UNIVERSITY OF SOUTHERN QUEENSLAND

FACULTY OF ENGINEERING AND SURVEYING

DECISION SUPPORT SYSTEM FOR ASSESSING THE BENEFITS OF INCORPORATING SWABBING FACILITIES INTO WATER PIPELINES

A DISSERTATION BY

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ABSTRACT

This project has examined the benefits of pigging pipelines and incorporated any findings into creating a decision support system to assist decisions in including swabbing facilities at the design stage of pipelines, on a case by case scenario. A literature review has been conducted in order to assess the current knowledge of the benefits of pigging a pipeline.

Anecdotal evidence has been gathered from various, experienced pipeline operators which has been based on the intimate knowledge of particular pipelines. These pipelines were selected on the basis that some do get pigged regularly and some rarely get pigged, if at all. Pipeline data, including flow rates and power usage before and after pigging was collected on some pipelines to measure the effects of pigging.

Results were analysed in *Microsoft Excel*. The research showed that pigging does have a financial benefit if biomass growth on the internal pipeline wall was significant enough. However, the reasoning for some pipelines to rarely be pigged needed clarification for inclusion in a decision support system which is detailed in this dissertation.

University of Southern Queensland

Faculty of Engineering and Surveying

ENG4111 Research Project Part 1 & ENG4112 Research Project Part 2

LIMITATIONS OF USE

Professor Frank Bullen

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CERTIFICATION

I certify that the ideas, designs, 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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28/10/10
______________________ Date

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ABBREVIATIONS

The following abbreviations have been used throughout the text:

4WD	Four Wheel Drive
AHD	Australian Height Datum
DICL	Ductile Iron Concrete Lined
HDPE	High Density Polyethylene
HGL	Hydraulic Grade Line
MSCL	Mild Steel Concrete Lined
NPSHR	Net Positive Suction Head Required
NPV	Net Present Value
PN	Nominal pressure rating measured in bar. 1 bar = 100kPa
RC	Reinforced Concrete
SCADA	Supervisory Control and Data Acquisition
SI Units	System of International Units
USQ	University of Southern Queensland

1.0 INTRODUCTION

1.1 OVERVIEW

This research project seeks to develop a decision support system for water pipeline design. This system will assess the benefits of swabbing for a particular pipeline that is in its design phase, and determines whether swabbing facilities are necessary for that particular pipeline.

1.2 THE RESEARCH PROBLEM

As it stands SunWater has no process during the design phase of pipelines to determine whether swabbing facilities should be included in the design. SunWater operates over 2,000km of industrial pipelines, excluding irrigation purpose pipelines, and less than half of these pipelines are pigged regularly, if at all.

The pipelines that are not being pigged are still managing to fulfil their service requirements. For this reason, some SunWater Engineers believe that from a financial perspective, the need for swabbing facilities in some instances is questionable. It is considered that if a pipeline requires pigging at long irregular time intervals, that in-situ launching and catching locations could be created to overcome the need for expensive, permanent, and often unused swabbing facilities.

A decision support system will compare pipeline diameter, length, flow requirements, pumping costs and many other variables to evaluate the financial benefits of including swabbing facilities in the design phase of a pipeline. This system could benefit SunWater by enabling costs to be lowered, both initially as a capital investment and eventually over the pipelines lifetime with operational costs.

1.3 PROJECT OBJECTIVES

The objectives of this project are outlined below:

1. Research the theoretical benefits of swabbing and gather information from similar projects within SunWater, other Water Authorities in Australia (Public

and Private) Engineering Journals and USQ's library.

2. Design and carry out field experiment(s) during a swabbing procedure to measure the hydraulic performance before and after the event,
3. Discuss with operator/maintainers of the swabbed pipeline to establish anecdotal reasoning and evidence for the frequency of swabbing the pipeline.
4. Conduct a survey of various pipeline operator/maintainers around the country to establish a database of pipelines that do get swabbed and for what reasons.
5. Perform a cost benefit analysis comparing a normally operating pipe against a pipe that has been fouled for multiple design scenarios.
6. Analyse this data against available variables such as pipe material, diameter, length, head pressures, pumping power costs and otherwise.
7. Create a decision making tool for determining the economic benefits for swabbing of water pipelines to be used during the design stage. This will take account of the initial capital cost of including the swabs, the operational costs and potential power savings or otherwise over the life of the pipeline.

1.4 SUMMARY

This dissertation aims to decrease costs via unnecessary inclusion of swabbing facilities for pipelines that inevitably will never be used. Its intention is not to prove that pipeline pigging is an unnecessary art. The literature review and data recordings from actual pigging events prove that pigging does increase the hydraulic performance of a pipeline.

The subsequent chapters include the background of pigging, literature review findings and address the objectives of this dissertation. The final chapters conclude the dissertation with provision of a decision support system. The outcome is expected to make recommendations and will make way for further work to be completed in the future.

2.0 PIGGING AND THE FUNDAMENTALS OF PUMPED PIPELINE DESIGN

2.1 BACKGROUND

There are many components to consider when designing a water pipeline. Typically, essential design aspects include the pipeline alignment, required capacity, pipe diameters, outlet locations, pumping requirements, pipe material types and if necessary, balance tanks and reservoirs. Preceding these design aspects is the approval stage which includes cultural heritage and environmental management.

There are also operation and maintenance appurtenances to consider which include the air valves, scour locations, meter outlets, stand pipes, surge tanks and if required, break pressure structures. These items are a small percentage of all of the operation and maintenance structures required in the design. However, the main thing to consider with these structure costs is that they are necessary for adequate operation of a pipeline.

One structure that often creates much debate, when designing pipelines, is the swabbing structure. Swabbing structures, or pigging structures as they are also known, are used to gain access to the inside of the pipeline to insert a swab or ‘pig’ to clean the pipeline (e.g. Figure 2.1). If pigging of a pipeline is required regularly the structures create a valid, simple access point to the inside of the pipeline.

The ‘pig’ is then ‘launched’ from one structure location and regathered at another swab structure location further downstream. The pressure of the pipeline pushes the pig along and it simultaneously ‘scrubs’ the internal wall of the pipeline

Without the prior inclusion of the swabbing structure major work is required to pig a pipeline including excavating around and cutting into the pipeline. More work and material cost follows the pigging event to re-establish the pipeline connection. For this reason swabbing structures are commonly incorporated in the design phase. This sounds as though it reinforces the requirement for swabbing structures. However, not all pipelines require regular pigging and thus the installation of these facilities is often a wasted investment as will be explained further throughout this document.

Figure 2.1 – Swab Structure (above ground type) on the Burdekin Moranbah Pipeline. Note the removable pipe (1200mm diameter) to launch/catch the swab.

Over time, due to many variables, the hydraulic performance of the pipeline can decline and only be restored to original condition through cleaning. This decline in performance is caused by the growth of bacteria and algae on the internal walls, as well as a build up of sediment in opportunistic locations along the pipeline. This can affect the operation of the pipeline in many ways, which is ultimately financially detrimental for the pipeline owner.

Swabbing structures used for launching and regathering pigs are often included or excluded in the design based on combined input from the designer, asset owner, operator or other stakeholders. These decisions are based on anecdotal reasoning and therefore the outcome on whether to include swabbing structures has no justification. A decision support system needs to be established that identifies the necessity for such structures on a case by case scenario.

2.2 WHAT IS PIGGING?

2.2.1 Definition

Pigging has been performed on pipelines for many years to clean large diameter pipelines in the water and oil industries. Its purpose is to clean the internal walls of pipes to increase the hydraulic performance of the pipeline system. It is done so by sending a cleaning device known as a 'swab' or a 'pig' down through the pipeline to 'scrub' the internal walls of the pipe as it is pushed through by the flow of the pipeline.

Figure 2.2 – Various types of pigs and swabs. Swabs are the foam pieces in the bottom left of photo.

The operation of cleaning the pipeline is commonly referred to as pigging. This is because in the early days the scraping device sent down the pipeline included spring-loaded rakes. These rakes made a characteristic loud squealing noise similar to a pig.

A book by Tiratsoo (1999) gives detailed input into the process of pipeline pigging. Within the book it was noted that swabbing refers to soft foam type pigs and that pigging relates to hard foams and disc pigs. In figure 2.2 above various types of pigs are arranged. The foam pieces in the bottom left corner of the figure are swabs.

Swabbing is usually limited to drying the pipeline after disinfection. In figure 2.2 the pieces with plastic discs are the pigs. Figure 2.3 below depicts a pig in a pipeline with some of the pipeline exterior exposed for better visualisation.

Figure 2.3 – Pig in a pipeline

Pigging is usually done to clean pipelines and remove biofilm from the pipeline walls. However for the purposes of this dissertation we will continue to refer to the launching structures as swabbing structures and the process of cleaning the pipes will be referred to as pigging.

2.2.2 Biofilms and Pipe Deposits

According to the *First Microbiology Reader* (2010), a Biofilm is a thin layer of cells of a microorganism such as a bacterium or a fungus, which is held to a surface by the material the microorganisms produce. Biofilms are usually found on solid substrates submerged in or exposed to some aqueous solution. The biofilm grows though a combination of cell division and recruitment.

Biofilms are common in nature, which includes things like dental plaque. It also exists in the medical industry impanted within tubes and wires which can lead to infections in patients. Floors and counters also contain biofilm which is detrimental to sanitation and food preparation standards. Biofilm is what covers the internal walls of a pipeline. An example of this can be seen below in Figure 2.4

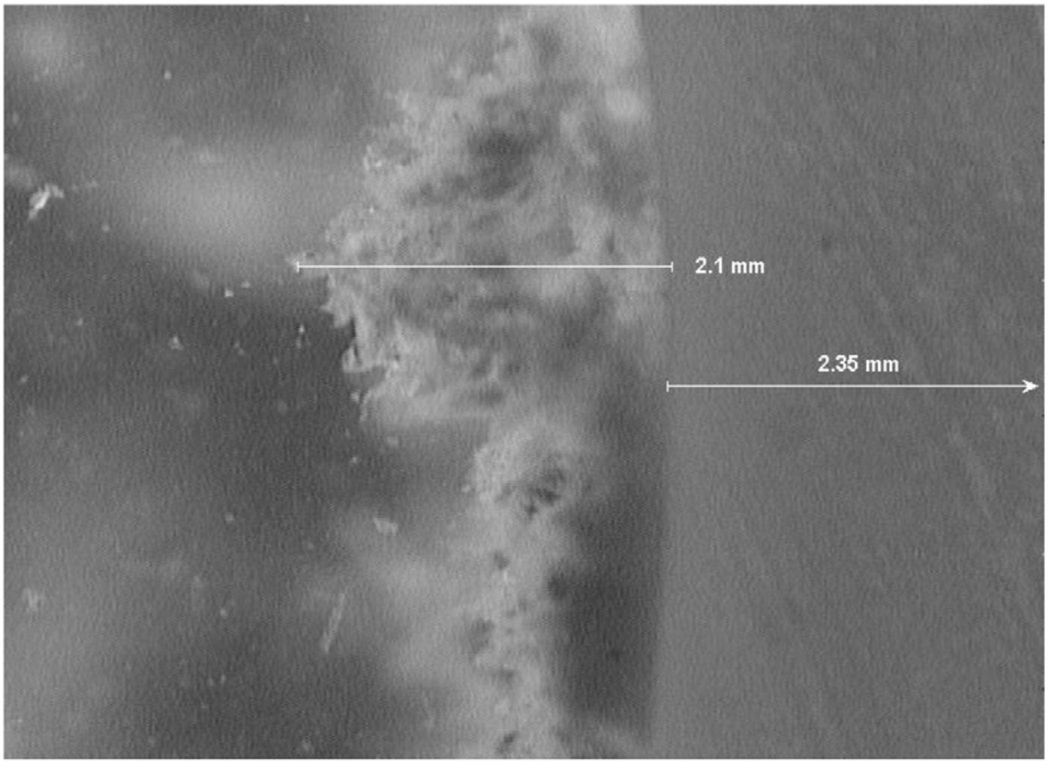

Fig 2.4 – Sectional view of Biofilm on internal wall of a pipe. Note pipe wall on right side. (Barton, 2008)

2.3 PIPELINE HYDRAULICS

2.3.1 Basic Principles

The main reason for pigging is it creates financial benefits due to the increase in hydraulic performance. Therefore it is necessary at this point to discuss pipeline hydraulics in order to fully understand how sending a pig down a pipeline may create financial gain.

Flow within a pipeline can be described by two main principles, conservation of mass (continuity) and conservation of energy. Continuity simply states that the flow into the system must be equal to the flow out of the system. Water is never lost or created and the entire volume can be accounted for. Conservation of energy states that energy may neither be created nor destroyed, only transferred from one form to another (Chadwick et al. 2004). Both principles can be described in equation form.

According to Chadwick et al. (2004), the Continuity equation is:

$$Q_{in} = Q_{out}$$
$$A_{in}V_{in} = A_{out}V_{out}$$

Eq 2.1

Where:

- Q is the flow rate in the pipeline, also known as the capacity of the pipeline, in m^3/s;
- A is the internal (wetted) cross-sectional area of the pipeline in m^2;
- V is the average velocity of the fluid flow, in m/s.

The energy equation is a real world application of Bernoulli's principle. In basic terms Bernoulli states that for a fluid with no viscosity, an increase in the speed of the fluid occurs simultaneously with a decrease in pressure or a decrease in the fluid's potential energy. The Bernoulli equation is expressed as:

$$\frac{P_1}{\rho g} + \frac{\alpha V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{\alpha V_2^2}{2g} + Z_2$$

Eq 2.2

Where:

- ρ is the density of the fluid, which in this case is water and is $1000 kg/m^3$;
- P is the pressure in Pascals, (Pa);
- g which is the local acceleration due to gravity in m^2/s.;
- z is the elevation of the point above a reference plane in *m;*

On the left hand side of the equation, the subscripted number 1, indicates the upstream conditions of a pipeline. Imagine the pipeline goes through a reduction in diameter. The downstream side of this pipeline would be indicated by the subscripted number 2.

The theory as explained above is summarised by stating that energy entering the pipe reduction will equal the energy leaving the pipeline after the reduction in diameter.

Application of the continuity equation (Eq 2.1) shows that for an incompressible fluid, such as water, a reduction in diameter and therefore area (*A*) will cause an increase in the fluid velocity. Applying the energy equation (Eq. 2.2), an increase in velocity (*V*) will result in an increase in the velocity head which in turn will require either the pressure head or elevation head (*Z*) to decrease.

However in practice the total energy throughout a pipeline does not remain constant. Therefore the continuity equation is a basic representation of the effects diameter can have to the flow of water. In reality energy is 'lost' through friction and fitting losses, requiring some additional terms in the energy equation. This being :

$$Z_1 - Z_2 = H = h_f + h_L \qquad \text{Eq 2.3}$$

Where:
- h_f is the head loss due to friction in m;
- h_L is the head loss due to bends, valves and fittings in m (often termed the minor loss)
- H is the total head in m.

Head is a concept that relates the energy within the pipeline to the height of an equivalent static column of water. Once again, from Bernoulli's principle, the total energy at a given point in a fluid is the energy associated with the movement of the fluid, plus energy from pressure in the fluid, plus energy from the height of the fluid. Therefore in basic terms, head loss is a measure of the reduction in the total head of water as it moves through a pipeline. The potential amount of head is a resultant of many variables with one of the most important being pipe friction.

2.3.2 Pipe Friction

In general, pipe friction is a measure of the shear force resisting the flow of the water. This resistance is caused by the pipe wall and is dependant on the roughness, or irregularities of the wall. The amount of friction in a pipeline is usually described using the friction factor. The following clarifies the tie between head loss and friction

The best known formula for calculating head loss within pipelines is the Hazen-Williams equation, or alternatively a combination of the Darcy-Weisbach and Colebrook-White equations.

the Hazen-Williams equation in its general form is:

$$V = 0.355.C.D^{0.63}.(\frac{h_f}{L})^{0.54} \quad ; \qquad \text{Eq 2.4}$$

or, alternatively,

$$h_f = \frac{6.78L}{D^{1.165}}\left(\frac{V}{C}\right)^{1.85} \quad ; \qquad \text{Eq 2.5}$$

where:

- *L* is the length of the pipe in m;
- *D* is the hydraulic diameter (for a pipe of circular section, this equals the internal diameter of the pipe) usually in m;
- *C* is the Hazen-Williams coefficient and is dimensionless.

The Hazen-Williams coefficient is often used as an indicator of pipe fouling (growth of biofilm on the pipe wall) which will be explained further on.

The Darcy-Weisbach formula is as such:

$$h_f = f.\frac{L}{D}.\frac{V^2}{2g}; \qquad \text{Eq 2.6}$$

where all variable are as per the above equations and the rest being:

- *f* is a dimensionless coefficient called the Darcy friction factor. It can be found from a Moody diagram or by using the Colebrook-White equation below.

$$\frac{1}{\sqrt{f}} = -2\log_{10}(\frac{k}{3.7D} + \frac{2.51}{Nr\sqrt{f}}); \qquad \text{Eq 2.7}$$

The Colebrook-White equation above is an implicit formula and thus requires a trial and error solution. This is mostly due to the fact that friction is stated on both sides of the equation. Later, the Moody diagram eventuated which made engineering calculations somewhat easier. The Moody diagram is a plot of the Reynolds number against friction and (*k/D*).

Use of the Darcy-Weisbach formula as stipulated earlier requires calculation of the friction factor, *f*. When modelling pipelines for cost analysis, engineers have to iterate through multiple combinations of pipe diameter, length and other variables. It can be a painstakingly long process to use the Colebrook-White equation in tandem with the Moody diagram. This is why a more recent publication of the Colebrook-White equation is used to calculate *f*. It is known as the Barr equation.

The Barr equation only has *f* on one side of the equation and thus it can be directly calculated. In this formula the smooth law component of pipe flow (2.51/Nr$\sqrt{f}$) has been replaced with an approximation being (5.1286/Nr^(0.89). This is the most commonly used form of the Colebrook-White equation amongst practicing engineers due to its ability to directly compute *f* thus avoiding trial and error science. The Barr equation is used for the remainder of the project and is as follows:

$$\frac{1}{\sqrt{f}} = -2\log_{10}\left(\frac{k}{3.7D} + \frac{5.1286}{Nr^{(0.89)}}\right); \qquad \text{Eq 2.8}$$

where:

- k is the pipe roughness height of the internal pipe wall, in m;
- Nr is the Reynolds number.

The pipe roughness height is also often used as an indicator of pipe fouling which will be explained in more detail later in this dissertation.

The Reynolds number was created by Osborne Reynolds (1842-1912) who performed experiments that are used as a guide to predict laminar, transitional and turbulent flows. These experiments created a numbering system known as the Reynolds Number (Nr). Reynolds (Chadwick et al. 2004), stated that numbers above 4000 usually indicate that the flow is turbulent where as numbers below 2000 can be considered laminar or steady. The Reynolds Number equation is expressed as:

$$Nr = \frac{\rho DV}{\mu}; \qquad \text{Eq 2.9}$$

where all variables are as per the above equations and the rest being:

- μ is the dynamic viscosity of the fluid which for water is 1.002 m.Pa.s, or 1.002 centi-Poise at 20 degrees Celcius.

By being introduced to the Bernoulli's principle and the formulae that calculate friction it is obvious that equation 2.2 is not entirely accurate. By including the headlosses due to friction and fittings we get a much more realistic interpretation of how the conservation of energy behaves in pipelines.

$$\frac{P_1}{\rho g} + \frac{\alpha V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{\alpha V_2^2}{2g} + Z_2 + h_f + h_L \qquad \text{Eq 2.10}$$

It is also important, to fully understand the direction of this project, the significance pipe roughness has on the friction factor. There are two forms of describing roughness on a pipe wall. One is the Hazen-Williams coefficient and the other the pipe roughness height.

2.3.3 Hazen Williams Coefficient

The Hazen-Williams coefficient relates the flow of water in a pipe with the physical properties of the internal lining of the pipe, and the pressure drop caused by friction. Some typical Hazen-Williams coefficient values for different pipe types are listed in Table 2.1. It must be noted that the component of the pipe that has the effect on the Hazen-Williams coefficient is the internal lining of the pipe.

Table 2.1 – Typical Hazen-Williams values for various pipe types. (*The Engineering Toolbox 2010)*

Pipe Material (Internal Lining indicated where appropriate)	Hazen-Williams Coefficient (C)
Aluminum	130 - 150
Asbestos Cement	140
Brass	130 - 140
Cast-Iron - new unlined (CIP)	130
Cast-Iron 10 years old	107 - 113
Cast-Iron 20 years old	89 - 100
Cast-Iron 30 years old	75 - 90
Cast-Iron 40 years old	64-83
Cast-Iron, asphalt coated	100
Cast-Iron, cement lined	140
Cast-Iron, bituminous lined	140
Concrete	100 - 140
Concrete, old	100 - 110
Copper	130 - 140
Corrugated Metal	60
Ductile Iron Pipe (DIP)	140
Ductile Iron, cement lined	120
Fiber Glass Pipe - FRP	150
Galvanized iron	120
Glass	130
Lead	130 - 140
Plastic	130 - 150
Polyethylene, PE, PEH	140
Polyvinyl chloride, PVC, CPVC	130
Steel new unlined	140 - 150
Steel, corrugated	60
Steel, welded and seamless	100

2.3.4 Colebrook White and Roughness Height

The pipe roughness height was a value created by Nikuradse through experimental work (Chadwick et al. 2004). Nikuradse made a major contribution to the theory of pipe flow by objectively differentiating between smooth and rough turbulence in pipes. He carried out a series of experiments to determine both the friction factor and the velocity distributions at various Reynolds' Numbers. In these experiments, pipes were artificially roughened by sticking uniform sand grains on to smooth pipes. He defined relative roughness (k/D) as the ratio of sand grain size to the pipe diameter. By using pipes of different diameter and sand grains of different size, he produced a set of experimental results for the friction factor and Reynolds' Number for a range of relative pipe roughness.

The pipe roughness height is used in the Barr formula. Some typical pipe roughness height values for different pipe types are provided in Table 2.2:

Table 2.2 – Typical Colebrook-White pipe roughness values for various pipe types. (The Engineering Toolbox 2010)

Pipe Internal Lining Material	Absolute Roughness Heights (k) (m x 10^{-3})
Copper, Lead, Brass, Aluminum	0.001 - 0.002
PVC and Plastic Pipes	0.0015 - 0.007
Stainless steel	0.015
Steel commercial pipe	0.045 - 0.09
Stretched steel	0.015
Weld steel	0.045
Galvanized steel	0.15
Rusted steel (corrosion)	0.15 - 4
New cast iron	0.25 - 0.8
Worn cast iron	0.8 - 1.5
Rusty cast iron	1.5 - 2.5
Sheet or asphalted cast iron	0.01 - 0.015
Smoothed cement	0.3
Ordinary concrete	0.3 - 1
Coarse concrete	0.3 - 5
Well planed wood	0.18 – 0.9
Ordinary wood	5

2.4 DESIGN OF PUMPED PIPELINES

2.4.1 Definition of a pump

More often than not, pipelines are driven by pumps. Typical applications of pumps are for river or headwater extraction. Pumps boost the pressure of the water within the pipeline, which is also known as the head, to enable the water to overcome the friction and fitting losses throughout the pipeline system. As well as the losses within the pipeline, there must be sufficient head created to overcome the addition of the static head as eluded to earlier by the *z* value in Bernoulli's equation.

The main types of pumps used in the design of large, industrial pipelines are centrifugal pumps. Centrifugal pumps use an impeller to increase the energy of the water. The impeller accelerates the water into the pipeline. It works by converting kinetic energy into potential energy and is measureable by a static column of water, which is the total head mentioned earlier.

There are many types of centrifugal pumps which can be further classified by some examples such as:

- End suction pumps;
- In-line pumps;
- Self-priming pumps;
- Submersibles pumps;
- Axial-flow pumps;
- and many more.

The other form of pump is the Positive Displacement Pump. These pumps are not common in civil engineering and are mostly used for specialised Agricultural applications. For this reason they will not be discussed further here.

The pump is powered by a motor. The power required to drive this motor can either be diesel generated or electricity generated. The power imparted into a fluid will increase the energy of the fluid, or the generated pumping head. Therefore the amount of mechanical energy being used to create the fluid energy has a direct consequence on the operational costs of the pumped system. Before this can be calculated the expectations of the pump must be determined.

2.4.2 Pump Head and the System Curve

The static head is the head that must be delivered when there is zero flow. Generally it is a measurement between the elevation of the source of the headwater and highest elevation that the water has to overcome to supply at the downstream end.

