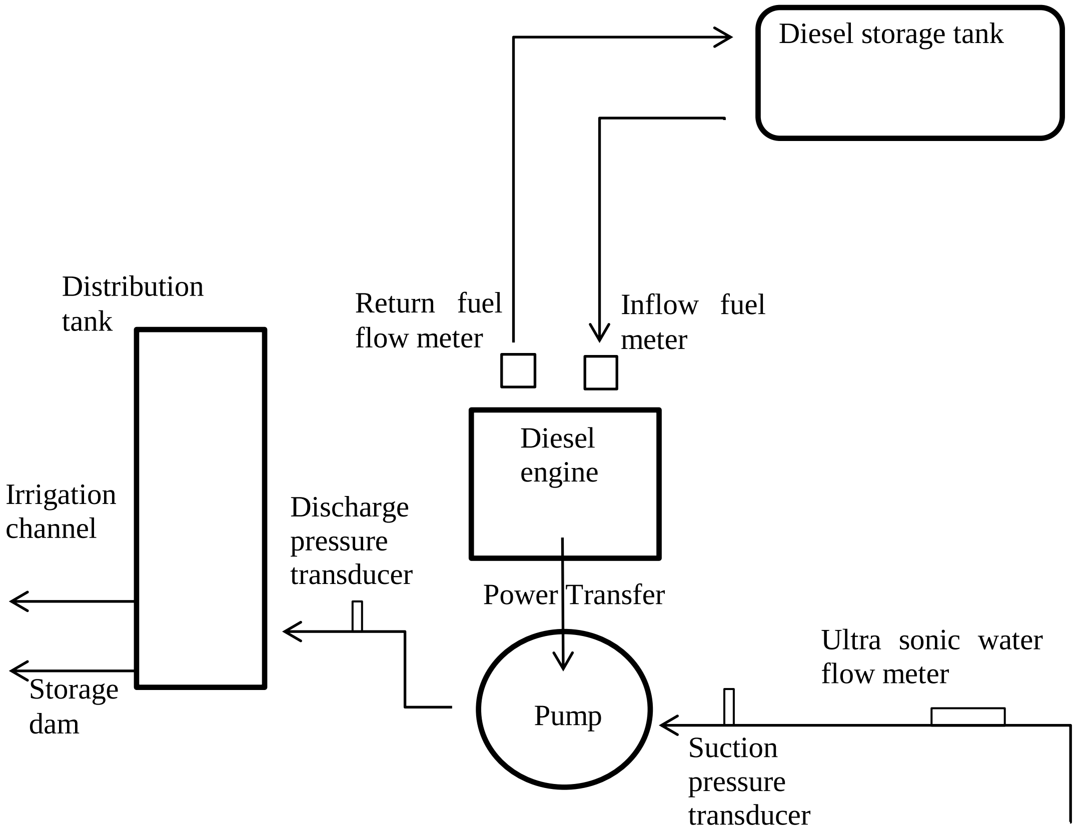
Design of the Pump Efficiency Monitor

3.1 Methodology

A Pump Efficiency Monitor (PEM) has been developed to identify pump efficiency problems. The PEM consists of four types of electronic measuring sensors with data logging capability. This enables the continuous measurement of several pump variables to assess efficiency and monitor energy use during an irrigation season. Conducting a pump test will verify how the pump is operating at a single point in time. The ability to record an entire pumping event will highlight trends and provide information on how to improve the efficiency of the irrigation process.

Figure 8 and 9 identifies the layout of the pump station and the location for each of the sensing instruments. Fuel consumption of the diesel engine is measured via two Macnaught fuel flow meters with a range of 15-500L/hr . These meters are installed on the inflow and return fuel lines and produce a pulse output equivalent to 2.5mL of diesel per pulse. Two types of instruments are used to measure the energy output of the pump. First are two WIKA pressure transducers a -1 to 0 bar installed on the inlet and a 0 to 1 bar installed on the outlet. This will measure the total dynamic head (TDH) across the pumping system. The second is a Dalian Zerogo ultra sonic flow meter used to measure water flow rate. This requires an onsite calibration and outputs the results in a 4-20mA format.

Figure 8: Layout for pump station.



All the measurements are recorded in a Campbell Scientific data logger and processed to determine fuel consumption/cost per mega litre per metre head (Diesel L/ML/m).The pump efficiency monitor contains telemetry equipment to allow access to the data where a 3G network is available. A battery was installed to ensure an adequate power supply to the PEM and access to the data. Battery charging is conducted via the 24V system on the diesel engine plus a 10W solar panel. Figure 10 illustrates the location of the internal components in the pump efficiency monitor. The following sections within Chapter 3 provide a detailed explanation on how individual components function and provide accurate data for analysis.

Figure 9: Pump station used for trial of pump efficiency monitor.

Table 3: Identification of components in PEM.

Components in PEM			
A	Data logger	F	Modem control relay
B	Modem	G	Sensor control relay
C	Ultra sonic flow meter	H	Solar charge controller
D	Fuse box	I	12V Battery
E	DC-DC converter		

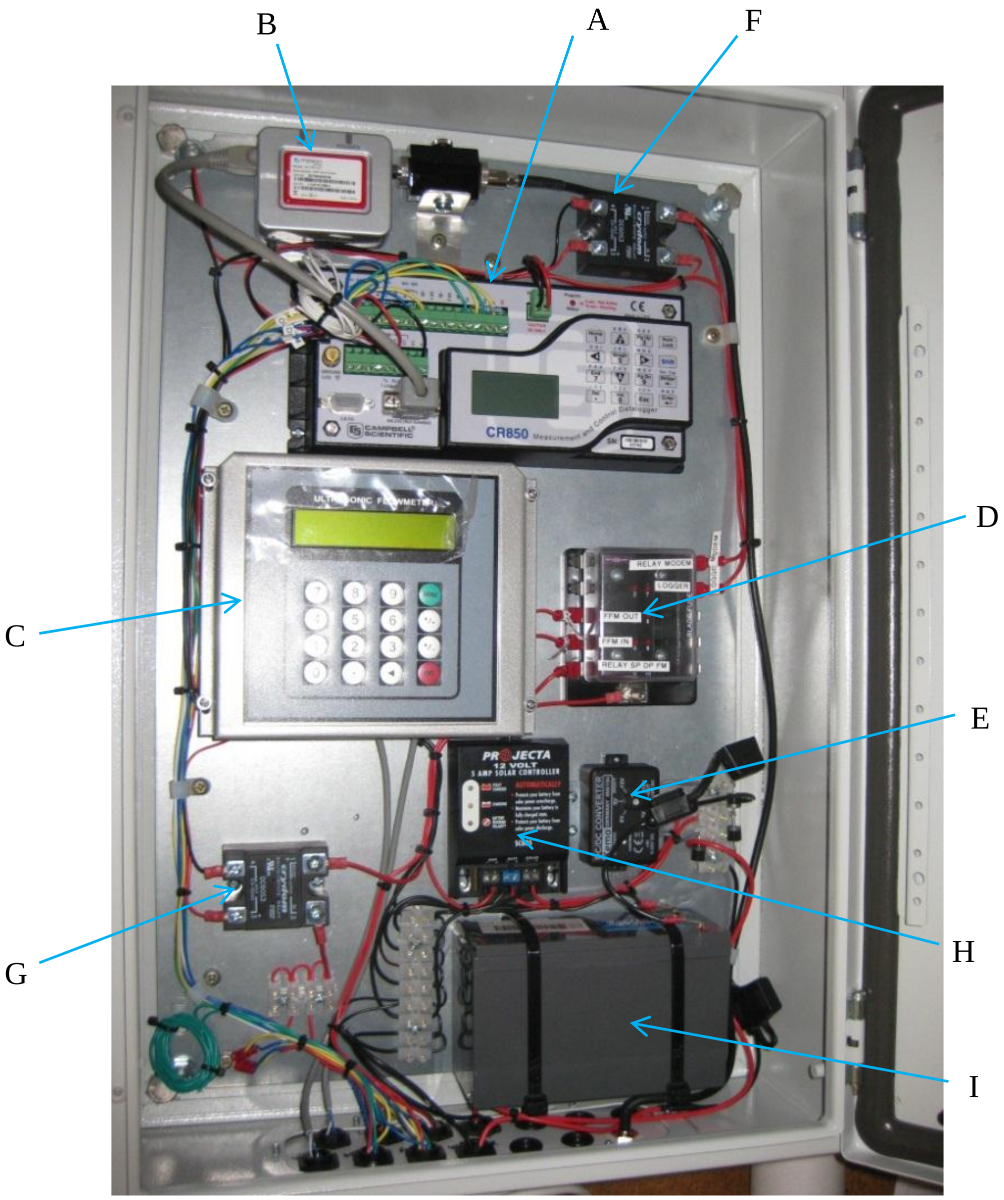


Figure 10: Layout of components in PEM

3.2 Fuel Flow Meters

According to Equation 2 in Section 4.1 the fuel consumption of the diesel engine will be in the vicinity of 50 L/h when producing 200 kW. This has little significance to the selection of the fuel flow meters as a diesel engine has two fuel lines, an inlet and return. The purpose of the return line is to send the excess diesel, not used for combustion, back to the fuel tank to allow for cooling. A diesel fuel pump supplies a greater capacity than required by the engine for combustion. The excess diesel lubricates various components within the pump and injectors; the diesel also supplies a cooling medium for the injectors. With this knowledge, it is necessary to determine the diesel pump capacity and select the appropriate size fuel flow meter. Perusal of the literature provided by the manufacture (Volvo) of the engine, revealed the pump capacity was not specified. However through discussions with the maintenance department for the engines on site it was ascertained that the pump capacity is approximately 3-4 times the maximum theoretical fuel consumption. Therefore the requirement for a fuel flow meter is to manage a maximum capacity of 200 L/h. The installation of the fuel flow metres as displayed in Figure 11.

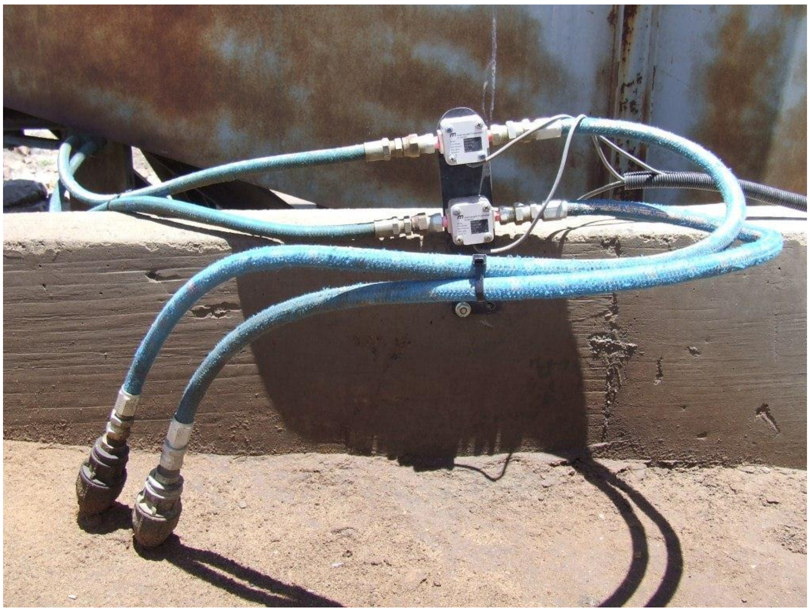


Figure 11: Installation of fuel flow metres.

Macnaughton offers a fuel flow meter with a capacity of 15-500 L/h. The meter is of pulse type, one pulse is equivalent to 2.5 ml of diesel. There are two methods to measure the pulse, the first is a mechanical Reed Switch and the second a Hall Effect Sensor. Both systems have advantages and disadvantages. The following two sections will describe how each system works and why the Hall Effect Sensor was chosen for the first PEM, to then be changed to the Reed Switch for the second PEM.

Each fuel flow cable is constructed from a 15m length, 5.7mm diameter, 6 core shielded cable. The shield is to provide protection from outside interference. Table 4 identifies the colour code and function of each wire, with Figure 12 indicating the connector pattern and Figure 13 illustrating the wiring diagram within the fuel flow meter.

Table 4: Fuel flow sensor wire functions (Gavin 2009).

Output Type	**Wire**	**Function**	**Wire**	**Function**	**Wire**	**Function**	**Note**
Reed Switch	Green		Yellow				No Polarity Required
Hall Effect Sensor	Red	+VDC	Black	Gnd (0V)	White	Signal	NPN Open Collector

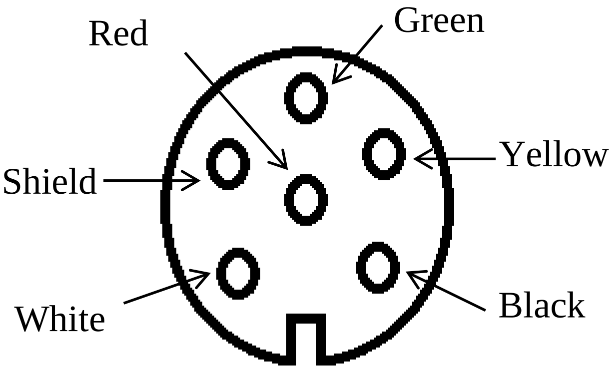


Figure 12: Connector for fuel flow meters.

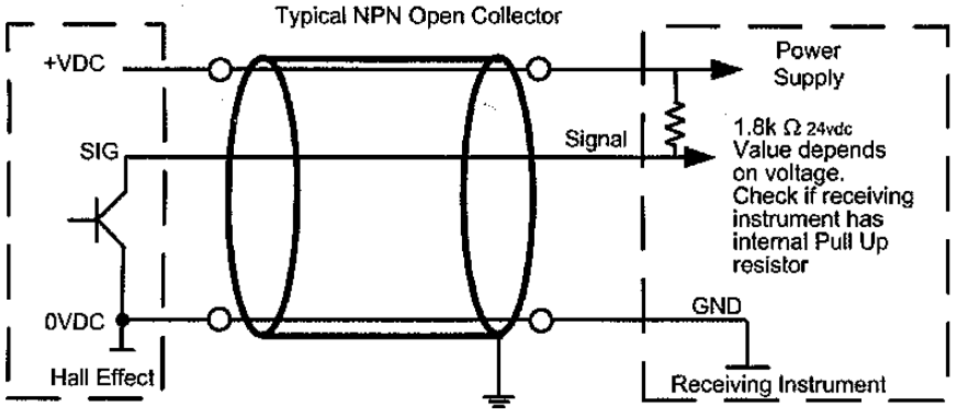


Figure 13: Fuel flow sensor wiring diagram (Gavin 2009).

3.2.1 Hall Effect Sensor

The principle of the Hall Effect Sensor was discovered by an American physicist Edwin Herbert Hall in 1879. Edwin Hall discovered that when a magnetic field is applied at right angles to a current carrying conductor a small voltage is produced (Ramsden 2006). With the use of appropriate instrumentation it is possible to measure the created voltage. In effect this is the creation of a simple transducer with applications ranging from signal processing, proximity sensing, current sensing plus speed and timing sensors. The benefits of a Hall Effect Sensor are its insusceptibility to dust, dirt, mud and water. There are no additional mechanically moving parts which would provide an infinite life, in theory a Hall Effect Sensor should never fail. In current sensing applications such as the McNaughton fuel flow meter a shunt resistor must be applied to the primary circuit. The disadvantage of the Hall Effect is the voltage range produced is only in the order of millivolts which is inadequate to directly drive actuators and requires the installation of a transistor based circuit to amplify the signal. While this has no direct implications for the pump efficiency monitor, objects that produce a magnetic flux in the area surrounding the fuel flow meter will. The sensor is required to detect a magnetic flux should the surrounding environment contain any devices or materials that produce a magnetic flux this may have a detrimental effect on the fuel flow meter by either enhancing or diminishing the desired results.

For the construction of the first pump efficiency monitor power consumption was not an issue. Therefore the reliability of the Hall Effect sensor was ideal. The sensor draws a constant 7.5mA which is not a large amount of current and did not pose a problem when the diesel engine was in operation. However due to the installation of solar power to the pump efficiency monitor to allow regular accessibility to the data logger it was deemed suitable to change from using the Hall Effect sensor within the fuel flow meter to the Reed Switch. Section 3.5 will provide further information of the power supply systems.

3.2.2 Reed Switch

A Reed Switch is best described as an electromechanical component containing two Ferro magnets known as Reeds that are hermetically sealed in a glass casing (Gurevich 2006). In 1922 Professor Kovalenkov from Leningrad Electrotechnical University invented the Reed Switch and research continued in 1936 by Bell Telephone Laboratories (Gurevich 2006). A Reed Switch is activated by a magnet that moves towards and away from the Reeds. The switch will close as the magnet approaches and in the case of the fuel flow meter generate an electrical pulse to be counted. The advantage of the Reed Switch is that it does not consume any power while on standby which allows the fuel flow meters to be continuously active. The drawback of a mechanical switch is that the component is susceptible to failure. From testing conducted by Digi-Key Corporation in the United States of America the life expectance of a Reed Switch can be in the order of 800 million operations when operated at 10V and 4.0mA (Meder 2013). One pulse equates to 2.5 ml of diesel, from this the expected quantity of fuel to be measured is approximately 2 ML of diesel. At an average flow rate of 125 L/h the life expectance from the sensors is approximately 16,000 hours. By this estimate a pump station operating for 1000 hours a season, will require replacement of the fuel flow meters every sixteen years.

3.3 Pressure Transducers

There are three types of pressures that can be measured in a pipe flow system these include static, stagnation and dynamic pressure (Pritchard & Leylegian 2011). In regards to the pressure sensors on the PEM they are required to take measurements of the static pressure at both the pump inlet and outlet. The installation of the pressure sensors will measure the total dynamic head (TDH) added to the irrigation water by the pump. Therefore it is important to install the sensors as close to the inlet and outlet of the pump as reasonably possible. The sensors must also be perpendicular to the flow so as not to induce any partial dynamic pressure into the static pressure reading. It was requested that the grower install two one inch ball values at pre-determined locations on the inlet and outlet of the pump, for the installation of the pressure sensors. Ball values where used to allow the removal of the pressure sensors without having to shut down the pump or engine. It was not possible to install the sensors directly before the inlet or after the outlet due to the pump casings which are made from cast iron and drilling into the casing would more than likely cause the casing to crack. However it was possible to install a suction pressure sensor approximately one metre before entry into the pump.

Unfortunately the flange between the pump and pipe on the outlet could create too much disturbance to the flow and may produce poor quality data. This section of pipe was immediately followed by one 90^o bend with a 30^o inclination to the horizontal and a further 30^o bend 800 millimetres downstream reverting back to a horizontal pipe. Appendix C provides the layout of both suction and discharge pipe lines in the pump station design. The most suitable location for the discharge pressure sensor was the mid-point on a straight section of pipe between the 30^o bend and the exit to the distribution tank. While it was not ideal it was the most suitable position. Due to the unaccounted head loss, given that the discharge pressure sensor was not immediately after the pump outlet and the suction sensor was not immediately before the pump inlet, a full analysis is provided in Section 4.2, while Figure 14 indicates the location of both suction and discharge pressure sensors.

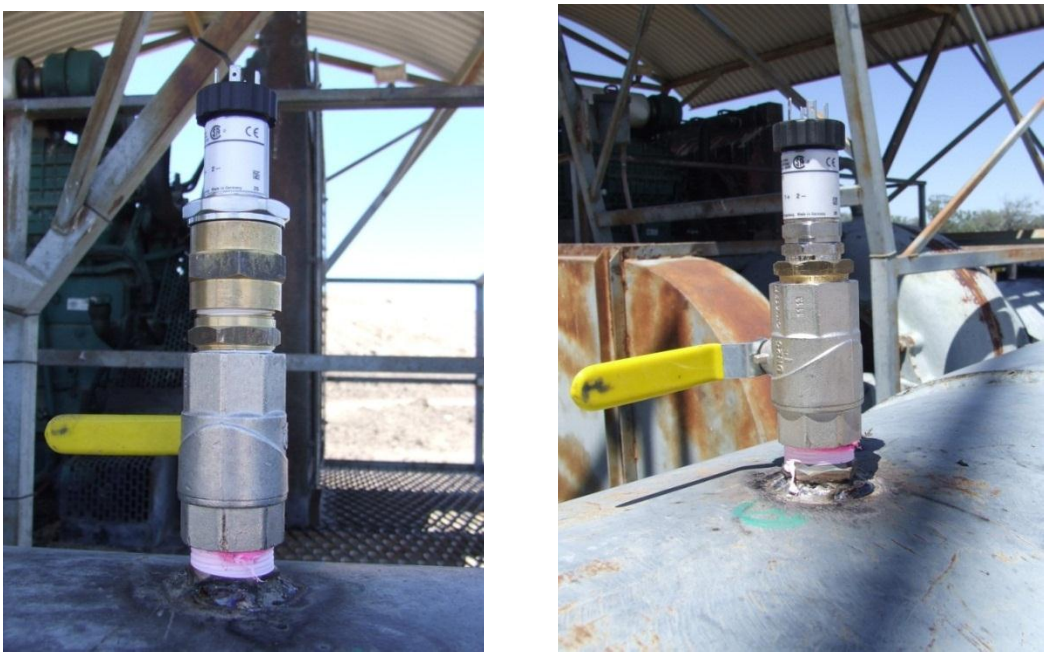


Figure 14: Location of suction and discharge pressure sensors.