The addition of the friction losses, h_f, the fitting losses, h_L, and the static head, h_s, determine the pumps required head. The required head is known as the lift or duty that the pump has to achieve to meet the required discharge, *Q*.

$$H = h_f + h_L + h_s \qquad \text{Eq 2.11}$$

The discharge is usually established from the annual volumetric allocation required within the pipeline. The volume is divided by the amount of days the pump is expected to run throughout the year, given maintenance and shut-downs will occur throughout the pipeline. Within SunWater, as a general rule, 300 days is the total expected pumping days of a pump throughout a year. Therefore this volume per day figure can be translated into the SI units for flow of m^3/s.

The distance that the pipeline is to cover must also be established. This is important as length has a large bearing on friction, as seen in the Darcy-Weisbach formula earlier.

Once the three variables, *H, Q* and *L*, have been obtained some system analysis for the optimum pump-pipeline configuration can be performed.

Given that the total head has been calculated, this can be used to determine the appropriately sized diameter for the pipeline. This is done be analysing calculations using the continuity, Darcy-Weisbach, Barr and Reynold's formulae described earlier.

As a general rule in pipeline diameter analysis, as the diameter of a pipe increases, the allowable flow rate increases and so too does the tolerable head. This simply means that the bigger the pipe is the more water that can be transported. This is shown by a system curve which is displayed in Figure 2.5 below.

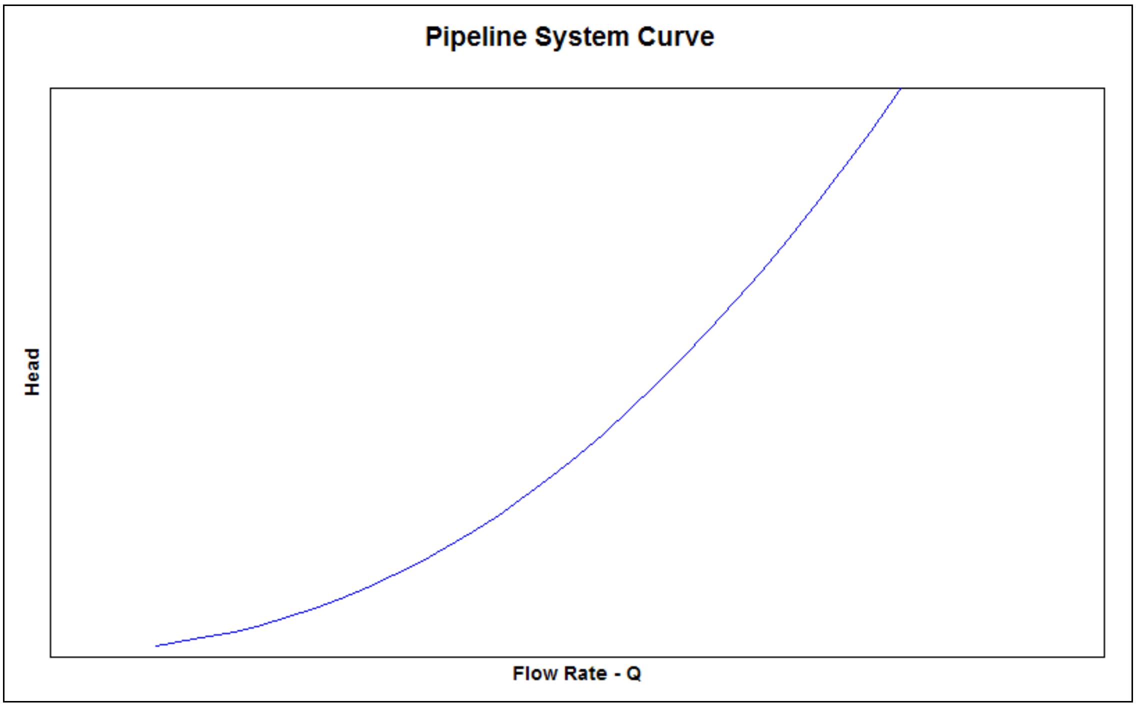

Figure 2.5 – Example of a System Curve

If the diameter is decreased and flow is maintained through the pipeline, the pressure within the pipe increases. This analysis is all part of the pipeline optimisation. For a smaller diameter pipe the supply and install costs may cost less, however the friction losses and pressure within the pipe increases. Increase in pipeline pressure is often acceptable if there is sufficient head remaining at the end of the pipeline. However, often the pressure can increase to a rate so high that the pressure class of the pipe must be increased. This is an added expense. Not to mention the extra pumping costs which will be explained below.

2.4.3 Pump Curves and the Operating Point

The pump characteristics are normally described graphically by the manufacturer as a pump performance curve. The pump curve describes the relationship between flow rate and head for the actual pump at a particular drive speed and impeller diameter. Other important information for proper pump selection is also included on pump curves such as the efficiency curves, NPSHR curve, and power consumption. Often several pump curves are plotted on a single pump chart for a range of different pump speeds or impeller diameters.

Efficiency curves are a measure of the mechanical transfer of losses through the transmission gear and bearings in the pump motor through the motor shaft and pump impeller. It is measured as a percentage and is a ratio of power actually gained by the water to the shaft power supplied. During testing of the pumps the efficiency is measured and plotted on the pump curve against a secondary axis.

The Net Postive Suction Head Required (NPSHR) is a function of the pump design at the operating point on the pump curve. The NPSHR is defined as the absolute head required to prevent reduced efficiency, damage and cavitation. Cavitation is the act of passing air through the pump. Cavitation occurs when the water level in the suction well is several metres below the pump and the water pressure falls sufficiently far below atmospheric pressure at any point in the machine to reach the vapour pressure. However the explanation of cavitation is beyond the scope of this project and will not be discussed further.

Finally power is displayed on the pump curve. This shows how much power is required to drive the pump at a particular flow rate. Power is ultimately one of the most important factors of the pumped pipeline as this converts directly into cost. An equation describing the calculation of power will be discussed later. An example of a typical pump curve can be seen in figure 2.6 below.

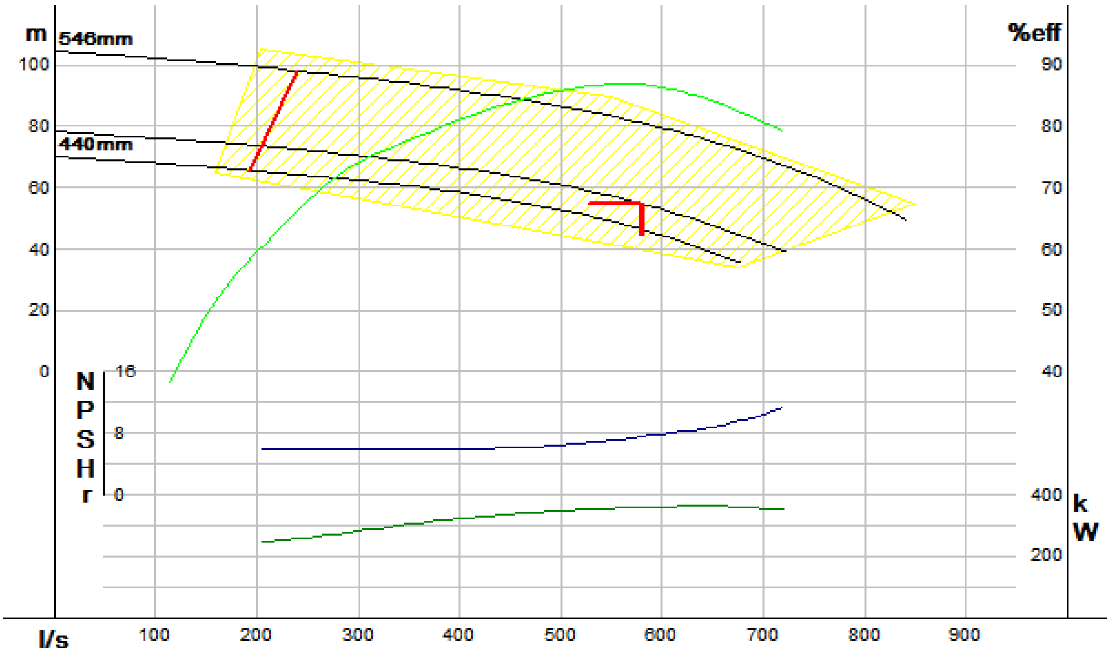

Figure 2.6 – Example of a Pump Curve from *Epsilon* (Pump Selection Software)

As part of the hydraulic design of the pumped system there is some initial, essential information to be sought. The primary requirement is to determine the discharge. The discharge is a function of both the pump and pipeline. For any given pump the head-discharge characteristics can be superimposed on the pipeline system curve to establish the duty points or operation point of a pumped system.

The operating point of a pumped pipeline is established by superimposing the pump curve over the system curve. As can be seen in Figure 2.5, with a system curve, *H* rises as *Q* increases. As seen with the pump curve above in Figure 2.6, H decreases as *Q* increases. The intersection of these two curves is the operation point of the pumped system, which is also known as the duty point. Figure 2.7 shows two system curves graphed against one pump curve. The significance of the differing *k* values for system curves will be made clearer as this report continues. However, for the purposes of understanding system curves, note that changes in pipeline variables have significance on the system curve. There are obviously two duty points created in this example.

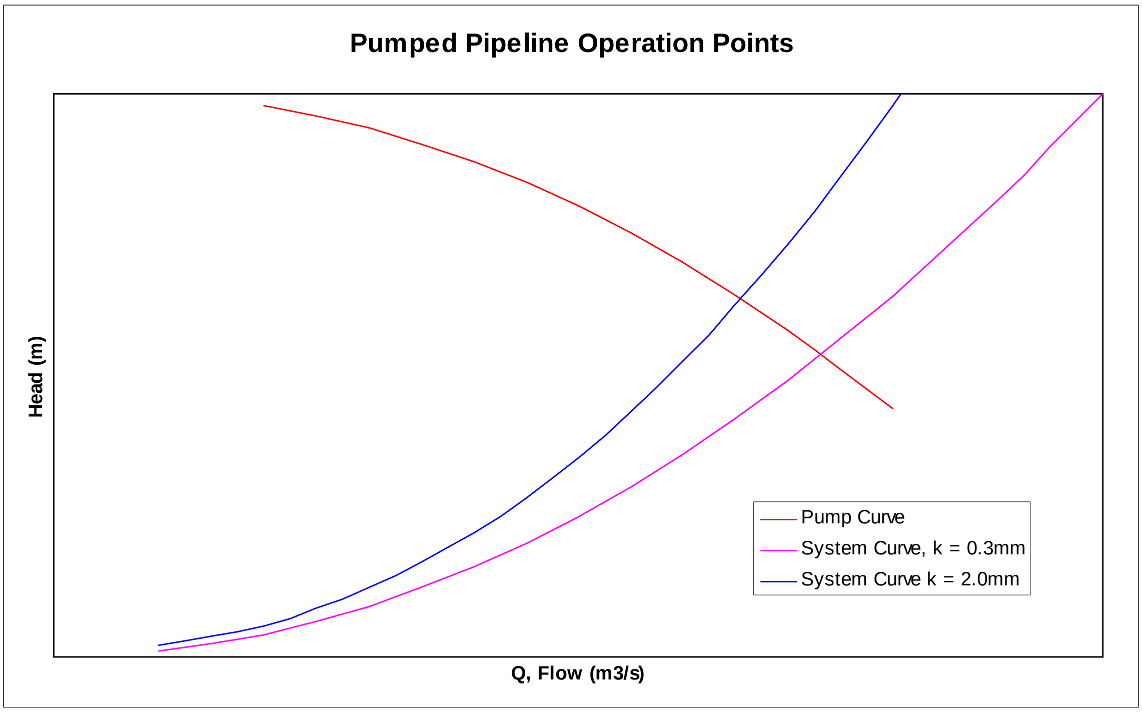

Figure 2.7 – Establishment of the Pumped Pipelines Operating Point showing a system curve graphed against a pump curve.

To obtain the pipelines required discharge, it may be necessary to investigate several pump and pipe combinations. In addition it is desirable that the pump should be running at or near peak efficiency at the design discharge for economic benefit. As witnessed on the pump curve in Figure 2.6, the efficiency curve reaches its peak somewhere in the middle of the pumps operating range and declines on either side of this point.

Now that pipeline pumping has been introduced there is a basic understanding of the hydraulics within pumped pipeline systems. The significance of pipeline hydraulics and its effects on cost will now be introduced.

2.5 SYSTEM COST ANALYSIS

There are two components to analysing costs during pipeline design; the capital expenditure and the operational expenditure. Both forms of expenditure must be established when performing the optimisation to fully understand which option is the best for the scenario. The optimum pipeline design is established by comparing the best combination of capital investment against the ongoing power costs to operate the pump. This can be seen in Figure 2.8 below.

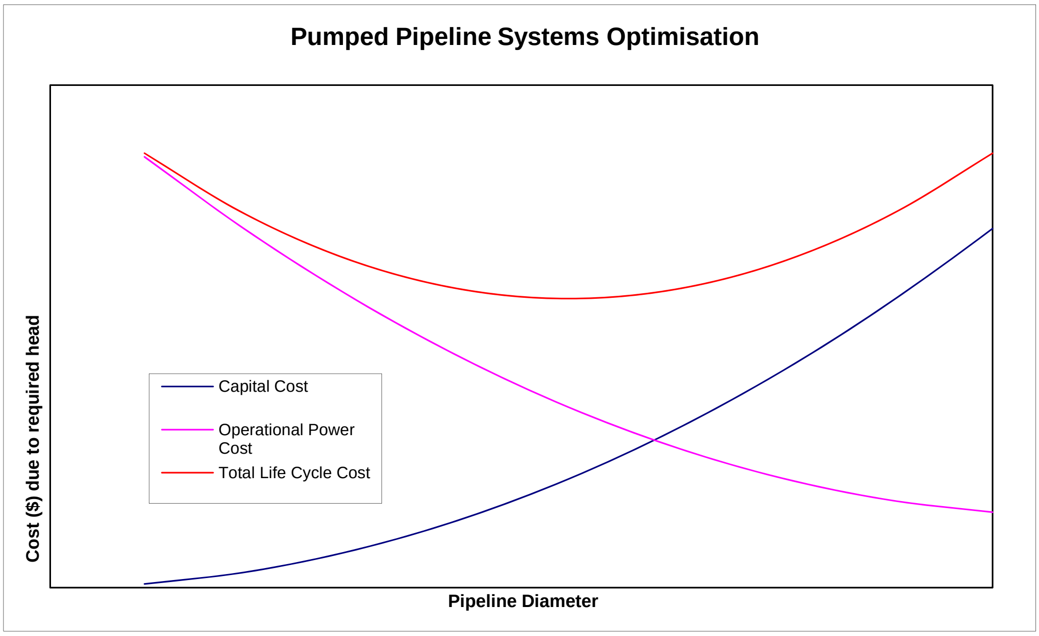

Figure 2.8 – Typical Graph depicting establishment of the Optimum pumped pipeline, measured financially

2.5.1 Capital Costs

Capital expenditure is defined as the upfront costs to construct the system. The pipelines capital expenditure exists in the design and construction of all elements required for a satisfactorily operational pipeline, which were briefly eluded to in section 2.1. The major component that alters cost when optimising the pipeline is diameter and pipe material.

Different pipe material types with similar diameters vary in cost. In addition there is the cost to supply the pipe materials and the difference in installation of the pipes. This is a complex scenario because some pipe types are easier and quicker to install than others. However, some materials are cheaper to manufacture than others.

In Table 2.3 to 2.5 below, different supply and installation costs are listed for various pipe types and diameters. This data has been accumulated by SunWater over time which has only been available through experience in pipeline design and construction. They are current costs to December 2009. Note that not all pipe types are included, but the types included are those that are more frequently used by SunWater in recent history.

Table 2.3 - HDPE Pipe Supply and Installation costs for varying pressure classes and diameter.

Nominal Outside Diameter	PN 4.0			PN 6.3		PN 8.0	
	Mean Dia	Mean Inside Diameter *Di*	Installation Cost	Mean Inside Diameter *Di*	Installation Cost	Mean inside diameter *Di*	Installation Cost
DN	(mm)	(mm)	($/m)	(mm)	($/m)	(mm)	($/m)
2000	1850.3	1902.5	2,468.14	1843.4	3,577.24	1804.9	4,279.61
1800	1665.7	1712.7	2,023.78	1659.5	2,922.36	1624.9	3,492.34
1600	1481.0	1522.6	1,621.02	1475.6	2,331.21	1444.9	2,782.04
1400	1296.5	1332.6	1,247.98	1293.1	1,768.32	1263.9	2,142.51
1200	1112.1	1143.1	942.49	1108.5	1,333.99	1084.7	1,595.99
1000	927.1	952.9	598.02	924.1	829.94	904.2	977.82
900	834.3	857.6	485.22	831.6	675.13	813.8	794.43
800	741.2	761.9	396.06	738.8	542.44	723.0	643.27
710	624.5	676.3	323.82	655.6	442.69	541.6	519.94
630	583.8	600.1	272.84	581.8	362.31	569.5	422.77
560	518.9	533.4	225.32	517.2	299.51	506.1	347.95
500	463.1	476.0	182.53	461.7	235.05	451.7	270.33
450	416.9	428.6	143.01	415.5	186.56	406.5	215.30
400	370.5	380.9	119.98	369.3	154.36	361.3	177.08
355	328.9	338.1	103.40	327.8	130.86	320.9	148.19
315	291.8	300.0	89.88	290.7	111.87	284.7	125.86
280	259.4	266.6	74.82	258.6	91.96	252.9	103.59
250	231.5	237.8	64.69	230.7	78.32	225.9	86.83
225	208.3	214.2	58.28	207.7	69.44	203.1	76.82
200	185.1	190.4	52.45	184.5	61.62	180.5	67.38
180	166.7	171.4	47.08	166.2	55.61	162.6	60.16
160	148.0	152.2	43.52	147.5	50.45	144.4	54.14
140	129.5	133.1	37.24	129.1	40.00	126.4	42.76
110	101.6	104.6	35.68	101.2	35.97	99.1	38.35
50	45.9	46.7	33.02	45.9	33.02	45.0	35.11

Table 2.4 - RC Pipe Supply and Installation costs for varying pressure classes and diameter.

DIAMETER	100 kPa		200 kPa		300 kPa	
	INTERNAL DIAMETER (ID)	INSTALL COST	INTERNAL DIAMETER (ID)	INSTALL COST	INTERNAL DIAMETER (ID)	INSTALL COST
mm	mm	$ / m	mm	$ / m	mm	$ / m
300	300	105.67	300	115.05	300	127.90
375	380	138.58	380	151.69	380	171.08
450	450	172.33	450	192.94	450	221.41
525	530	227.34	530	258.09	530	295.36
600	610	263.17	610	295.64	610	340.09
750	760	362.85	760	468.64	760	549.26
900	910	551.62	910	710.61	910	832.88
1050	1050	704.28	1050	913.16	1050	1073.55
1200	1200	877.34	1200	1136.41	1200	1337.30
1500	1524	1265.33	1524	1656.01	1524	1954.86
1800	1828	1769.70	1828	2300.71	1828	2713.58
2100	2160	2324.38	2160	3041.52	2160	3593.79
2400	2438	2601.49	2438	3564.84	2438	4150.10

Table 2.5 – DICL and MSCL Pipe Supply and Installation costs for varying pressure classes and diameter.

Pipe Type	Diameter	Internal Diameter (k9)	PN 20 Installation Cost	Internal Diameter (k12)	PN 35 Installation Cost
(mm)	(mm)	(mm)	($/m)	(mm)	($/m)
MSCL	2000	2135	2549.73	2127	3243.44
	1800	1805	2161.35	1797	2747.63
	1750	1726	2068.67	1718	2629.24
	1500	1480	1471.48	1468	2191.23
	1200	1274	1185.48	1258	1410.65
	1000	1047	919.12	1043	1071.35
	900	902	793.43	898	916.70
	800	803	673.14	799	772.05
DICL	750	752	602.63	746	667.53
	600	601	474.13	600	509.33
	500	500	362.93	500	391.53
	450	450	262.79	450	314.49
	375	375	219.54	375	255.84
	300	300	168.61	300	191.71
	250	250	151.17	250	164.37
	225	225		225	149.26
	200	200		200	132.76
	150	150		150	87.75
	100	100		100	69.67

2.5.2 Operational Costs

As briefly mentioned earlier whilst discussing system curves, change in pipe diameter alters the allowable pressure within a pipe. Increase in the required head of a pipeline has a direct effect on the operational costs of a pumped pipeline. Therefore on top of the capital costs described above there are operational costs. Operational costs are the annual costs required to maintain supply of water once the pipeline is constructed and fully operational.

One of the only varying operational costs in pipeline operation is pumping costs. Smaller pipe diameters eventuate to higher friction losses which lead to more head loss. Therefore a pump has to work harder to generate enough pressure to ensure there is sufficient pressure at the downstream end of the pipeline. This is best described in Figure 2.9 below. This graph shows the head being generated at the start of the pipeline and the gradient on the hydraulic grade line falling away due to head losses. If the pipe was smaller in diameter this gradient would be steeper and consequently the initial head generated by the pump would have to be greater.

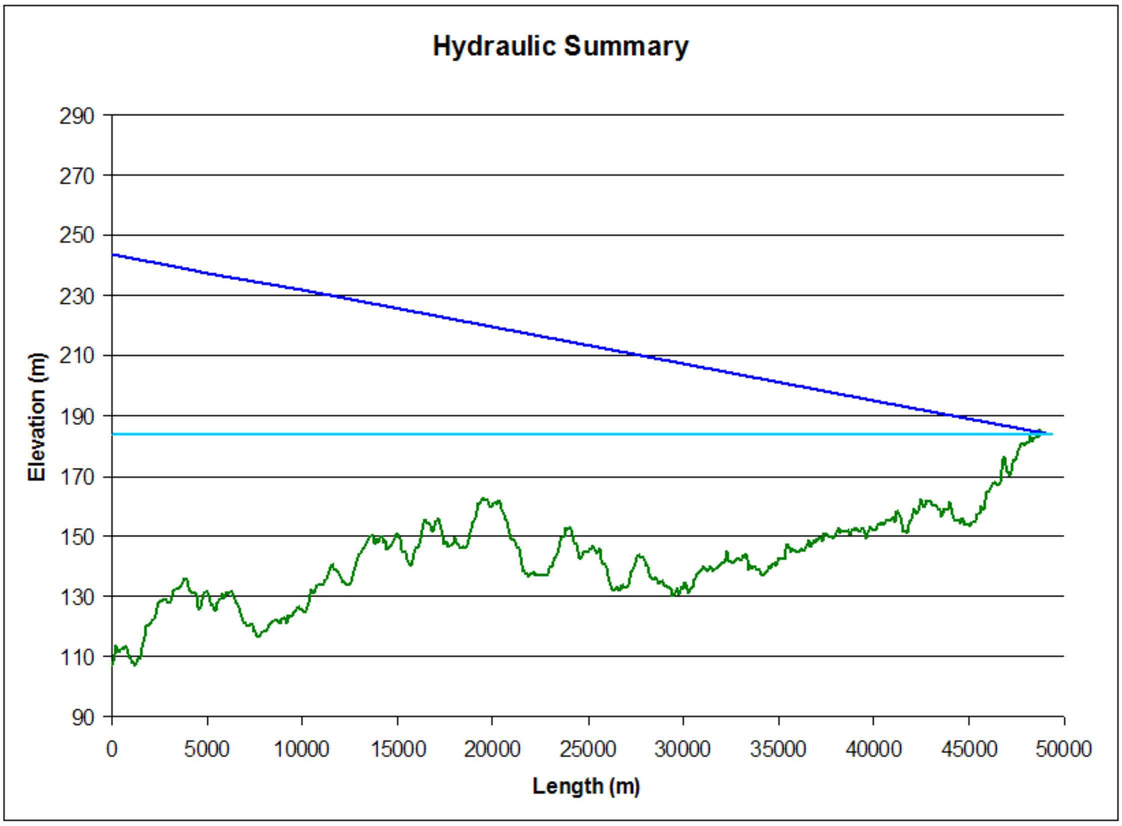

Figure 2.9 – Typical Graph showing the hydraulic grade line (HGL) through a pipeline. The green line is terrain, cyan line the minimum static level and blue the HGL.

After calculating the required lift for each pipeline diameter the annual power required to run the pumps can be established. Power (P) is calculated with the following equation;

$$P = \frac{\rho . g . H . Q}{\eta} \qquad \text{Eq 2.12}$$

- ρ the density of water and is 1000kg/m^3;
- Q is the flow rate in the pipeline, also known as the capacity of the pipeline, in m^3/s;
- H is the total head in m;
- g is gravity, 9.81m^2/s;
- P is the power required to drive the pump in Watts (W);
- η is the efficiency of the pump as a %.

Then the cost of power has to be calculated. The SI Units of Watts have been changed to kW and hours because this is how *Ergon Energy* measures their power readings. The conversion to total cost of power is shown below;

Total Cost = Power (kW) x Time (hrs) x Cost Rate ($/kW.hrs) Eq 2.13

The cost of power is much more simply described by calculating how much power it takes to lift 1 Mega-Litre (ML) or 1000m^3 of water, 1 metre in elevation in one hour. To do so we need to assume the efficiency of the pump. We will assume an efficiency of 75%. This is considered a conservative figure that includes both the efficiency of the pump and the motor. Now this is substituted into the formula;

Total Cost = ((ρ x g x H x Q) / η) x Time x Cost Rate;

where;

=> Time = Quantity Pumped / Q;

Time = 1ML / Q, note that Q is unknown at this stage;

=> Total Cost = (1000 x 9.81 x 1 Q / 0.75)*(1000 / Q / 3600), note that the 1000/Q/3600 is a conversion of flow in m^3/s to ML/hour;

Total Cost = 3600W.hrs / 1000 x Cost Rate,

Total Cost = 3.6kW.hrs x Cost Rate;

Removing the Cost Rate as it is unknown at this stage we get;

Power = 3.6 kW.hrs to pump 1ML of water, 1 metre in elevation.

Now the rate must be established. This is best done by attaining current Ergon Energy power tariffs for industrial applications. There are many different types of tariff but one tariff used by SunWater for pumping is the application of tariff 41. This is shown below in Figure 2.10.

Tariff 41 Low Voltage General Supply Demand

Commercial & Industrial Prices - effective 1 July 2010	**Pricing structure**	**GST inclusive Notified Price Cents per kWh**
This tariff can be appropriate for customers having a monthly usage of about 18,000kWh or greater and a load factor over 35%. As well as having an electrical energy (kWh) charge, there is also a charge for the power demand that is imposed on the electricity supply system by the installation. This demand is affected by the amount of equipment operated at the same time. No other tariffs are available for use in conjunction with Tariff 41.	**Tariff 41 Low Voltage General Supply Demand**	
Energy Charge - All Consumption - Cents per kWh		7.414
Demand Charge# (per kW of chargeable demand per month)*		$35.24
Service fee per metering point per month*		$50.20

#The maximum demand recorded in that month or 60% of highest maximum demand from any of the previous 11 months or 75kW, whichever is the highest figure.

*The minimum payments and service fees cover the cost of maintaining supply, the provision of equipment and general administration.

Figure 2.10 – Ergone Energy Tariff 41 – (Ergon Energy 2010)

With these tariff prices available the cost of pumping 1ML.m can be calculated. Therefore the calculation of three pipeline scenario's will be performed. An average price will be established and a contingency cost applied to ensure the calculation of power costs for the remainder of any cost analyses will not be under estimated.

Scenario 1

Total Head = 50m, Annual Volume = 30,000ML

Remembering that the power generated to pump 1ML.m = 3.6kW.hrs.

Assume 300 days of pumping x 24 hours in one year.

Assume pump is operating at 75% efficiency.

=> Therefore Flow = 30,000ML x 1000000/1000/(300*60*60*24) = 1.16 m^3/s

=> To convert to the power generated for the required lift and annual volume to kw.hrs/Annum

= 3.6kw.hrs x 50m x 30,000ML

= 5,400,000kW.hrs/Annum

=> Now calculate the actual instantaneous power demand using the power formula

$$P = \frac{\rho . g . H . Q}{\eta}$$

P = (1 x 9.81m^2/s x 50m x 1.16m^3/s) / 0.75

P = 757kW

Now to apply Ergon Energy's tariff 41. As per the tariff rules in figure 2.10, a stipulation on power demand asks that whichever is the highest figure of either the maximum demand recorded in that month OR 60% of the highest maximum demand from any of the previous 11 months, OR 75kW, be multiplied by the demand rate of \$35.24. In this case the instantaneous demand of 757kW is higher than 75kW so it will be taken as the highest maximum demand.

=> Therefore:

Total Year Power Costs = Total Energy for Year x Charge Rate 1 + Highest Maximum Demand per Month of Power x Charge Rate 2 + Service Fee for Metering per Month x Charge Rate 3.

Total Year Power Costs = \$5,400,000kW.hrs/Annum x \$0.07414 + 12 x 757kW x \$35.24 + 12 x \$50.20

Total Year Power Costs = $721,055.

Now to convert the Annual Power Costs into an average price per ML.m.

=> Average $/ML.m = $721,055 / (50m x 30,000ML)

Average $/ML.m = $0.48/ML.m

Scenario 2

Total Head = 150m. Annual Volume = 15,000ML

Applying the same process as above we have Total Year Power Costs of $1,081,281. Now converting the Annual Power Costs into an average price per ML.m.

=> Average $/ML.m = $1,081,281 / (150m x 15,000ML)

Average $/ML.m = $0.48/ML.m

Scenario 3

Total Head = 25m. Annual Volume = 5,000ML

Applying the same process as above we have Total Year Power Costs of $65,681. Now converting the Annual Power Costs into an average price per ML.m.

=> Average $/ML.m = $65,681 / (25m x 5,000ML)

Average $/ML.m = $0.53/ML.m

The three prices in scenario's 1, 2 and 3 were $0.48/ML.m, $0.48/ML.m and $0.53/ML.m respectively. From this it can clearly be seen that an average price can be created to fit almost all pumping scenarios.

Therefore for the remainder of any cost benefit analyses including pumping power calculations the price of $0.60/ML.m will be adopted. The equation to be used to calculate the net present value (NPV) of operation costs in a pumped pipeline system is:

NPV of Operational Costs = Head x Annual Volume x \$0.60/ML.m x NPV Factor

Now that the calculation of operational and capital costs has been understood, NPV will be discussed.

2.5.3 Net Present Value

In finance, the NPV is an indicator of how much value an investment or project adds to the firm. According to The Business Dictionary (2010), it is the difference between the present value of the future cash flows from an investment and the amount of investment. In Engineering the concept is similar, however it is more accurately described as a measure of calculating a projects upfront cost for its intended life cycle.

NPV takes into account the time cost of money. It takes also considers all incoming and outgoing expenditure. Essentially in the construction of pumped water pipelines, the incoming cost is the interest earned, and outgoing costs are operational costs such as pumping power. The NPV is useful to collate this data and convert it into a required upfront cost. To put it simply the NPV is the required upfront cost required to earn interest whilst still being able to afford the annual power costs for the pipelines life cycle.

To calculate the NPV you need:

- The discount rate;
- The projects expected life cycle.

The discount rate is used to discount future cash flows. Much debate is had as to what value should be assigned as the discount rate. At SunWater this value ranges between 6 and 8 percent depending on the current market. The value is determined and assigned by SunWater accountants.

The NPV factor is calculated using the following formula:

NPV Factor = 1 / (Discount Rate per period / (1-(1+Discount Rate per Period) ^ (-Number of Periods))) Eq 2.14

To calculate the NPV of ongoing power costs the NPV factor is multiplied by the annual power costs. As explained in section 2.5 this is:

NPV of Operational Costs = Head x Annual Volume x $0.60/ML.m x NPV Factor.

The NPV of operational costs should then be added to the estimated capital costs to design and construct the pipeline. The NPV of the project has then been established.

The fundamentals of pipeline hydraulics and pumped pipeline design have been identified. Knowing how pumped pipelines are designed, it is important to look into what the effects on pipelines are after pigging. This will help understand how pigging effects the pipeline hydraulics.

2.6 THE EFFECTS OF PIGGING

2.6.1 Pipeline Fouling and Friction

The affects on the hydraulic performance of a pipeline after pigging has been researched to a small degree. Thomas M. Walski (1986) listed findings from research into predicting costs of pipe cleaning and lining pipeline internal walls. His aim was to develop a cost estimator for cleaning and lining water pipelines so project managers could accurately plan for pipeline cleaning. The resultant estimator would be quite useful as its suggested accuracy was within 16%. However no clear discoveries were made regarding the purpose of or outcomes from pipeline pigging. Walski (1986) merely stated that pigging improved pipeline carrying capacities and that the pipe roughness, pumping costs and pressure ratings were also improved. One interesting suggestion from his findings was that it was considered necessary to re-line the internal walls of the pipe with a cement mortar lining. Most steel pipelines are often constructed with a cement mortar internal lining, however it was thought that this was for corrosion purposes only. Therefore the literature review was expanded to find alternative reasons for internal lining of pipes and if it assisted or delayed the need for pipe cleaning.

Walker (1985) focuses on the corrosive protecting properties of cement mortar internal lining of pipes. However this article did not look into its effect on pipeline roughness or pipeline cleaning. A comprehensive search of credible literature did not find anything relating to cement mortar lining and its affect on pipe cleaning. Therefore it is assumed that Walski (1986) was implying that internal pipe lining is damaged during pigging and consequently requires repair.

As stated in a pipeline design publication (Tyco Flow Control Pacific Pty Ltd 2008), specific design requirements are required for hydraulic calculations, when using ductile iron cement-lined (DICL) pipelines. *Tyco* is Australia's leading manufacturer of ductile iron and steel pipelines. Here it is recommended that the Colebrook-White formula be used when designing pipelines with DICL pipes, and that a *k* value of 0.01mm be adopted. The reasons *SunWater* uses the Barr equation to calculate friction factors have been explained already.

An interesting suggestion also stated within the design guidelines (Tyco Flow Control Pacific Pty Ltd, 2008), is that when biofilms exist, particularly in sewerage systems, a *k* value of 0.03mm should be adopted. This indicates that testing of the effect of biofilms on friction has already occurred, by *Tyco Pty Ltd* or otherwise, and evidence of this should be researched. The results of these studies could significantly assist in the findings of this project. Given that *Tyco Pty Ltd* suggests a higher *k* value should be used when determining the hydraulic performance of a pipeline, it is proof that the pipe roughness and friction of a pipeline is affected by the growth of biofilm.

Although the design guideline (Tyco Flow Control Pacific Pty Ltd, 2008) suggests the *k* value of 0.03mm to be used in the hydraulic design of a pipeline, SunWater uses much different values. SunWater bases its *k* values on the Irrigation Design Manual for pipelines (Department of Primary Industries, 1995) with a recommended *k* value of 0.3mm. This value also aligns with the suggested pipe roughness height on smoothed concrete surfaces listed earlier in Table 2.2

Lambert et al. (2009) studied the impacts of biofilms on pipe roughness and the velocity of the pipeline. Lambert et al. (2009) conducted the study using 25mm and 50mm diameter water reticulation systems, which are much smaller in diameter than the pipelines considered in this project. Some of the findings by Lambert et al. (2009) were:

- that biofilms grown under high velocities were less rough than those grown under low velocities as shown in figure 2.11 below. The pipe roughness height is plotted against time. It also clearly indicates an increase in roughness height over time. Eventually the roughness height either ceases to increase, or begins dropping. It also shows that the pipe roughness height is affected dramatically more in pipelines with low velocity.

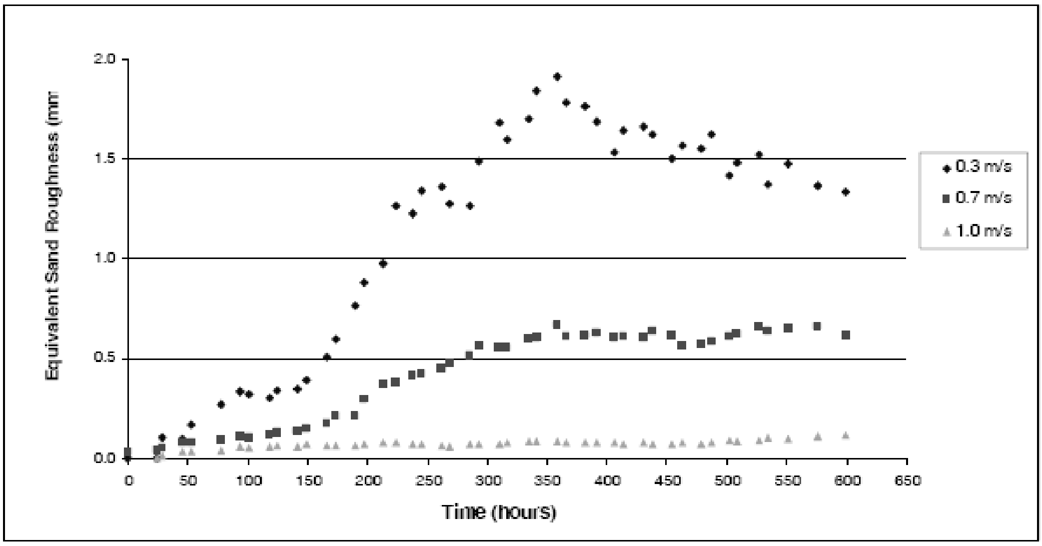

Figure 2.11 – Equivalent Roughness for 25mm diameter pipes with varying velocity (Lambert et al. 2009)

- That biofilm growth is independent of pipeline diameter and highly dependent on pipeline velocity.

- Velocity has a greater impact on friction than the initial inoculum (treatment placed in pipe during experiment to reduce biofilm growth).

- Sudden large drops in friction occurred at higher Reynolds Numbers (11,000 and above in 25mm diameter pipes and 30,000 and above in 50mm diameter pipes). This drop in friction was suggested to be caused by the shearing of the biofilm at high velocities. All recorded Reynolds numbers in Lambert's experiments were above 4000 thus suggesting the water flow was highly turbulent when friction began to drop. This is shown in Figure 2.12 below.

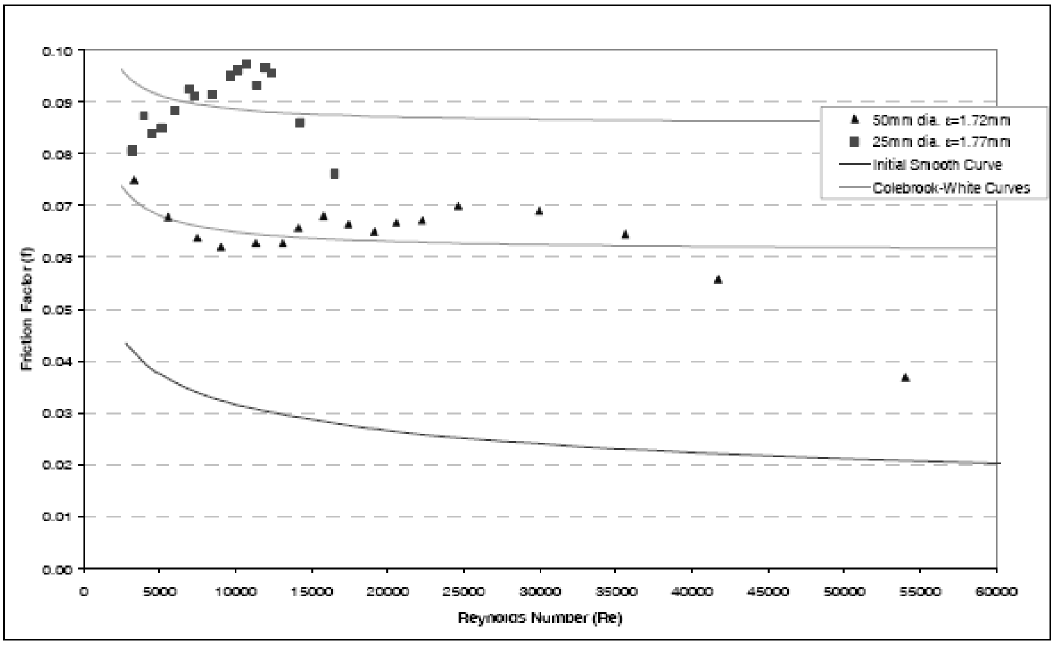

Figure 2.12 – Friction factor variation for pipes with velocity at 0.3m/s (Lambert et al. 2009)

Therefore Lambert et al. (2009) has made excellent progress in determining that pipeline velocity has a large influence on biofilm growth, or non-growth, on pipeline walls. This will definitely be of use in the decision support system and will be analysed further.

Barton et al. (2008) studied the improvements to the hydraulic efficiency of a pipeline after cleaning. Barton's study was carried out on three pipelines located in Tasmania, Australia. Some of the findings from this study were:

- As long as the wall lining of the pipeline is still in good condition after pigging a pipeline, hydraulic gains can be made from cleaning biofilm.
- The headloss, friction factor and roughness factor are all reduced after a pipeline pigging event.

- The term fouling refers to the decrease in pipeline performance due to the growth of biofilm on the pipeline walls, or addition of debris and sediment within the pipeline.

Therefore Barton (2008) indicates clearly that pigging, when performed on heavily fouled pipelines, does improve the hydraulic efficiency of the pipeline.

2.6.2 Pipeline Fouling and Money

The hydraulic effect fouling has on pipelines has a direct effect on operational costs. As explained in section 2.4 increases in friction, and consequently head, cause the pumps to work harder and increases operation costs of the pipeline. To further highlight this, the outcome of a study by *JLR* Engineering (2006) suggested there was a cost saving by calculating an appropriate time to swab. This report was catered around the Awoonga-Callide Pipeline which commences at the Awoonga Dam south-west of Gladstone in Queensland (Figure 2.13). Gladstone is located approximately 530km north of Brisbane.

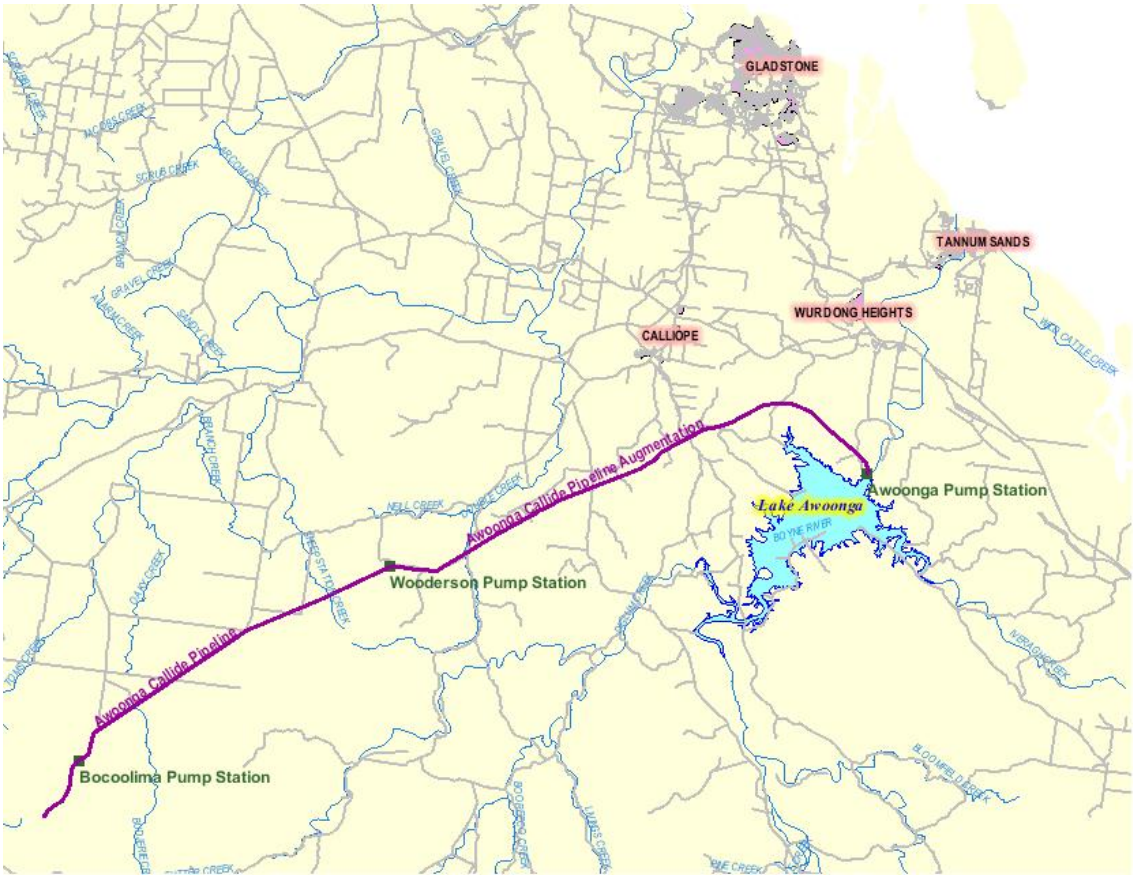

Fig 2.13 – Map of Awoonga-Callide Pipeline near Gladstone, Queensland.

From the study a calculator was generated to be used by the operator of the pipelines. The calculator measured the additional costs created in the electricity accounts, due to the extra power required for the pumps to overcome the increasing pipe friction. A graph from the report showing this is included in Figure 2.14.

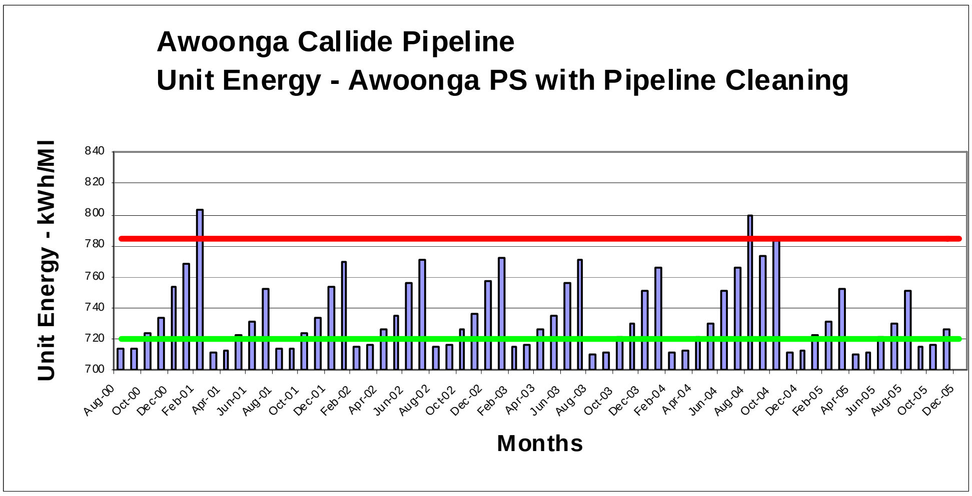

Fig 2.14 – Graph (JLR Engineering, 2006) showing the Pump Unit Energy results following pigging on the Awoonga-Callide Pipeline. The red line depicts the Unit Energy Rate at which to pig, the green line depicts the designed pumping Unit Energy Rate. The blue columns indicate Unit Energy in time and show its improvement after pigging.

In Figure 2.14 the red line is the indicator where the estimated cost to pig the pipeline is offset by the costs saved by the average accumulated unit energy rates. The unit energy was determined by obtaining the total power in kW for that month and dividing it by the total amount of water pumped in that month. The total increase in electricity costs is compared to the cost to pig the pipeline. As can be seen in this figure there is a cost saving by pigging.

However when you look at the section of the Awoonga Callide pipeline that has never been pigged (Figure 2.15), you will notice that, although initially the unit energy rate increases, it eventually flattens out. This somewhat proves the theory that biofilm eventually ceases to grow. It reaches an equilibrium in the conditions on the pipeline wall.

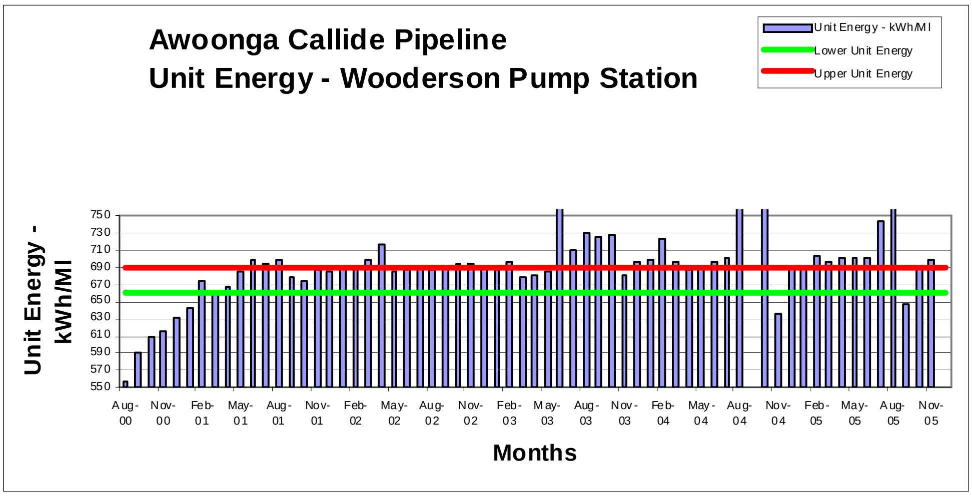

Fig 2.15 – Graph (JLR Engineering, 2006) showing the Pump Unit Energy results without pigging. There is no increase in Unit Energy after a period of time.