The pressure transducer selected for this role is a WIKA S-11 with an external diaphragm. Static pressure within the pipe is converted into an electrical signal through the deflection of the external diaphragm which varies the electrical signal between 4-20 mA and proportional to the fluid pressure. Cables connecting the sensor to the cabinet are 15m in length and consist of 4 core shielded cable 4.8mm in diameter with the pin placement represented in Figure 15.

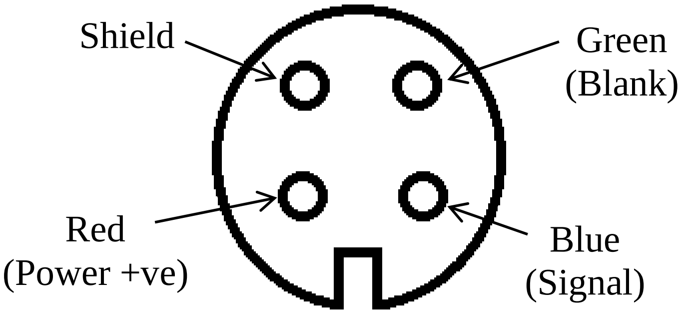


Figure 15: Connector for pressure transducers.

3.4 Water Flow Meter

The ultrasonic flow meter is designed to measure the velocity of a fluid within a closed pipe. The principle involved is known as the transit-time flow measurement and utilises a pair of transducers mounted upstream and downstream on the pipe as illustrated in Figure 16. Each transducer operates as a transmitter and receiver. The internal circuitry of the unit operates by consecutively transmitting and receiving a coded burst of sound energy between the two transducers. The transit-times from both the upstream and downstream transducers are measured. The difference between the two transient times will develop a direct relationship for the velocity of the fluid within the pipe as displayed in Equation 1.

$$V = \frac{MD}{sin2\theta} \times \frac{\Delta T}{T_{up} \times T_{down}} \qquad (1)$$

M = *The number of times the sound traverses the flow.*
D = *Diameter of the pipe.*
Θ = *The angle between sound path and direction of flow.*
T_{up} = *Time taken for sound to travel from upstream to downstream transducer*
T_{down} = *Time taken for sound to travel from downstream to upstream transducer.*
ΔT = *Difference in* T_{up} *and* T_{down} (T_{up} - T_{down}).

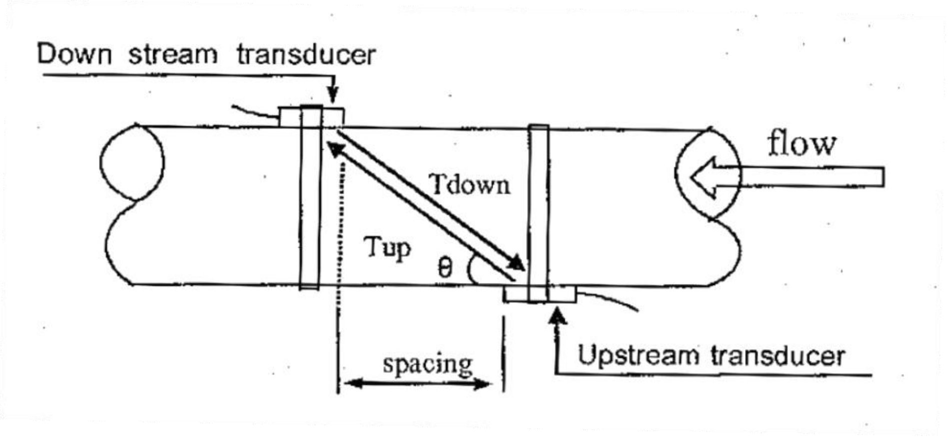


Figure 16: Location of transducers for the ultra-sonic flow metre.

The flow rate in the pipe is calculated from the velocity along with pipe material and construction parameters entered by the user. These include:

- Outer and/or inner pipe diameter.
- Wall thickness.
- Material of the pipe.
- Material of liner and thickness if required.
- The type of fluid in the pipe.
- Transducer type (in the case of the PEM a Standard M1 transducer was used).
- Transducer mounting method (Z method).

From the data entered above the unit will compute the spacing required between the two transducers as indicated in Figure 16 and 17.

Figure 17: Display for ultrasonic flow meter.

Space inside the PEM cabinet is at a premium and for this reason the ultrasonic flow meter was stripped from its IP68 cabinet as illustrated in Figure 17. The stripped unit was evaluated to determine correct functioning with the display disconnected, as this provided additional space to install further equipment. Upon completion of stage one construction the additional space was not required and for ease of installation and data entry in the field the flow meter interface was reinstalled.

The output signal from the flow meter consists of an analogue 4-20mA reading. 4mA corresponds to zero flow rate and 20mA maximum flow rate. This highlights the disadvantage of operating such a system to measure flow rates as it is necessary to obtain a value for the maximum flow rate possible within the pumping system. To try and reduce any induced error, the maximum flow corresponding to the edge of the pump curve is utilised, this is displayed as 1,800 L/s. Connecting the transducers to the cabinet is 20m of 3 core shielded cable with an IP66 connector as illustrated in Figure 18. The transducers units are rated to IP68 and are water submersible to 3m.

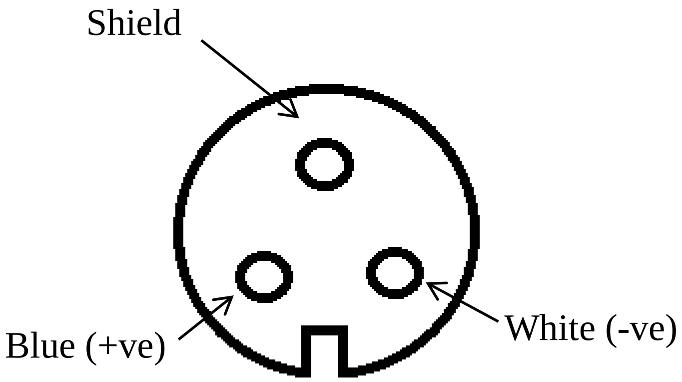


Figure 18: Connector wiring for both ultrasonic transducer units.

3.5 Power Supply System

The design of power system in the original pump efficiency monitor is not overly complex. The diesel engines alternator supplied the electrical energy requirements for the PEM. The engines alternator produces 80A which is sufficient for the operation of the diesel engine accessories plus the 500mA to operate the PEM and then charge the PEM’s internal battery. Power is supplied from the diesel engine electrical system when the battery clamps are connected; this only occurs during a pumping event which results in limited access to the data logger for download requirements. In designing the second pump efficiency monitor it was decided that access to the data logger was required outside when the diesel engine was in operation. The final design allowed the user to log on to the data logger five minutes before and five minutes after the hour, a total of ten minutes. For further details on the communication network see Section 3.6

The power source for the second PEM consists of a 12V 7Ahr battery. The battery is charged from a 10W solar panel and the 24V alternator on the diesel engine. To protect the electrical components inside the cabinet from a reverse polarity connection on the battery of the diesel engine a 3A fuse and 6A 1kV diode is wired in series. The 24V's supplied from the engine continues onto a DC-DC convertor where the voltage is reduced to 15V. The setting of 15V is chosen because it allows for a charging voltage of 14V on the battery and a voltage drop within the electrical supply system of approximately 1V, as measured during construction. The 15V passes through another diode which will stop the battery discharging to the diesel engine electrical system. Solar power also enters the cabinet at this point via a diode to also control battery discharge. Both 24V diesel engine and solar power are wired together into the 12V 5A solar charge controller. By wiring them together the battery can be charged by either 24V or solar power. The source with the highest voltage will enter the solar charge controller. The solar charge controller has two outlets the first is directly to the battery with a 3A protection fuse, the second is to the fuse box which will distribute power to the various components.

Indicated below is the voltage range and current consumption of each component in the pump efficiency monitor. It is important to identify the limitations of each component to reduce the possibility of overload. Note that the voltage range of the data logger is in close proximity to the voltage output of the power system.

Voltage range:

- Data Logger: 9.6-16VDC
- Modem: 6-32VDC
- Ultrasonic Flow Meter: 8-36VDC
- Fuel Flow Meter (Hall Effect): 4.5-24VDC
- Pressure Transducers: 10-30VDC

Current usage:

- Data logger current drain 100 Hz Sample Rate (one fast SE meas. w/ RS-232 communications): 27.6 mA optional keyboard display on: add 7 mA to current drain. Backlight on: add 100 mA to current drain. Total 0.14A
- Modem: Idle 50mA, Maximum 150mA at 12VDC.
- Ultra Sonic flow meter consumes less than 2W therefore current drain at 12V is 0.17A.
- Fuel flow Meters: Hall Effect 7.5mA, Reed Switch no current draw
- Pressure transducers: 20mA

As mentioned earlier the solar panel will be installed to allow access to the data logger via the modem when the diesel engine is not operating. The selection of the battery required research into how many amperes where consumed when the PEM was in standby mode. The 12V 7Ahr battery will run the fuel flow meters (no current draw), data logger (30mA) and modem (5mA) in their relative standby modes. Battery life will be conserved by shutting down the remaining components. A current draw of 35mA, from the data logger and modem, on a 7Ahr battery equates to a standby life of approximately 200hrs (8.3days).

The start-up sequence for the components in shut down mode relies on the fuel flow meters. The power supply for the ultrasonic flow meter and pressure sensors are controlled by a Crydom DC60S3 solid state relay. The control input for the relay is a 5V output from the data logger and becomes active once the data logger registers a positive reading from the fuel flow meters. This indicates that the engine is running and for the system to switch on. Once the diesel engine is operating and fuel is flowing through the meters, producing pulses, a signal is sent from the data logger to a relay. This relay opens and allows power to activate the remaining components. Once this sequence has occurred power will be supplied to the PEM from the diesel engine and continue to charge the battery. Relying on the 10W 12V solar panel to charge the battery, producing 0.83A, will require 8.4 hours for a complete charge from a drained state.

The cables used to connect the solar panel and diesel battery to the PEM is 3mm twin core copper cable at 10 metres in length, with a connector rated to IP68. Figure 19 illustrates the correct wiring procedure to supply power.

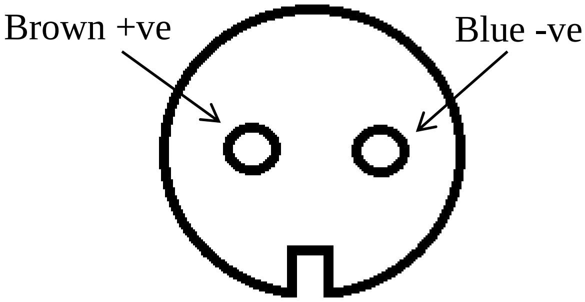


Figure 19: Connector wiring for power supply both 24V and solar.

3.6 Communication Network

The location of the PEM is 300km from NCEA’s office and while it is possible to travel to site and manual download the data logger it is not an efficient method. To enhance the capability of the pump efficiency monitor a modem was installed for remote access. Reduction in power consumption on the battery was enabled by the installation of a Crydom DC60S3 solid state relay. The data logger is programmed to activate the relay and energise the modem for 10 minutes of every hour to allow remote connection and data download.

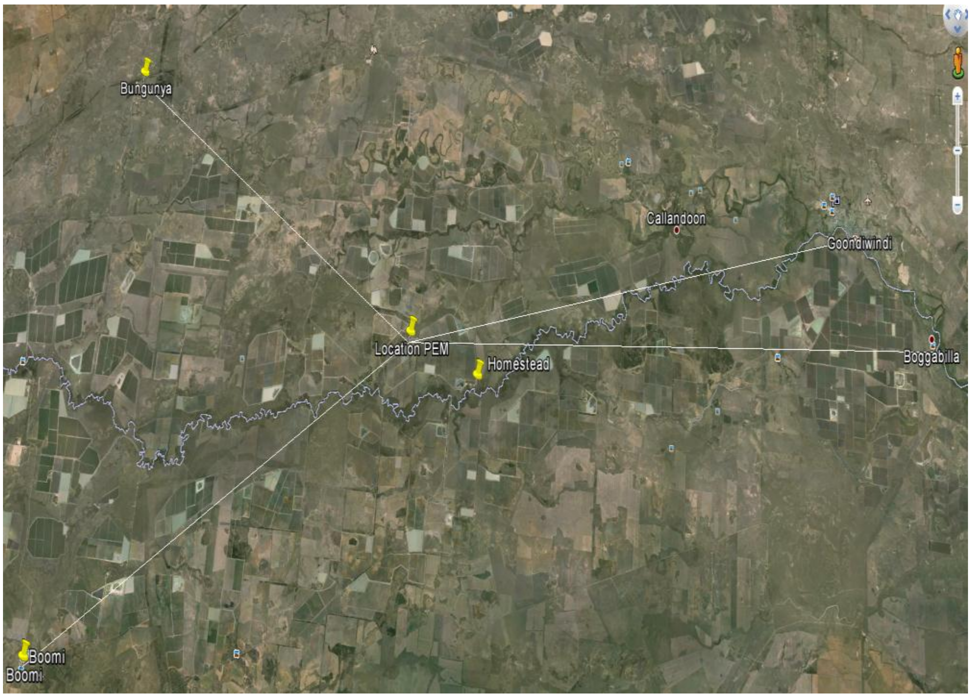


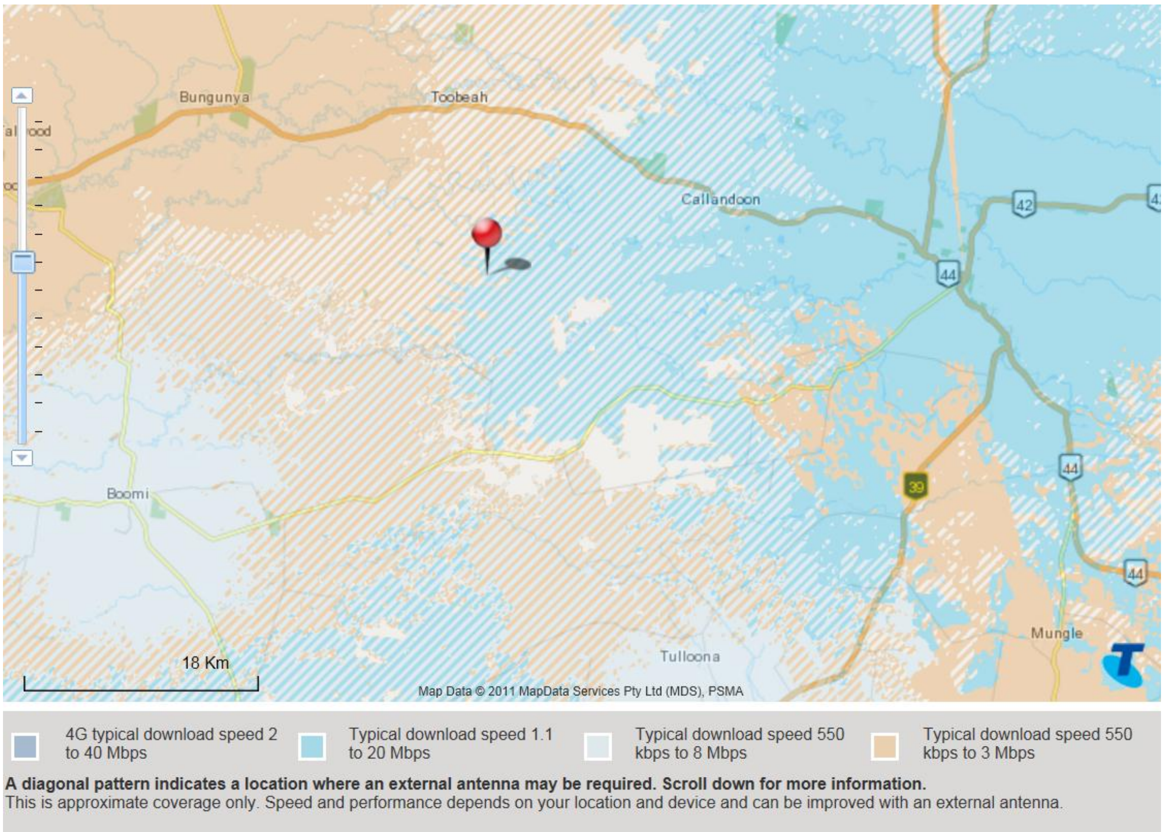
Figure 20: Location of PEM relative to Telstra 3G towers (not to scale)(Google Earth).

Table 5: Location of Telstra towers surrounding PEM.

Telstra Tower	GPS Coordinate	Distance (km)	Elevation above sea level (m)	Maximum Elevation Between PEM and Tower (m)
Boomi	28^{o}43’29.02”S 149^{o}34’42.88”E	35.3	184	204
Bungunya	28^{o}25’24.89”S 149^{o}39’27.86”E	29.6	191	203
Goondiwindi	28^{o}33’46.69”S 150^{o}06’19.30”E	40.2	220	229
Boggabilla	28^{o}36’29.00”S 150^{o}21’36.89”E	45	224	225
PEM Location	28^{o}34’53.89”S 149^{o}54’02.53”E	NA	196	NA

To establish a good communication link between NCEA head office and the PEM station it was necessary to identify which tower is suitable to setup the communication network for the PEM. Research into the location of each surrounding tower was conducted to determine whether an omni-directional antenna would be suitable for communications or if further expense was required to install a uni-directional antenna.

Figure 20 shows a geographical representation, from Google Earth, between the Telstra towers and the pump site. Table 5 displays the GPS coordinate of the Telstra towers distance between the tower and the PEM station, elevation of the Telstra tower above sea level and the highest point that may interfere with a direct line of sight between the tower and the PEM station. Analysing the gathered data from Table 5 a 9dB omni-directional antenna was selected to establish the communication link. For verification the Telstra coverage map in Figure 21 locates the position of the PEM and indicates that a typical download speed of 550 kbps to 3 Mbps are expected with the installation of an external antenna.



A diagonal pattern indicates a location where an external antenna may be required. Scroll down for more information.
This is approximate coverage only. Speed and performance depends on your location and device and can be improved with an external antenna.

Figure 21: Identification of Telstra download speed at PEM location.

3.7 Data Logger

A Campbell Scientific CR850 data logger was selected to record and process the data generated from the instrumentation. The unit controls what instruments are operating and when it also performs calculations to elevate what level of efficiency the pump station is operating. This particular unit allows for six 4-20mA inputs and four pulse counters. In addition there are four channels that supply a 5V output two of which are used to control the solid state relays. A requirement of the project was to allow for on-site grower interaction with the PEM to identify how the pump is operating. The CR850 incorporates a display that outputs the current reading of fuel consumption, total dynamic head and water flow rate. This function allows the grower to make decisions on how best to operate the pump station to achieve maximum efficiency.

Chapter Four

Verification of Results from Pump Efficiency Monitor

4.1 Fuel Consumption Measurements

The diesel engine installed at the pump station is a 12 Litre 6 cylinder turbocharged Volvo Penta TWD 1211V. At a maximum speed of 1,800 RPM the engine would produce 1,644 Nm of torque. The manufacture claims the specific fuel consumption at 100% power is 220 g/kWh (Volvo 1997). The engine is connected to the pump via a belt driven system, with a ratio of 2.8:1 and reduces the drive speed to the required level for the pump. The pump is a Macquarie Centrifugal 26HBC-40 lift pump that encases a 26 inch impeller. The pump is capable of a maximum volume flow rate at 1,800 L/s. According to the manufactures pump curve the maximum speed of the pump is 650 RPM. The power required to drive the pump at peak efficiency is 200 kW. From the supplied data it is possible to determine an estimate of the fuel consumption for the diesel engine operating at maximum power, as displayed in Equation 2. Furthermore this estimate will allow for comparison of the fuel consumption data gathered during the trail test. The specific gravity of Caltex diesel in the Australian market place is 0.85 at 15^{o}C (Caltex 2007).

$$Fuel\ Consumption = \frac{0.220 kg/kWh \times 200\ kW}{0.85\ kg/L} = 51.8 L/h \qquad (2)$$

4.1.1 Fuel Flow Metre Laboratory Tests

The PEM integrates five instruments that produce various readings to evaluate the efficiency of a pump station. Verification that the recorded readings of the individual sensors where accurate took place before the PEM was installed onto a pump station. It was not possible to test the PEM as one unit therefore the verification process was broken down into the three stages.