Within the report by JLR Engineering (2006) were some other interesting discoveries. The main aim of the report was to assess when a pipeline should be pigged. Some of the more interesting discoveries found from the study were the following:

- Generally softer foam swabs are proven to be less effective than disc pigs for raw water pipeline cleaning.

- Gravity pipelines are only to be pigged if fouling compromises the pipeline capacity.

- Pipeline operating characteristics are set during the design of pumped pipelines. These characteristics set the operating and maintenance requirements for the pipeline and the economic justification for the design. These operating characteristics are never handed, or explained to pipeline operators.

- Existing pipeline design standards are inadequate for pipelines that are required to be regularly cleaned to maintain performance characteristics. This statement refers to the use of the hydraulic equations in the design process as opposed to what is really happening, in terms of hydraulics, when a pipe is fouled.

- Unit energy measurement and monitoring should be the performance indicator for measuring, evaluating and controlling fouling losses in industrial pipelines. This data can be taken from existing electricity accounts and flow readings from Pump Station flow meters.

- It is generally thought that the change in the Hazen-Williams factor over time indicates when a pipeline has to be pigged. However JLR Engineering (2006), suggests this coefficient gives erratic output.

The unpredictability of the Hazen-Williams coefficient and validation of the accuracy of the Colebrook-White formula were justified by Ramakrishna Rao et al. (2006) who studied the effect on the friction factor on different pipe roughness values in all pipe conditions; smooth, transition and rough. They trialled the Colebrook-White formula for accuracy in calculating the friction factor and found that in smaller diameter pipes the formula did have large inconsistencies. However, in pipes with diameters of 25mm and greater the inaccuracies in predicting the friction factor with the Colebrook-White formula ranged between +/-1%. Thus the inconsistencies can be ignored due to their insignificance with respect to the analyses requirements. Rao et al. (2006) stated that the Hazen-Williams formula is considered not to be dimensionally homogenous and its ranges of predictability were considered limited due to the formula's empirical form.

JLR Engineering (2006) suggested many factors can influence the pipeline fouling process, with each pipeline being different. It recommends that the development of an equation to link these causes to the rate of fouling in the pipeline is impractical due to its inevitable complexity. By looking at the variables involved below it is plainly clear to understand why. It is important to note that the end effects of fouling can be readily measured by parameters that are already routinely collected. Some of the drivers for fouling of pipelines may include some or all of the following:

  - The type of bacteria;
  - Life cycle of the bacteria;
  - The level of dissolved oxygen;
  - Any metals involved, including in the solution;
  - The temperature of water over the length of the pipeline;

- Water quality including pH and turbidity;
- The water velocity;
- Pipe surface roughness;
- Timing of the pipeline cleaning;
- The cleanliness of the pipe wall after cleaning;
- The storage level of the upstream balancing storage/reservoir or headwater system;
- The amount of rainfall in the headwater system.

2.7 SUMMARY

From all findings some essential knowledge was gathered to be used in the creation of this decision support tool.

One is that gravity pipelines are only to be pigged if fouling compromises pipeline capacity. This is because there are no other financial repercussions in gravity pipelines other than the ability to maintain its service capabilities. This does not mean that gravity pipelines are excluded from the decision support system. However, the fact must be taken into account.

In addition to this, pumped pipelines should only be pigged when summative operational costs are recoverable by pigging. As the pipeline fouls more power for pumping is required due to the increase in friction along the pipeline. Consequently this should be taken into account at the design stage and long term cost analyses be performed.

Another finding was that the Hazen-Williams equation gave erratic results when trying to determine if a pipeline requires cleaning once a pipeline was already fouled. A pipeline is believed not to follow the principals of this formula once fouling beings. The Colebrook-White and Barr equations are also expected to give somewhat erratic results, however the inconsistencies are insignificant and not worth worrying about.

The suggested measurement for fouling on the Awoonga-Callide pipeline was the unit energy measurement produced by the pumps in the pipeline. However, this information can only be recovered from the electricity accounts and flow meter readings. Therefore this method of measurement is only applicable after the pipeline is commissioned and operating. Therefore the Unit Energy rate will not be used in the decision support system given it only applies to pipelines constructed pipelines. The scope of this project pertains to pipelines in the design stage. Therefore the Barr and Darcy-Weisbach equations will be adopted for the measurement in the decision support system.

Of most importance was the introduction into pumped pipeline design. This understanding established a theory on how to measure pipeline fouling at the design stage. By using Barr and Darcy-Weisbach equations as calculators, variations in NPV costs will be analysed using differing pipe roughness height values.

The maximum value for pipe roughness height, k, of 2.0mm will be adopted for industrial pipelines (see figure 2.11). This is deemed highly conservative for industrial pipelines compared to those tested by Lambert et al. (2009). Due to the larger volumes required by industrial pipelines, velocities generally average between 1.0 and 1.5 metres per second. Referring back to the graph in Figure 2.11, as velocity increases, the effect on pipe roughness decreases in height. Pipe roughness, k, only reaches 2.0mm at low velocities. As the velocity increases the effect on pipe roughness height decreases.

More evidence of the effect k has on pipeline power costs will be obtained from an actual pigging event. An attempt to reinforce a maximum k value will also be pursued. This is performed in section four of this report. The basis behind the decision support system is discussed in the next section.

3.0 WHY INSTALL SWABBING FACILITIES?

3.1 OVERVIEW

Swabbing facilities are installed in a pipeline to make the pigging process easier. A minimum of two swabbing structures are required in a pipeline. One is required to launch the pig, and another to catch the pig downstream. Multiple arrangements of swabbing structures are possible and are dependent on what the client wants and the information he has been supplied by the operators and designers regarding pigging.

The major output of this project will be a smoother decision making process when assessing the need for swabbing structures in water pipelines. Not only will the decision process be smoother, but it will add justification to any decision from this point forward. It must be remembered that multiple questions arise when contemplating the need for these structures. Some of these questions are:

- Do any nearby pipelines undergo pigging? If so how often does pigging occur on these nearby pipelines and would the same pigging principles apply to the pipeline being designed?
- What pressure is the pipeline under and what is the velocity/capacity of the pipeline?
- Is it a pumped pipeline or gravity fed pipeline?
- What is the head loss over the pipeline?
- What is the expected pipe type, for example mild steel concrete lined, polyethylene (HDPE), poly vinyl-chloride (PVC) or reinforced concrete?
- What is the expected life cycle of the pipeline?
- If swabbing structures are included what is the desired arrangement? The answer to this question would depend on the expected regularity of the swabbing which is usually unknown, and unable to be accurately calculated until fouling

begins and trends are warranted, as found in the literature review. The answer to this question is a project in itself and will not be considered in this dissertation.

After all these questions are answered there is still no definitive answer on whether swabbing structures are required or not. Arguments arise at the suggestion that many pipelines are constructed with elaborate swabbing structures installed that rarely, if ever, are utilised. This is evident with many pipelines around the country having never been pigged whilst still providing a satisfactory level of service.

3.2 CONSIDERATIONS

When the discussion of swabbing structure installation arises during the design phase, various suggestions from different disciplines in the water supply industry are considered. Pipeline operators will generally argue to have swabbing structures installed “just in case”, because it is normal practice, or because of their experience in pigging other pipelines during their careers. Asset owners will generally ask that the option be considered whilst taking the final cost into consideration. Each pipeline designer generally has differing opinions on the subject, but is obviously happy to design and construct them given the appropriate budget to do so.

Some theories exist that the life cycle capital expenditure to install several swabbing structures and perform regular pigging events can be catered for in other design aspects. Therefore the consequences of any pipeline fouling occurring in the pipeline over its life should be considered at the design stage. This analysis is never performed during a pipeline design and thus, as explained earlier, the installation of swabbing structures is not justified.

Some methods of catering for the extra costs for swabbing structure installation, or annual pigging, could be made by increasing the pipeline diameter of the pipeline. However, the rise in costs would be highly dependent on the overall length of the pipeline. This would be compensated by the decrease on the effect on friction so ultimately this would be the best mix of both scenarios.

This is further enhanced when a pump is introduced into the system. As discussed in section 2.5, pumped pipeline systems are optimised when the best mix of capital investment (pump station and pipeline diameter) is measured against the pipelines expected ongoing, life cycle costs.

Therefore why not perform a similar optimisation analysis for both a normally operating pipeline, and a fouled pipeline. The first optimisation analysis would be done with a *k* value of 0.3mm, or whatever the recommended *k* value is for that particular pipe type. This design assumes no pipeline fouling and is the normal practice for pipeline design.

If pipeline fouling does occur are the extra operating costs measurable during the design stage? This is why the optimisation must be performed twice. The second optimisation analysis would be performed on a fouled pipe with an estimated *k* value. As discovered during the research performed within this project, pipe fouling affects the pipe roughness of the pipeline. As suggested earlier a conservative value of 2.0mm will be adopted within this report for the pipe roughness value and the analysis will be performed again.

The difference in operation costs is known as the marginal costs. The amount of this marginal cost should be less than the cost for installation of swabbing structures and the additional costs involved in pigging the pipeline regularly.

Obviously the magnitude of effects caused by the increase in *k* is dependent on many variables, especially pipeline length and diameter. However, if the increase in pumping head is reasonably high to overcome the higher friction loss along the pipeline, would the installation of the larger pumps be a solution to all this.

Before fouling commences the pump and motor would be operating at a duty point slightly lower than its optimum efficiency. In general it is difficult to predict if initially power usage will be low or normal. This would depend on the efficiency of the pump when the pipeline is in an unfouled state. However, as the biofilm grows, the efficiency of the pump will change and potentially the energy use would increase. As suggested in earlier theories, the fouling should eventually reach an equilibrium in growth. Then the oversized pump would continue its service at this level for the remainder of its asset life.

There is one other check that has to be made on the chosen pump before it can be adopted. As explained earlier, pumps have an operating range that they work in to perform adequately. The increase in head loss that has to be catered for by the pump must be within this pumps operating range. The pump has two duty points to operate between. The minimal duty point is that of a normally operating pumped system with a k of 0.3mm, or as recommended by the pipe manufacturer. It is then expected to peak at a much higher k value. As explained earlier, for the purposes of comparison in the analysis a k value of 2.0mm will be adopted. This value is considered extremely conservative.

3.3 SUMMARY

With the research gathered purely from the literature review, some interesting discoveries and theories have already evolved. These theories will provide the basis to which the analysis will occur. The results will be used to create the decision support system.

4.0 PIGGING OF STANWELL PIPELINE

4.1 OUTLINE

Attendance of the pigging of Stanwell pipeline in Rockhampton occurred in order to fully understand the process of pipeline pigging. The aim was also to gather data from the event to understand the effects on the pipeline after pigging. The Stanwell pipeline provides water to the Stanwell Power Station near Rockhampton (Figure 4.1). Rockhampton is 650km north of Brisbane.

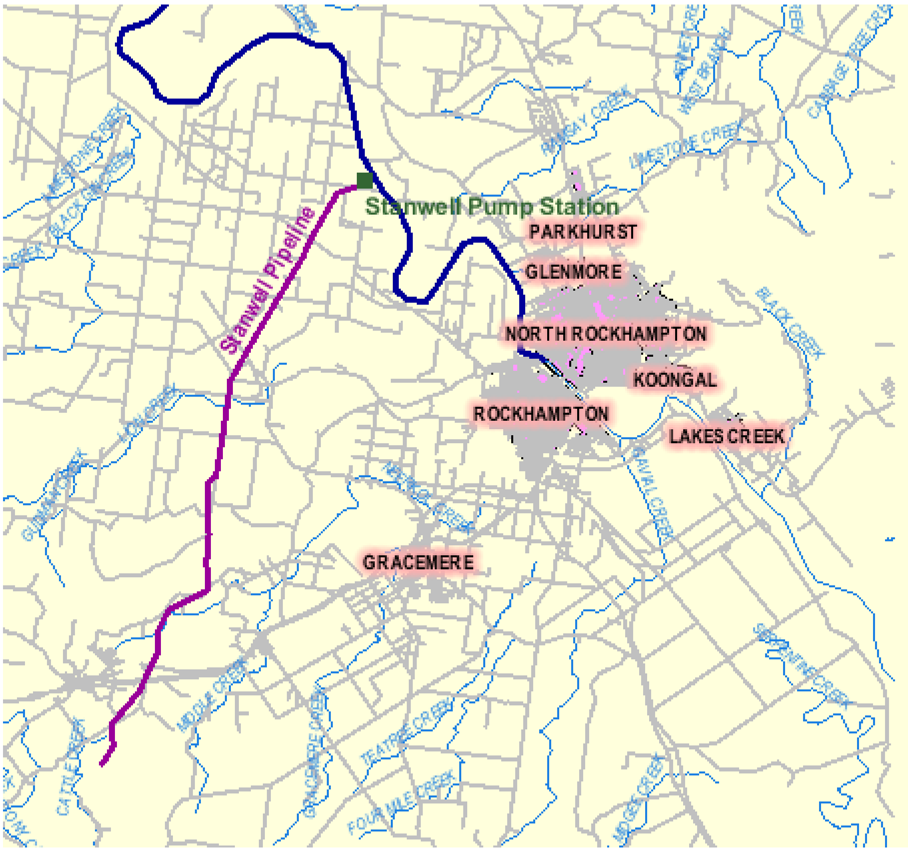

Figure 4.1 – Map of Stanwell Pipeline near Rockhampton.

The basic service requirement for the Stanwell pipeline is to deliver a minimum flow rate of 915L/s to the Stanwell Power Station. It is approximately 28 kilometres in length and consists of 900mm nominal diameter mild steel concrete lined pipe. It has swabbing structures at the start and end of the pipeline. It is pigged annually because the capacity is compromised by pipeline fouling and often falls below the service requirement level of 915L/s.

A *Microsoft Excel* spreadsheet has data added to it each day with recordings of pressure readings, flow rate, power usage, the river level that the pipeline is extracting from and the balancing storage level at the downstream end of the pipeline. From this, the flow rates are monitored and a Hazen-Williams factor is calculated for information purposes. Once the flow rate declines to 920L/s the pipeline is pigged as soon as practically possible. This ensures the capacity does not fall below the required service level of 915L/s.

An example of the spreadsheet with the information recorded daily can be viewed in Appendix B. The first example of this monitoring spreadsheet is of June, 2010. The following month the pipeline was pigged. It was this pigging event that is documented in this report. The figures in July, 2010 follow those of June and it is evident that flow rates improve significantly. It should be noted that the pigging event occurred on the 13th July 2010.

From the data gathered some back calculations can occur to establish the *k* values before and after the pigging event. This will assist in predicting a reasonable, maximum *k* value to be used in the analysis of a fouled pipeline.

4.2 EQUIPMENT

Minimal equipment is required to pig the Stanwell pipeline. Other than the three 4WD vehicles, four Operations personnel and one Electrician, the actual equipment required is listed below.

4.2.1 Disc Pig

The major component of the pigging operation is the Disc Pig. It consists of a galvanised steel body that has two replaceable polyethylene plastic discs on each end. These replaceable discs are bolted in place and are changed before each pigging event. The disc pig has a mass of approximately 1 tonne and can be seen in Figure 4.2.

This type of pig was chosen because it was the most efficient type of pig for the Stanwell Pipeline. In the first trials of pigging of the Stanwell pipeline, foam swabs were used. Within three months the pipeline had to be pigged again because the pipeline capacity had dropped below the level of 915L/s. It was clear that the foam swab was not cleaning the internal lining sufficiently and the pipeline capacity was not increasing enough after the event. The pipeline was then pigged with a disc pig and results were much better. The pipeline capacity after the event was higher and the pipeline was able to sustain a capacity above the 915L/s for much longer. The only problem with the disc pig was that due to the robust polyethylene discs, the internal concrete lining was being damaged in places. However, this risk was accepted due to the financial repercussions caused by failing to meet the service requirement capacity of 915L/s.

Figure 4.2 – Pipeline Pig used for Stanwell Pipeline.

4.2.2 12 Tonne 'Franna' Crane

This crane is used for removing the spool pipe piece for placing the pig in the 'launching' pit and also for removing the pig at the downstream 'catching' pit. It can be seen removing the spool piece at the launching pit in Figure 4.3.

Figure 4.3 – 12 tonne 'Franna' Crane removing Pipe Spool Piece.

4.2.3 Personal Protective Equipment (PPE)

For safety reasons, the appropriate personal protective equipment is required such as:

- Long sleeve shirt, long pants, safety boots, sun glasses;
- Safety Helmet;
- Tagged Slings for lifting;
- Mobile phone and two-way radio for emergency contact;

- Gloves for handling of pipework.

4.3 METHODOLOGY

The general methodology for the pigging of Stanwell Pipeline is detailed in Appendix C. Included with it is a work method statement. A work method statement depicts the safety issues associated with the pigging event. The document is reviewed by all involved prior to the pigging event commencing to ensure the safety of the workers and their knowledge of the procedures involved.

Additional to the witnessing of the pigging methodology, the analysis that has to be performed after the pigging event must also be considered.

By referring to the Barr and Darcy-Weisbach equations it was important to gather the following data from the Stanwell Pipeline before and after pigging:

- Pressure reading on discharge pipeline immediately downstream of pump to establish total head being generated by the pump;
- Pressure reading on the suction pipeline immediately upstream of the pump to establish the head from the river water;
- Static Head, measured by obtaining:
    - the rivers water level
    - the downstream dam level;
- Flow Meter readings;
- Pipeline Length;
- Pipeline Internal Diameter;
- Any additional data considered appropriate such as power used.

All of this data was measured by a SCADA system. SCADA is a telemetry system that sends data from remote sites to a SunWater system linked to the telemetry. This data will assist in back calculating the pipe roughness height that the pipeline was experiencing.

4.4 OUTCOME OF PIGGING STANWELL PIPELINE

As discussed above, whilst observing the process of pipeline pigging, data was gathered on the effect on the hydraulic performance. The total length of Stanwell Pipeline was 28.04km and it had an internal diameter of 856mm. Prior to pigging commencing, the following data was recorded:

- Flow Meter Reading at Chainage 0.1km = 936.7L/s
- Flow Meter Reading at Chainage 27.7km = 918.8L/s
- River Level in AHD = 3.72m
- Stanwell Dam Level in AHD = 86.67m
- Pressure Reading Suction Line = 74.66kPa
- Pressure Reading Discharge Line = 1648.77kPa
- Pump Power = 1775kW

Following the pigging event the data recorded read as follows:

- Flow Meter Reading at Chainage 0.1km = 1020.8L/s
- Flow Meter Reading at Chainage 27.7km = 1004.2L/s
- River Level in AHD = 3.75m
- Stanwell Dam Level in AHD = 86.61m
- Pressure Reading Suction Line = 54.65kPa
- Pressure Reading Discharge Line = 1494.15kPa
- Pump Power = 1828kW

The decrease in pipe roughness height obviously had an effect on the friction factor and consequently the flow rate increased. The upstream flow meter recorded an increase from 936.7L/s to 1020.8L/s. This is an increase of flow of 84.1L/s. The downstream flow meter recorded an increase from 918.8L/s to 1004.2L/s. This is an increase of flow of 85.4L/s. More information is displayed in the monthly report in Appendix B.

The difference in flow meter readings at the upstream and downstream ends of the pipeline is not understood fully. It is assumed this is due to one or more of the following:

- Pipe leaks;
- Customers along the pipeline and between the flow meter locations taking water;
- Flow meter inaccuracies.

It is a SunWater specification that flow meters are accurate to within 2%. Therefore if the readings were different by approximately 16L/s (1020.8L/s and 1004.2L/s) after the pigging event, this is an inaccuracy of less than 2% which indicates an acceptable level. The fact that both meters changed by similar amounts also assists in accepting the flow meter data's integrity. Given that it is unknown whether pipe leaks or customer usage was occurring throughout the pipeline, the data extracted from the upstream flow meter at chainage 0.1km will be adopted for any analysis.

The biofilm within the pipe was also analysed, however not from a biological composition perspective. The structure of the biofilm seemed to be similar to an algae and attached itself to the wall. The image below shows the biofilm within the pipelines. It must be noted that this is after 20 years growth.

Figure 4.4 – Biofilm on Stanwell Pipeline, 20 years growth.

All the data captured above was analysed to predict the pipe roughness height within the Stanwell pipeline. This will later help to give an indication on what an appropriate pipe roughness height would be if modelling a fouled pipeline.

4.5 DATA ANALYSIS

It is important to back calculate what the *k* value might be to understand the effects the pigging event had on pipe friction and flow. The results of this back calculation are interesting.

First we must calculate the head loss over the pipeline. This is then followed by the static head so we can get the friction factor using the Darcy-Weisbach formula. From there the Barr formula can be used to get the *k* value of the pipelines internal wall.

A pressure reader was fitted immediately downstream of the pump on the Stanwell Pipeline, reading the total head being generated by the pump. On the 12th July, the day prior to pigging, the pressure reading on the discharge end of the pump was 1648.8kPa. The pressure on the suction end of the pump was 74.7kPa.

The pressure on the suction pipeline is subtracted from the discharge pressure because the river height is above the location of the discharge pressure gauge. The pumps are located in a very deep well below the water level, thus the reason for subtracting the suction pressure from the discharge pressure. In cases when the pump station is situated on a river bank and above the water level and intake line, the opposite would be performed and the suction pressure added to the discharge pressure. To convert this to a value of head in metres the following is done:

$$\Rightarrow H = (1648.8-74.7) \times 1000 / (\rho\ g)$$

$$H = 160.46\text{m}$$

The static head is the difference between the elevations at the Stanwell Dam and the river level. The values on the 12th July were:

$$\Rightarrow h_s = \text{Stanwell Dam Level} - \text{River Level}$$

$$h_s = 86.67\text{m} - 3.72\text{m}$$

$$h_s = 82.95\text{m}$$

We now must include entry, exit and fitting losses along the pipeline. Fitting losses are calculated by multiplying a fitting loss factor, K (not to be confused with the pipe roughness k), by the velocity head. Each pipe fitting, bend, valve, tee piece etc along the pipeline has a fitting loss factor associated with it. The fitting loss factors of various fittings can be seen in Appendix D. The extract within the appendix has been taken from the *Irrigation Design Manual for Pipelines* (Department of Primary Industries, 1995). To perform the addition of these factors for the entire 28km of Stanwell pipeline would be an extremely long and arduous task.

Fortunately *SunWater* have performed these sums on multiple different pipelines throughout the years in order to obtain a factor that can be applied to all pipeline designs conducted in house. An average fitting loss factor of 3.0 per kilometre of pipeline has been calculated. Therefore by multiplying a K of 3.0 by the length of the pipeline in kilometres and the velocity head we get a fitting head loss in metres.

$$h_L = K.\frac{L}{1000}.\frac{V^2}{2g} \quad \text{Eq 4.1}$$

$h_L = 3.0 \text{ x } (28{,}040/1000) \text{ x } (V^2/(2\text{x}9.81)$

To finalise the calculation the velocity must be established using the continuity equation. Then while this is occurring the Reynolds number should be calculated from the velocity for use later in the Darcy-Weisbach equation.

=> $Q = AV$

936.7L/s / 1000 = [3.14 x (.856 / 2)^2] x V

V = 1.63m/s

=> Nr = D x V / u

Nr = 0.856m x 1.63m/s / 0.000001

Nr = $1.39 \text{ x } 10^6$

So substituting the velocity into the fitting loss formula again:

$h_L = 3.0 \text{ x } (28{,}040/1000) \text{ x } (1.63^2/(2\text{x}9.81)$

h_L = 11.36m

Thus the total head due to friction is:

=> $h_f = H - h_s - h_L$

h_f = 160.46m – 82.95m – 11.36m

h_f = 66.15m

Now by back calculating using the Darcy-Weisbach equation we can get the friction factor.

$$h_f = f.\frac{L}{D}.\frac{V^2}{2g}$$

66.15 = f x (28040 / 0.856) x (1.63^2/(2 x 9.81);

f = 0.015

Now that the friction factor has been calculated the Barr equation can be used to back calculate for k:

$$\frac{1}{\sqrt{f}} = -2\log_{10}(\frac{k}{3.7D} + \frac{5.1286}{Nr^{(0.89)}})$$

1/SQRT(0.015) = -2log$_{10}$[(k/(3.7x0.856))+(5.1286/(1.39x10^6^(0.89)))]

k = (3.7x0.856) x (10^(1/(SQRT(0.015))/-2) - (5.1286/(1.39x10$^{6\wedge}$(0.89)))) x 1000

k = 0.20mm

Therefore the pipe roughness height, *k*, is 0.20mm prior to pigging. This indicates that the pipe roughness height is a little more than 0.20mm when pigging must occur again due to the bearing it has on the flow rate.

By repeating the above sequence of calculations and with the data provided after pigging we get the following values for head:

=> H = 146.74m;

=> hs = 82.86m;

=> h_L = 13.49m; and thus

=> h_f = 50.30m.

By running through the same process as above we can calculate the friction factor for when the pipe is unfouled after pigging. The friction factor is:

$f = 0.010$

By substituting into the Barr equation we get:

$k = 0.020\text{mm}$.

It is interesting to note that for a head differential of 13.7m, (160.46m-146.74m), which is almost 10% of the total head, the friction factor value does not change much at all. However, the pipe roughness heights differ by 1000% (0.20mm to 0.02mm).

What is also interesting to note is that the highest, fouled pipe value of 0.20mm is nowhere near the maximum assumed value for *k* of 2.0mm that was adopted earlier in this report. It is actually very much near, and below, the adopted design value of 0.3mm.

However, is it possible to use the daily recorded data from Stanwell pipeline and form a predictive plot for what the *k* value may be in the future? In Figure 4.5 below a period of time in the last financial year has been extracted from the daily monitoring data of Stanwell pipeline. The *k* values at each day have been calculated by using the suction and discharge pressures as well as the Stanwell Dam and river levels. The spreadsheet for calculation of the data can be viewed in Appendix E. The period chosen was between the 21st December 2009 and the 9th July 2010. The 9th July was just prior to when the author witnessed the pigging of Stanwell pipeline on the 12th July, 2010.

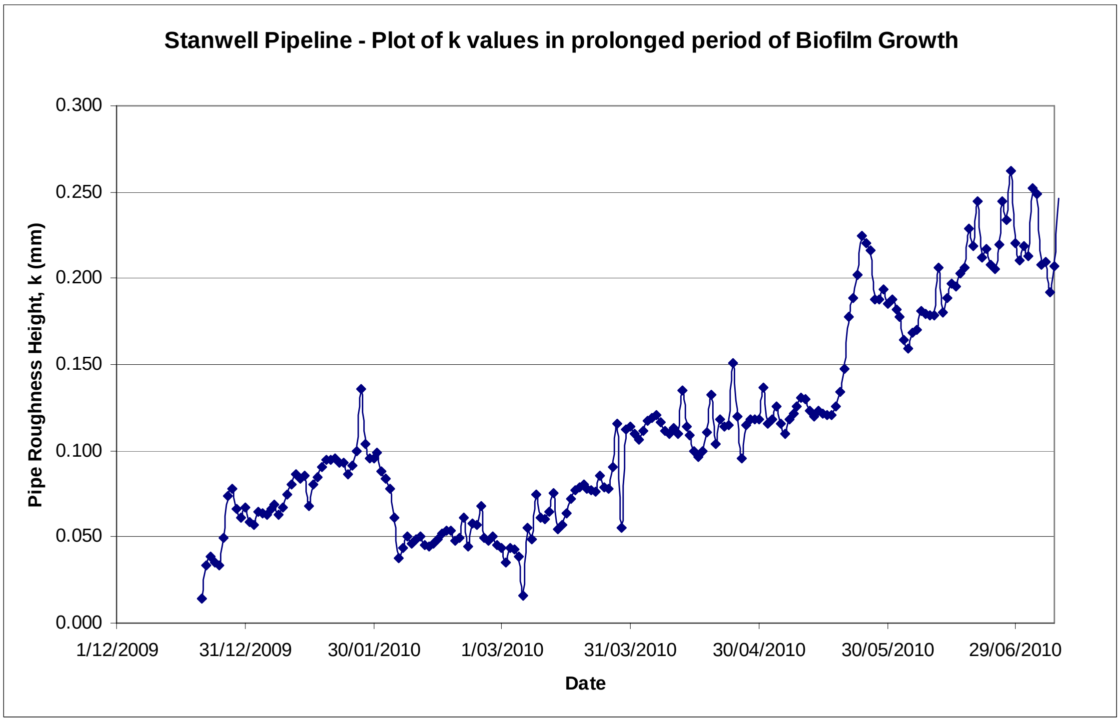

Figure 4.5 – Plot of *k* against time on Stanwell Pipeline.

Now using the *Microsoft Excel* function of predicting values the *k* value can be forecast over time. The prediction line was selected to be a logarithmic function given its declining gradient over time. Included within the graph is the trend line equation and the formula's R^2 value. An R^2 value is a measure of fit for the trend line when compared to the data. It is a fraction between 0.0 and 1.0. A value of 1.0 indicates a perfect fit. In Figure 4.6 on the next page, it can be seen that the trend line fit is reasonable.

The most interesting point to take out of this graph is the establishment of a maximum *k* value. Although the trend line is still rising slightly, it has somewhat peaked. The value it has peaked on is 1.2mm. It has taken approximately 20,000 days to reach this peak value. 20,000 days equates to a little bit more than 54 years.

Although this is only a prediction model of which the data only ranges over 7 months, it does tell an interesting story. Coupled with the equilibrium of power usage on the Awoonga-Callide pipeline discussed in section 2.6 this gives a lot of confidence that biofilm growth does eventually slow dramatically. It also provides integrity in the assumption that a *k* value of 2.0mm is considered conservative. Later in this dissertation, an analysis will be performed on a pipeline designated with a life cycle of 20 years. According to Figure 4.6 below, an assumed maximum *k* value of 0.9mm would be sufficient for that analysis.

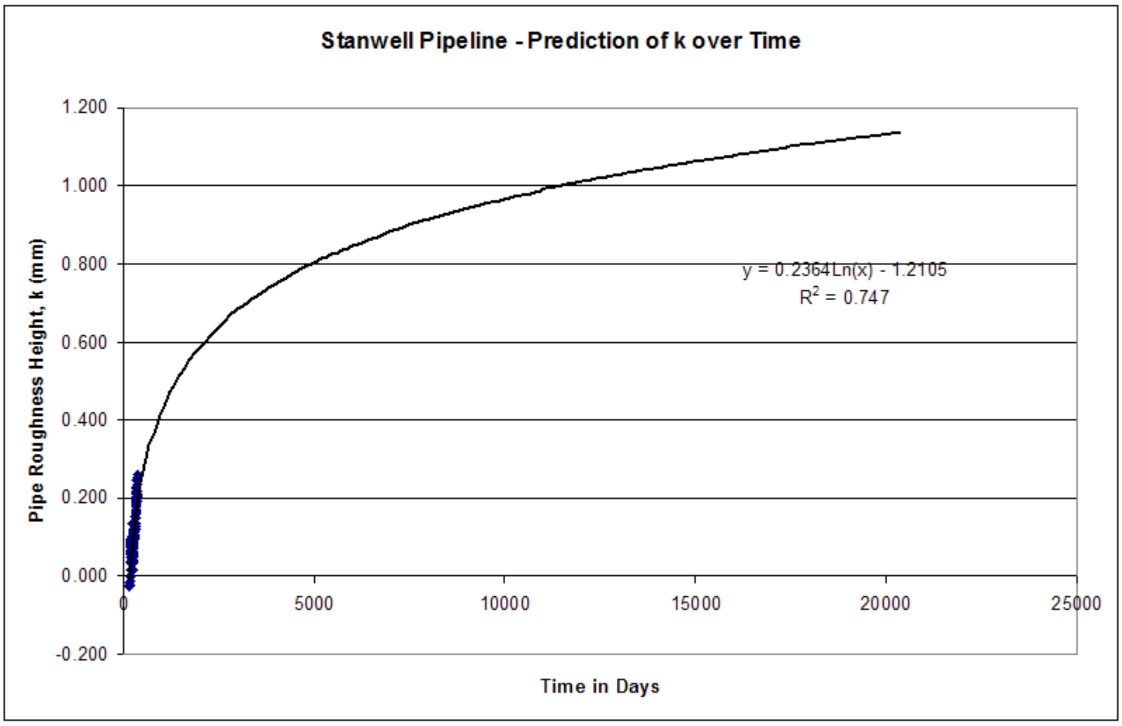

Figure 4.6 – Prediction of *k* against time on Stanwell Pipeline. Note that k does not equal 2.0mm until 20,000 days or 54 years.

However for the purposes of the option analysis to be done in chapter 6.0, a maximum *k* value of 2.0mm for the cost benefit analysis will still be adopted. Engineers generally use a contingency value for cost estimation, or a factor of safety for design calculations. By using 2.0mm as the maximum value for the effects on friction by pipe roughness height, the calculated marginal costs will be more than adequate. It will ensure the integrity of the pipeline from an operational view, meaning the pipeline should definitely operate adequately for its entire life span.

In actual fact the costs calculated using a *k* value of 2.0mm will amount to NPV power costs far greater than what the actual power costs will be in real life application. However, such is the art of estimating, that in cases where a lot of assumptions are being made, it is important to be over compensating in these areas.

4.6 SUMMARY

The attendance of the pigging event for Stanwell pipeline was extremely beneficial. Its primary objective was to assist in fully understanding the pigging process. This was appreciated and it ultimately lead to the formation of a cost estimate to pig a pipeline which is discussed further in latter sections of this report.

The critical finding from the pigging event was the effects fouling had on the head loss due to friction. Ultimately this helped develop reassurance that using a k value of 2.0mm, to assess marginal costs between a fouled and unfouled pipeline within the analysis, although conservative, is adequate.

5.0 PIPELINE OPERATOR QUESTIONNAIRE

5.1 OUTLINE

Several pipeline operators around Australia were contacted to verify any anecdotal reasoning on the benefits of pipeline pigging and the installation of swabbing structures. It was considered essential that operators of pipelines were contacted for their input. Particularly given that they often experience phenomena that are potentially not considered within the design.

5.2 OBJECTIVE

The objective of the survey was to record anecdotal evidence of the benefits of pipelines pigging from an operational perspective. It was important to survey a widespread audience and obtain suggestions from operators that pigged pipelines regularly. In addition to this, it was extremely important to gather advice from operators that do not pig pipelines.

Only common, repeated statements or suggestions were adopted as credible assumptions to potentially be adopted in the creation of the decision support system. However all suggestions were duly noted and somewhat factored, sometimes indirectly, into all considerations in the creation of the decision support system. Suggestions from all operators should be duly noted given that all pipelines and environmental conditions differ in many ways.

5.3 QUESTIONNAIRE

Pipeline operators were contacted from around Queensland, Western Australia and Victoria. The pipeline operators contacted are listed in Appendix F. The operators chosen were from a vast range of pipeline pigging backgrounds. Some of these pipelines were pigged regularly while others did not require pigging or had never been pigged. This was beneficial because it gave a balanced set of results for the benefits of, and reason underlying the decision to pig.

A formulation of questions were put together to fully understand the effects of pigging or the non-event of such. It is important to get operational views of the subject instead of only applying theory to the analysis. Inclusion of operational viewpoints will add weight to the final decision as these people are dealing with practical and real life scenarios.

Some questions are aimed at the pipeline operator's experience. This gives a brief insight into how much knowledge the operator has regarding the pipeline in question and pipeline operation in general. The more experience the operator has the more reliable the input.

Then questions were asked relating to the operational components of the pipeline. This will assist in comparison of pipelines with a matrix of different diameter, lengths, flow rates and age. Pipelines of high age that did not require pigging were of interest so anecdotal evidence of the reasoning for this could be captured.

If pipelines were pigged it was important to understand how the operator knew when the ideal time was to perform the pigging. This lead to other questions pertaining to the hydraulic performance of the pipe. If the operator was monitoring the pipeline for an opportunity to pig, this would mean data may be available for hydraulic effects before and after the events.

Finally any other comments the operator would like to add were gathered. This was usually in the form of the type of pig used, how many swab structures were in the pipeline and their thoughts on anything regarding the performance of the pipeline and pigging in general.

The questions asked of the operators were:

- How many years of experience do you have in the operation of water pipelines, specifically in pipeline pigging?
- How often do you pig the pipeline?
- What is the pipeline length, diameter and flow rate?
- How do you know when to pig the pipeline?

- What factors delay or onset the requirement for pipeline pigging in your opinion?
- Can you report any evidence of increases in hydraulic performance of the pipeline after pigging?
- Can you report any evidence of decreases in hydraulic performance of the pipeline before or without pigging?
- Do you have any other helpful comments or suggestions?

Each of these questions are establishing the scenario that the pipelines were operating in. It also gathered information on the benefits, or lack there of, in pigging of pipelines. As an afterthought following discussions with some of the operators, it was considered important to obtain more detail regarding the environmental conditions that the pipelines existed in. This may have created some links between the pipeline environment and fouling of the pipelines.

5.4 RESULTS

The data supplied by the various operators was very helpful. Some of the more common suggestions by the operators were as follows.

- If the pigging event occurs at the right time, efficiency of the pipeline, measured in terms of flow rate, can improve by up to 10%;
- Most pipelines that are pigged regularly are done once a year as part of the pipelines annual maintenance shutdown;
- Treated Water Systems do not require pigging. The treatment deters the growth of biofilm and, although is an added operational cost, removes the requirement for swabbing infrastructure;
- Swabs (foam pigs) are not as efficient at cleaning the internal walls as disc pigs;
- Disc pigs are the most efficient at cleaning the pipeline but cause damage to the internal concrete lining. Some evidence is seen in figure 5.1 below;

Figure 5.1 – An example of evidence of damage to the internal concrete lining of pipelines after pigging. This fact was highlighted numerous times throughout performance of the survey.

- A pig or swab generally travels along the pipeline at around the same velocity of the pipeline. On average this is about 1.5m/s;
- If able to be done in one straight run, 25km of pipeline is approximately the maximum amount of pipeline that can be pigged in one day. The pipeline must be fully operational at the end of the day so that pumping can occur overnight again. Then the pumps are shut down again the following day if further pigging is required, especially on long pipelines;
- Pipelines with manufactured bends along them must be swabbed, as opposed to pigging. The length of the swab used is dependent on the angle of the bends it will encounter to ensure it can travel the entire length of the pipeline. There is a maximum limit on allowable bend angles for disc pigs although this varies depending on the type of pig used;

- Some pipelines cannot avoid pigging, particularly those with a metallic compound within the solution such as iron or manganese. Reference is made to Figure 5.2 below for an example of the fouling occurring on a pipe transporting water with high iron content. This highlights the importance that operators of pipelines that extract from headwaters similar to the pipeline being designed should be contacted for advice on the behaviour of these pipelines with respect to pigging.

Figure 5.2 – Photo of pipeline fouled by water with high iron content. WaterCorp (2010).

Those operators that pigged pipelines regularly considered it essential for the adequate performance of the pipeline and saw the obvious benefits. However, those that were operating pipelines without the requirement of pigging, in some cases considered it an unnecessary event. These trends are assumed to have arisen due to each individual operators experience on the matter. It is no wonder that operators that have witnessed the increase in hydraulic efficiency after pigging consider the art a necessary one for adequate operation of a pipeline.

It is interesting to graph the results from the questionnaire regarding the number of times per year each surveyed pipeline was pigged. Almost all were hardly pigged at all. Another unknown fact is that almost all the pipelines had elaborate swabbing structures installed at regular intervals along the pipeline. The only pipeline without swabbing facilities was the Kalgoorlie Pipeline. This can be seen in figure 5.3 below.

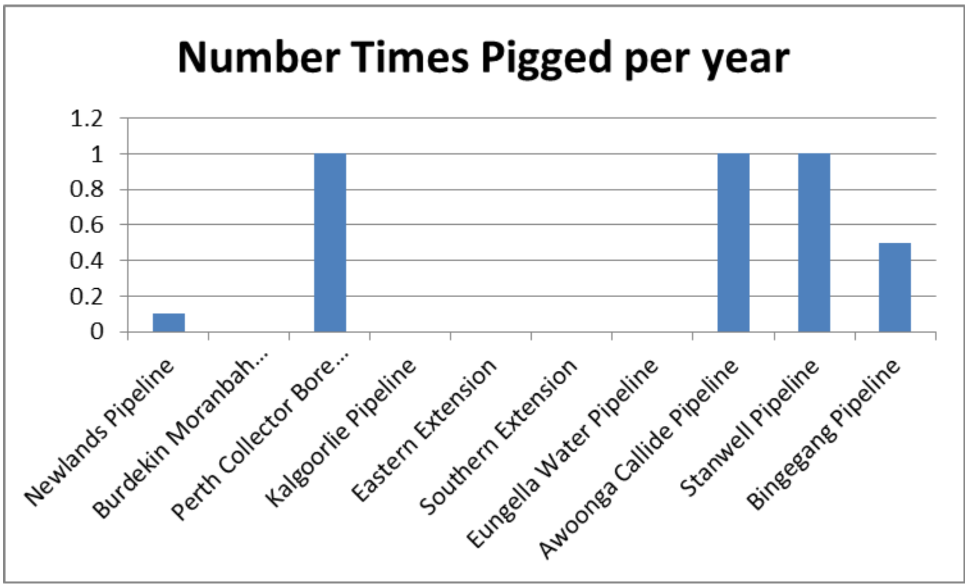

Figure 5.3 – Graph displaying the number of times each surveyed pipeline is pigged each year. The Kalgoorlie Pipeline is the only pipeline not to have permanent swabbing facilities.

5.5 DISCUSSION

The most obvious result from the survey was the reinforcement that operators must be approached when deciding on whether to incorporate the swabbing facilities or not. Although the costs can be predicted financially by comparing the costs of an unfouled pipe against a normally operating pipe there are other factors to consider.

One example of this was the pipes that had high metallic content within them. The fouling of the pipe was different than the normal fouling as seen after the pigging of Stanwell pipeline. This finding confirmed the requirement to definitely include operators in the decision support system. The operators would have to be local to the area in which the pipeline was being designed. It would also be important to gather operational input that only pertained to the same headwater system. This would ensure that the behaviour of potential pipeline fouling, if known, would be consistent with the operator's experiences.

It was also evident that of those operators that pigged pipelines almost all saw a benefit in pigging. Flow rates increased in a majority of cases. One such example of differential opinion was the Newland Pipeline. It had been 10 years since this pipeline was last pigged until it was cleaned recently. The results following the recent pigging did not see show an increase in flow rate.

This meant that fouling was not occurring on this particular pipeline. The pipeline was pigged purely because it was evident that it had not been done for ten years. In this case the operation was a wasted investment. Particularly when it was discovered that 6 x 12 hour continuous shifts were endured to perform the pigging of the entire pipeline. An extremely preliminary cost estimate of the procedure assuming 4 men, a crane and accommodation puts the events at costing $50,000. This is by no means an accurate cost estimate given that the logistics behind the procedure have not been investigated, but it does give some insight into the financial repercussion of the potentially wasted operational expenditure on pipelines. This does not itake into account the capital cost invested in the swabbing structures as well.

The damage disc pigging inflicts on the pipelines internal walls is also of concern. The internal lining is important for corrosion protection of the pipeline. The damage of the lining would have repercussions on the asset life of the structure that is not fully understood. Each time the pipeline is pigged, the damage along the pipeline increases, therefore making the pipeline even more susceptible to corrosion. The scary thought is that where this damage is occurring is unknown.

The location of damaged sections of the pipeline would only arise when a leak occurs. Even still, depending on the severity of the leak, the pipeline would have to be excavated for a large area to find the leak. A very expensive and tedious process without including the materials, labour and ceased operation of the pipeline required to mend the problem.

This is why the use of swabs (high density foam) has become more popular. However, as noted from the questionnaire this procedure is not as effective at cleaning the pipeline. Which means improvement in the hydraulic performance is compensated by decisions regarding the sustainability of the pipeline. This leads to the increased requirement of pigging because the biofilm is not being removed adequately. This could potentially lead to the misleading thought that pigging was a necessary practice. More reason to consider the fouling of the pipeline at the design stage to avoid unnecessary spending of operational costs, where appropriate.

5.6 SUMMARY

These anecdotal suggestions will be used in the decision support system. A section within the flowchart of the decision support system will prompt the designer to consult local operators for advice. It is likely that they will be of more benefit to those pipelines that do not have clear direction, after utilising the support system, on whether to install swabbing structures or not. However it would be ridiculous to design a pipeline without consulting the operator at some stage. The operators often know more about the headwater system and the behaviour of pipe fouling than any equation might tell you.

6.0 PUMPED PIPELINE OPTIMISATION

6.1 OUTLINE

As discussed briefly in earlier sections of the report, an analysis is required comparing operational costs for fouled and unfouled pipes. The theory is that a budget for installing swabbing facilities must be determined to assist in the decision making process. The general methodology for achieving this is done by designing a pipeline with pumps for an unfouled system. Then comparisons are made with a fouled system.

The allocation of the two *k* values is the most important step in the analysis at this stage. The previous chapters have explained pipeline hydraulics and the design of pumped systems, as well as the effects pipe roughness has on operational costs and how pigging ties into it all.

The *k* value of 2.0mm for a fouled pipe and 0.3mm for a unfouled pipe has already been determined, as described in Chapter 4, and have been adopted for the subsequent analysis.

6.2 METHODOLOGY

A process had to be created to establish how pipeline fouling could be predicted and compared financially with the cost involved with pipeline pigging. This is how the decision support system would work. The best way to achieve this, is to simulate and compare results amongst many different pipeline design scenarios.

The best way to do this was to simulate the design approach for a pipeline. In order to ensure that a large cross-section of potential pipeline design scenarios were captured, 30 different scenarios were employed.

When a pipeline is in its conceptual stage, as explained earlier in chapter 2, three variables are required. Initially the annual volume is provided by the client as they usually know how much water is required. From this annual volume the discharge *Q* can be determined.

Then the pipeline designer will try to establish the pipeline alignment. This will ultimately produce the length and terrain of the pipeline. Once complete the static head requirement is known and later the system operating point is determined by hydraulic analysis.

The matrix of scenarios was developed, comprised of differing lengths and annual volumes.

Five different pipeline lengths were analysed:

- 2,000m;
- 5,000m;
- 10,000m;
- 20,000m;
- 50,000m;

and six different annual volumes to be produced by the pipeline were analysed:

- 1,800ML;
- 5,000ML;
- 10,000ML;
- 15,000ML;
- 20,000ML;
- 30,000ML.

The figures above represent annual volumes encountered across many different pipelines that SunWater has designed and constructed in the past. It represents a good cross-section of pipeline sizes (flow rate and diameter) and lengths.

The length of 50km was adopted as the maximum length based on a general rule within SunWater's finding following experience with pipeline design. Pipelines with a length greater than 50km tend to recommend installation of a second pump station. For reasons of consistency and simplicity it was decided that it was important that all pipeline scenarios were similar in cost in terms of pump station design and construction costs. Therefore 50km was adopted as the maximum length.