The first stage of the verification process took place in the Engine Lab (P7) located at the University of Southern Queensland. The engine within the lab used for the test procedure is a 4L41C Hatz diesel engine. According to the manufactures specifications, taking into account the de-rating parameters listed in Table 6, the engine consumes 280.3g/kWh when set at 2200RPM (Strabe 2008).

Table 6: De-rating parameters for Hatz diesel engine (Strabe 2008).

De-rating	Percentage (%)	Parameter
Run-in Period	5	
Altitude	1	For every 100m above 100m
Temperature	4	For every 10^{o}C above 25^{o}C

The assessment of the fuel flow meters consisted of setting the Hatz engine to 2,200 RPM increasing the load on the engine to the maximum permissible of 54 kW and allowing the system to run for ten minutes. To further increase the reliability of the data gathered the volume of fuel consumed before and after the test procedure was measured. This was achieved by filling the fuel tank to a recorded level at the start of the test run and then measuring how much fuel was required to fill the tank to the original start point. The calculation in Equation 3 determines the expected fuel consumption within the ten minute running period. This includes a 5% de-rating as the engine was still within its run-in period plus an additional 6.9% de-rated because Toowoomba is location 691 metres above sea level.

$$Fuel\ Consumption\ in\ 1hr = 0.2803kg/kWh \times 54kW \tag{3}$$

$$= 15.1kg/hr \times\ 0.85 \times 1.119$$

$$= 14.4L/hr$$

The results from the test procedure are in Appendix D. The average hourly fuel consumption calculated from the results of the ten minute running period is 17.6L/hr. This indicates an 18% error when measured against the parameters dictated by the manufacture of the Hatz engine. It is important to note that the manufactures of the Hatz engine performed their testing under ISO 3046-1 Standards. This was not achieved or attempted during the test conducted in the Engine Lab at the University of Southern Queensland. In addition there was no testing conducted to verify the energy contained in the diesel used to perform this test procedure. The ISO 3046-1 Standard states that fuel must contain 42.5 MJ/kg to compile. The Department of Climate Change and Energy Efficiency (2012) indicates the energy content of diesel in Australia is only 38.6 MJ/L

The second part of the test relating to the fuel consumption measured from the tank suggests a much more accurate and reasonable assessment. A one litre beaker was filled exactly three times to replace the fuel consumed from the tank during the test, a total of three litres. From the results, calculating the fuel consumed in ten minutes using the average hourly fuel consumption of 17.6 L/h equates to 2.93 litres in ten minutes. From this test the error associated with the method employed to measure the fuel consumed from a diesel engine is 2.2%.

4.2 Total Dynamic Head

Total dynamic head is the energy added by the pump to the water and is measured across the pump inlet and outlet. To remove variability of the fluid density the units of measure used are metres. Ideally the pressure transducers should be installed directly before the pump inlet and directly after the pump outlet. This approach accounts for all the losses within the system and elevations between water levels, this provides a true measure of total dynamic head. The following two subsections 4.2.1 and 4.2.2 will establish the accuracy of the results collected from the pump efficiency monitor in determining the total dynamic head. All equations, charts, tables and figures referred to in the following two subsections are sourced from Pritchard and Leylegian (2011).

4.2.1 Discharge Pipe

Unfortunately the pump station setup did not allow for the ideal installation of the pressure transducer on the discharge pipe. Appendix C illustrates the layout of the pump station and Figure 22 highlights the detailed view of the discharge pipe to the distribution tank. Immediately after the pump outlet into the discharge pipe is a 90 degree bend constructed from cast steel. Due to the difficultly to insert a pressure transducer and location it was deemed unsuitable to measure pressure. This is consistent with the following 800 millimetre section of pipe at an elevation of 30^o. The first suitable location for the discharge pressure sensor was identified at the mid-point of a straight section of pipe with an overall length of 2.4 metres.

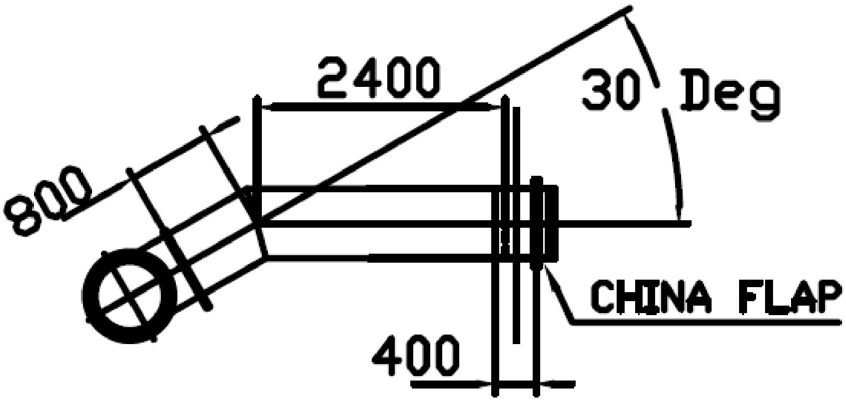


Figure 22: Schematic of discharge pipe.

In selecting the discharge pressure location it is necessary to determine the losses between the pump outlet and pressure sensor to account for unmeasured pipe losses. The result is added to the measured sensor reading to establish a discharge pressure. Completing an analysis of the discharge system establishes a source to determine accuracy from the measured readings plus accounts for the unmeasured section of pipe. Equation 4 will calculate the losses within segments of the discharge system.

$$h_l = f \times \frac{L_e}{D} \times \frac{v^2}{2g} \qquad (4)$$

$$Gravity\ (g) = 9.81ms^{-2}$$

The minimum flow rate required by the grower to service the needs of the cotton crop is 120ML/day this converts to 1.38m^3/s (Q). While the flow rate does vary 120ML/day will be used as a base line.

$$A = \pi r^2 \qquad (5)$$

$$A = \pi \times 0.33^2$$

$$A = 0.342m^2$$

From the continuity equation, velocity of the water in the discharge pipe, as shown in Equation 6, with a cross sectional area of 0.342 m^2 determined from Equation 5 is:

$$v = Q/A \tag{6}$$

$$v = 1.38/0.342$$

$$v = 4.04ms^{-1}$$

An equivalent length (Le/D) for a standard 90^{o} elbow Table 8.4 (Pritchard & Leylegian 2011) is 30.

The evaluation of the friction factor (*f*) is achieved with the Moody diagram (Pritchard & Leylegian 2011) by calculating the Reynolds number (Re), from Equation 7 and the Relative Roughness (e/D) of the pipe, from Equation 8. The kinematic viscosity (v) of water at 15^{o}C is 1.14e^{-6}m^{2}s^{-1}.

$$Re = \frac{vD}{\mathrm{v}} \tag{7}$$

$$Re = \frac{4.04 \times 0.66}{1.14e^{-6}}$$

$$Re = 2.3e^{6}$$

Roughness (e) for commercial steel pipes is sourced from Table 8.1 (Pritchard & Leylegian 2011) is 0.046 millimetres:

$$\frac{e}{D} = \frac{0.046}{660} = 6.97e^{-5} \tag{8}$$

The frictional factor (*f*) evaluated with Reynolds number and Relative Roughness from the Moody diagram in (Pritchard & Leylegian 2011) is:

$$f = 0.0159$$

Therefore from Equation 9 the head losses in the 90 degree bend is:

$$h_l = 0.0159 \times 30 \times \frac{4.04^2}{2\times9.81} \tag{9}$$

$$h_l = 0.397m$$

Working along the discharge section of pipe a straight length of 800 millimetres precedes the standard elbow. Calculation from Equation 10 determines the minor losses for the 800 millimetre section of pipe. Variables previously calculated that do not change, such as water velocity and friction factor will continue through the following equations.

$$h_l = f \times \frac{L}{D} \times \frac{v^2}{2g} \tag{10}$$

$$h_l = 0.0159 \times \frac{0.8}{0.66} \times \frac{4.04^2}{2 \times 9.81}$$

$$h_l = 0.016m^2$$

An equivalent length (Le/D) for a 30^{o} deflection in the pipe refer to 7 Figure 8.17(b) (Pritchard & Leylegian 2011). Calculations to determine head losses in 30^{o} pipe bend and 2.4 metre straight section of discharge pipe are from Equation 11 and 12 respectively.

$$h_l = 0.0159 \times 7 \times \frac{4.04^2}{2 \times 9.81} \tag{11}$$

$$h_l = 0.093m^2$$

$$h_l = 0.0159 \times \frac{2.4}{0.66} \times \frac{4.04^2}{2 \times 9.81} \tag{12}$$

$$h_l = 0.048m^2$$

The exit of the water into the distribution tank dissipates all the kinetic energy. The loss coefficient (K) equates to 1 in this situation Figure 8.15 (Pritchard & Leylegian 2011). The calculations for minor exit losses are from Equation 13.

$$h_l = K \times \frac{v^2}{2g} \tag{13}$$

$$h_l = 1 \times \frac{4.04^2}{2 \times 9.81}$$

$$h_l = 0.832m^2$$

The total head losses for the discharge section of pipe equates to the addition of all the minor loses and displayed in Equation 14.

$$H_l = 0.397 + 0.016 + 0.093 + 0.048 + 0.832 \tag{14}$$

$$H_l = 1.386\, metres$$

Therefore if the distribution tank was full at 4.5 metres plus the addition of the total discharge head losses of 1.386 metres the discharge pressure would equate to 5.886 metres.

The total head losses between the pump outlet and discharge pressure transducer that have not been accounted for through the measurements, are calculated in Equation 15. This figure needs to be incorporated into the results to allow for an accurate measurement of total dynamic head (THD)

$$h_l = 0.397 + 0.016 + 0.093 + (0.048/2) \tag{15}$$

$$h_l = 0.53\, metres$$

4.2.2 Suction Line

The suction line is illustrated in Figure 23 and consists of a concentric taper at the entrance followed by a vertical straight section of pipe at a length of 4.94 metres. A 90 degree bend re-directs the pipe into a horizontal direction with a 5.0 metre straight section towards the pump inlet, before the inlet to the pump there is an eccentric taper reducing the pipe from 750 to 660 millimetres in diameter.

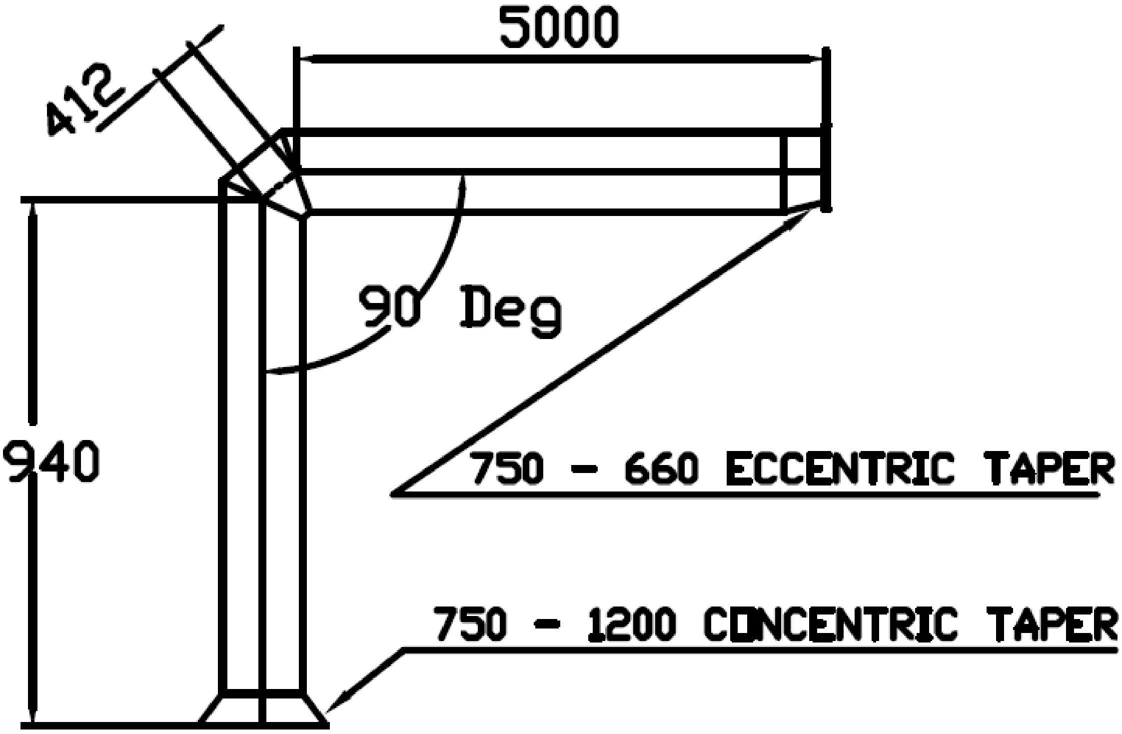


Figure 23: Schematic of suction pipe.

A complete suction side analysis will establish a reference to determine accuracy of the measured readings plus account for the unmeasured section of pipe. A flow rate of 120ML/day will be maintained as the diameter of the suction pipe is larger thus by continuity the fluid velocity will be lower and displayed in Equation 16 and 17 respectively.

$$A = \pi r^2 \tag{16}$$

$$A = \pi \times 0.375^2$$

$$A = 0.442m^2$$

$$v = Q/A \tag{17}$$

$$v = 1.38/0.442$$

$$v = 3.14ms^{-1}$$

The minor loss coefficient (K) for the type of pipe entrance is sourced from Table 8.2 in Pritchard and Leylegian (2011) and equates to 0.5. Head losses caused by the pipe entrance are calculated in Equation 18.

$$h_l = K \times \frac{v^2}{2g} \tag{18}$$

$$h_l = 0.5 \times \frac{3.14^2}{2 \times 9.81}$$

$$h_l = 0.252m^2$$

The following section of the suction pipe consists of the vertical length at 4.94 metres. As the velocity and pipe diameter have changed it is necessary to re-calculate the friction factor (*f*) and then continue to determine the head loss. Reynolds number and relative roughness are calculated in Equation 19 and 20 respectively.

$$Re = \frac{vD}{\mathrm{v}} \tag{19}$$

$$Re = \frac{3.14 \times 0.75}{1.14e^{-6}}$$

$$Re = 2.1e^{6}$$

Roughness (e) for commercial steel pipes is sourced from Table 8.1 (Pritchard & Leylegian 2011) is 0.046 millimetres:

$$\frac{e}{D} = \frac{0.046}{750} = 6.13e^{-5} \tag{20}$$

The frictional factor (*f*) evaluated with Reynolds number and Relative Roughness from the Moody diagram in Pritchard and Leylegian (2011) is:

$$f = 0.0161$$

Therefore the head loss in 4.94 metres of piping is calculated in Equation 21:

$$h_l = f \times \frac{L}{D} \times \frac{v^2}{2g} \tag{21}$$

$$h_l = 0.0161 \times \frac{4.94}{0.75} \times \frac{3.14^2}{2 \times 9.81}$$

$$h_l = 0.053m^2$$

The next section is a 90 degree bend with an equivalent length (Le/D) of 60 from Figure 8.17(b) Pritchard and Leylegian (2011). The head losses from the 90 degree bend are calculated in Equation 22.

$$h_l = f \times \frac{L_e}{D} \times \frac{v^2}{2g} \tag{22}$$

$$h_l = 0.0161 \times 60 \times \frac{3.14^2}{2 \times 9.81}$$

$$h_l = 0.487m$$

The last section of the suction pipe line before entering the pump consists of 4.5 metres of pipe before an eccentric taper reducing the pipe diameter to 660 millimetres. Calculations from Equation 23 and 24 will determine the losses in the 4.5 metres of pipe and the eccentric taper respectively.

$$h_l = f \times \frac{L}{D} \times \frac{v^2}{2g} \tag{23}$$

$$h_l = 0.0161 \times \frac{4.5}{0.75} \times \frac{3.14^2}{2 \times 9.81}$$

$$h_l = 0.049m^2$$

The minor loss coefficient (K) for the eccentric taper is 0.05, sourced from Table 8.3 Pritchard and Leylegian (2011)

$$h_l = K \times \frac{v^2}{2g} \tag{24}$$

$$h_l = 0.05 \times \frac{3.14^2}{2 \times 9.81}$$

$$h_l = 0.025m^2$$

The total head losses for the suction section of pipe equates to the addition of all the minor loses demonstrated in Equation 25.

$$H_l = 0.252 + 0.053 + 0.487 + 0.049 + 0.025 \tag{25}$$

$$H_l = 0.866\, metres$$

The head losses not measured by the suction pressure transducer include the eccentric taper and 0.5 metre of straight piping calculated in Equation 26.

$$h_l = 0.025 + (0.049/9) \tag{26}$$

$$h_l = 0.030\, metres$$

Combining the head losses not measured by the pressure transducer on the discharge pipe plus the losses not measured on the suction pipe will give the total error across the pumping system in regards to energy losses as displayed in Equation 27. This figure must be added to pressure readings to provide an accurate measurement for total dynamic head or energy added by the pump station.

$$H_l = 0.53 + 0.03 \tag{27}$$

$$H_l = 0.56\, metres$$

The maximum total dynamic head achievable includes the calculated head losses, plus the level of water in the storage dam above the centreline of the pump and the level of the tail water below the centreline of the pump. It is important to note that the head losses have been calculated using the minimum flow rate required by the grower as the flow rate increases the head losses within the pipes and bends will increase. Equation 28 below displays a theoretical calculation for the total dynamic head when the storage dam is at a maximum capacity of 4.5 metres and the tail water level is at 3 metres. A survey was conducted to determine the level of the tail water. The results indicate that the level can vary from 2-5 metres depending on rain events and watering procedure, a level of 3 metres is relatively standard as stated by the grower.

$$TDH = 3.0 + 0.866 + 1.386 + 4.5 \tag{28}$$

$$TDH = 9.752\ metres$$

A TDH of 9.752 metres represents a mathematical engineering solution of the total dynamic head pressure across the pump station. The value is used as a comparison against the measured values from the PEM. It must be highlighted that the mathematical value for TDH is not an exact answer. There are uncertainties associated with the calculation, one such uncertainty includes the minor loss coefficients sourced from two text books highlighted throughout the calculations. The exit and entrance losses required a level of engineering judgement to calculate head losses, as there was little information found on the minor loss coefficient. A better approximation of the total dynamic head is determined using the maximum measured head pressure of 7.48 metres, plus the additional calculated friction losses of 0.56 metres to give a total dynamic head of 8.04 metres. The measured pressure 7.48 metres corresponds to the flow rate used in the calculation to determine TDH in Equation 28. There is 21.3% difference between the measured and calculated values. The current setup of the PEM is unlikely to under estimate the head pressure, there are sections of unmeasured pipe and corrosion on internal surfaces that will increase head lose. The standard error associated with the measured total dynamic head is estimated to be 2.5 times the difference of the measured and calculated pressure for the positive, +53.3% and – 21.3% of the measured value for the negative.

4.3 Water Flow Meter

Verifying the accuracy of the ultrasonic water flow meter is a complex and difficult task but necessary to gather reasonably accurate data to calculate the efficiency of pump stations. The Australian National Association of Testing Authorities (NATA) is one suitable solution although it is an expensive and time consuming process at such an earlier stage of the PEM's development. Testing the PEM through a NATA lab will be required after further development of the monitor and closer to the completion of an automated system. It was not deemed necessary at such an early stage of the design phase. The simplest method employed for the earlier stage of development encompassed the use of another water flow meter for comparison. The verification of the water flow meter was conducted on three water flow meters at three separate locations. The first comparison was conducted by two engineers in the hydraulics lab at the University of Southern Queensland. The second and third comparisons where conducted in the field with the PEM installed on a pump station. The meters used for field testing include a Panametric Flow Meter and a Siemens Meter. Across all three comparisons the greatest variation noted was 500m^3/h on the Siemens Meter. The Siemens Meter was reading ~5500 m^3/h and the PEM ~5000 m^3/h at its greatest range. It was noticed that on all three meters the reading was not stable and would range up to 500m^3/h as noticed on the Siemens Meter, which displayed the maximum range. This indicates a possible 9% error in the readings on the PEM's ultrasonic flow meter. Further testing of the flow meter will be conducted at a later stage of development.

Chapter Five

Result from Pump Efficiency Monitor

5.1 Data Collection

A suitable location to trial test the pump efficiency monitor was identified on a cotton farm 45km's west of Goondiwindi. On the 30th of October 2012 a site visit was conducted to find a pumping station that allowed easy installation and setup of the pump efficiency monitor. The cotton grower presented three suitable candidates, a river harvest pump and two lift pumps. One of the lift pumps was selected as it comprised of long stretches of piping which is necessary to produce accurate readings for the water flow meters and pressure sensors. The suction and discharge pressure gauges where easily installed and accessible, although they could not be installed immediately before or after the pump inlet or outlet. To overcome the issue of unaccounted minor losses due to the location of the sensors, full calculations are provided in Section 4.2. The fuel flow meters would be installed in an appropriate position without having to directly cut into the fuel line, a joiner could be disconnected which allowed for easy fitment. Adequate filtration for the fuel flow meters are connected to the outlet on the fuel storage tank. The most important benefit of this particular lift pump over the other stations on site is the expected high frequency of usage throughout the 2012 – 2013 irrigation season, with varying tasks and duty points. The grower anticipated pumping events to be approximately 10-14 days in duration. This allowed for large amounts of data to be collected in a short period of time.

The first reliable collection of data from the pump efficiency monitor came from a pumping event that started on the 27th January 2013 at 12:30pm and finished on the 7th February 2013 at 5:30pm. The purpose of the pumping event was to fill an empty 1800ML ring tank as quickly as possible after a 250mm rain event. The monitor gave sound results continuously throughout the pumping event. Appendix E presents the data gathered from the PEM. The capability of the data logger allowed measurements to be recorded at time intervals that suit the situation. This can range from recording measurements in milliseconds to days. After trailing various recording times it was deemed suitable to measure each parameter every minute and then to take the average reading at the end of every thirty minute block. Any recording arrangement less than this produced large amounts of data that proved very difficult and time consuming to process without any added benefit to the results. Whereas time blocks larger than thirty minutes reduced the accuracy of the results as any changes within the system could either be missed or not accounted for.

5.2 Data Processing

After collection, the raw data required processing to provide information in a relevant format that would establish what level of efficiency the pump station was operating. It is essential to determine how much energy is being consumed and what it costs to pump one mega litre of water per metre of head. Reading the results in Appendix E from left to right the first two columns indicate the suction and discharge pressure with the units in metres. From these two measurements it is possible to calculate the total dynamic head (TDH) or energy added across the pump. Note that the unaccounted losses calculated in Section 4.2 have been incorporated to give a true measurement for total dynamic head (TDH). Section 4.2 provides the calculations and reasoning for this addition. Equation 29 is a representation on how to determine the total dynamic head from the results in Appendix E.

$$TDH = (-1 \times (suction\ pressure\ )) + discharge\ pressure + unmeasured\ losses \tag{29}$$

The water flow rate requires no post processing once the data has been captured and is transferred to the final results table without modification. Fuel consumption is calculated by subtracting the pulses generated from the return flow fuel meter from the pulses generated by the inflow fuel meter as displayed in Equation 29. This process was undertaken within the data logger and required no post processing.

$$Fuel\ Consumption = Inflow\ fuel - Return\ fuel \tag{30}$$

5.2.1 Calculation of Combined Efficiency

Combined efficiency is a measure of how well the diesel engine produces power through the combustion process and then for the pump to transfer the power onto the water. At this stage of the project it is not possible to calculate the efficiency of the individual item that is either the pump or the diesel engine. Measurement of individual efficiency requires the installation of a torque meter and will be discussed further in Chapter 6.1 Future Work. The combined efficiency is calculated using Equation 31 (Growcom 2005).

$$Combined\ Efficency = \frac{Water\ power\ output}{Engine\ power\ input} \tag{31}$$

$$Water\ power\ output = 2.725 \times Flow\ Rate\ (Q) \times TDH$$

$$Engine\ power\ input = Fuel\ Consumption\ (L/sec) \times 38.6MJ/L$$

De-rating the engine must be included in the calculation which consists of altitude, temperature and transmission type. As the altitude of the pump station increases the density of air decreases thus reducing the amount of oxygen available for combustion which inherently reduces the performance of the engine. The ambient temperature has a similar effect, as the temperature increases the density of air decreases and once again reduces the amount of oxygen available for combustion. In accordance with the engine manufactures specification there will be no de-rating applied for altitude or temperature. The altitude de-rating factor applies above 1000m; the altitude of the pump station is 200m and temperature de-rating begins above 40^{o}C, this limitation was not exceeded during the pumping event. As discussed in Chapter 2.3.2 Power Transfer Efficiency the type of transmission used to transfer the power from the diesel engine to the pump will have an effect on the quantity of power transferred. From the research conducted a transmission de-rating factor of 0.94 will be implemented. Appendix F contains the results of the calculated combined efficiency from the data collected during the pumping event.

5.2.2 Calculation for energy cost and consumption

A common method for comparing either the energy cost or consumption is to measure the amount of diesel consumed for every mega litre of water pumped, for each metre of head across the pump. The data collected in Appendix E is sufficient to establish a benchmark for comparison between various pumps across different industries. The calculations are demonstrated in Equation 32.

$$Energy\ Cost = Fuel\ Consumption\ \left(\frac{L}{hr}\right) \times \$1.50/\ WaterFlow\ Rate\ ((ML/hr))/\ Total\ head\ (m) \tag{32}$$

There is an assumed cost of diesel at \$1.50/L to give a monetary value for pumping water. The variability in energy cost across the pumping event is recorded in Appendix F. Figure 24 defines the trend quite clearly. The combined efficiency of the diesel engine and pump starts from just above 10% with an energy cost of \$3.37 /ML/m head. As the pumping event continues and the storage dam starts to fill, the combined efficiency increases and achieves a peak at 24% while the cost to pump the irrigation water reduces to \$1.44/ML/m head, a 57.3% reduction in running cost.

Cotton growers tend to be interested in comparing running costs across internal pump stations or other pumps in the cotton industry. To achieve a cost comparison, the cost to pump one mega litre of water is calculated. The calculation is demonstrated in Equation 33 and sample results from the calculations illustrated in Appendix F.

$$Energy\ Cost = Fuel\ Consumption\ (L/hr) \times \$1.50/\ WaterFlow\ Rate\ ((ML/hr)) \tag{33}$$

5.3 Pump Station Duty Point

The results calculated for energy cost in Equation 32 are illustrated in Figure 24 comparing against the pump stations combined efficiency. The results indicate a dramatic drop in fuel cost and an equivalent rise in combined efficiency. To evaluate why the performance of the pump station improved over the pumping event Figure 25 was constructed and displays the data gathered from individual sensors.

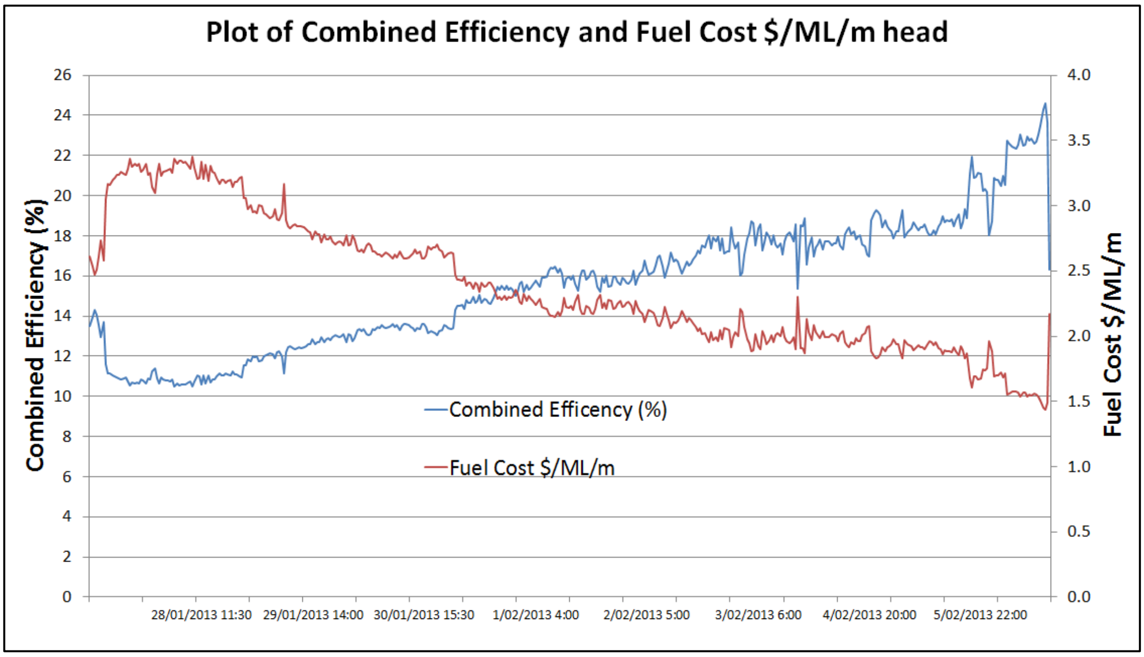


Figure 24: Comparison of combined efficiency and energy costs.

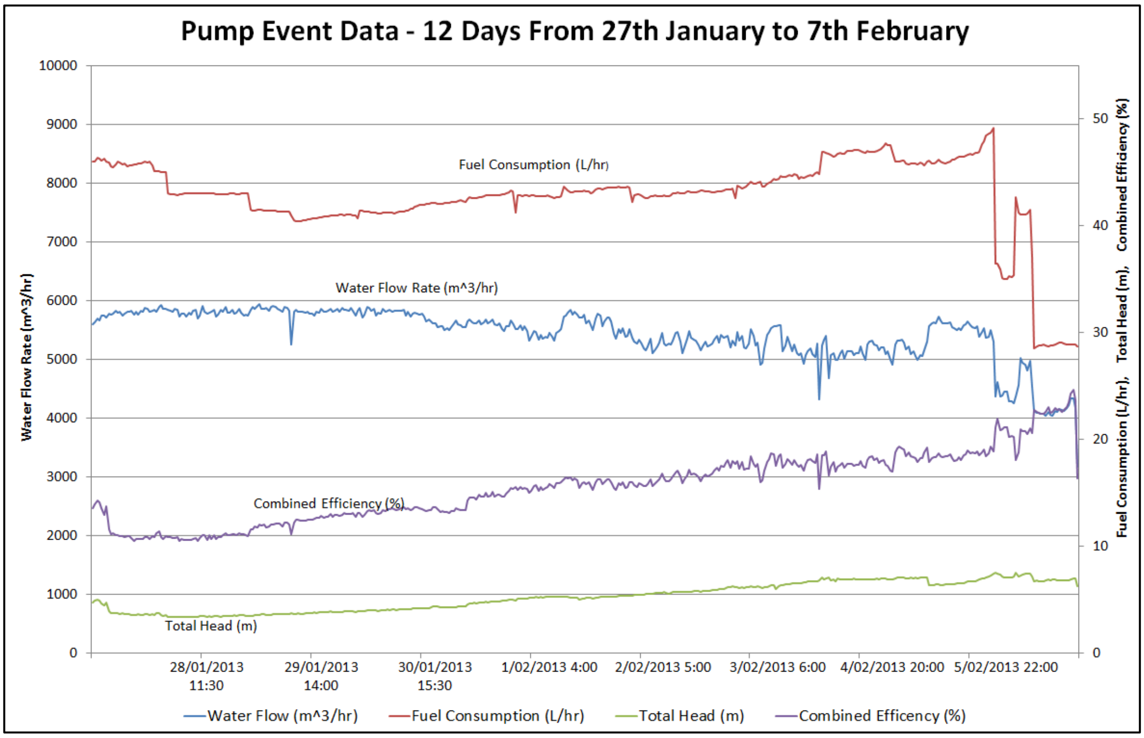


Figure 25: Continuous collection of data from pump event.

The water flow rate remained relatively consistent up until the 30 January averaging approximately 5,700 m^3/h and reduced to 5,200m^3/h for the remainder of the pumping event. The total dynamic head started at a minimum of 3 metres due to the storage dam being empty and increase to 7.5 metres once the storage dam was filled to capacity.

Operating at such a low head pressure has caused a high fuel consumption rate due to the severe cavitation occurring within the pump. As the head pressure increases the fuel consumption decreases because cavitation is reduced. A minimum fuel consumption rate of 40.39 L/h corresponds to 3.69 metres of head. While the pump may continue to cavitate at a head pressure of 3.69 metres the head pressure progressively increases thus increasing the rate of energy consumption. The poor result of 10% for combined efficiency is at the start of the pumping event and is understood to occur from the lack of pressure on the discharge of the pump therefore causing cavitation. To achieve a greater understanding of the system the data points at the start and end of the pumping event were plotted onto the manufactures pump curve to give an idea on the duty point of the pump in Figure 26.

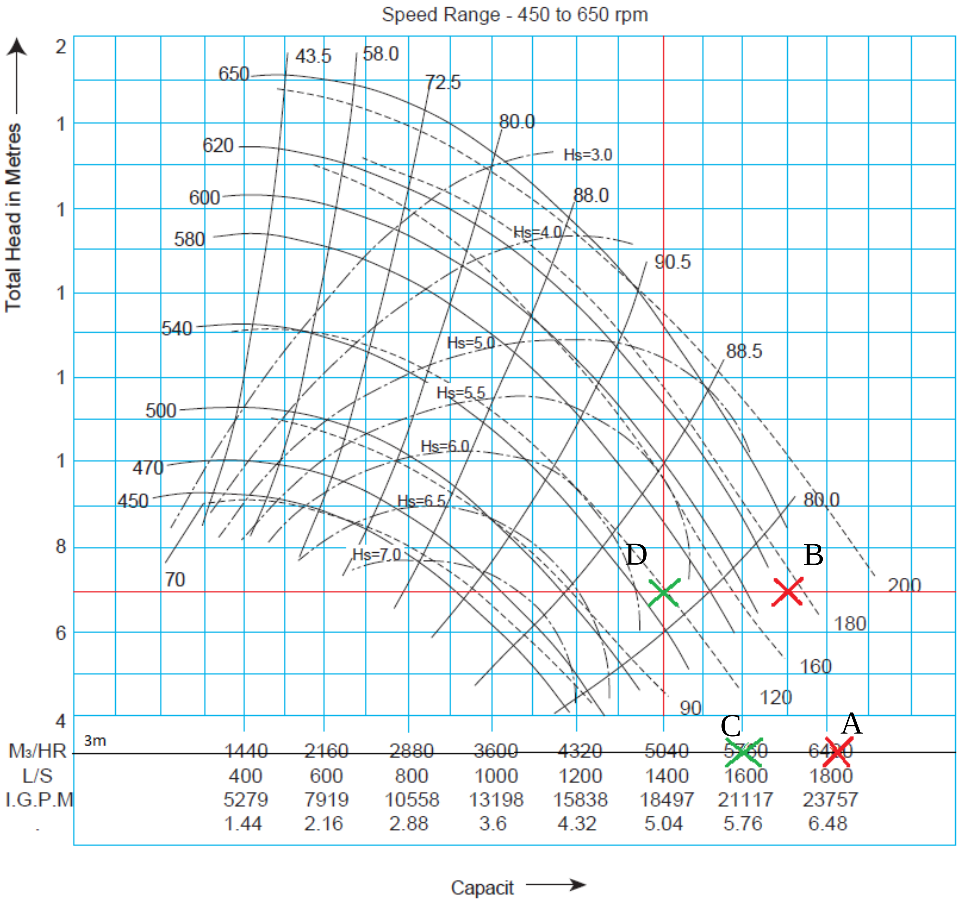


Figure 26: China Pump 26HBC-40 Performance Curves

The pump manufactures performance curves in Figure 26 have been utilised to demonstrate what the cotton industry are using. There is a lot of information on the curves which may be daunting to some cotton irrigators. The horizontal and vertical red lines on the performance curve highlights the limitations experienced during the trial test. The vertical red line on the pump curve is the minimum water flow rate that the grower will accept. This is the amount of water the grower needs to pump to maintain the requirements of the cotton crop or in the case of this pumping event to store as much flood water as quickly as possible while it is available. The horizontal red line demonstrates the maximum head pressure achieved during the trial test. Further works needs to be conducted to verify the maximum head pressure achievable on this pump station.

The two green duty points C and D indicate the start (C) and finish (D) of the pumping event, plotting the head pressure against water flow rate. Duty point C exhibits 3 metres of head and a flow rate of 5,760 m^3/h, while duty point D at the end of pumping displays 7.5 metres head and a flow rate 5,040 m^3/h. However the pump speed does not correspond to the recorded reading of 650 RPM. Duty points C and D indicate a pump speed of 550 RPM. For comparison duty points A and B were plotted, A represents the head pressure and pump speed of 650 RPM at the start of pumping while B displays the end of pump with a pump speed of 650 RPM and head pressure of 7.5 metres. The problem with points A and B are that they do not reflect the corresponding water flow of 6,480 m^3/h and 6,120 m^3/h respectively. From plotting the four representative duty points it is evident that points A and C are completely off the performance curve to the point that the three metre head line was required to be pencilled in. The result of being so far off the pump curve is severe cavitation which reinforces the earlier results from Figure 25. During the field setup and operation it was not possible to hear the pump cavitating due to the noise produced from the diesel engine.

Extrapolating the lines indicating RPM on the pump curve for points C and D, it appears that both points fall on the same pump speed of 550RPM. A notion was conceived that if the pump speed was reduced to 550RPM, what would be the corresponding water flow rate and fuel consumption? To investigate a spot check of the engine set to 1,550 RPM with the corresponding pump speed of 550 RPM proved that there was no noticeable change in water flow rate but the fuel consumption reduced to 25L/hr. In theory if the pump speed is reduced then the water flow rate should also reduce. However since the pump is cavitating severely it is believed that the RPM reduction is actually significantly reducing the slip of the impeller and therefore increasing performance markedly. Due to the trial test occurring at the end of the cotton irrigation season it was not possible to conduct any further testing in the 2012 – 2013 irrigation season and further testing would be conducted in the 2013-2014 cotton irrigation season to verify this theory. It is clear from the plotted duty points on the pump curve that the current setup for this pump station is not correct for the task the station is required to perform. This point is further confirmed when the torque curve for the diesel engine is interrogated, as this identifies that at 1,800 RPM the engine is not operating in its peak torque band, rather its peak power, thus reducing the performance of the engine (Volvo 1997).

5.4 Pump Efficiency Improvements

5.4.1 Cost Benefit Analysis

On the basis that the theory of reducing engine RPM to reduce cavitation is correct a simple cost benefit analysis was performed to ascertain what the benefit of an engine RPM reduction would be. The first stage is to determine how much fuel is consumed by the pump station in one season. From the gathered data an average fuel consumption of 45 L/h was calculated. The grower estimates 1000 operating hours for this particular pump station in a typical season. Therefore the total fuel consumption for the season is 45,000 L/season. According to the spot check performed with the engine set to 1550RPM and a fuel consumption of 25L/h the total amount of fuel consumed in one cotton season will reduce to 25,000 L/season. This is equivalent to a 44% gain in efficiency with diesel at an assumed cost of $1.50/L this has the potential to save the grower $30,000 a season on this particular pump station. This does not infer that any grower is able to reduce their pump operating speed by 250RPM and save over $30,000 in energy cost. It simple illustrates the need to perform pump tests and benchmark performance as this has the potential to highlight possible energy savings and to thus reduce operating costs. Table 7 displays the cost benefit analysis while Figure 27 illustrates the benefit over a twenty year period.

Table 7: Results from cost benefit analysis.

Consumption	
Existing Consumption	45,000 L/year
Proposed Consumption	25,000 L/year
Efficiency Gain	44%
Energy Costs	
Assumed Diesel Cost	$1.50
Existing Diesel Cost	$67,500/year
Proposed Diesel Cost	$37,500/year

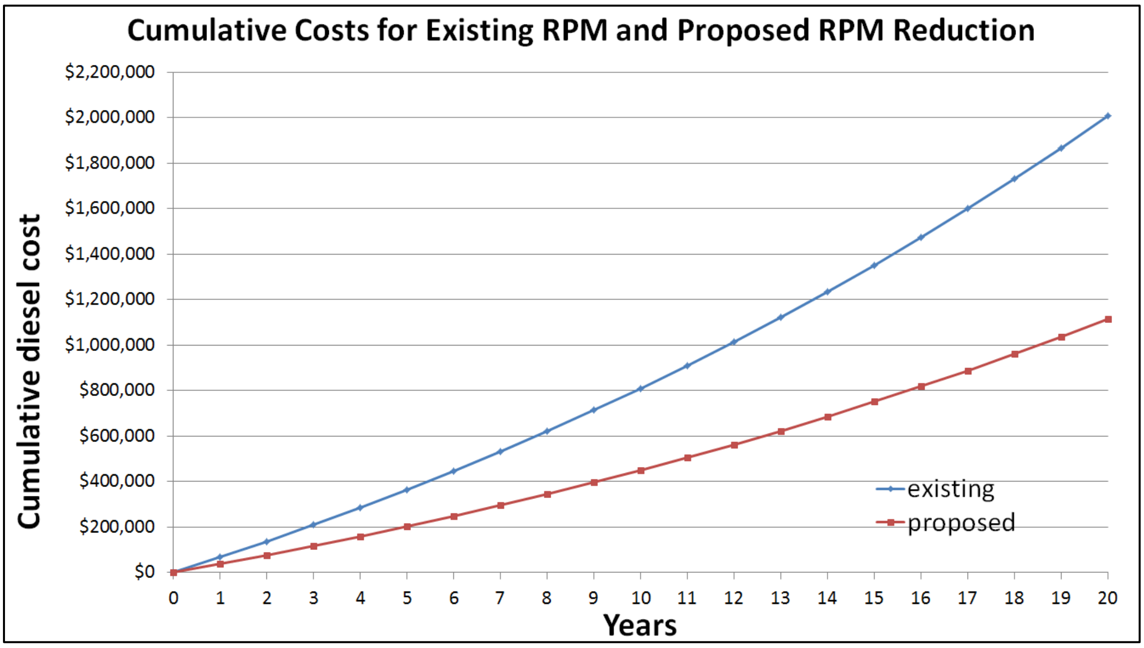


Figure 27: Cumulative costs for existing RPM and Proposed RPM reduction.