Each scenario was compared in terms of cost for installation and operational costs using NPV's. Each combination of design length and capacity was optimised individually. This optimisation process determines the most economical design considering both capital and operational costs for the pipeline life cycle. Firstly the optimisation was performed using a k value of 0.3mm, then again using a k value of 2.0mm. The following assumptions applied:

- A static lift of 50m is required. This value is the approximate average of required lift for many pipelines designed by SunWater of late;
- Ductile iron concrete lined pipes would be used for pipelines up to 750mm diameter and mild steel concrete lined pipes for diameters greater than 750mm. This is to remove the complication where other pipe material types could be considered. By using DICL and MSCL pipe there is some consistency with pipe supply and installation costs;
- Fitting loss factor is 3. This is to make allowances for losses created by entry and exit losses as well as those created by valves, bends, fittings and otherwise. This fitting loss factor is an adequate approximation for most pipelines in pratice;
- The marginal cost for the difference in pump and motor size is $100,000. This is the difference in cost between a pump station required to cater for a k of 0.3mm, versus a pump station that is to cater for a k value of 2.0mm. When pump designs only differ due to the duty point required, the difference in installation cost for the pump station is minimal. It is usually in the order of $50,000 to $75,000, as experienced in recent SunWater pipeline designs. Simply put, the costs to design and construct infrastructure for a pump station that is to pump water in a normally operating pipeline is no different to the costs for a pump station catered to pump water in a fouled pipeline. The infrastructure is still required and is no different in either scenario. The only difference may be the cost of the pumps and slightly higher electrical capabilities. Therefore

this figure of $100,000 is considered conservative and compensates for changes in pump station costs, ie the marginal cost;

- The life expectancy of the pipeline is 20 years. Recently SunWater has designed and constructed most of their pipelines for Mines. Typical Mine lives are between 20 and 30 years. They only need the water supply for that duration of time and SunWater needs to secure the costs to construct that pipeline before that time expires. Often the Mine will exist for a longer period of time, but to ensure costs are recovered before the operation of the Mine ceases, a design life is established. Look at it similarly to a home loan repayment term;
- The NPV multiplication factor using a discount rate of 8% is 10. This is calculated using the formula explained in an earlier section. A discount rate between 6% and 8% is generally used by SunWater designers, based on advice from SunWater accountants. Remember that the design life is 20 years;
- Swabbing Structures are deemed to cost $300,000 each (multiplied by 2 given both a launching and catching structure is required). A pigging event is deemed to cost $20,000. Thus the NPV of Swabbing for a pipeline less than 25km long (maximum length that can be pigged in one day as explained earlier) is valued at $800,000. It is remembered that prices will differ depending on pipeline diameter. However for the purposes of this analysis, simplicity and consistency on price will be introduce The cost estimation of a pipeline pigging event and capital infrastructure are both included in Appendix G;
- For pipelines greater than 25km, the NPV of Swabbing is $1,200,000. This is due to the extra swabbing structure required and the extra day for the pigging event. As determined from the operator questionnaire, 25km is considered the average, maximum length of pipeline that can be pigged in one day. Therefore another swabbing structure must be installed if the pipeline is greater than 25km long. This adds another day to the pigging process as well which must be captured in the cost estimate.

6.3 ANALYSIS

To perform the analysis the model was created in several steps.

6.3.1 Pipeline Diameter Establishment

The objective of this step is to establish the most cost beneficial pipeline diameter when comparing capital investment and the extra pumping required due to the effects of head loss.

As explained earlier, SunWater has accumulated data from recent projects to assist in cost estimation of pipeline supply and installation. Installation costs of various diameters of ductile iron and mild steel concrete lined pipelines are listed below. It must be remembered that for diameters below 750mm, ductile iron pipe must be used. For those over 750mm in diameter, mild steel pipe must be used. This is because Ductile Iron Pipe does not exist in sizes larger than 750mm diameter. Also DICL is cheaper in supply and installation costs below that diameter. The installation costs below include the supply of the pipes as well.

Table 6.1 – Supply and Installation Costs of Ductile and Mild Steel Pipelines

Pipe Type	Dia (mm)	Installation Cost ($/m)
DICL	250	152.00
	300	169.00
	375	220.00
	450	263.00
	500	364.00
	600	475.00
	750	604.00
MSCL	800	673.00
	900	793.00
	1000	919.00
	1200	1,185.00

By using both the above installation costs and formulae explained earlier we can calculate the best option for pipeline diameter.

Factors such as the cost to build a pump station, air valves, scour valves, meter outlets and otherwise are excluded from the cost estimates. This is because they are included in both designs regardless of which pump is selected and costs are similar to do so. However, as explained earlier, $100,000 was allocated to account for the marginal costs required for any subtle design differences between each system scenario.

A spreadsheet was created to analyse the multiple scenarios considered. A copy of the spreadsheet can be viewed in appendix H. All formulae have been adequately explained in prior sections. Thus it is assumed that the calculations do not require further acknowledgement.

Firstly all the assumptions were entered into the spreadsheet shown in appendix H, such as annual volume, static lift, life expectancy of the pipeline and pipeline length. The pipe roughness height, *k*, is an interchangeable value within the spreadsheet as it is going to be modelled twice with two differing values for each pipe configuration.

The velocity of the pipeline is calculated for each diameter as it can be calculated using the continuity equation. Q is known from the annual volume pumped per year.

Then calculate the Reynolds number and by using that we can get the friction factor using the Barr equation. The head loss due to friction can then be calculated using the Darcy-Weisbach equation. Using the same formula, and the assumed fitting loss of 3.0 per kilometre, the head loss due to fittings can also be calculated.

By adding the static head to the head loss due to friction, and the fitting losses, the required lift is known. This lift can be directly converted into an NPV for power by multiplying it by the $0.60/ML.m calculated earlier and also the annual volume and the NPV factor of 10.

As explained earlier the optimum pumped pipeline system is the lowest cost mix by adding the capital costs to the NPV of ongoing power. Reference is made to the spreadsheet in Appendix I which calculates the total NPV of each scenario and its marginal cost. The results are summarised in tables 6.2 – 6.6 below.

Table 6.2 – Marginal Costs of NPV of pipelines, Fouled versus Unfouled, 2km Length.

	Length (m)	2,000		
Volume (ML)		Diameter (mm)	Total Cost	Difference
1800	k=0.3mm	300	$ 954,179	$ 145,407
	k=2.0mm	300	$ 1,099,585	
5000	k=0.3mm	450	$ 2,226,219	$ 209,041
	k=2.0mm	450	$ 2,435,260	
10000	k=0.3mm	750	$ 4,326,872	$ 154,440
	k=2.0mm	750	$ 4,481,311	
15000	k=0.3mm	800	$ 6,132,911	$ 231,781
	k=2.0mm	800	$ 6,364,692	
20000	k=0.3mm	900	$ 7,960,939	$ 266,214
	k=2.0mm	900	$ 8,227,153	
30000	k=0.3mm	1000	$ 11,577,241	$ 421,337
	k=2.0mm	1000	$ 11,998,578	

Table 6.3 – Marginal Costs of NPV of pipelines, Fouled versus Unfouled, 5km Length.

	Length (m)	5,000		
Volume (ML)		Diameter (mm)	Total Cost	Difference
1800	k=0.3mm	300	$ 1,575,446	$ 213,517
	k=2.0mm	300	$ 1,788,963	
5000	k=0.3mm	450	$ 3,315,547	$ 372,602
	k=2.0mm	450	$ 3,688,149	
10000	k=0.3mm	750	$ 6,317,179	$ 236,099
	k=2.0mm	750	$ 6,553,278	
15000	k=0.3mm	800	$ 8,582,277	$ 429,453
	k=2.0mm	800	$ 9,011,730	
20000	k=0.3mm	900	$ 10,902,348	$ 515,535
	k=2.0mm	900	$ 11,417,882	
30000	k=0.3mm	1000	$ 15,443,103	$ 903,343
	k=2.0mm	1000	$ 16,346,446	

Table 6.4 – Marginal Costs of NPV of pipelines, Fouled versus Unfouled, 10km Length.

	Length (m)	10,000		
Volume (ML)		Diameter (mm)	Total Cost	Difference
1800	k=0.3mm	300	$ 2,610,893	$ 327,033
	k=2.0mm	300	$ 2,937,926	
5000	k=0.3mm	450	$ 5,131,095	$ 645,203
	k=2.0mm	450	$ 5,776,298	
10000	k=0.3mm	600	$ 9,578,972	$ 1,026,741
	k=2.0mm	600	$ 10,605,713	
15000	k=0.3mm	800	$ 12,664,554	$ 758,906
	k=2.0mm	800	$ 13,423,460	
20000	k=0.3mm	900	$ 15,804,695	$ 931,070
	k=2.0mm	900	$ 16,735,765	
30000	k=0.3mm	1000	$ 21,886,207	$ 1,706,685
	k=2.0mm	1000	$ 23,592,892	

Table 6.5 – Marginal Costs of NPV of pipelines, Fouled versus Unfouled, 20km Length.

	Length (m)	20,000		
Volume (ML)		Diameter (mm)	Total Cost	Difference
1800	k=0.3mm	300	$ 4,681,786	$ 554,066
	k=2.0mm	300	$ 5,235,852	
5000	k=0.3mm	450	$ 8,762,189	$ 1,190,407
	k=2.0mm	450	$ 9,952,596	
10000	k=0.3mm	750	$ 16,268,717	$ 644,396
	k=2.0mm	750	$ 16,913,113	
15000	k=0.3mm	800	$ 20,829,108	$ 1,417,812
	k=2.0mm	800	$ 22,246,920	
20000	k=0.3mm	900	$ 25,609,390	$ 1,762,139
	k=2.0mm	900	$ 27,371,530	
30000	k=0.3mm	1000	$ 34,772,414	$ 3,313,370
	k=2.0mm	1000	$ 38,085,784	

Table 6.6 – Marginal Costs of NPV of pipelines, Fouled versus Unfouled, 50km Length.

	Length (m)	50,000		
Volume (ML)		Diameter (mm)	Total Cost	Difference
1800	k=0.3mm	300	$ 10,894,464	$ 1,235,166
	k=2.0mm	300	$ 12,129,630	
5000	k=0.3mm	450	$ 19,655,473	$ 2,826,017
	k=2.0mm	450	$ 22,481,490	
10000	k=0.3mm	750	$ 36,171,793	$ 1,460,990
	k=2.0mm	750	$ 37,632,784	
15000	k=0.3mm	800	$ 45,322,769	$ 3,394,531
	k=2.0mm	800	$ 48,717,299	
20000	k=0.3mm	900	$ 55,023,476	$ 4,255,348
	k=2.0mm	900	$ 59,278,824	
30000	k=0.3mm	1000	$ 73,431,034	$ 8,133,426
	k=2.0mm	1000	$ 81,564,460	

The difference in costs tabulated above can be compared to the NPV of pigging calculated earlier. In each case where the cost is less than $800,000 there is reason to avoid the installation of swabbing structures. However for the purposes of ensuring that the decision is thought through, values +/- 25% of the $800,000 are coloured in orange. Therefore all scenarios between $600,000 and $1,000,000 are categorised together and coloured orange.

Because the decision to exclude swabbing structures is not obvious for values in this range, a further decision support system must be referenced. As mentioned earlier there are many forms of swabbing facilities. Some are very basic which lowers capital expenditure, but increases the costs for the pigging event as it is made much more difficult to perform. Other swabbing facilities are more elaborately designed which increases capital costs, but decrease the effort and cost involved in performing the event.

This extra decision support system would assist the user in choosing a swabbing facility that would be possible with the available marginal cost. The marginal cost created by the potential fouling of the pipe is seen as the available budget for swabbing facilities. This extra decision support system will not be covered in this report as it is not within its scope. However, it warrants further research and work for another student or engineer to establish this tool.

Those marginal costs which are under $600,000 warrant the potential exclusion of swabbing facilities. These are coloured green. However, this is not before checking that a pump can cater for the difference in required lift. This will be followed through in the next step of the decision support system.

All scenario costs coloured red cannot avoid the installation of swabbing structures. The marginal costs are far too high to exclude permanent provisions to ensure healthy operation of the pipeline in the future. Of course the pumps would operate happily when the pipeline is in a fouled state. However, the operational cost would be extreme and there would be more benefit in pigging the pipeline when required. The risk is far too high to exclude swabbing structures, just in case fouling occurs. Therefore these pipelines must have large elaborate swabbing facilities installed and pigging performed, as required.

6.3.2 Pump Selection

Now that the marginal costs have been established, the pump and motor size can be verified. This is to ensure that the differing head losses caused by the fouling of the pipe are able to be catered for by the selected pump. As explained earlier, all pumps have an operating range and can be determined from the pump curve.

The pump curves were established from a pump selection software known as *Epsilon*. To narrow the search field, *Super-Titan* pumps manufactured by *Thompson, Kelly and Lewis*, were made to be the pump of choice. Each pump has different design criteria for suction and discharge diameters, motor sizes and impeller sizes. Pump curves for all scenarios calculated here have been determined and can be viewed in appendix J.

For the *Epsilon* software to select the required pump design it is required to know the flow rate and the required lift. The lift for each scenario is listed in the tables 6.7 - 6.11 below. Take into consideration the colours of the scenarios as determined by the marginal costs established in tables 6.2 to 6.6 earlier. Those scenarios in which a pump cannot cater for the large difference in lift have now been coloured red as well. Those that have pumps able to supply the required lift have remained the same colour. Remembering green designates pipelines that can avoid installing swabbing facilities. Orange is for pipelines that do not have a clear direction on whether to install swabbing facilities or not and should be referenced to another decision support system for assessing this. Red was for pipelines that must have swabbing facilities installed.

Table 6.7 – Required Lift in Fouled versus Unfouled Pipeline, 2km Length

	Length (m)	2,000		
Volume (ML)		Diameter (mm)	Total Lift (m)	Difference (m)
1800	k=0.3mm	300	57.1	4.2
	k=2.0mm	300	61.3	
5000	k=0.3mm	450	56.7	3.6
	k=2.0mm	450	60.3	
10000	k=0.3mm	750	52.0	0.9
	k=2.0mm	750	52.9	
15000	k=0.3mm	800	53.2	1.5
	k=2.0mm	800	54.6	
20000	k=0.3mm	900	53.1	1.4
	k=2.0mm	900	54.5	
30000	k=0.3mm	1000	54.1	1.8
	k=2.0mm	1000	55.9	

Table 6.8 – Required Lift in Fouled versus Unfouled Pipeline, 5km Length

	Length (m)	5,000		
Volume (ML)		Diameter (mm)	Total Lift (m)	Difference (m)
1800	k=0.3mm	300	67.8	10.5
	k=2.0mm	300	78.3	
5000	k=0.3mm	450	66.7	9.1
	k=2.0mm	450	75.8	
10000	k=0.3mm	750	55.0	2.3
	k=2.0mm	750	57.2	
15000	k=0.3mm	800	58.0	3.7
	k=2.0mm	800	61.6	
20000	k=0.3mm	900	57.8	3.5
	k=2.0mm	900	61.3	
30000	k=0.3mm	1000	60.3	4.5
	k=2.0mm	1000	64.7	

Table 6.9 – Required Lift in Fouled versus Unfouled Pipeline, 10km Length

	Length (m)	10,000		
Volume (ML)		Diameter (mm)	Total Lift (m)	Difference (m)
1800	k=0.3mm	300	85.5	21.0
	k=2.0mm	300	106.6	
5000	k=0.3mm	450	83.4	18.2
	k=2.0mm	450	101.6	
10000	k=0.3mm	600	80.4	15.4
	k=2.0mm	600	95.9	
15000	k=0.3mm	800	65.9	7.3
	k=2.0mm	800	73.2	
20000	k=0.3mm	900	65.6	6.9
	k=2.0mm	900	72.5	
30000	k=0.3mm	1000	70.5	8.9
	k=2.0mm	1000	79.5	

Table 6.10 – Required Lift in Fouled versus Unfouled Pipeline, 20km Length

	Length (m)	20,000		
Volume (ML)		Diameter (mm)	Total Lift (m)	Difference (m)
1800	k=0.3mm	300	121.1	42.0
	k=2.0mm	300	163.1	
5000	k=0.3mm	450	116.8	36.3
	k=2.0mm	450	153.1	
10000	k=0.3mm	750	69.8	9.1
	k=2.0mm	750	78.9	
15000	k=0.3mm	800	81.8	14.6
	k=2.0mm	800	96.5	
20000	k=0.3mm	900	81.2	13.9
	k=2.0mm	900	95.0	
30000	k=0.3mm	1000	91.1	17.9
	k=2.0mm	1000	108.9	

Table 6.11 – Required Lift in Fouled versus Unfouled Pipeline, 50km Length

	Length (m)	50,000		
Volume (ML)		Diameter (mm)	Total Lift (m)	Difference (m)
1800	k=0.3mm	300	227.7	105.1
	k=2.0mm	300	332.8	
5000	k=0.3mm	450	217.0	90.9
	k=2.0mm	450	307.9	
10000	k=0.3mm	750	99.6	22.7
	k=2.0mm	750	122.3	
15000	k=0.3mm	800	129.6	36.6
	k=2.0mm	800	166.2	
20000	k=0.3mm	900	127.9	34.6
	k=2.0mm	900	162.6	
30000	k=0.3mm	1000	152.6	44.6
	k=2.0mm	1000	197.3	

The pump curves that were created from the *Epsilon* Software can be viewed in Appendix J. It is noted that some matrix combinations could not produce pump curves. This was because the lift to be generated was much too high for one pump to create.

6.4 DISCUSSION

The results from the analysis of the 30 pipeline scenarios indicated that there is evidence to avoid the installation of swabbing facilities in some design cases. It seems that any pipelines less than 10 km in length can avoid the installation of swabbing structures provided that pipeline fouling is catered for in the design. It would seem that most pipelines above this length require swabbing however there is reason to suggest otherwise.

Taking into account the research conducted by Lambert et al. (2009), and the back calculations performed on data from Stanwell pipeline it has been suggested multiple times throughout this report that the use of 2.0mm as the *k* value is too high. The appropriate, maximum *k* value for a particular design case should be reconsidered and determined depending on an acceptable level of risk.

Discussions with operators of pipelines within the vicinity of the designed pipelines may indicate that pipeline pigging is not a necessity. An example of this would be on the Burdekin Moranbah Pipeline. In Figure 6.1 below it may be suggested that there is no evidence of biofilm after 4 years of operation. Therefore, having some confidence that pipeline fouling is unlikely to occur a *k* value of 0.5 could be adopted.

Figure 6.1 – The internal lining of a swab structure on the BMP (4 years old). Pipeline Fouling is not evident.

As previously stated, the pipelines designer may consider a *k* value of 2.0mm much too high for use to simulate a fouled pipeline. According to modelling generated from Stanwell Pipeline data a maximum value of 1.0mm could be considered relative and an acceptable level of risk.

If a HDPE or PVC pipe material type is adopted for the design pipe type, table 2.2 indicates *k* values range between 0.0015mm and 0.0017mm. This is 0.5% of the recommended value of the recommended 0.3mm for DICL and MSCL pipe types. At a guess, without researching or analysing further, an assumed maximum value of 0.1mm may be adopted by the pipeline designer to simulate a theoretically fouled HDPE pipeline. This could be considered acceptable noting the frictionless surface PVC and

HDPE pipe has. It would be theoretically unlikely that biofilm could create a strong bond to the pipe surface.

Use of these lower, maximum pipe roughness values for indication of pipeline fouling will result in a lower predicted operational cost. This would consequently reduce the marginal costs between a fouled and unfouled system and potentially then remove the requirement of swabbing facilities on a much broader range of pipeline scenarios.

Evidence of this is shown in table 6.12 below. As stated above, if using HDPE pipe and k values of 0.0015mm and 0.1mm, the marginal costs would be reduced. The example in this table is of the pipelines with a length of 50km. Admittedly the installation and supply costs used within this table were for DICL pipe. However, this is of no concern given that the capital costs would be the same in both scenarios regardless because the same diameter pipe is being installed in each case. Therefore the marginal capital cost, whether analysing HDPE or DICL pipe installation would be zero in both cases. What is of more concern is the marginal cost of power which is what will be calculated here.

Remembering from table 6.6, these calculations were performed using k values of 0.3mm and 2.0mm respectively. All outcomes from the 50km scenarios were coloured red except for the 10,000ML and 1,800ML options. This was due to the high marginal costs which were much larger than the NPV for pigging established earlier. The adopted k values for a simulated HDPE pipe indicates in table 6.12 below that all options except the 30,000ML scenario could potentially avoid the installation of swabbing facilities.

Table 6.12 – Marginal Costs in Fouled versus Unfouled Pipeline, 50km Length with minimum *k* value of 0.0015mm and maximum *k* value of 0.1mm.

	Length (m)	50,000		
Volume (ML)		Diameter (mm)	Total Cost	Difference
1800	k=0.0015mm	300	$ 10,340,374	$ 349,838
	k=0.1mm	300	$ 10,690,212	
5000	k=0.0015mm	450	$ 18,230,602	$ 759,668
	k=0.1mm	450	$ 18,990,269	
10000	k=0.0015mm	750	$ 35,499,616	$ 398,517
	k=0.1mm	750	$ 35,898,134	
15000	k=0.0015mm	800	$ 43,579,345	$ 901,617
	k=0.1mm	800	$ 44,480,962	
20000	k=0.0015mm	900	$ 52,788,029	$ 1,134,364
	k=0.1mm	900	$ 53,922,393	
30000	k=0.0015mm	1000	$ 68,893,126	$ 2,251,164
	k=0.1mm	1000	$ 71,144,291	

Another element for consideration of improvement is the pump selection process. For simplicity within the simulated scenarios, during the analysis it was stated that only one particular type of pump was to be considered. There is almost an infinite amount of pump types and arrangements available and other alternatives could have been introduced if time permitted.

It is also interesting to note that most of the pumps that could not meet the fouled duty, could not meet the unfouled duty either. This was due to the extremely high lift required of the pumps which in some cases exceeded 200 metres. Therefore multi-staged pumps or pumps in series would be required for both options in this case. Therefore the avoidance of swabbing facility installation is still a possibility if the designer considers much more complex pump designs.

6.5 CONCLUSION

The above proves that different scenarios and practical applications of pipe roughness predictions can remove the requirement for the installation of swabbing facilities. The analysis also establishes some financial justification to the decision.

It is important to realise that the analysis performed above can be reproduced using many different variations of pipe type, adopted minimum and maximum *k* values, pump types and otherwise. The variations are dependant on the design scenario and applicability to the situation at hand. If these variables are practically applied, this analysis could become a valuable step for both the designer and the eventual operator of the pipeline.

Formalisation of the process needs to occur so it can be utilised on specific design cases. Given the complexity of the process it would be best documented via a step by step flowchart.

7.0 THE DECISION SUPPORT SYSTEM

7.1 INTRODUCTION

The decision support system will act in the form of a schematic flow chart. It is shown in figure 7.1 on the following page.

7.2 HOW TO USE THE SYSTEM

Please make reference to the decision support system flowchart on the following page. The flowchart is to be used as a guide to ensure the designer follows the procedure correctly and does not forget any aspects of the decision support system.

7.2.1 Foundation Information

The decision support system would not be referenced until the pipeline alignment has been finalised. The process involved in choosing a pipeline alignment takes many factors into account. These include:

- Land tenure. This is a complex process which considers the landholders contractual agreement to the existence of a pipeline on their property. Legal documents describing an easement over part of the landholders property are drafted and signed by both parties. This includes a price agreed upon between both parties which is paid by the eventual incumbent of the easement to the landholder. This is a time consuming process, however verbal agreements can be established in the interim so that design can continue whilst the contract is being drafted up.
- Terrain. In most cases the avoidance of high elevations is encouraged so to reduce the required lift of the pumps. This adds to operational costs as well as the requirement for surge tanks and break pressure tanks in some instances. Pipe class can be affected in the initial sections of the pipeline due to the pump having to create a high lift if terrain is extremely undulating. Rises in pipe class also adds to the cost which needs to known for consideration in the pipeline optimisation.

DECISION SUPPORT SYSTEM FOR ASSESSING THE BENEFITS OF INSTALLING SWABBING FACILITIES INTO WATER PIPELINES AT THE DESIGN STAGE

FLOWCHART

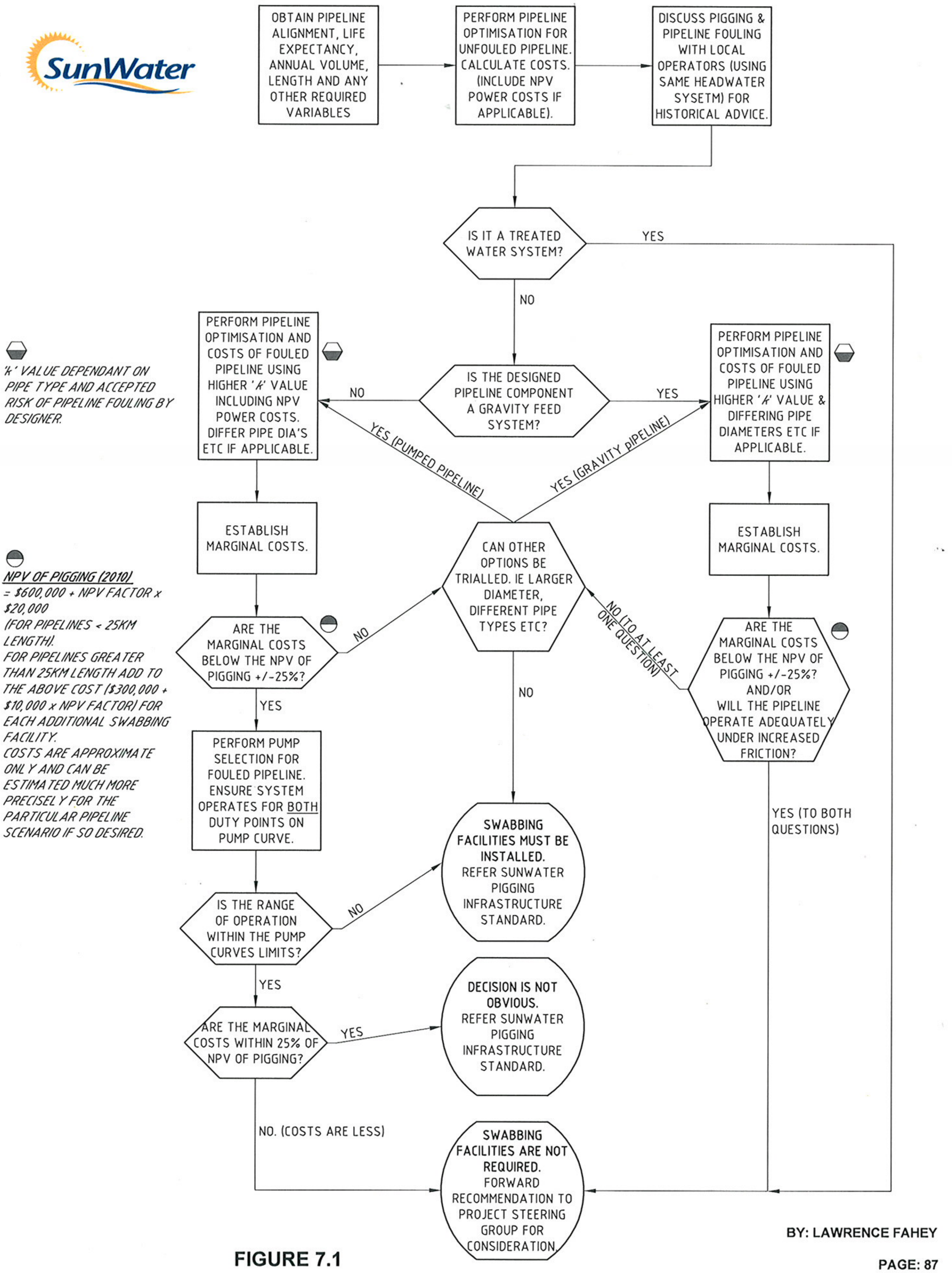

FIGURE 7.1

BY: LAWRENCE FAHEY

Environmental and Vegetation Approvals. Alignments must avoid some areas due to their protection under the Environmental Protection Agency legislation.

- Cultural Heritage and Native Title. Traditional owners of the land in some instances, have to be contacted for approval of the pipeline alignment. This too can be a long process, especially where native title is concerned.
- Pump station locations are also a complex process which also must go through the above approval processes. They also need to acquire River Protection Permits from the Environmental Protection Agency. Not to mention that the depth of the river must be stable and deep enough to ensure all year round availability of water.

Due to the many factors involved in pipeline alignment selection it is critical that it be established before going through the decision support system for swabbing facility incorporation. This will avoid a repeat of the process if and when the pipeline alignment changes and ultimately affects the required duty points of the pump due to terrain and length changes.

Following this all other variables can be established including pipeline length, terrain, flow rates, and agreement on the pipeline life expectancy.

The flowchart then progresses to the optimisation of a normally operating pipeline. This includes all operational costs and establishment of the adopted pipeline diameter, or diameters if the optimisation discovers that a drop in size somewhere along the pipeline is cost effective. Remember that the normally recommended design *k* value should be adopted for the optimisation process.

At this point the pipeline operators existing in the area local to the designed pipeline should be contacted. Discussions with operators of pipelines extracting from the same headwater source would be extremely beneficial. Questions pertaining to the pigging of this existing pipeline should be asked. Not to mention questions regarding the rate of pipeline fouling, type of biofilm, experiences with pigging and the availability of monitoring data for a prediction on pipeline fouling.

At this point it is important to acknowledge whether the pipeline is a treated system or not. Research conducted on pipeline operators has indicated that treated water systems do not require pigging. Thus the decision support system can cease here. An answer of 'Yes' takes the designer immediately to a decision of 'Swabbing Facilities are not required'.

The next step can follow two directions.

7.2.2 Gravity Feed System

An answer of 'No' to the questions below leads to a query regarding the type of pipeline system that will be designed. The question is 'Is the designed pipeline component a Gravity Feed system?'. The term component is important. In the case of an existing pipeline being added to by this designed pipeline, the designer is to only consider the pipeline components under design.

If the answer is 'Yes' the designer is directed to the right hand side of the flowchart. From here an optimisation is performed using a *k* value of a fouled pipeline. The process follows a similar path to that performed in the analysis in chapter 6.0. It is important to mention that the adopted *k* value is dependant on the pipe type being used in the optimisation. It is also subject to an assessment of acceptable risk by the designer. In the analysis in chapter 6.0 a *k* value of 2.0mm was adopted for DICL pipe. If considered acceptable the designer can choose a *k* value for optimisation analysis lower than that.

The designer now has two cost estimates. The first is that established under a normally operating pipe. The second is the one that has just been completed on a fouled pipe. By subtracting the two values the designer obtains a marginal cost.

These marginal costs are compared with the NPV of pigging. The NPV of pigging is described within the flowchart as being $600,000 + NPV factor x $20,000. The $600,000 has been determined in appendix G as the cost of two swabbing facilities for a 750 diameter pipeline. The cost of $20,000 has been determined to be the cost of pigging a pipeline of 25km or less. For a pipeline of length greater than 25km the formula changes. The designer must add a cost of \$300,000 + \$10,000 for each additional 25km of pipeline (or extra swabbing facility required). The reasoning for these requirements were stipulated within chapter 6.0.

The logistics of the cost of the NPV of pigging can be altered by the designer. The particular pipeline may be smaller or larger in diameter and thus a more accurate cost estimate can be created. However, the amount of pigging that can be done in one day must be acknowledged in the creation of the NPV of pigging to ensure accuracy of the operational process costs.

In the case of gravity pipelines the marginal costs will not be different because there are no operational costs involved, ie pumping. The designer is simply ensuring that by using a higher *k* value, that the design criteria are not compromised. An example of this may be that the friction within the pipe increases to such a large degree that water cannot get to the end of the pipeline due to the heads inability to overcome terrain.

If the pipeline will fail to adequately perform under the increased friction the user is encouraged to consider the performance of another optimisation of a fouled pipeline design. An example may be that the normal optimisation considered it appropriate to have, 500 diameter pipe for the first half of the pipeline. The pipeline may reduce in diameter to 375 diameter pipe at this point until the end.

The re-optimisation may look at having 500 diameter pipe for the entire length of the pipeline, which will reduce the pressure of the pipeline but will increase the marginal cost of the two scenarios. The user then cycles back through the same steps and returns to the questions asking if the marginal costs are less than the NPV of pigging, and if the pipeline will function adequately.

If the answer is 'Yes' to both these questions, then the user is informed that swabbing facilities are not required. This decision should then be taken to the project steering group. A project steering group, in large design companies, is usually formed in the initial stages of the pipeline design process. They make decisions based on findings throughout the design such as this. They act on advice given from appropriate representatives, with the projects scope and objectives in mind.

If the answer is "No' once again and the designer cannot perform another optimisation, they are informed that swabbing facilities must be installed. This decision is also another difficult one given the many variances of swabbing facility arrangements. Fortunately the flowchart directs the user to a SunWater standard that is currently being created. This standard uses the marginal cost established from this decision support system. The marginal cost will become the 'budget' for swabbing facilities. Within the standard different arrangements are available each with a cost estimate. The user can compare the marginal cost to these arrangements and adopt the most affordable.

7.2.3 Pumped Pipeline

Refer back to when the user is asked if the pipeline design component is a gravity feed system. If at this point if the user answers 'No' to this question, the flowchart directs the designer to perform an optimisation of their pumped pipeline.

This optimisation will include costs for the NPV of pumping. Once the marginal cost are established the user is asked to compare the marginal costs against the NPV of pigging. It must be remembered that the NPV of pigging cost estimates can be reviewed if deemed necessary. If the costs are more than the NPV of pigging, +/-25%, the user is asked to review the optimisation once again. Similar to the gravity system the user may choose to adopt larger pipe diameters to reduce operational costs, or adopt smaller pipe to reduce capital costs. Remember that an optimised pipeline design is the best combination of capital and operational expenditure. The user can perform this optimisation as many times as deemed pracitical.

If the user returns to the question asking whether the marginal costs are less than the NPV of pigging, and the answer is "No', and considers that all possible design avenues have been explored, they are informed of a decision. Swabbing facilities are considered necessary and the user is directed to the SunWater standard for pigging infrastructure.

If the answer is 'Yes' the user is reminded that the pumps must operate adequately and thus are requested to analyse the data against a pump curve. The pump curve can be generated from a pump selection software. The user should select an operating point using a fouled pipeline. When the pump curve is generated it should be investigated to ensure an adequately operating pump for both ranges of operations, fouled and unfouled. It is important that the pump be selected to run in a fouled state initially. This will ensure that as the pump fouls, flow rate requirements are not compromised.

If the pump cannot operate in both ranges the user is requested to refer to the pigging infrastructure standard for selection of appropriate infrastructure. If the pump can operate in both ranges the user is asked about the marginal costs once again. If the marginal costs are within 25% of the NPV of pigging the pigging infrastructure standard is referenced once again. This is because the decision is not completely obvious.

If the marginal costs are well below the NPV of pigging then swabbing facilities are considered unnecessary. The designer is encouraged to pass this information onto the project steering group for a formal and justified decision.

7.3 SUMMARY

The flowchart documents the step by step procedure quite well. It is recommended that this section of the report be referenced if any confusion exists when executing the decision support system.

There are other variables to consider as well when making decisions that are not quite obvious to the designer. These will be discussed in the next section. However from a financial perspective, the decision support system will become a very useful tool.

8.0 CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

8.1 CONCLUSIONS

This research has uncovered some very interesting findings. Its scope was reasonably broad as well. It considered the effects pigging has on pipeline operation. There is no doubt that pigging in some cases is a necessary and beneficial art.

However, it also found that pigging in some cases, can be avoided. This was reinforced in studies by Lambert el al. (2009), Barton (2008) and JLR Engineering (2006) that biofilm growth does eventually peak. This encouraged the theory that there was a possibility to exclude swabbing facilities from some pipeline designs, as long as it was accounted for within the determination of the cost estimation and pipeline functioning.

The visit to Rockhampton to review the pigging of Stanwell pipeline was extremely beneficial. The major findings were an appreciation for the pigging process and what was involved in the organisation and cost of such an operation. It also established a prediction into the estimation of the maximum pipe roughness height for Stanwell Pipeline. This predicted value installed confidence that the adopted maximum *k* value for the analysis was conservative and thus ensured a theoretical, fully operational pipeline.

The questionnaire conducted upon several pipeline operators around the country established some excellent anecdotal insight into the affects of pigging and its benefits, or lack there of. Some of the more commonly suggested advice was adopted for inclusion into the decision support system.

The analysis of several pipeline scenarios suggested that from a financial perspective there is definitely a method to justify the omission of swabbing facilities in some cases. From this analysis a flow chart was able to be created to help a designer make this decision with financial justification.

There are some things to consider when, after performing the optimisation by using the flowchart, the decision to install swabbing facilities is still not clear. These are:

- That pigging using a disc pig can damage the internal lining of cement lined pipes;
- That swabbing (pigging using a high density foam device) is not as efficient as cleaning the internal walls as disc pigs. Not withstanding the fact that disc pigs do cause damage to the internal walls as suggested above;
- That the adopted *k* value, by the designer, for use as the maximum pipe roughness height has a large bearing on the eventual marginal costs. Care must be taken not to manipulate the outcome by using a very low, maximum value, purely to argue the exclusion of the swabbing facilities. Nor is it ideal to adopt an extremely high *k* value, as done so in the analysis within this dissertation, due to the impractical and probably unlikely variance in marginal costs. The decision on what *k* value should warrant careful and knowledgeable engineering to ensure an appropriate analysis result.
- The decision support system compares a normally operating pipeline against an immediately fouled pipeline. This is an impractical scenario because as suggested from the conducted research, pipeline fouling occurs over time. This means that the calculated operational costs are higher than would what exist in reality due to the impractical suggestion that the pipeline would immediately foul. Therefore this is another example that the decision support tool is recommending marginal costs that would most likely be on the high side of reality and should be taken into consideration.

Therefore in circumstances when the decision to include swabbing facilities is not clear cut, the above should strongly be considered. More often than not, other than in circumstances where local operators offer advice that confidently recommends pigging as a necessity, swabbing facilities would be excluded in these unobvious cases.

This research has observed the hydraulic affects pigging has on pipelines. It has also determined an analysis tool that predicts the financial repercussions pipeline fouling has on a pipeline. Utilisation of the tool gives justification to decisions, at the design stage, regarding the installation of swabbing structures. In cases where the tool establishes the recommendation of swabbing facility installation within the pipeline, from this point forward this can no longer be viewed as a wasted investment.

8.2 RECOMMENDATIONS FOR FUTURE RESEARCH

Further research could assist in the following areas:

- The creation of a further decision support system to assist in the selection of a swabbing facility most appropriate for the available 'budget'. This support tool would be applicable after utilising the system designed in this report. The initial system would evaluate a budget for swabbing infrastructure and operation costs which is the marginal cost established between a fouled and unfouled pipeline. The extra support tool would remove the painstaking process of negotiating what would be considered a reasonable structure whilst taking price, frequency of use and safety into account.
- A study into an indicator of biofilm growth within pipelines. This would act as a predictor for pipeline fouling taking water quality, turbidity, temperature, pipeline environment and otherwise into account. If the rate of fouling can be predicted a more accurate assumption of the financial repercussions could be established.
- It is recommended that further study into the effects pipeline fouling has on different pipe types should be investigated.. This could include the obtaining of data suggesting average maximum *k* values for different pipe types. This would further enhance the decision support system and potentially reduce marginal costs by using lower, more practical and confident pipe roughness height values for pipeline fouling.

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APPENDIX A

PROJECT SPECIFICATION

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG4111/4112 RESEARCH PROJECT

PROJECT SPECIFICATION

FOR:	**LAWRENCE FAHEY**
TOPIC:	DECISION SUPPORT SYSTEM FOR ASSESSING THE BENEFITS OF INCORPORATING SWABBING FACILITIES INTO WATER PIPELINES
SUPERVISORS:	Dr. Malcolm Gillies Dr. Vasanthadevi Aravinthan (co-supervisor) Mr Dan Coutts, SunWater Ltd.
ENROLMENT:	ENG 4111 – S1, EXT, 2010; ENG 4112 – S2, EXT, 2010
PROJECT AIM:	To create a decision support tool for water pipeline design that assesses the benefits of swabbing and determines whether pipe swabbing structures are necessary.
SPONSORSHIP:	SunWater Ltd.
PROGRAMME:	**Issue D, 22nd September 2010**

1. Research the theoretical benefits of swabbing and gather information from similar projects within SunWater, other Water Authorities in Australia (Public and Private) and USQ's library.
2. Design and carry out field experiment(s) to capture data and consequentially measure the effects on hydraulic performance before and after a swabbing procedure,
3. Discuss with operator/maintainers of the swabbed pipeline to establish anecdotal reasoning and evidence for the frequency of swabbing the pipeline.
4. Conduct a survey of various pipeline operator/maintainers around the country to establish a database of pipelines that do get swabbed and for what reasons.
5. Perform a cost benefit analysis comparing a normally operating pipe against a pipe that has been fouled.
6. Compare the cost benefit analysis against available variables such as pipe material, diameter, length, head pressures, pumping power costs and otherwise.
7. Create a decision making tool for determining the economic benefits for swabbing of water pipelines to be used during the design stage. This will take account of the initial capital cost of including the swabs, the operational costs and the potential power savings, or otherwise over the life of the pipeline. It will be in the form of a schematic flow chart.

As time permits:

8. Determine the effects water quality, temperature and otherwise has on the growth on the internal lining of pipelines.

AGREED:

L. Fahey (Student) M. Gillies, D. Coutts (Supervisors)

6/10/2010 6/10/2010 6/10/2010

Examiner/Co-examiner: **APPROVED**

APPENDIX B

STANWELL MONITORING DATA

STANWELL PIPELINE & PUMP STATION MONITORING

SunWater-Operations & Maintenance

Month: July **YEAR - 2010**

DATE	WATER PUMPING DETAILS				ENERGY CONSUMPTION			PUMP HOURS			PUMPING PERFORMANCE				PIPELINE PERFORMANCE		
	PUMP STATION METER (ML)	END METER (ML)	G.Ht RIVER (AHD)	G.Ht STANWELL (AHD)	ENERGY USED (kWh)	Motor Load (kW)	ENERGY PER ML (kWh/ML)	PUMP NO	RUN TIME	HOURS PER ML (hrs/ML)	AVERAGE SUCTION (m)	AVERAGE DISCHARGE (m)	STATIC HEAD (m)	ACTUAL EFFIC. (%)	AVERAGE VELOCITY (m/s)	FRICTION LOSS (m)	HAZEN-WILLIAMS (C)
1	33.005	32.609	3.721	86.326	17,607	1,788	539.9	1&2	9.85	0.302	7.68	168.33	82.61	84.4	1.598	78.05	118.8
2	27.360	26.921	3.707	86.248	14,621	1,821	543.1	2	8.03	0.298	8.05	169.14	82.54	84.1	1.618	78.55	119.9
3	80.649	79.511	3.707	86.388	42,945	1,809	540.1	1&2	23.74	0.299	7.63	167.88	82.68	84.1	1.617	77.57	120.6
4	80.622	79.385	3.714	86.552	42,563	1,773	536.2	1	24.00	0.302	7.20	166.32	82.84	84.2	1.597	76.28	120.2
5	80.700	79.498	3.737	86.677	42,751	1,781	537.8	1	24.00	0.302	7.20	166.26	82.94	83.9	1.599	76.12	120.5
6	25.983	25.677	3.741	86.680	13,826	1,784	538.5	1&2	7.75	0.302	7.65	168.27	82.94	84.6	1.599	77.68	119.2
7	29.168	28.805	3.766	86.483	15,476	1,783	537.3	1&2	8.68	0.301	7.66	168.23	82.72	84.7	1.602	77.85	119.3
8	27.422	27.025	3.789	86.456	14,673	1,827	542.9	2	8.03	0.297	8.09	168.95	82.67	84.0	1.624	78.19	120.6
9	27.418	26.913	3.766	86.403	14,653	1,825	544.5	2	8.03	0.298	8.10	169.01	82.64	83.8	1.618	78.27	120.1
10	81.070	79.901	3.699	86.563	43,147	1,817	540.0	1&2	23.74	0.297	7.62	167.81	82.86	84.1	1.625	77.33	121.4
11	81.002	79.786	3.707	86.715	42,700	1,779	535.2	1	24.00	0.301	7.17	166.56	83.01	84.5	1.605	76.38	120.7
12	29.073	28.683	3.721	86.665	15,356	1,775	535.4	1&2	8.65	0.302	7.62	168.34	82.94	85.1	1.601	77.78	119.3
13	41.572	39.953	3.729	86.665	21,643	1,796	541.7	1	12.05	0.302	7.05	163.36	82.94	81.8	1.600	73.37	123.0
14	29.261	28.835	3.745	86.613	14,585	1,828	505.8	1	7.98	0.277	6.54	153.94	82.87	82.6	1.744	64.53	143.7
15	29.365	28.958	3.774	86.574	14,613	1,822	504.6	1	8.02	0.277	5.58	152.55	82.80	82.6	1.743	64.17	144.0
16	29.369	28.984	3.782	86.537	14,600	1,820	503.7	1	8.02	0.277	5.62	152.59	82.76	82.7	1.744	64.22	144.1
17	84.352	83.180	3.804	86.739	41,832	1,820	502.9	1	22.98	0.276	5.57	152.59	82.94	82.9	1.747	64.09	144.5
18	26.420	26.042	3.812	86.725	13,069	1,810	501.8	1	7.22	0.277	5.60	152.74	82.91	83.1	1.741	64.23	143.8
19	25.289	24.877	3.796	86.680	12,556	1,825	504.7	1	6.88	0.277	5.61	152.76	82.88	82.7	1.745	64.27	144.1
20	28.122	27.720	3.751	86.620	13,994	1,822	504.8	1	7.68	0.277	5.57	152.61	82.87	82.6	1.742	64.17	144.0
21	29.315	28.921	3.699	86.554	14,584	1,818	504.3	1	8.02	0.277	5.54	152.49	82.86	82.6	1.741	64.10	144.0
22	29.317	28.925	3.707	86.486	14,573	1,817	503.8	1	8.02	0.277	5.53	152.45	82.78	82.7	1.741	64.14	143.9
23	29.321	28.945	3.714	86.425	14,619	1,823	505.1	1	8.02	0.277	5.53	152.55	82.71	82.5	1.742	64.31	143.8
24	87.972	86.592	3.737	86.592	43,760	1,823	505.4	1	24.00	0.277	5.52	152.49	82.86	82.5	1.741	64.12	143.9
25	83.156	81.930	3.751	86.734	41,335	1,821	504.5	1	22.70	0.277	5.50	152.63	82.98	82.7	1.742	64.15	144.0
26	25.204	24.814	3.751	86.652	12,544	1,818	505.5	1	6.90	0.278	5.54	152.86	82.90	82.6	1.736	64.42	143.2
27	29.276	28.812	3.766	86.579	14,600	1,820	506.7	1	8.02	0.278	5.53	152.82	82.81	82.4	1.734	64.48	142.9
28	29.292	28.699	3.782	86.509	14,574	1,817	507.8	1	8.02	0.279	5.56	152.80	82.73	82.2	1.727	64.51	142.3
29	29.285	28.640	3.789	86.446	14,549	1,814	508.0	1	8.02	0.280	5.57	152.82	82.66	82.2	1.724	64.59	142.0
30	29.280	28.816	3.789	86.359	14,537	1,813	504.5	1	8.02	0.278	5.57	152.78	82.57	82.7	1.734	64.64	142.7
31	87.797	86.493	3.789	86.512	43,653	1,819	504.7	1	24.00	0.277	5.56	153.00	82.72	82.8	1.739	64.72	143.1
TOTAL	1,386.437	1,364.850			710538	56,111			393.07								
AVE						1,870	519.4			0.287	6.44	158.97	82.80		1.684	69.72	133.8

Comments - When pumps run for small periods of time, (kWh/ML), (hrs/ML) & other performance indicators are not always representative.
Thus indicated by N/A - Not Applicable. This is due to pump flow and energy not having sufficient time to stabilise.

On the 01st Pump No 1 -7.23 hours & Pump No 2 - 2.62 hours.
On the 03rd Pump No 1 - 5.22 hours & Pump No 2 - 18.52 hours.
On the 6th Pump No 1 - 7.70 hours & Pump No 2 - 0.05 hours.
On the 7th Pump No 1 - 7.58 hours & Pump No 2 - 1.10 hours.