Chapter Six

Conclusion and Future Work

6.1 Future Work

The first stage of the construction and testing for the pump efficiency monitor is complete. The final objective is to create an autonomous pump efficiency monitor which requires further development of the current system. During the process of creating an autonomous pump efficiency monitor, it is possible to provide the cotton industry a greater depth of knowledge on cotton irrigation pumps. The knowledge gained will aim at reducing energy costs with improved resource management and increase grower profits, while also reduces greenhouse gas emission leading to a decreased carbon foot print for the cotton industry.

The next stage in the development of a pump efficiency monitor will add pump and engine speed counters, to record and identify pump and engine speeds. Counters will negate the need to refer to the engine tachometer, grower’s diary or speculate from the measured fuel consumption. Installing counters on both pump and engine will detect any slippage between the belts and pulleys. The calculated pulley ratio of 2.8 between the engine and pump is used in Equation 34 to identify slippage. Once the slippage exceeds a predetermined level a warning to the grower can be issued to rectify the issue and maintain an efficient system.

$$Slippage = engine\ speed - (pump\ speed\ \times 2.8) \tag{34}$$

The current results from the collected data only calculate the combined efficiency of the pump station. Without assuming a level of efficiency for either the pump or the engine it is currently not possible to determine individual component efficiencies. To overcome the issue it is mandatory to develop a method of either measuring the torque output on the engine or preferably the torque input to the pump. Retrofitting a torque meter to a rotating pulley or shaft is a complex problem that requires further investigation to achieve a successful outcome.

At the completion of installing the engine and pump speed counters plus a torque meter on the pump input shaft, it is necessary to devise a software program that develops an interface between the grower and the pump station. The concept is to display the engine and pump parameters onto a tablet for viewing by the grower. The basic interface informs the grower of fuel consumption, quantity of water pumped and the efficiency at which the task is being performed. Through the software program the pump station will alter inputs such as the engine throttle and outlet gate valves to maintain the operation of the pump at the peak efficiency for the task set by the grower. There will be potential to display further parameters that will be identified as the development of the pump efficiency monitor progresses. Other ideas include the grower to manage the operation of the pump via the tablet by initiating start up and shut down of the pump station and also adjusting engine speed and the position of gate valves should the need arise. The benefit of grower interaction allows for remote access and reduces the need to drive to and from pump stations to perform the same tasks. This results in reduced fuel consumption and maintenance on vehicles plus labour, ultimately contributing to the grower’s profit margin.

During the literature review there was no work identified to confirm the pump manufactures performance curves. With the aim to provide further knowledge to the cotton industry it would be beneficial to perform pump tests in accordance with ISO 5198:2000 Centrifugal, Mixed Flow and Axial Pumps - Code For Hydraulic Performance Tests - Precision Class. Figure 28 illustrates the variable pump speeds at total heads verse water flow rate. The results from the pump tests can be plotted onto the reproduced performance curves to verify the accuracy of the manufactures performance curves and provide information to the cotton industry to improve management practices.

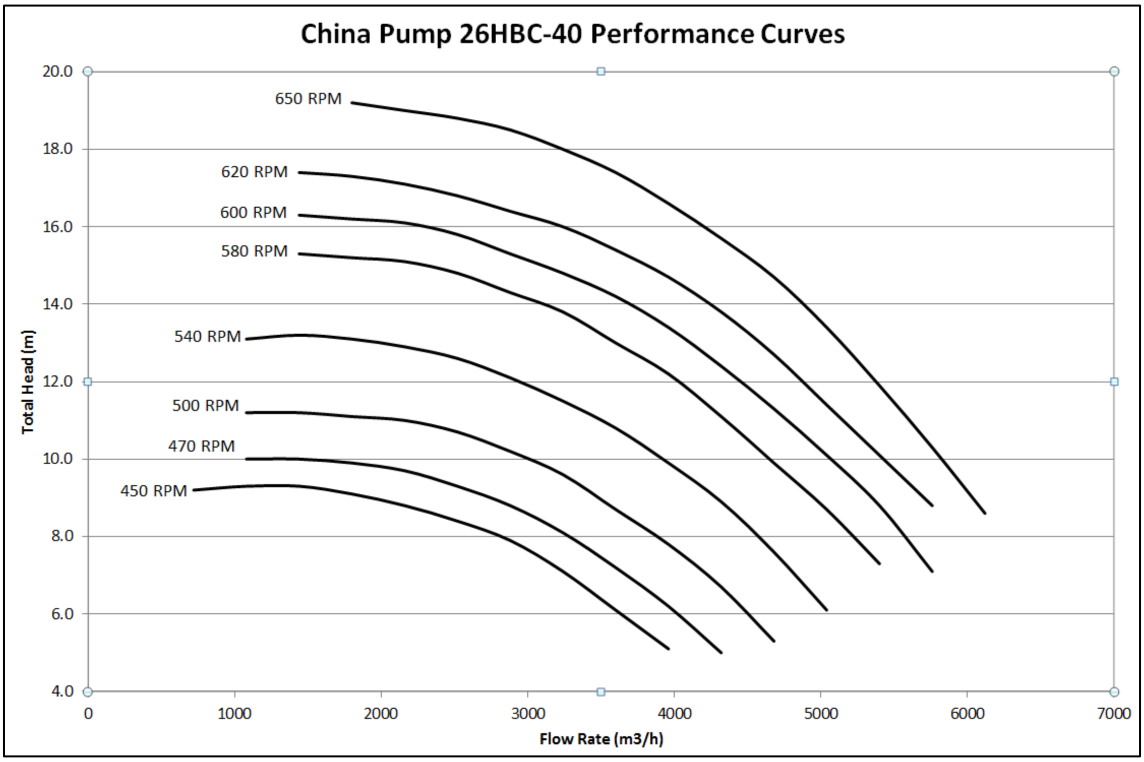


Figure 28: Reproduction of 26HBC-40 China pump performance curve.

There are numerous 26HBC-40 China pumps in the cotton industry; a single cotton farm can have a dozen or more pumps. Currently there is no information provided to growers to determine how efficiently their pumps are operating within their own property let alone within the industry. During further development of the pump efficiency monitor it is possible to install the current model to perform energy assessments and determine the efficiency of pump stations. Collecting the measured data and combining into a data base will allow for the development of an industry benchmark that cotton growers and industry representatives can access. Growers will have the ability to determine where there individual pump station efficiency is performing.

Understanding where the performance of an individual pump stands when compared to industry levels, gathered from the benchmarking program, only gives a partial solution. Should a pump be under performing to the industry standard the grower may require further information on how to improve the pump station performance. Several case studies will be performed to provide such information. Alterations to the operation of a pump station are either a management change or an infrastructure change. A management change generally requires minimal or no financial input while an infrastructure alteration would require substantial investment. Some of the ideas that can be incorporated into the case studies include:

- Alternating pipe diameters to reduce water velocity,
- Alter pulley sizes to allow the engine to run at peak torque and
- Lower the pump station to reduce the suction head.

Anyone of these ideas can incur a significant cost. As part of the case studies an economic analysis can be conducted to identify the cost and benefit to the grower, once again allowing for a more informed decision.

6.2 Conclusions

The ability of the PEM to continuously log various pump variables not only provides data to assess diesel engine and pump efficiency, it also provides accurate information concerning energy use for on-farm energy assessments. The trial of the PEM has indicated that large energy and cost savings are achievable. The trial highlights the importance to test each individual pumping set-up to identify the optimum operating point to achieve maximum efficiency. Significant savings are possible for individual operators and the industry collectively.

The scope of this project was to design and develop monitoring system to assess pump efficiency by measuring energy input to the diesel engine and the energy output of the irrigation pump. The design and development stage of the project has successfully been completed with an operating pump efficiency monitor that is in current use out in the field to assess pump station efficiency and for further development. The next stage of the project was to gather and analyse the data to determine a cost per mega litre per metre elevation head (/ML/m head). The cost of pumping from one event has been assessed, with the start of the pumping event at a cost of $3.37 /ML/m head and reducing to $1.44 /ML/m head. Through futher analysis of the data it was also identified that if the engine speed was reduced by 250 RPM there was an efficiency gain of 44%. The trial test highlights the poor operation of cotton irrigated pump stations and the need to monitor their performance. The pump efficiency monitor can now be used to conduct pump assessments to assist in identifing any improvements to reduce energy consumption within cotton irrigation pumping stations and quantify cost savings.

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Appendix A: Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG 4111/4112 Research Project
PROJECT SPECIFICATION

FOR: **PHILLIP SZABO**

TOPIC: DEVELOPMENT OF A PUMP EFFICIENCY MONITOR FOR USE IN COTTON IRRIGATION

SUPERVISOR: Dr David Buttsworth

ENROLMENT: ENG 4111 – S1, ONC, 2013;
ENG 4112 – S2, ONC, 2013

PROJECT AIM: This project seeks to develop equipment to perform a level three energy audit for cotton irrigation pumping stations. A monitoring system will be designed and developed to assess pump efficiency by measuring energy input to the diesel engine and the energy output of the irrigation pump. The gathered data will be analysed to determine a cost per mega litre per metre elevation head (/ML/m head). This will be used determine a benchmark to evaluate pumping stations in the future. The monitoring system can then be used to conduct pump assessments to identify any improvements to reduce energy consumption within cotton irrigation pumping stations and quantify cost savings.

PROGRAM:

1. Research the background information relating to on farm energy consumption for cotton irrigation and how to conduct an energy audit on diesel engine pumping stations.
2. Design, construct and test a monitoring system to record pump and diesel engine parameters.
3. Analyse the data to determine the efficiency of the pump and the cost to pump the irrigation water.
4. Evaluate the results to identify areas for improvement in pump efficiency.

AGREED:

Mr Phillip Szabo ___ /___ /___ Dr David Buttsworth ___ /___ /___

Appendix B: Risk Assessment

The pump station site is located approximately 45km west of Goondiwindi, 280km from the University of Southern Queensland (USQ) Toowoomba campus. To conduct work at the pump site it is necessary to travel 560km on return trip taken approximately 6.5 hours of driving. USQ's Motor Vehicles and Travel Fatigue policy states that:

> *"A distance of no more than 800 kilometres should normally be driven per day in any ten (10) hour period."*

This leaves a maximum of 240km for travel on farm, plus any trips into Goondiwindi township for incidentals. The chosen pump site is located approximately 20km from the farm house and it is an NCEA and Prime Ag requirement to report to the farm manager once on site. The policy also states that:

> *"Driving time plus non-driving duties must not normally exceed a total of twelve (12) hours in any twenty-four hour period and"*
>
> *"The total time spent driving, inclusive of breaks, must not normally exceed ten (10) hours in any twenty-four hour period. This applies to a single driver or where the driving is shared by two (2) or more employees."*

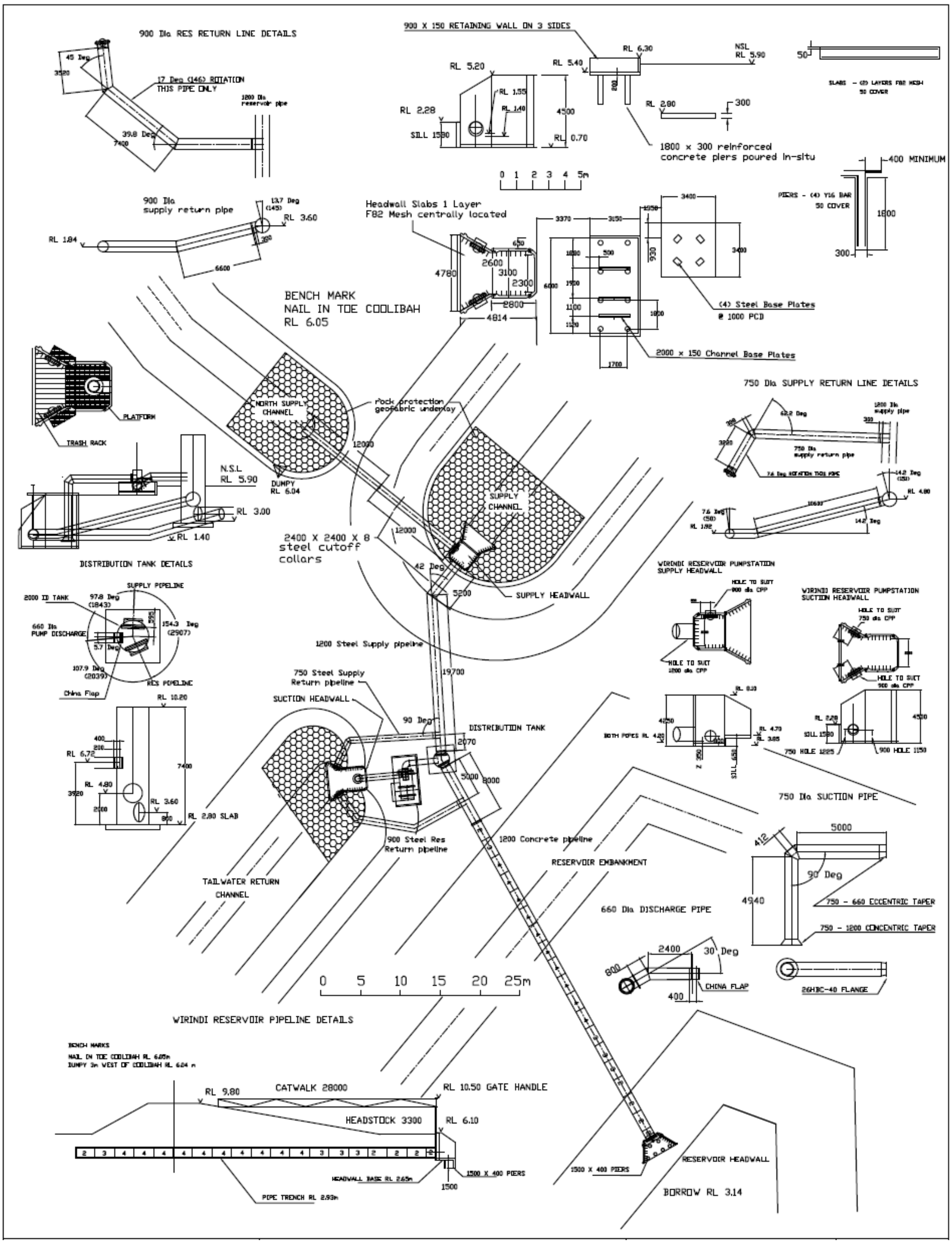
All aspects of the policy must be adhered too; the points mentioned above are highlighted as a single day may not be sufficient to conduct all the work required. In which case, a suitable plan will need to be developed to comply with university policy, such as staying overnight.

Once on site it is necessary to comply with the National Centre for Engineering in Agriculture's risk management plan for Conducting Field Work. Some of the risks associated with working on diesel pump stations are highlighted below. It is important to employ the control measures indicated in the risk management plan to keep the level of risk as low as reasonably practicable.

- If noise levels exceed the safe working level of 88db(A) for four hours work when the diesel engine is operating, appropriate hearing protect must be worn
- Prime Ag has defined the area around the diesel engine as a confined space, loose article such as tools and clothing must avoid moving parts, ventilation must be maintained to remove exhaust gases and the possibility of asphyxiation.
- The installation of the communication aerial requires working at heights. The aerial is installed at the top of the distribution tank which is four metres above ground level. Three points of contact must be maintained at all times.
- The pump is located outside with minimal cover, the work carried out is during the hotter summer months, sun burn and dehydration are risks that must be managed by wearing appropriate clothing, applying sunscreen and remaining hydrated with the intake of water.
- There is a known risk of poisonous snakes within the area, an appropriate first aid kit, first aid training and communication should be easily available.

These points highlight some of the common risks associated on this particular pump site. It is important to consult the risk management plan to become aware of the other possible risks that may be relevant.

Appendix C: Pump Station Layout



Appendix D: Results from Test Procedure on Hatz Engine

Date and Time	Pulses (/10sec)			Fuel Flow Rate (L/hr)		Fuel Consumption (L/hr)
	Return	Inflow	Consumption	Return	Inflow	
4/10/2012 12:57	65	84	19	58.5	75.6	17.1
4/10/2012 12:57	65	84	19	58.5	75.6	17.1
4/10/2012 12:57	65	85	19	58.5	76.5	17.1
4/10/2012 12:57	65	85	19	58.5	76.5	17.1
4/10/2012 12:57	65	85	20	58.5	76.5	18.0
4/10/2012 12:58	65	85	20	58.5	76.5	18.0
4/10/2012 12:58	65	85	20	58.5	76.5	18.0
4/10/2012 12:58	65	84	19	58.5	75.6	17.1
4/10/2012 12:58	66	85	19	59.4	76.5	17.1
4/10/2012 12:58	66	86	20	59.4	77.4	18.0
4/10/2012 12:58	65	85	20	58.5	76.5	18.0
4/10/2012 12:59	65	85	20	58.5	76.5	18.0
4/10/2012 12:59	66	85	19	59.4	76.5	17.1
4/10/2012 12:59	65	85	20	58.5	76.5	18.0
4/10/2012 12:59	66	84	18	59.4	75.6	16.2
4/10/2012 12:59	65	84	19	58.5	75.6	17.1
4/10/2012 12:59	66	85	19	59.4	76.5	17.1
4/10/2012 13:00	66	86	20	59.4	77.4	18.0
4/10/2012 13:00	66	86	20	59.4	77.4	18.0
4/10/2012 13:00	65	85	20	58.5	76.5	18.0
4/10/2012 13:00	65	85	20	58.5	76.5	18.0
4/10/2012 13:00	65	85	20	58.5	76.5	18.0
4/10/2012 13:00	65	85	20	58.5	76.5	18.0
4/10/2012 13:01	66	85	19	59.4	76.5	17.1
4/10/2012 13:01	65	85	20	58.5	76.5	18.0
4/10/2012 13:01	65	85	20	58.5	76.5	18.0
4/10/2012 13:01	65	85	20	58.5	76.5	18.0
4/10/2012 13:01	65	85	20	58.5	76.5	18.0
4/10/2012 13:01	65	85	20	58.5	76.5	18.0
4/10/2012 13:02	65	84	19	58.5	75.6	17.1
4/10/2012 13:02	65	85	20	58.5	76.5	18.0
4/10/2012 13:02	66	85	19	59.4	76.5	17.1
4/10/2012 13:02	65	84	19	58.5	75.6	17.1
4/10/2012 13:02	65	84	19	58.5	75.6	17.1
4/10/2012 13:02	66	84	18	59.4	75.6	16.2
4/10/2012 13:03	65	84	19	58.5	75.6	17.1
4/10/2012 13:03	66	85	19	59.4	76.5	17.1

Date and Time	Pulses (/10sec)			Fuel Flow Rate (L/hr)		Fuel Consumption (L/hr)
	Return	Inflow	Consumption	Return	Inflow	
4/10/2012 13:03	65	84	19	58.5	75.6	17.1
4/10/2012 13:03	65	85	20	58.5	76.5	18.0
4/10/2012 13:03	65	85	20	58.5	76.5	18.0
4/10/2012 13:03	65	85	20	58.5	76.5	18.0
4/10/2012 13:04	66	85	19	59.4	76.5	17.1
4/10/2012 13:04	65	85	20	58.5	76.5	18.0
4/10/2012 13:04	66	85	19	59.4	76.5	17.1
4/10/2012 13:04	65	85	20	58.5	76.5	18.0
4/10/2012 13:04	66	84	18	59.4	75.6	16.2
4/10/2012 13:04	65	84	19	58.5	75.6	17.1
4/10/2012 13:05	66	85	19	59.4	76.5	17.1
4/10/2012 13:05	66	85	19	59.4	76.5	17.1
4/10/2012 13:05	65	86	21	58.5	77.4	18.9
4/10/2012 13:05	65	86	21	58.5	77.4	18.9
4/10/2012 13:05	65	85	20	58.5	76.5	18.0
4/10/2012 13:05	65	85	20	58.5	76.5	18.0
4/10/2012 13:06	66	86	20	59.4	77.4	18.0
4/10/2012 13:06	65	85	20	58.5	76.5	18.0
4/10/2012 13:06	66	86	20	59.4	77.4	18.0
4/10/2012 13:06	65	85	20	58.5	76.5	18.0
4/10/2012 13:06	66	85	19	59.4	76.5	17.1
4/10/2012 13:06	65	84	19	58.5	75.6	17.1
4/10/2012 13:07	66	84	18	59.4	75.6	16.2
4/10/2012 13:07	65	85	20	58.5	76.5	18.0
4/10/2012 13:07	65	85	20	58.5	76.5	18.0
4/10/2012 13:07	65	85	20	58.5	76.5	18.0
4/10/2012 13:07	65	84	19	58.5	75.6	17.1
4/10/2012 13:07	66	86	20	59.4	77.4	18.0

Appendix E: Results from PEM

Time Stamp	Suction	Discharge	Water Flow (m^3/h)	Fuel Consumption (L/h)
27/01/2013 19:30	-4.42	0.30	5596.45	46.03
27/01/2013 20:00	-4.39	0.45	5626.00	46.03
27/01/2013 20:30	-4.42	0.52	5692.36	46.32
27/01/2013 21:00	-4.38	0.50	5653.32	46.24
27/01/2013 21:30	-4.39	0.24	5735.31	46.13
27/01/2013 22:00	-4.35	0.07	5735.40	46.24
27/01/2013 22:30	-4.36	0.33	5705.29	46.02
27/01/2013 23:00	-4.33	-0.41	5766.11	45.91
27/01/2013 23:30	-4.29	-0.54	5751.17	45.59
28/01/2013 0:00	-4.27	-0.54	5781.30	45.49
28/01/2013 0:30	-4.22	-0.54	5830.74	45.75
28/01/2013 1:00	-4.22	-0.51	5784.55	45.96
28/01/2013 1:30	-4.18	-0.51	5802.53	45.93
28/01/2013 2:00	-4.16	-0.46	5736.45	45.72
28/01/2013 2:30	-4.14	-0.49	5776.53	45.78
28/01/2013 3:00	-4.09	-0.45	5801.86	45.57
28/01/2013 3:30	-4.09	-0.44	5802.51	45.64
28/01/2013 4:00	-4.08	-0.49	5823.88	45.66
28/01/2013 4:30	-4.04	-0.49	5755.85	45.74
28/01/2013 5:00	-4.02	-0.45	5812.85	45.77
28/01/2013 5:30	-4.01	-0.42	5759.55	45.83
28/01/2013 6:00	-3.99	-0.42	5817.40	45.80
28/01/2013 6:30	-3.96	-0.39	5804.64	45.88
28/01/2013 7:00	-3.95	-0.35	5876.35	45.99
28/01/2013 7:30	-3.95	-0.36	5856.39	45.95
28/01/2013 8:00	-3.94	-0.37	5811.01	45.97
28/01/2013 8:30	-3.86	-0.22	5824.69	45.63
28/01/2013 9:00	-3.83	-0.28	5847.40	45.11
28/01/2013 9:30	-3.84	-0.13	5805.72	45.11
28/01/2013 10:00	-3.82	-0.11	5890.08	45.07
28/01/2013 10:30	-3.81	-0.30	5926.56	45.02
28/01/2013 11:00	-3.80	-0.32	5858.37	45.03
28/01/2013 11:30	-3.80	-0.22	5856.45	45.01
28/01/2013 12:30	-3.77	-0.38	5833.32	43.00
28/01/2013 13:00	-3.76	-0.38	5828.45	42.91
28/01/2013 13:30	-3.75	-0.36	5799.60	42.92
28/01/2013 14:00	-3.73	-0.38	5848.64	42.91
28/01/2013 14:30	-3.74	-0.35	5832.77	42.86
28/01/2013 15:00	-3.73	-0.39	5722.58	42.90
28/01/2013 15:30	-3.72	-0.36	5767.39	42.94
28/01/2013 16:00	-3.70	-0.36	5772.91	43.03

Time Stamp	Suction	Discharge	Water Flow (m^3/h)	Fuel Consumption (L/h)
28/01/2013 16:30	-3.73	-0.36	5727.62	43.02
28/01/2013 17:00	-3.68	-0.33	5786.72	43.05
28/01/2013 17:30	-3.68	-0.32	5754.86	43.03
28/01/2013 18:00	-3.71	-0.36	5821.94	42.99
28/01/2013 18:30	-3.70	-0.33	5841.34	43.02
28/01/2013 19:00	-3.71	-0.35	5694.85	43.01
28/01/2013 20:00	-3.70	-0.30	5749.63	43.02
28/01/2013 20:30	-3.71	-0.29	5897.77	42.99
28/01/2013 21:00	-3.72	-0.25	5798.86	43.00
28/01/2013 21:30	-3.70	-0.34	5777.57	43.06
28/01/2013 22:00	-3.70	-0.22	5797.80	43.07
28/01/2013 22:30	-3.69	-0.33	5803.28	43.04
28/01/2013 23:00	-3.72	-0.25	5831.79	43.06
28/01/2013 23:30	-3.71	-0.30	5730.22	42.96
29/01/2013 0:00	-3.68	-0.25	5750.78	42.92
29/01/2013 0:30	-3.68	-0.29	5831.81	42.93
29/01/2013 1:00	-3.69	-0.24	5813.10	42.96
29/01/2013 1:30	-3.71	-0.25	5887.32	42.95
29/01/2013 2:00	-3.70	-0.22	5783.22	42.97
29/01/2013 2:30	-3.68	-0.20	5795.61	43.02
29/01/2013 3:00	-3.71	-0.23	5838.68	42.99
29/01/2013 3:30	-3.71	-0.21	5778.43	42.99
29/01/2013 4:00	-3.71	-0.23	5792.80	42.96
29/01/2013 4:30	-3.70	-0.20	5851.88	42.96
29/01/2013 5:00	-3.71	-0.21	5785.76	42.99
29/01/2013 5:30	-3.70	-0.17	5748.47	43.02
29/01/2013 6:00	-3.70	-0.21	5762.70	43.02
29/01/2013 6:30	-3.69	-0.21	5739.78	42.99
29/01/2013 7:30	-3.67	-0.20	5846.22	41.46
29/01/2013 8:00	-3.65	-0.20	5896.84	41.39
29/01/2013 8:30	-3.68	-0.11	5858.44	41.43
29/01/2013 9:00	-3.68	-0.18	5909.93	41.48
29/01/2013 9:30	-3.68	-0.12	5936.29	41.50
29/01/2013 10:00	-3.67	-0.08	5863.41	41.48
29/01/2013 10:30	-3.67	-0.06	5863.53	41.44
29/01/2013 11:00	-3.64	-0.12	5867.65	41.44
29/01/2013 11:30	-3.67	-0.12	5828.86	41.41
29/01/2013 12:00	-3.67	-0.08	5887.77	41.39
29/01/2013 12:30	-3.66	-0.08	5898.73	41.39
29/01/2013 13:00	-3.69	-0.09	5896.95	41.39
29/01/2013 13:30	-3.69	-0.05	5848.63	41.32
29/01/2013 14:00	-3.71	-0.07	5833.79	41.32
29/01/2013 14:30	-3.68	-0.09	5814.79	41.30
29/01/2013 15:00	-3.68	-0.04	5882.36	41.34
29/01/2013 15:30	-3.69	-0.04	5871.59	41.28

Time Stamp	Suction	Discharge	Water Flow (m^3/h)	Fuel Consumption (L/h)
29/01/2013 16:00	-3.67	-0.05	5820.97	41.28
29/01/2013 16:30	-3.81	-0.11	5245.07	40.97
29/01/2013 17:30	-3.66	-0.04	5810.91	40.46
29/01/2013 18:00	-3.66	-0.01	5842.88	40.41
29/01/2013 18:30	-3.67	0.02	5807.10	40.39
29/01/2013 19:00	-3.66	0.00	5806.91	40.44
29/01/2013 19:30	-3.67	0.00	5800.21	40.47
29/01/2013 20:00	-3.69	0.01	5787.80	40.54
29/01/2013 20:30	-3.69	0.00	5800.01	40.55
29/01/2013 21:00	-3.68	0.02	5782.21	40.63
29/01/2013 21:30	-3.69	0.04	5770.14	40.67
29/01/2013 22:00	-3.70	0.06	5745.29	40.71
29/01/2013 22:30	-3.69	0.06	5806.08	40.72
29/01/2013 23:00	-3.71	0.07	5786.10	40.81
29/01/2013 23:30	-3.70	0.10	5860.71	40.79
30/01/2013 0:00	-3.70	0.07	5805.78	40.82
30/01/2013 0:30	-3.71	0.09	5803.96	40.86
30/01/2013 1:00	-3.72	0.07	5815.40	40.87
30/01/2013 1:30	-3.73	0.12	5849.09	40.92
30/01/2013 2:00	-3.71	0.09	5815.13	40.93
30/01/2013 2:30	-3.71	0.13	5823.19	40.93
30/01/2013 3:00	-3.72	0.11	5857.89	40.98
30/01/2013 3:30	-3.72	0.12	5809.86	41.02
30/01/2013 4:00	-3.71	0.13	5872.68	41.00
30/01/2013 4:30	-3.73	0.17	5836.58	40.99
30/01/2013 5:00	-3.71	0.16	5844.15	41.00
30/01/2013 5:30	-3.71	0.16	5825.59	41.01
30/01/2013 6:00	-3.72	0.14	5866.64	41.00
30/01/2013 6:30	-3.73	0.18	5820.65	40.97
30/01/2013 7:00	-3.68	0.17	5748.71	40.92
30/01/2013 7:30	-3.75	0.14	5828.77	40.71
30/01/2013 8:00	-3.74	0.18	5866.41	41.37
30/01/2013 8:30	-3.74	0.18	5715.71	41.36
30/01/2013 9:00	-3.74	0.19	5751.13	41.34
30/01/2013 9:30	-3.75	0.22	5884.83	41.31
30/01/2013 10:00	-3.75	0.24	5870.21	41.31
30/01/2013 10:30	-3.76	0.23	5831.34	41.25
30/01/2013 11:00	-3.74	0.25	5856.62	41.21
30/01/2013 11:30	-3.74	0.25	5739.42	41.19
30/01/2013 12:00	-3.71	0.22	5784.92	41.13
30/01/2013 12:30	-3.73	0.24	5767.50	41.16
30/01/2013 13:00	-3.72	0.27	5850.54	41.21
30/01/2013 13:30	-3.73	0.29	5804.24	41.19
30/01/2013 14:00	-3.75	0.29	5818.29	41.19
30/01/2013 14:30	-3.75	0.28	5835.22	41.25

Time Stamp	Suction	Discharge	Water Flow (m^3/h)	Fuel Consumption (L/h)
30/01/2013 15:00	-3.77	0.31	5807.72	41.18
30/01/2013 15:30	-3.75	0.30	5817.82	41.17
30/01/2013 16:00	-3.74	0.29	5820.70	41.25
30/01/2013 16:30	-3.75	0.30	5829.90	41.36
30/01/2013 17:00	-3.74	0.33	5826.79	41.29
30/01/2013 17:30	-3.77	0.32	5846.65	41.33
30/01/2013 18:00	-3.76	0.35	5745.94	41.39
30/01/2013 18:30	-3.75	0.36	5806.74	41.41
30/01/2013 19:00	-3.76	0.35	5718.17	41.56
30/01/2013 19:30	-3.77	0.36	5773.53	41.61
30/01/2013 20:00	-3.78	0.40	5782.57	41.74
30/01/2013 20:30	-3.80	0.39	5777.43	41.87
30/01/2013 21:00	-3.79	0.40	5764.72	41.94
30/01/2013 21:30	-3.81	0.36	5766.62	41.96
30/01/2013 22:00	-3.80	0.38	5722.21	41.98
30/01/2013 22:30	-3.79	0.41	5641.45	42.01
30/01/2013 23:00	-3.81	0.41	5675.63	42.02
30/01/2013 23:30	-3.78	0.45	5635.88	42.11
31/01/2013 0:00	-3.77	0.57	5613.16	42.11
31/01/2013 0:30	-3.78	0.58	5604.41	42.15
31/01/2013 1:00	-3.80	0.54	5551.03	42.06
31/01/2013 1:30	-3.77	0.45	5566.88	42.06
31/01/2013 2:00	-3.79	0.46	5563.34	42.07
31/01/2013 2:30	-3.79	0.51	5495.53	42.10
31/01/2013 3:00	-3.79	0.48	5524.48	42.14
31/01/2013 3:30	-3.81	0.44	5495.37	42.15
31/01/2013 4:00	-3.82	0.46	5547.26	42.17
31/01/2013 4:30	-3.82	0.44	5610.43	42.19
31/01/2013 5:00	-3.83	0.47	5657.61	42.24
31/01/2013 5:30	-3.85	0.49	5587.04	42.30
31/01/2013 6:00	-3.84	0.49	5570.49	42.36
31/01/2013 6:30	-3.83	0.51	5538.56	42.27
31/01/2013 7:00	-3.82	0.51	5543.08	42.23
31/01/2013 7:30	-3.92	0.65	5649.66	42.47
31/01/2013 8:00	-3.95	0.69	5668.02	42.65
31/01/2013 8:30	-3.96	0.70	5622.38	42.55
31/01/2013 9:00	-3.98	0.71	5617.05	42.58
31/01/2013 9:30	-3.98	0.66	5610.85	42.60
31/01/2013 10:00	-3.99	0.75	5659.35	42.64
31/01/2013 10:30	-3.99	0.76	5598.41	42.67
31/01/2013 11:00	-4.00	0.73	5631.95	42.79
31/01/2013 11:30	-4.01	0.79	5671.93	42.81
1/02/2013 0:00	-4.02	0.73	5606.41	42.82
1/02/2013 0:01	-4.02	0.73	5636.49	42.82
1/02/2013 0:30	-4.04	0.79	5677.32	42.82

Time Stamp	Suction	Discharge	Water Flow (m^3/h)	Fuel Consumption (L/h)
1/02/2013 1:00	-4.02	0.75	5599.04	42.88
1/02/2013 1:30	-4.05	0.79	5580.69	42.86
1/02/2013 2:00	-4.04	0.76	5612.85	42.87
1/02/2013 2:30	-4.06	0.80	5504.84	42.94
1/02/2013 3:00	-4.08	0.80	5473.69	42.96
1/02/2013 3:30	-4.11	0.79	5560.21	43.02
1/02/2013 4:00	-4.13	0.86	5564.56	43.13
1/02/2013 4:30	-4.15	0.87	5659.12	43.25
1/02/2013 5:00	-4.19	0.83	5610.41	43.22
1/02/2013 5:30	-4.12	0.81	5506.95	41.25
1/02/2013 6:00	-4.20	0.85	5519.23	42.87
1/02/2013 6:30	-4.23	0.82	5583.43	42.81
1/02/2013 7:00	-4.21	0.85	5500.62	42.78
1/02/2013 7:30	-4.24	0.82	5553.40	42.87
1/02/2013 8:00	-4.22	0.88	5472.70	42.86
1/02/2013 8:30	-4.25	0.87	5321.56	42.79
1/02/2013 9:00	-4.25	0.89	5378.90	42.83
1/02/2013 9:30	-4.29	0.89	5480.54	42.85
1/02/2013 10:00	-4.29	0.93	5458.53	42.76
1/02/2013 10:30	-4.26	0.91	5331.68	42.71
1/02/2013 11:00	-4.27	0.94	5416.33	42.72
1/02/2013 11:30	-4.27	0.92	5348.57	42.80
1/02/2013 12:00	-4.27	0.94	5376.45	42.77
1/02/2013 12:30	-4.31	0.96	5360.20	42.80
1/02/2013 13:00	-4.29	0.97	5441.68	42.72
1/02/2013 13:30	-4.29	0.97	5377.38	42.69
1/02/2013 14:00	-4.28	0.97	5322.72	42.59
1/02/2013 14:30	-4.29	0.99	5454.49	42.64
1/02/2013 15:00	-4.31	0.96	5476.66	42.67
1/02/2013 15:30	-4.30	0.96	5519.30	42.79
1/02/2013 16:00	-4.28	0.98	5721.98	43.64
1/02/2013 16:30	-4.25	1.03	5735.12	43.45
1/02/2013 17:00	-4.19	1.02	5785.55	43.32
1/02/2013 17:30	-4.14	1.02	5836.91	43.10
1/02/2013 18:00	-4.11	1.05	5750.27	43.12
1/02/2013 18:30	-4.11	1.07	5809.01	43.24
1/02/2013 19:00	-4.08	1.07	5751.08	43.25
1/02/2013 19:30	-4.06	0.90	5704.31	43.25
1/02/2013 20:00	-4.06	1.04	5708.62	43.24
1/02/2013 20:30	-4.11	1.00	5750.86	43.32
1/02/2013 21:00	-4.10	1.07	5616.38	43.17
1/02/2013 21:30	-4.10	1.10	5653.77	43.22
1/02/2013 22:00	-4.08	1.04	5580.25	43.06
1/02/2013 22:30	-4.06	1.03	5492.06	43.15
1/02/2013 23:00	-4.09	1.07	5700.29	43.43

Time Stamp	Suction	Discharge	Water Flow (m^3/h)	Fuel Consumption (L/h)
1/02/2013 23:30	-4.11	1.09	5780.33	43.48
2/02/2013 0:00	-4.09	1.13	5745.00	43.49
2/02/2013 0:30	-4.11	1.13	5562.15	43.34
2/02/2013 1:00	-4.12	1.10	5643.96	43.50
2/02/2013 1:30	-4.14	1.12	5707.46	43.57
2/02/2013 2:00	-4.15	1.13	5716.85	43.58
2/02/2013 2:30	-4.13	1.12	5640.39	43.59
2/02/2013 3:00	-4.15	1.12	5431.47	43.58
2/02/2013 3:30	-4.13	1.14	5349.34	43.55
2/02/2013 4:00	-4.17	1.18	5514.61	43.65
2/02/2013 4:30	-4.16	1.17	5438.36	43.54
2/02/2013 5:00	-4.17	1.18	5533.56	43.56
2/02/2013 5:30	-4.14	1.19	5379.60	43.61
2/02/2013 6:00	-4.14	1.18	5399.59	43.61
2/02/2013 6:30	-4.15	1.21	5509.29	43.58
2/02/2013 7:00	-4.13	1.20	5367.73	42.25
2/02/2013 7:30	-4.20	1.19	5304.61	42.88
2/02/2013 8:00	-4.16	1.24	5260.01	42.97
2/02/2013 8:30	-4.18	1.25	5336.58	42.92
2/02/2013 9:00	-4.19	1.25	5281.39	42.81
2/02/2013 9:30	-4.19	1.28	5186.73	42.70
2/02/2013 10:00	-4.20	1.28	5154.36	42.58
2/02/2013 10:30	-4.21	1.28	5209.75	42.60
2/02/2013 11:00	-4.22	1.29	5349.58	42.72
2/02/2013 11:30	-4.24	1.30	5107.60	42.75
2/02/2013 12:00	-4.26	1.32	5171.83	42.80
2/02/2013 12:30	-4.28	1.33	5219.64	42.77
2/02/2013 13:00	-4.25	1.33	5282.25	42.72
2/02/2013 13:30	-4.25	1.35	5439.76	42.78
2/02/2013 14:00	-4.29	1.37	5258.95	42.83
2/02/2013 14:30	-4.26	1.32	5225.46	42.77
2/02/2013 15:00	-4.26	1.30	5266.27	42.79
2/02/2013 15:30	-4.28	1.36	5249.94	42.88
2/02/2013 16:00	-4.30	1.38	5312.90	42.99
2/02/2013 16:30	-4.30	1.37	5450.92	43.04
2/02/2013 17:00	-4.31	1.40	5458.87	43.12
2/02/2013 17:30	-4.31	1.39	5293.49	43.05
2/02/2013 18:00	-4.32	1.38	5094.36	43.01
2/02/2013 18:30	-4.34	1.38	5206.77	43.05
2/02/2013 19:00	-4.32	1.37	5347.96	43.19
2/02/2013 19:30	-4.37	1.37	5481.75	43.21
2/02/2013 20:00	-4.36	1.36	5359.42	43.08
2/02/2013 20:30	-4.36	1.40	5336.59	43.10
2/02/2013 21:00	-4.34	1.42	5317.62	43.16
2/02/2013 21:30	-4.37	1.39	5240.68	43.22

Time Stamp	Suction	Discharge	Water Flow (m^3/h)	Fuel Consumption (L/h)
2/02/2013 22:00	-4.36	1.38	5155.92	43.27
2/02/2013 22:30	-4.36	1.44	5221.67	43.31
2/02/2013 23:00	-4.37	1.43	5299.16	43.24
2/02/2013 23:30	-4.39	1.43	5209.35	43.23
3/02/2013 0:00	-4.39	1.43	5235.49	43.24
3/02/2013 0:30	-4.44	1.42	5258.51	43.16
3/02/2013 1:00	-4.43	1.43	5328.82	43.13
3/02/2013 1:30	-4.44	1.44	5392.13	43.23
3/02/2013 2:00	-4.47	1.47	5284.34	43.20
3/02/2013 2:30	-4.48	1.46	5412.97	43.22
3/02/2013 3:00	-4.52	1.45	5361.34	43.28
3/02/2013 3:30	-4.52	1.56	5380.14	43.36
3/02/2013 4:00	-4.55	1.61	5400.48	43.41
3/02/2013 4:30	-4.55	1.60	5204.91	43.35
3/02/2013 5:00	-4.57	1.65	5321.06	43.45
3/02/2013 5:30	-4.54	1.59	5232.33	42.60
3/02/2013 6:00	-4.61	1.50	5457.17	43.72
3/02/2013 6:30	-4.60	1.42	5316.31	43.61
3/02/2013 7:00	-4.61	1.50	5399.16	43.51
3/02/2013 7:30	-4.58	1.52	5201.07	43.57
3/02/2013 8:00	-4.63	1.52	5178.66	43.65
3/02/2013 8:30	-4.66	1.45	5259.64	43.89
3/02/2013 9:00	-4.69	1.58	5509.48	44.14
3/02/2013 9:30	-4.71	1.41	5395.73	43.94
3/02/2013 10:00	-4.72	1.46	5240.75	43.90
3/02/2013 10:30	-4.74	1.53	5276.14	44.04
3/02/2013 11:00	-4.54	1.58	4906.67	44.13
3/02/2013 11:30	-4.54	1.53	4932.55	43.69
3/02/2013 12:00	-4.55	1.55	5176.38	43.64
3/02/2013 12:30	-4.58	1.57	5411.34	43.89
3/02/2013 13:00	-4.60	1.60	5463.63	44.02
3/02/2013 13:30	-4.63	1.71	5530.78	44.09
3/02/2013 14:00	-4.71	1.60	5567.84	44.38
3/02/2013 14:30	-4.69	1.24	5557.91	44.33
3/02/2013 15:00	-4.69	1.54	5572.84	44.41
3/02/2013 15:30	-4.69	1.62	5573.44	44.61
3/02/2013 16:00	-4.75	1.63	5139.29	44.60
3/02/2013 16:30	-4.76	1.63	5233.92	44.52
3/02/2013 17:00	-4.76	1.65	5376.82	44.65
3/02/2013 17:30	-4.80	1.66	5277.47	44.73
3/02/2013 18:00	-4.82	1.69	5132.22	44.69
3/02/2013 18:30	-4.85	1.68	5251.85	44.82
3/02/2013 19:00	-4.86	1.68	5107.02	44.74
3/02/2013 19:30	-4.81	1.67	5074.88	44.41
3/02/2013 20:00	-4.86	1.68	5097.67	44.54

Time Stamp	Suction	Discharge	Water Flow (m^3/h)	Fuel Consumption (L/h)
3/02/2013 20:30	-4.88	1.68	4920.04	44.48
3/02/2013 21:00	-4.92	1.69	5063.44	44.54
3/02/2013 21:30	-4.95	1.71	5137.14	44.69
3/02/2013 22:00	-4.95	1.71	5182.45	44.72
3/02/2013 22:30	-4.95	1.75	5093.69	44.68
3/02/2013 23:00	-4.95	1.75	5043.40	44.88
3/02/2013 23:30	-4.98	1.76	5273.82	44.97
4/02/2013 0:00	-5.00	1.77	4320.89	44.79
4/02/2013 13:00	-4.99	2.07	5230.47	46.93
4/02/2013 13:30	-4.98	1.91	5338.19	46.86
4/02/2013 14:00	-4.95	2.01	5393.98	46.83
4/02/2013 14:30	-4.91	2.14	4671.66	46.74
4/02/2013 15:30	-4.86	1.96	5061.28	46.67
4/02/2013 16:00	-4.89	2.03	5107.49	46.41
4/02/2013 16:30	-4.84	1.88	4981.76	46.52
4/02/2013 17:00	-4.85	2.08	4990.76	46.75
4/02/2013 17:30	-4.84	2.03	5094.03	46.83
4/02/2013 18:00	-4.85	2.00	5155.29	46.75
4/02/2013 18:30	-4.83	2.05	5005.83	46.74
4/02/2013 19:00	-4.83	2.07	5130.04	46.97
4/02/2013 19:30	-4.85	2.04	5135.58	46.99
4/02/2013 20:00	-4.84	2.05	5138.54	47.01
4/02/2013 20:30	-4.85	2.08	5064.12	47.07
4/02/2013 21:00	-4.83	2.08	5094.37	47.10
4/02/2013 21:30	-4.84	2.07	5102.17	47.04
4/02/2013 22:00	-4.84	2.03	5221.09	46.98
4/02/2013 22:30	-4.84	2.01	5098.63	46.92
4/02/2013 23:00	-4.84	2.06	4992.04	46.83
4/02/2013 23:30	-4.86	2.00	5253.71	46.97
5/02/2013 0:00	-4.86	2.02	5295.68	46.92
5/02/2013 0:30	-4.88	2.04	5314.24	46.94
5/02/2013 1:00	-4.86	2.02	5243.80	46.95
5/02/2013 1:30	-4.87	2.08	5231.32	46.99
5/02/2013 2:00	-4.87	2.03	5152.12	47.04
5/02/2013 2:30	-4.87	2.06	5195.91	47.16
5/02/2013 3:00	-4.88	2.11	5202.32	47.45
5/02/2013 3:30	-4.86	2.14	5090.47	47.68
5/02/2013 4:00	-4.84	2.04	5129.23	47.54
5/02/2013 4:30	-4.82	2.09	4987.95	47.57
5/02/2013 5:00	-4.75	2.14	4908.37	46.92
5/02/2013 5:30	-4.88	2.10	5252.87	46.01
5/02/2013 6:00	-4.91	2.13	5313.28	46.04
5/02/2013 6:30	-4.94	2.13	5319.37	45.96
5/02/2013 7:00	-4.92	2.13	5325.98	46.10
5/02/2013 7:30	-4.91	2.14	5276.02	46.06

Time Stamp	Suction	Discharge	Water Flow (m^3/h)	Fuel Consumption (L/h)
5/02/2013 8:00	-4.82	2.11	5172.98	45.83
5/02/2013 8:30	-4.86	2.13	5214.27	45.77
5/02/2013 9:00	-4.88	2.18	5084.61	45.82
5/02/2013 9:30	-4.85	2.11	5133.36	45.84
5/02/2013 10:00	-4.84	2.19	5050.30	45.82
5/02/2013 10:30	-4.83	2.13	4986.83	45.71
5/02/2013 11:00	-4.85	2.17	5066.96	45.92
5/02/2013 11:30	-4.84	2.17	5048.29	45.78
5/02/2013 12:00	-4.86	2.21	5153.88	45.62
5/02/2013 12:30	-4.92	2.18	5302.74	46.01
5/02/2013 14:00	-4.10	2.20	5567.23	46.09
5/02/2013 14:30	-4.09	2.24	5603.70	45.86
5/02/2013 15:00	-4.11	2.21	5632.00	45.82
5/02/2013 15:30	-4.10	2.27	5615.67	45.95
5/02/2013 16:00	-4.12	2.28	5726.05	46.20
5/02/2013 16:30	-4.11	2.25	5665.96	46.03
5/02/2013 17:00	-4.10	2.26	5610.45	45.93
5/02/2013 17:30	-4.12	2.27	5616.64	45.82
5/02/2013 18:00	-4.13	2.27	5616.61	45.92
5/02/2013 18:30	-4.15	2.29	5633.19	46.03
5/02/2013 19:00	-4.15	2.29	5547.90	46.20
5/02/2013 19:30	-4.14	2.26	5524.16	46.20
5/02/2013 20:00	-4.17	2.31	5500.91	46.35
5/02/2013 20:30	-4.19	2.34	5524.74	46.43
5/02/2013 21:00	-4.19	2.31	5490.91	46.49
5/02/2013 21:30	-4.25	2.30	5569.42	46.44
5/02/2013 22:00	-4.26	2.33	5586.57	46.57
5/02/2013 22:30	-4.33	2.33	5646.42	46.64
5/02/2013 23:00	-4.33	2.33	5572.21	46.70
5/02/2013 23:30	-4.37	2.33	5552.52	46.64
6/02/2013 0:00	-4.42	2.32	5525.42	46.79
6/02/2013 0:30	-4.43	2.31	5554.30	46.81
6/02/2013 1:00	-4.48	2.36	5387.44	46.93
6/02/2013 1:30	-4.54	2.42	5458.47	47.63
6/02/2013 2:00	-4.60	2.40	5529.78	47.85
6/02/2013 2:30	-4.65	2.39	5372.07	48.43
6/02/2013 3:00	-4.76	2.41	5377.71	48.60
6/02/2013 3:30	-4.91	2.37	5495.09	48.74
6/02/2013 4:00	-5.07	2.38	5295.30	49.17
6/02/2013 11:30	-5.03	2.45	4366.85	36.48
6/02/2013 12:00	-4.96	2.42	4602.15	36.44
6/02/2013 12:30	-4.81	2.48	4372.00	35.92
6/02/2013 13:00	-4.67	2.45	4374.31	35.05
6/02/2013 13:30	-4.63	2.44	4447.07	35.03
6/02/2013 14:00	-4.64	2.42	4444.10	35.04

Time Stamp	Suction	Discharge	Water Flow (m^3/h)	Fuel Consumption (L/h)
6/02/2013 14:30	-4.62	2.46	4283.39	35.29
6/02/2013 15:00	-4.63	2.46	4286.69	35.19
6/02/2013 15:30	-4.67	2.45	4255.30	35.33
7/02/2013 3:30	-4.87	2.61	4371.26	42.70
7/02/2013 4:00	-4.66	2.52	4564.13	41.19
7/02/2013 4:30	-4.65	2.61	5024.27	41.08
7/02/2013 5:00	-4.69	2.66	4930.18	41.04
7/02/2013 5:30	-4.71	2.68	4904.42	41.03
7/02/2013 6:00	-4.75	2.70	4810.15	41.13
7/02/2013 6:30	-4.81	2.64	4968.73	41.47
7/02/2013 7:00	-4.50	2.64	4534.46	37.05
7/02/2013 7:30	-4.13	2.57	4116.32	28.52
7/02/2013 8:00	-4.15	2.60	4080.85	28.69
7/02/2013 8:30	-4.13	2.59	4082.64	28.75
7/02/2013 9:00	-4.11	2.62	4063.68	28.76
7/02/2013 9:30	-4.12	2.60	4072.77	28.83
7/02/2013 10:00	-4.11	2.71	4039.69	28.77
7/02/2013 10:30	-4.11	2.75	4095.64	28.72
7/02/2013 11:00	-4.12	2.67	4048.07	28.79
7/02/2013 11:30	-4.14	2.69	4039.99	28.80
7/02/2013 12:00	-4.17	2.66	4122.56	28.92
7/02/2013 12:30	-4.15	2.65	4109.26	28.98
7/02/2013 13:00	-4.13	2.64	4159.26	29.05
7/02/2013 13:30	-4.11	2.64	4127.21	29.05
7/02/2013 14:00	-4.12	2.66	4126.54	28.98
7/02/2013 14:30	-4.13	2.66	4161.20	28.91
7/02/2013 15:00	-4.15	2.67	4222.55	28.87
7/02/2013 15:30	-4.20	2.68	4336.41	28.92
7/02/2013 16:00	-4.27	2.71	4326.76	28.90
7/02/2013 16:30	-4.28	2.67	4170.60	28.84
7/02/2013 17:00	-4.39	1.88	3166.89	28.66

Appendix F: Analysis of Results

Time Stamp	Combined Efficency (%)	Fuel Use / ML	Fuel Cost $/ML/m	Total Head (m)
27/01/2013 19:30	13.53	8.22	2.61	0.65
27/01/2013 20:00	13.95	8.18	2.53	0.67
27/01/2013 20:30	14.28	8.14	2.47	0.59
27/01/2013 21:00	14.06	8.18	2.51	0.61
27/01/2013 21:30	13.55	8.04	2.61	0.62
27/01/2013 22:00	12.93	8.06	2.73	0.56
27/01/2013 22:30	13.69	8.07	2.58	0.66
27/01/2013 23:00	11.59	7.96	3.05	0.58
27/01/2013 23:30	11.15	7.93	3.17	0.63
28/01/2013 0:00	11.17	7.87	3.16	0.66
28/01/2013 0:30	11.04	7.85	3.20	0.59
28/01/2013 1:00	10.98	7.95	3.22	0.54
28/01/2013 1:30	10.92	7.92	3.23	0.54
28/01/2013 2:00	10.91	7.97	3.24	0.59
28/01/2013 2:30	10.83	7.93	3.26	0.57
28/01/2013 3:00	10.89	7.85	3.24	0.62
28/01/2013 3:30	10.92	7.86	3.23	0.61
28/01/2013 4:00	10.76	7.84	3.28	0.59
28/01/2013 4:30	10.52	7.95	3.36	0.56
28/01/2013 5:00	10.70	7.87	3.30	0.57
28/01/2013 5:30	10.63	7.96	3.32	0.55
28/01/2013 6:00	10.69	7.87	3.30	0.56
28/01/2013 6:30	10.64	7.90	3.32	0.54
28/01/2013 7:00	10.85	7.83	3.26	0.53
28/01/2013 7:30	10.80	7.85	3.27	0.53
28/01/2013 8:00	10.62	7.91	3.32	0.52
28/01/2013 8:30	10.91	7.83	3.24	0.61
28/01/2013 9:00	10.85	7.71	3.25	0.72
28/01/2013 9:30	11.24	7.77	3.14	0.75
28/01/2013 10:00	11.41	7.65	3.09	0.77
28/01/2013 10:30	10.88	7.60	3.25	0.74
28/01/2013 11:00	10.64	7.69	3.32	0.73
28/01/2013 11:30	10.95	7.69	3.23	0.75
28/01/2013 12:30	10.83	7.37	3.26	1.19
28/01/2013 13:00	10.81	7.36	3.27	1.21
28/01/2013 13:30	10.79	7.40	3.27	1.21
28/01/2013 14:00	10.75	7.34	3.29	1.21
28/01/2013 14:30	10.85	7.35	3.25	1.23
28/01/2013 15:00	10.50	7.50	3.36	1.18
28/01/2013 15:30	10.63	7.45	3.32	1.18
28/01/2013 16:00	10.56	7.45	3.34	1.16
28/01/2013 16:30	10.57	7.51	3.34	1.16
28/01/2013 17:00	10.60	7.44	3.33	1.16
28/01/2013 17:30	10.59	7.48	3.33	1.16
28/01/2013 18:00	10.69	7.39	3.30	1.18

Time Stamp	Combined Efficency (%)	Fuel Use / ML	Fuel Cost $/ML/m	Total Head (m)
28/01/2013 18:30	10.75	7.37	3.29	1.18
28/01/2013 19:00	10.47	7.55	3.37	1.15
28/01/2013 20:00	10.73	7.48	3.29	1.18
28/01/2013 20:30	11.02	7.29	3.20	1.22
28/01/2013 21:00	11.00	7.42	3.21	1.21
28/01/2013 21:30	10.59	7.45	3.34	1.16
28/01/2013 22:00	11.03	7.43	3.20	1.20
28/01/2013 22:30	10.66	7.42	3.31	1.17
28/01/2013 23:00	11.06	7.38	3.19	1.21
28/01/2013 23:30	10.69	7.50	3.30	1.19
29/01/2013 0:00	10.84	7.46	3.26	1.21
29/01/2013 0:30	10.86	7.36	3.25	1.21
29/01/2013 1:00	10.98	7.39	3.22	1.22
29/01/2013 1:30	11.16	7.30	3.16	1.24
29/01/2013 2:00	11.04	7.43	3.20	1.22
29/01/2013 2:30	11.04	7.42	3.20	1.21
29/01/2013 3:00	11.13	7.36	3.17	1.23
29/01/2013 3:30	11.08	7.44	3.19	1.22
29/01/2013 4:00	11.05	7.42	3.20	1.23
29/01/2013 4:30	11.23	7.34	3.14	1.25
29/01/2013 5:00	11.08	7.43	3.19	1.23
29/01/2013 5:30	11.10	7.48	3.18	1.22
29/01/2013 6:00	10.99	7.47	3.21	1.21
29/01/2013 6:30	10.96	7.49	3.22	1.21
29/01/2013 7:30	11.54	7.09	3.06	1.64
29/01/2013 8:00	11.56	7.02	3.05	1.66
29/01/2013 8:30	11.86	7.07	2.98	1.69
29/01/2013 9:00	11.75	7.02	3.00	1.67
29/01/2013 9:30	11.98	6.99	2.95	1.69
29/01/2013 10:00	11.95	7.07	2.96	1.70
29/01/2013 10:30	12.00	7.07	2.94	1.71
29/01/2013 11:00	11.75	7.06	3.01	1.67
29/01/2013 11:30	11.79	7.10	3.00	1.69
29/01/2013 12:00	12.00	7.03	2.94	1.73
29/01/2013 12:30	12.04	7.02	2.93	1.73
29/01/2013 13:00	12.10	7.02	2.92	1.74
29/01/2013 13:30	12.15	7.07	2.91	1.76
29/01/2013 14:00	12.10	7.08	2.92	1.76
29/01/2013 14:30	11.88	7.10	2.97	1.73
29/01/2013 15:00	12.19	7.03	2.90	1.76
29/01/2013 15:30	12.23	7.03	2.89	1.78
29/01/2013 16:00	12.01	7.09	2.94	1.75
29/01/2013 16:30	11.15	7.81	3.17	1.70
29/01/2013 17:30	12.22	6.96	2.89	1.99
29/01/2013 18:00	12.43	6.92	2.84	2.04
29/01/2013 18:30	12.48	6.96	2.83	2.05
29/01/2013 19:00	12.38	6.96	2.85	2.02
29/01/2013 19:30	12.36	6.98	2.86	2.01
29/01/2013 20:00	12.41	7.01	2.85	2.00

Time Stamp	Combined Efficency (%)	Fuel Use / ML	Fuel Cost $/ML/m	Total Head (m)
29/01/2013 20:30	12.43	6.99	2.84	2.00
29/01/2013 21:00	12.42	7.03	2.84	1.98
29/01/2013 21:30	12.44	7.05	2.84	1.97
29/01/2013 22:00	12.51	7.09	2.82	1.97
29/01/2013 22:30	12.60	7.01	2.80	1.98
29/01/2013 23:00	12.62	7.05	2.80	1.96
29/01/2013 23:30	12.86	6.96	2.75	2.01
30/01/2013 0:00	12.61	7.03	2.80	1.96
30/01/2013 0:30	12.71	7.04	2.78	1.96
30/01/2013 1:00	12.72	7.03	2.78	1.96
30/01/2013 1:30	12.97	7.00	2.72	1.99
30/01/2013 2:00	12.72	7.04	2.78	1.95
30/01/2013 2:30	12.87	7.03	2.74	1.97
30/01/2013 3:00	12.88	7.00	2.74	1.96
30/01/2013 3:30	12.78	7.06	2.76	1.93
30/01/2013 4:00	12.95	6.98	2.73	1.96
30/01/2013 4:30	13.05	7.02	2.71	1.98
30/01/2013 5:00	13.01	7.02	2.72	1.97
30/01/2013 5:30	12.96	7.04	2.72	1.96
30/01/2013 6:00	13.00	6.99	2.72	1.97
30/01/2013 6:30	13.09	7.04	2.70	1.99
30/01/2013 7:00	12.72	7.12	2.78	1.95
30/01/2013 7:30	13.11	6.99	2.69	2.07
30/01/2013 8:00	13.08	7.05	2.70	1.89
30/01/2013 8:30	12.74	7.24	2.77	1.84
30/01/2013 9:00	12.88	7.19	2.74	1.86
30/01/2013 9:30	13.30	7.02	2.65	1.93
30/01/2013 10:00	13.34	7.04	2.65	1.94
30/01/2013 10:30	13.26	7.07	2.66	1.94
30/01/2013 11:00	13.36	7.04	2.64	1.97
30/01/2013 11:30	13.10	7.18	2.70	1.94
30/01/2013 12:00	13.04	7.11	2.71	1.94
30/01/2013 12:30	13.11	7.14	2.69	1.94
30/01/2013 13:00	13.33	7.04	2.65	1.96
30/01/2013 13:30	13.32	7.10	2.65	1.97
30/01/2013 14:00	13.44	7.08	2.63	1.98
30/01/2013 14:30	13.43	7.07	2.63	1.97
30/01/2013 15:00	13.53	7.09	2.61	2.00
30/01/2013 15:30	13.45	7.08	2.63	1.99
30/01/2013 16:00	13.39	7.09	2.64	1.96
30/01/2013 16:30	13.44	7.09	2.63	1.94
30/01/2013 17:00	13.52	7.09	2.61	1.97
30/01/2013 17:30	13.62	7.07	2.59	1.97
30/01/2013 18:00	13.46	7.20	2.62	1.93
30/01/2013 18:30	13.57	7.13	2.60	1.94
30/01/2013 19:00	13.32	7.27	2.65	1.87
30/01/2013 19:30	13.50	7.21	2.62	1.88
30/01/2013 20:00	13.61	7.22	2.60	1.86
30/01/2013 20:30	13.61	7.25	2.60	1.82

Time Stamp	Combined Efficency (%)	Fuel Use / ML	Fuel Cost $/ML/m	Total Head (m)
30/01/2013 21:00	13.56	7.28	2.60	1.79
30/01/2013 21:30	13.47	7.28	2.62	1.78
30/01/2013 22:00	13.40	7.34	2.63	1.76
30/01/2013 22:30	13.26	7.45	2.66	1.73
30/01/2013 23:00	13.39	7.40	2.64	1.75
30/01/2013 23:30	13.35	7.47	2.65	1.72
31/01/2013 0:00	13.59	7.50	2.60	1.75
31/01/2013 0:30	13.63	7.52	2.59	1.74
31/01/2013 1:00	13.47	7.58	2.62	1.75
31/01/2013 1:30	13.15	7.56	2.69	1.71
31/01/2013 2:00	13.24	7.56	2.67	1.72
31/01/2013 2:30	13.19	7.66	2.68	1.70
31/01/2013 3:00	13.17	7.63	2.68	1.69
31/01/2013 3:30	13.07	7.67	2.70	1.67
31/01/2013 4:00	13.25	7.60	2.67	1.69
31/01/2013 4:30	13.32	7.52	2.65	1.69
31/01/2013 5:00	13.55	7.47	2.61	1.71
31/01/2013 5:30	13.49	7.57	2.62	1.69
31/01/2013 6:00	13.40	7.60	2.64	1.66
31/01/2013 6:30	13.38	7.63	2.64	1.68
31/01/2013 7:00	13.40	7.62	2.64	1.69
31/01/2013 7:30	14.30	7.52	2.47	1.73
31/01/2013 8:00	14.53	7.53	2.43	1.71
31/01/2013 8:30	14.49	7.57	2.44	1.73
31/01/2013 9:00	14.56	7.58	2.43	1.73
31/01/2013 9:30	14.37	7.59	2.46	1.70
31/01/2013 10:00	14.81	7.54	2.38	1.74
31/01/2013 10:30	14.65	7.62	2.41	1.71
31/01/2013 11:00	14.67	7.60	2.41	1.68
31/01/2013 11:30	14.96	7.55	2.36	1.71
1/02/2013 0:00	14.66	7.64	2.41	1.67
1/02/2013 0:01	14.74	7.60	2.40	1.68
1/02/2013 0:30	15.07	7.54	2.34	1.72
1/02/2013 1:00	14.66	7.66	2.41	1.65
1/02/2013 1:30	14.85	7.68	2.38	1.68
1/02/2013 2:00	14.82	7.64	2.38	1.68
1/02/2013 2:30	14.65	7.80	2.41	1.64
1/02/2013 3:00	14.63	7.85	2.41	1.63
1/02/2013 3:30	14.90	7.74	2.37	1.64
1/02/2013 4:00	15.16	7.75	2.33	1.63
1/02/2013 4:30	15.45	7.64	2.29	1.62
1/02/2013 5:00	15.33	7.70	2.30	1.62
1/02/2013 5:30	15.50	7.49	2.28	2.27
1/02/2013 6:00	15.30	7.77	2.31	1.73
1/02/2013 6:30	15.51	7.67	2.28	1.77
1/02/2013 7:00	15.33	7.78	2.30	1.76
1/02/2013 7:30	15.42	7.72	2.29	1.74
1/02/2013 8:00	15.32	7.83	2.31	1.73
1/02/2013 8:30	15.00	8.04	2.35	1.72

Time Stamp	Combined Efficency (%)	Fuel Use / ML	Fuel Cost $/ML/m	Total Head (m)
1/02/2013 9:00	15.20	7.96	2.32	1.73
1/02/2013 9:30	15.61	7.82	2.26	1.77
1/02/2013 10:00	15.70	7.83	2.25	1.81
1/02/2013 10:30	15.21	8.01	2.32	1.77
1/02/2013 11:00	15.57	7.89	2.27	1.81
1/02/2013 11:30	15.30	8.00	2.31	1.75
1/02/2013 12:00	15.42	7.96	2.29	1.77
1/02/2013 12:30	15.55	7.99	2.27	1.78
1/02/2013 13:00	15.77	7.85	2.24	1.83
1/02/2013 13:30	15.59	7.94	2.26	1.82
1/02/2013 14:00	15.44	8.00	2.29	1.83
1/02/2013 14:30	15.90	7.82	2.22	1.87
1/02/2013 15:00	15.91	7.79	2.22	1.86
1/02/2013 15:30	15.96	7.75	2.21	1.83
1/02/2013 16:00	16.25	7.63	2.17	1.58
1/02/2013 16:30	16.40	7.58	2.15	1.66
1/02/2013 17:00	16.38	7.49	2.16	1.70
1/02/2013 17:30	16.45	7.38	2.15	1.78
1/02/2013 18:00	16.18	7.50	2.18	1.74
1/02/2013 18:30	16.38	7.44	2.16	1.73
1/02/2013 19:00	16.13	7.52	2.19	1.70
1/02/2013 19:30	15.41	7.58	2.29	1.62
1/02/2013 20:00	15.86	7.58	2.23	1.67
1/02/2013 20:30	15.95	7.53	2.21	1.65
1/02/2013 21:00	15.81	7.69	2.23	1.69
1/02/2013 21:30	16.02	7.64	2.20	1.70
1/02/2013 22:00	15.61	7.72	2.26	1.70
1/02/2013 22:30	15.27	7.86	2.31	1.64
1/02/2013 23:00	15.96	7.62	2.21	1.62
1/02/2013 23:30	16.27	7.52	2.17	1.63
2/02/2013 0:00	16.26	7.57	2.17	1.63
2/02/2013 0:30	15.82	7.79	2.23	1.63
2/02/2013 1:00	15.94	7.71	2.22	1.59
2/02/2013 1:30	16.22	7.63	2.18	1.60
2/02/2013 2:00	16.28	7.62	2.17	1.60
2/02/2013 2:30	16.00	7.73	2.21	1.57
2/02/2013 3:00	15.48	8.02	2.28	1.52
2/02/2013 3:30	15.24	8.14	2.32	1.51
2/02/2013 4:00	15.91	7.92	2.22	1.54
2/02/2013 4:30	15.68	8.01	2.25	1.55
2/02/2013 5:00	15.99	7.87	2.21	1.58
2/02/2013 5:30	15.48	8.11	2.28	1.51
2/02/2013 6:00	15.53	8.08	2.27	1.52
2/02/2013 6:30	15.96	7.91	2.21	1.57
2/02/2013 7:00	15.96	7.87	2.21	2.01
2/02/2013 7:30	15.69	8.08	2.25	1.77
2/02/2013 8:00	15.55	8.17	2.27	1.72
2/02/2013 8:30	15.89	8.04	2.22	1.78
2/02/2013 9:00	15.80	8.11	2.24	1.80

Time Stamp	Combined Efficency (%)	Fuel Use / ML	Fuel Cost $/ML/m	Total Head (m)
2/02/2013 9:30	15.66	8.23	2.26	1.82
2/02/2013 10:00	15.61	8.26	2.26	1.86
2/02/2013 10:30	15.81	8.18	2.23	1.88
2/02/2013 11:00	16.25	7.99	2.17	1.89
2/02/2013 11:30	15.58	8.37	2.27	1.80
2/02/2013 12:00	15.87	8.28	2.22	1.82
2/02/2013 12:30	16.11	8.20	2.19	1.85
2/02/2013 13:00	16.25	8.09	2.17	1.89
2/02/2013 13:30	16.76	7.86	2.11	1.93
2/02/2013 14:00	16.37	8.15	2.16	1.86
2/02/2013 14:30	16.06	8.18	2.20	1.85
2/02/2013 15:00	16.11	8.13	2.19	1.85
2/02/2013 15:30	16.24	8.17	2.18	1.83
2/02/2013 16:00	16.52	8.09	2.14	1.82
2/02/2013 16:30	16.91	7.90	2.09	1.85
2/02/2013 17:00	17.02	7.90	2.07	1.83
2/02/2013 17:30	16.48	8.13	2.14	1.80
2/02/2013 18:00	15.89	8.44	2.22	1.75
2/02/2013 18:30	16.28	8.27	2.17	1.78
2/02/2013 19:00	16.61	8.08	2.13	1.77
2/02/2013 19:30	17.15	7.88	2.06	1.82
2/02/2013 20:00	16.73	8.04	2.11	1.82
2/02/2013 20:30	16.80	8.08	2.10	1.82
2/02/2013 21:00	16.71	8.12	2.11	1.79
2/02/2013 21:30	16.44	8.25	2.15	1.74
2/02/2013 22:00	16.11	8.39	2.19	1.69
2/02/2013 22:30	16.46	8.29	2.15	1.71
2/02/2013 23:00	16.73	8.16	2.11	1.76
2/02/2013 23:30	16.51	8.30	2.14	1.74
3/02/2013 0:00	16.61	8.26	2.13	1.75
3/02/2013 0:30	16.82	8.21	2.10	1.80
3/02/2013 1:00	17.04	8.09	2.07	1.83
3/02/2013 1:30	17.29	8.02	2.04	1.83
3/02/2013 2:00	17.10	8.18	2.07	1.82
3/02/2013 2:30	17.51	7.99	2.02	1.85
3/02/2013 3:00	17.42	8.07	2.03	1.82
3/02/2013 3:30	17.78	8.06	1.99	1.83
3/02/2013 4:00	18.05	8.04	1.96	1.84
3/02/2013 4:30	17.37	8.33	2.03	1.79
3/02/2013 5:00	17.94	8.17	1.97	1.81
3/02/2013 5:30	17.71	8.14	1.99	2.10
3/02/2013 6:00	17.97	8.01	1.97	1.72
3/02/2013 6:30	17.27	8.20	2.04	1.69
3/02/2013 7:00	17.85	8.06	1.98	1.78
3/02/2013 7:30	17.13	8.38	2.06	1.69
3/02/2013 8:00	17.20	8.43	2.05	1.67
3/02/2013 8:30	17.23	8.35	2.05	1.58
3/02/2013 9:00	18.42	8.01	1.92	1.60
3/02/2013 9:30	17.72	8.14	1.99	1.61

Time Stamp	Combined Efficency (%)	Fuel Use / ML	Fuel Cost $/ML/m	Total Head (m)
3/02/2013 10:00	17.39	8.38	2.03	1.59
3/02/2013 10:30	17.69	8.35	2.00	1.57
3/02/2013 11:00	16.01	8.99	2.21	1.39
3/02/2013 11:30	16.16	8.86	2.19	1.55
3/02/2013 12:00	17.06	8.43	2.07	1.66
3/02/2013 12:30	17.86	8.11	1.98	1.64
3/02/2013 13:00	18.13	8.06	1.95	1.62
3/02/2013 13:30	18.71	7.97	1.89	1.64
3/02/2013 14:00	18.64	7.97	1.89	1.52
3/02/2013 14:30	17.51	7.98	2.02	1.45
3/02/2013 15:00	18.39	7.97	1.92	1.49
3/02/2013 15:30	18.55	8.00	1.90	1.43
3/02/2013 16:00	17.29	8.68	2.04	1.34
3/02/2013 16:30	17.66	8.51	2.00	1.39
3/02/2013 17:00	18.19	8.30	1.94	1.39
3/02/2013 17:30	17.93	8.48	1.97	1.34
3/02/2013 18:00	17.59	8.71	2.01	1.32
3/02/2013 18:30	18.04	8.53	1.96	1.31
3/02/2013 19:00	17.58	8.76	2.01	1.30
3/02/2013 19:30	17.43	8.75	2.03	1.41
3/02/2013 20:00	17.63	8.74	2.00	1.38
3/02/2013 20:30	17.09	9.04	2.07	1.36
3/02/2013 21:00	17.70	8.80	2.00	1.39
3/02/2013 21:30	18.02	8.70	1.96	1.36
3/02/2013 22:00	18.18	8.63	1.94	1.36
3/02/2013 22:30	17.99	8.77	1.96	1.36
3/02/2013 23:00	17.74	8.90	1.99	1.27
3/02/2013 23:30	18.60	8.53	1.90	1.29
4/02/2013 0:00	15.36	10.37	2.30	1.12
4/02/2013 13:00	18.53	8.97	1.91	0.54
4/02/2013 13:30	18.48	8.78	1.91	0.56
4/02/2013 14:00	18.87	8.68	1.87	0.59
4/02/2013 14:30	16.57	10.01	2.13	0.55
4/02/2013 15:30	17.40	9.22	2.03	0.60
4/02/2013 16:00	17.92	9.09	1.97	0.71
4/02/2013 16:30	16.96	9.34	2.08	0.63
4/02/2013 17:00	17.41	9.37	2.03	0.57
4/02/2013 17:30	17.60	9.19	2.01	0.55
4/02/2013 18:00	17.80	9.07	1.98	0.58
4/02/2013 18:30	17.34	9.34	2.04	0.57
4/02/2013 19:00	17.72	9.16	1.99	0.50
4/02/2013 19:30	17.71	9.15	1.99	0.49
4/02/2013 20:00	17.72	9.15	1.99	0.48
4/02/2013 20:30	17.54	9.29	2.01	0.46
4/02/2013 21:00	17.60	9.25	2.01	0.45
4/02/2013 21:30	17.64	9.22	2.00	0.47
4/02/2013 22:00	17.99	9.00	1.96	0.50
4/02/2013 22:30	17.52	9.20	2.02	0.51
4/02/2013 23:00	17.30	9.38	2.04	0.54

Time Stamp	Combined Efficency (%)	Fuel Use / ML	Fuel Cost $/ML/m	Total Head (m)
4/02/2013 23:30	18.07	8.94	1.95	0.51
5/02/2013 0:00	18.29	8.86	1.93	0.53
5/02/2013 0:30	18.44	8.83	1.92	0.53
5/02/2013 1:00	18.09	8.95	1.95	0.52
5/02/2013 1:30	18.22	8.98	1.94	0.51
5/02/2013 2:00	17.80	9.13	1.98	0.47
5/02/2013 2:30	17.98	9.08	1.96	0.44
5/02/2013 3:00	18.02	9.12	1.96	0.33
5/02/2013 3:30	17.59	9.37	2.01	0.24
5/02/2013 4:00	17.48	9.27	2.02	0.29
5/02/2013 4:30	17.06	9.54	2.07	0.27
5/02/2013 5:00	16.97	9.56	2.08	0.50
5/02/2013 5:30	18.77	8.76	1.88	0.90
5/02/2013 6:00	19.12	8.67	1.85	0.91
5/02/2013 6:30	19.27	8.64	1.83	0.94
5/02/2013 7:00	19.17	8.66	1.84	0.89
5/02/2013 7:30	19.01	8.73	1.86	0.89
5/02/2013 8:00	18.44	8.86	1.92	0.95
5/02/2013 8:30	18.75	8.78	1.88	0.99
5/02/2013 9:00	18.46	9.01	1.91	0.96
5/02/2013 9:30	18.33	8.93	1.93	0.94
5/02/2013 10:00	18.23	9.07	1.94	0.95
5/02/2013 10:30	17.87	9.17	1.98	0.97
5/02/2013 11:00	18.23	9.06	1.94	0.91
5/02/2013 11:30	18.22	9.07	1.94	0.96
5/02/2013 12:00	18.79	8.85	1.88	1.05
5/02/2013 12:30	19.26	8.68	1.83	0.93
5/02/2013 14:00	17.91	8.28	1.97	0.83
5/02/2013 14:30	18.20	8.18	1.94	0.93
5/02/2013 15:00	18.29	8.14	1.93	0.95
5/02/2013 15:30	18.35	8.18	1.92	0.90
5/02/2013 16:00	18.68	8.07	1.89	0.82
5/02/2013 16:30	18.43	8.12	1.92	0.88
5/02/2013 17:00	18.30	8.19	1.93	0.91
5/02/2013 17:30	18.44	8.16	1.91	0.96
5/02/2013 18:00	18.44	8.18	1.92	0.92
5/02/2013 18:30	18.57	8.17	1.90	0.88
5/02/2013 19:00	18.20	8.33	1.94	0.80
5/02/2013 19:30	18.01	8.36	1.96	0.79
5/02/2013 20:00	18.09	8.43	1.95	0.74
5/02/2013 20:30	18.29	8.40	1.93	0.72
5/02/2013 21:00	18.05	8.47	1.96	0.69
5/02/2013 21:30	18.49	8.34	1.91	0.72
5/02/2013 22:00	18.60	8.34	1.90	0.68
5/02/2013 22:30	18.97	8.26	1.86	0.66
5/02/2013 23:00	18.70	8.38	1.89	0.63
5/02/2013 23:30	18.77	8.40	1.88	0.66
6/02/2013 0:00	18.73	8.47	1.89	0.60
6/02/2013 0:30	18.85	8.43	1.87	0.59

Time Stamp	Combined Efficency (%)	Fuel Use / ML	Fuel Cost $/ML/m	Total Head (m)
6/02/2013 1:00	18.47	8.71	1.91	0.54
6/02/2013 1:30	18.76	8.73	1.88	0.27
6/02/2013 2:00	19.06	8.65	1.85	0.19
6/02/2013 2:30	18.39	9.02	1.92	-0.04
6/02/2013 3:00	18.69	9.04	1.89	-0.10
6/02/2013 3:30	19.31	8.87	1.83	-0.16
6/02/2013 4:00	18.89	9.29	1.87	-0.33
6/02/2013 11:30	21.08	8.35	1.68	5.17
6/02/2013 12:00	21.96	7.92	1.61	5.40
6/02/2013 12:30	20.88	8.22	1.69	5.36
6/02/2013 13:00	20.93	8.01	1.69	5.75
6/02/2013 13:30	21.13	7.88	1.67	5.82
6/02/2013 14:00	21.09	7.88	1.67	5.80
6/02/2013 14:30	20.24	8.24	1.74	5.46
6/02/2013 15:00	20.34	8.21	1.74	5.53
6/02/2013 15:30	20.19	8.30	1.75	5.43
7/02/2013 3:30	18.03	9.77	1.96	2.10
7/02/2013 4:00	18.73	9.03	1.89	2.77
7/02/2013 4:30	20.91	8.18	1.69	3.14
7/02/2013 5:00	20.79	8.33	1.70	3.13
7/02/2013 5:30	20.80	8.37	1.70	3.14
7/02/2013 6:00	20.50	8.55	1.72	3.06
7/02/2013 6:30	20.99	8.35	1.68	2.98
7/02/2013 7:00	20.55	8.17	1.72	4.80
7/02/2013 7:30	22.75	6.93	1.55	9.32
7/02/2013 8:00	22.58	7.03	1.56	9.18
7/02/2013 8:30	22.46	7.04	1.57	9.10
7/02/2013 9:00	22.38	7.08	1.58	9.06
7/02/2013 9:30	22.36	7.08	1.58	9.02
7/02/2013 10:00	22.53	7.12	1.57	9.12
7/02/2013 10:30	23.03	7.01	1.53	9.35
7/02/2013 11:00	22.49	7.11	1.57	9.09
7/02/2013 11:30	22.56	7.13	1.57	9.12
7/02/2013 12:00	22.95	7.01	1.54	9.22
7/02/2013 12:30	22.72	7.05	1.55	9.10
7/02/2013 13:00	22.83	6.98	1.55	9.11
7/02/2013 13:30	22.59	7.04	1.56	9.02
7/02/2013 14:00	22.72	7.02	1.55	9.10
7/02/2013 14:30	23.03	6.95	1.53	9.26
7/02/2013 15:00	23.48	6.84	1.50	9.46
7/02/2013 15:30	24.30	6.67	1.45	9.76
7/02/2013 16:00	24.60	6.68	1.44	9.89
7/02/2013 16:30	23.67	6.91	1.49	9.55
7/02/2013 17:00	16.30	9.05	2.17	6.64