On the 10th Pump No 1 - 2.07 hours & Pump No 2 - 21.67 hours.
On the 12th Pump No 1 - 8.10 hours & Pump No 2 - 0.55 hours.
Note: Pipeline Ppigging carried out on the 13th July

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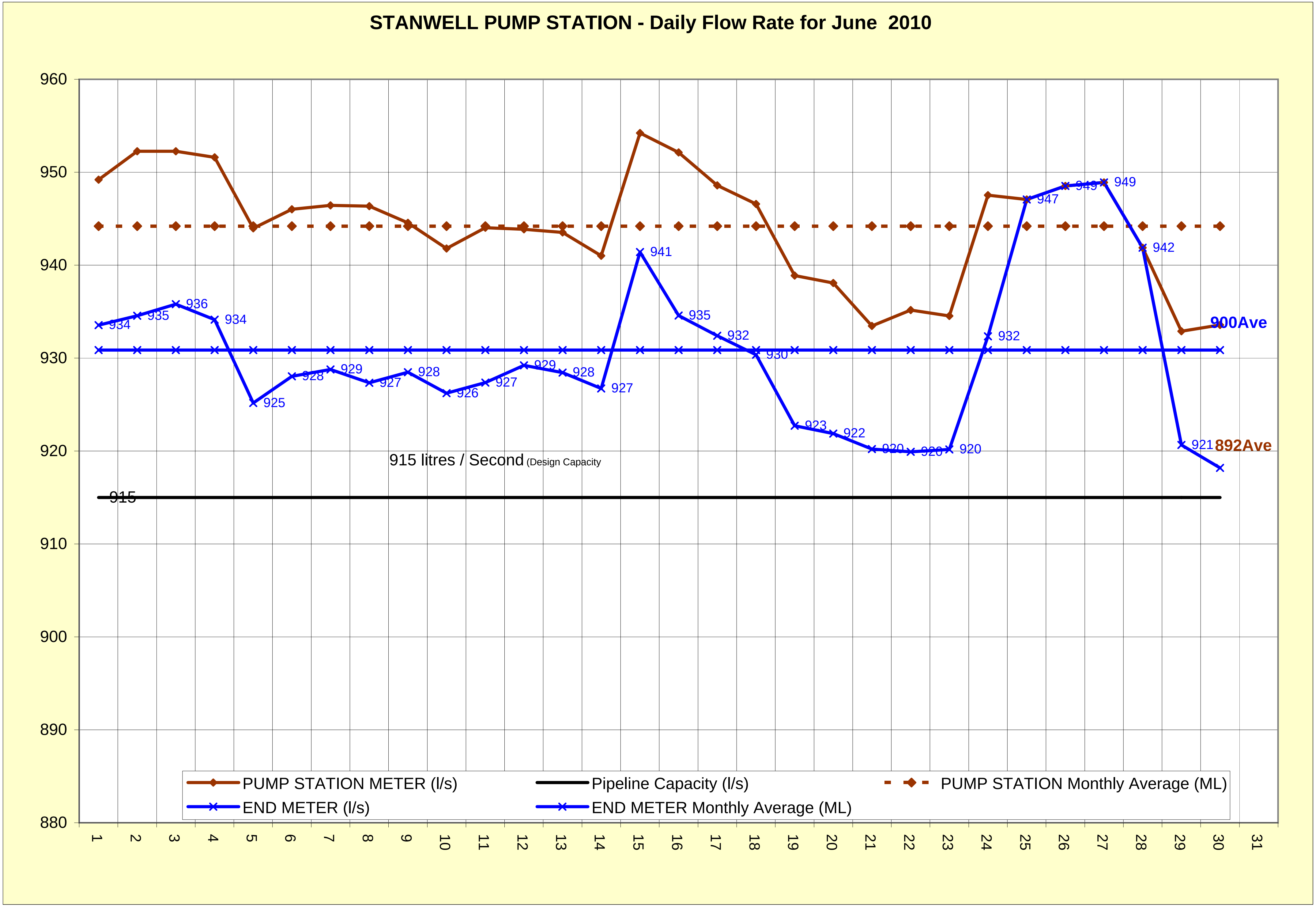

STANWELL PUMP STATION - Daily Flow Rate for June 2010
960
950
940
930
920
910
900
890
880
934
935
936
934
925
928
929
927
928
926
927
929
928
927
941
935
932
930
923
922
920
920
920
932
947
949
949
942
921
900Ave
892Ave
915 litres / Second (Design Capacity
915
PUMP STATION METER (l/s)
Pipeline Capacity (l/s)
PUMP STATION Monthly Average (ML)
END METER (l/s)
END METER Monthly Average (ML)
1
2
3
4
5
6
7
8
9
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STANWELL PIPELINE & PUMP STATION MONITORING

SunWater-Infrastructure Management **Month: June** **YEAR - 2010**

DATE	WATER PUMPING DETAILS				ENERGY CONSUMPTION			PUMP HOURS			PUMPING PERFORMANCE				PIPELINE PERFORMANCE		
	PUMP STATION METER (ML)	END METER (ML)	G.Ht RIVER (AHD)	G.Ht STANWELL (AHD)	ENERGY USED (kWh)	Motor Load (kW)	ENERGY PER ML (kWh/ML)	PUMP NO	RUN TIME (hrs)	HOURS PER ML (hrs/ML)	AVERAGE SUCTION (m)	AVERAGE DISCHARGE (m)	STATIC HEAD (m)	ACTUAL EFFIC. (%)	AVERAGE VELOCITY (m/s)	FRICTION LOSS (m)	HAZEN-WILLIAMS (C)
1	27.508	27.054	3.750	86.630	14,645	1,819	541.3	2	8.05	0.298	8.09	168.50	82.88	84.0	1.622	77.53	121.0
2	27.528	27.016	3.691	86.501	14,643	1,824	542.0	2	8.03	0.297	8.11	168.44	82.81	83.9	1.624	77.52	121.2
3	27.528	27.052	3.714	86.442	14,640	1,823	541.2	2	8.03	0.297	8.02	168.38	82.73	84.0	1.626	77.63	121.2
4	27.509	27.004	3.744	86.377	14,636	1,823	542.0	1&2	8.03	0.297	7.67	167.49	82.63	83.6	1.623	77.19	121.4
5	81.558	79.934	3.789	86.528	42,729	1,780	534.6	1	24.00	0.300	7.29	165.77	82.74	84.1	1.608	75.74	121.5
6	81.735	80.182	3.766	86.662	42,731	1,780	532.9	1	24.00	0.299	7.29	165.42	82.90	84.1	1.613	75.23	122.3
7	47.189	46.309	3.721	86.680	24,698	1,783	533.3	1	13.85	0.299	7.25	165.19	82.96	84.0	1.614	74.98	122.6
8	26.846	26.307	3.707	86.599	14,074	1,786	535.0	1	7.88	0.300	7.23	165.68	82.89	84.0	1.611	75.56	121.9
9	27.203	26.740	3.707	86.544	14,269	1,784	533.6	1	8.00	0.299	7.20	165.44	82.84	84.1	1.613	75.40	122.2
10	27.293	26.842	3.710	86.540	14,313	1,778	533.2	1	8.05	0.300	7.21	165.62	82.83	84.2	1.609	75.58	121.7
11	27.358	26.875	3.751	86.400	14,311	1,778	532.5	1	8.05	0.300	7.24	165.75	82.65	84.4	1.611	75.86	121.6
12	81.550	80.284	3.766	86.526	42,660	1,778	531.4	1	24.00	0.299	7.27	165.83	82.76	84.6	1.615	75.80	122.0
13	81.521	80.217	3.789	86.680	42,677	1,778	532.0	1	24.00	0.299	7.30	165.91	82.89	84.5	1.613	75.72	121.9
14	37.671	37.099	3.759	86.670	19,818	1,782	534.2	1&2	11.12	0.300	7.68	167.48	82.91	84.8	1.610	76.89	120.7
15	24.493	24.164	3.710	86.410	12,995	1,823	537.8	2	7.13	0.295	8.07	168.28	82.70	84.5	1.636	77.51	122.1
16	27.010	26.512	3.699	86.539	14,400	1,827	543.2	2	7.88	0.297	8.02	168.54	82.84	83.8	1.624	77.68	121.1
17	27.490	27.021	3.707	86.488	14,662	1,821	542.6	2	8.05	0.298	8.02	168.40	82.78	83.8	1.620	77.60	120.8
18	27.432	26.962	3.713	86.401	14,619	1,816	542.2	1&2	8.05	0.299	7.74	167.59	82.69	83.6	1.617	77.16	121.0
19	81.120	79.723	3.752	86.567	42,709	1,780	535.7	1	24.00	0.301	7.34	166.51	82.82	84.2	1.603	76.36	120.6
20	81.050	79.650	3.768	86.620	42,669	1,778	535.7	1	24.00	0.301	7.33	166.62	82.85	84.3	1.602	76.44	120.5
21	23.187	22.858	3.710	86.490	12,258	1,777	536.3	1	6.90	0.302	7.34	166.99	82.78	84.4	1.599	76.87	119.9
22	27.000	26.560	3.759	86.576	14,240	1,776	536.1	1	8.02	0.302	7.33	166.79	82.82	84.3	1.598	76.64	120.0
23	26.982	26.567	3.721	86.488	14,288	1,782	537.8	1&2	8.02	0.302	7.69	168.31	82.77	84.7	1.599	77.85	119.0
24	27.391	26.952	3.699	86.435	14,642	1,823	543.3	2	8.03	0.298	8.05	169.05	82.74	84.0	1.620	78.26	120.3
25	27.378	27.378	3.707	86.391	14,619	1,821	534.0	2	8.03	0.293	8.03	169.16	82.68	85.6	1.646	78.45	122.0
26	81.953	81.953	3.729	86.610	43,665	1,819	532.8	2	24.00	0.293	8.06	169.16	82.88	85.7	1.648	78.22	122.4
27	81.985	81.985	3.751	86.670	43,635	1,818	532.2	2	24.00	0.293	8.09	169.12	82.92	85.8	1.649	78.11	122.5
28	31.432	31.432	3.774	86.590	16,765	1,809	533.4	1&2	9.27	0.295	7.71	168.27	82.82	85.4	1.637	77.74	122.0
29	26.162	25.819	3.789	86.480	13,855	1,779	536.6	1&2	7.79	0.302	7.80	168.04	82.69	84.7	1.600	77.55	119.4
30	26.954	26.510	3.759	86.381	14,271	1,779	538.3	1	8.02	0.303	7.31	167.05	82.62	84.1	1.595	77.12	119.4
31																	
TOTAL	1,279.016	1,260.961			675136	53,922			376.28								
AVE						1,797	536.6			0.299	7.63	167.29	82.79		1.617	76.87	121.2

Comments - When pumps run for small periods of time, (kWh/ML), (hrs/ML) & other performance indicators are not always representative.
Thus indicated by N/A - Not Applicable. This is due to pump flow and energy not having sufficient time to stabilise.

On the 4th Pump No 1 - 0.88 hours & Pump No 2 - 7.15 hours.
On the 29th Pump No 1 - 7.77 hours & Pump No 2 - 0.02 hours.
On the 14th Pump No 1 - 10.22 hours & Pump No 2 - 0.90 hours.
On the 18th Pump No 1 - 0.88 hours & Pump No 2 - 7.13 hours.
On the 23rd Pump No 1 - 7.12 hours & Pump No 2 - 0.90 hours.
On the 28th Pump No 1 - 0.62 hours & Pump No 2 - 8.65 hours.

APPENDIX C

STANWELL PIPELINE PIGGING PROCEDURE AND WORK METHOD STATEMENT

METHODOLOGY FOR PIGGING OF STANWELL PIPELINE

1. Confirm with Ergon Energy, that there are no planned interruptions to Stanwell Pump Station supply on the date of pigging.
2. Notify Stanwell Power Station time and date of pigging and that water supply will be interrupted for the day.
3. Notify all consumers in advance of the pipeline shutdown.
4. The water level in the Stanwell Dam must be above EL 80.0m and below EL 86.7m to allow for water pumped while pigging and the refilling of the surge tank.
5. Isolate and tag both Stanwell main pumps.
6. Close the 900mm sluice valve and confirm that the bypass valve is closed at Chainage 123m.
7. Open the scour located in the swabbing pit at Chainage 123m.
8. Loosen the Straub coupling located in the swabbing pit at Chainage 123m.
9. Remove the spool piece from the pipeline swabbing at chainage 123m
10. Insert the pig into the spool piece and replace the spool into the pipeline with use of a mobile crane.
11. Open the 200mm bypass valve at Chainage 123m and fill the pipe.
12. Open the 900mm sluice valve at Chainage 123m.
13. Check every person is aware of their responsibilities and the communications are functioning correctly.
14. Close the consumer offtakes along the pipeline.
15. Remove tags and start main pump manually from the control room.
16. Monitor progress of the pig at air valves.
17. The downstream scour outlets can be opened as the pig passes the preceding air valves. The scours to be opened will be at Chainages 6.4km, 12.7km, 18.5km and 27.2km. The scour will be opened when directed by the person monitoring the pig at the preceding air valve. By watching the water you will notice the colour change to very dirty as the pig approaches. You may hear the pig or see

an interruption in the flow as the pig passes. The water will then start to clear and the scour can then be closed.

Clear water coming out of scour prior to pig arriving.

Colour of water out of scour as pig is passing this location.

Water clearing after pig has passed scour location.

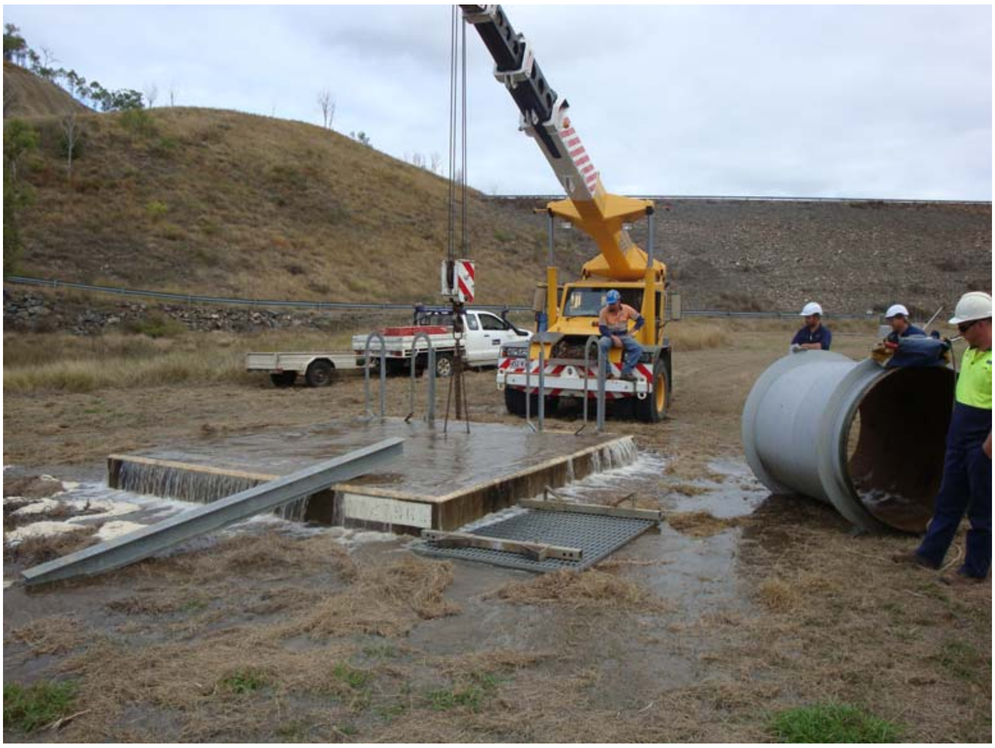
18. The pump station operator notified of pigs arrival at scour valve Chainage 27.2km and prepare to stop pumps.
19. Close the 900mm butterfly valve and 200mm bypass valve in the Stanwell Valve pit at Chainage 27.7km.
20. Open the scour valve at Chainage 27.7km and open the 25mm gate valve in the swabbing pit at Chainage 27.7km to observe drop off in pressure to a safe level to enable removal of Straub-flex couplings.
21. Close scour at Chainage 27.2km then loosen Straub-flex couplings at the swabbing spool piece and drain all water from the pipeline. The head from the surge tank may propel the pig to the swabbing pit location for retrieval.
22. Remove the swabbing pit spool piece and the spool support beams, block the down stream pipe with a bulkhead such as timber or pit grating to stop the pig from entering.
23. When it is safe the pump operator will be notified to start the pump manually and allow it to run until he is told to shut it off.

24. After arrival of the pig the pump may be left running for a short time to allow the water to clear before the stop signal is given.

Water clearing at downstream end catching pit. Walkway grate put in place to stop pig going down remaining 100m of pipeline.

Water getting dirtier.

Arrival of pig.



Overflow of pit until water clears up.

25. Stop and isolate pumps.
26. Retrieve pig and replace spool supports and the spool piece in the pipeline and shut off the 25mm drain valve.
27. Open the 200mm bypass valve in the Stanwell Valve Pit and fill the pipeline and surge tank at Chainage 15.0m.
28. Consumer offtakes can be returned to normal after the pig has passed.
29. Open the 900mm butterfly valve in the Stanwell Valve Pit and leave the 200mm bypass valve open before returning pipeline to normal operation.

Job Name: (Format: Job Location and Description): Lawrence Fahey USQ Research Project	***Work Order Number:N/A***
Site Supervisor (person in control on site):????????	***Work Commencement Date:???????***

1. Check Job Supervisor Responsibilities – completed by Job Supervisor

	Signature & Date
A. This Work Method Statement and the separate Permit, where applicable have been reviewed and communicated to all employees and contractors involved in the job.	
B. SunWater staff have been trained and are competent to carry out this job safely. An untrained person must NOT [insert any restrictions].	
C. Contractors engaged to perform this work have provided evidence of training and current competency, and copies of their Risk Assessment or Work Method Statement and Permit as applicable. If Contractors are undertaking this work in conjunction with SunWater employees, this Work Method Statement [and Permit if applicable] will apply.	

D. PPE&C has been checked prior to entry and is in good condition.	**PPE&C/Safety Equipment Required**	**PPE&C checked and in good condition (Signature Required)**	**PPE&C/Safety Equipment Required**	**PPE&C checked and in good condition (Signature Required)**
WHAT PPE&C and SAFETY EQUIPMENT IS REQUIRED FOR THIS SITE/JOB?	☒ Barricades and warning signs		☒ Mechanical lifting aids	
	☒ Broad brim hat		☐ Overalls	
	☐ Carry bag, rope		☐ Overalls for chemical use	
	☒ Communications equipment		☒ Personal flotation device (life jacket)	
	☐ Dustmask /vapour mask		☐ Personal isolation lock and key	
	☐ Ear muffs/plugs		☐ Rescue equipment	
	☒ Eye protection (clear or tinted)		☐ Respiratory protection/Breathing Apparatus	
	☒ First aid kit		☒ Safety footwear	
	☐ Fire extinguisher		☐ Safety harness and lines	
	☐ Fire blanket		☐ Shade protection	
	☒ Full coverage clothing		☒ Sunscreen, lip balm	
	☐ Gas detector		☐ Rubber boots	
	☐ Gloves - chemical		☐ Torch and batteries, neon sticks	
	☒ Gloves - cotton/leather		☒ Water	
	☐ Hard hat and chin strap		☐ Wasp/ant Spray	
	☐ Hi vis vest		☐ Other (List)	
	☐ Lights			

E. Is a Permit required?	☐ **Yes** / ☐ **No**	**If Yes, insert type of Permit**	

**Notes: Air-supplied breathing apparatus is only to be used by trained, competent personnel. No compressed air or liquid gas cylinders are to be taken into the confined space.*

2. IDENTIFY THE HAZARDS – PRELIMINARY ASSESSMENT. Consider and mark ALL hazards associated with the specific job tasks, the equipment that will be used in the job, the infrastructure, and the surrounding work environment.

WHAT ARE ALL OF THE POTENTIAL HAZARDS?	☐ Air Pollutants	☐ Excavation/Engulfment	☐ Fish Stranding	☐ Noise	☐ Tools
	☐ Air Pressure	☐ Eye Irritation/Injury	☐ Gas (LPG)	☐ Overhead Wires	☐ Traffic Management Plan
	☐ Asbestos	☒ Fall hazard	☐ Heat/Cold	☐ Oxygen Low/High	☐ Underground
	☐ Chemicals	☐ Fall from Heights	☐ Hydraulic Pressure	☐ Remote Area	☐ Vapours
	☒ Confined Space	☐ Fauna bites/stings	☐ Lift/Pull/Push	☐ Restricted Access	☐ Vehicles / Pedestrians
	☐ Contaminated Air	☐ Fatigue	☐ Mobile Plant	☐ Slips, Trips, Falls	☐ Water/Drowning
	☐ Electrical	☐ Fire/explosion/ignition	☐ Moving Parts	☐ Skin Irritation	☐ Weather Conditions
	☐ Others (List)			☐ Sun Exposure	☐ Wildlife

3. DOCUMENT EACH JOB STEP, POTENTIAL HAZARDS ASSOCIATED WITH EACH JOB STEP, AND RISK CONTROL ACTIONS. You must assess the risk and document the Risk Rating prior to and after implementing risk controls. Do not proceed with the work if the risk rating, after the controls are in place, remains at HIGH or EXTREME. Risk must be reduced to at least MEDIUM before proceeding. COMPLETE AND ATTACH A RELEVANT WORK PERMIT IF APPLICABLE.

Job Step No.	Activities Required to Complete the Job	Potential Hazards (WH&S, Environment, Other)	Initial Risk Rating	Risk Control Actions	Responsibility for the Risk Control Action	Residual Risk Rating (to be inserted by Site Supervisor)
1	Preliminary Preparation	• Unidentified hazards/risks. • Contact with underground services (if excavation required). • Contact with overhead powerlines (cranes, etc). • Licences/permits required. • Adverse effects to environment • Failure of equipment, e.g. valves, etc.	Possible x Catastrophic (If Underground Electrical Services are not located) **= Extreme**	• Notify clients in advance of the pipeline shutdown/water supply shutdown timeframe. • Service/site supervisor to carry out preliminary checks for underground services (Telstra, Ergon, Dial before you dig 1100, etc) if excavation is required and overhead powerlines. • Determine type of communication (i.e. radio) to be initiated between all persons involved with the operation. • Determine type of pig to be used and necessary procedures. • Ensure Environmental Assessment is conducted (if applicable). • Assess condition of valves located along the pipe to be cleaned.	SunWater – Biloela Pipeline Pigging Organisers	

2	Onsite Preparation. Induction.	1. Contact with underground services. 2. Contact with overhead powerlines. • Electrocution/burns. • Trench collapse. • Slips, trips & falls. • Falling objects. • Danger from traffic, e.g. road traffic, railway. • Inhalation of fumes.	Possible x Catastrophic (Worst case hazard - If Underground Electrical Services are not located or traffic is not aware of workers in vicinity of road) **= Extreme**	• Onsite Supervisor to assess: o Location of underground and overhead services and works planned to avoid contact. o Safety Observer to be used when operating plant/ machinery near overhead powerlines. o Problems associated with location of any nearby structures/buildings/water courses. o Removal of overhead falling risks, eg: tree branches. o Stability of rock/soil hence the depth/width ratios of required shoring/benching/battering back. • Erect barrier mesh fencing and signage if members of the public are in vicinity of excavation or if staff leave site. • Induction of all staff/contractors on work implementation and site safety, EM22 COP for In-Stream Works (if works involve watercourse). Complete WHS 28 F1 Excavation & Digging Permit (if applicable). Relevant signage and traffic management/direction to be installed/implemented where necessary. Staff to wear high visibility (fluoro) safety vests when working near roadways. Staff to wear safety helmets when in the vicinity of operating plant and when working in excavation. Test communication equipment prior to starting.		

3	**3. Operation of Pipeline Pigging**	• Adverse Manual Handling. • Extreme build up of pressure. • Inhalation of fumes from machinery. • Confined space, e.g. swabbing pits. • Slips, trips & falls. • Temperature Extremes. • Failure of equipment. • Failing objects. • Environmental contamination.	Likely x Catastrophic (Worst case hazard - high pipeline pressure before opening pipe) **= Extreme**	• Identify entry and exit points for the pig. Ideally there should be an isolation valve on either side of the pipeline entry and exit points and as close as possible to these points. • Once pig is ready to be inserted, the pumps should be shutdown and tagged out. • Ensure all energy sources are isolated, e.g. electrical, water, etc. • When inserting pig into pipe ensure correct manual handling. When possible use mechanical aides, e.g. crane. • If any machinery (mobile) is used ensure it is located downwind to prevent fumes from entering swabbing pit, trench, etc. • Wear correct PPE (e.g. safety helmet, safety footwear, gloves, eye/ear protection, protective clothing, sun block, etc). • Ensure staff are clear of valves when pigging is in operation (i.e. failure of valve). • Maintain communications with all operators. • Ensure section of pipe removed for insertion of pig is secured (prevent rolling). • Check conditions of ladders prior to entry of swabbing pit. • Prior to entry into swabbing pit check for wasps and snakes. • Prior to entry into swabbing pits all staff to don safety helmets (hard hats) to protect from falls, bumps and falling objects. • All persons working in swabbing pit are aware of all possible hazards/risks associated with work. • Work area is kept clean and clear of falling hazards. • Barricades are installed as necessary. • If releasing pigging water through scours or pits which enter a watercourse or gully, consult Environmental staff on monitoring requirements.		
4	**4. Manual Handling and Insertion of Pig.**	• Over Strain of personnel. • Excessive time exposed to elements for divers (water) and field workers (sun).	Almost Certain x Major (Worst case hazard - if excessive handling occurs) **= Extreme**	• Ensure correct manual handling/lifting procedures are practiced. • Use mechanical lifting aides where appropriate. • Ensure correct PPE is worn (e.g. safety helmet, gloves, sun protection, safety boots, protective clothing, eye/ear protection, etc).		

5	**5. Mechanically Snigging Pig into Pipeline.**	• Backlash from rope or chain breaking. • Overloading and mechanical equipment. • Sudden release of chain or rope. • Adequate and appropriate anchor points.	Possible x Major (Worst case scenario – Chain breaks) **= High**	• Ensure all ropes and chains, etc are inspected for any damage prior to use. • Operators of machinery and other relevant staff (e.g. Doggers, Crane Operators, etc) are appropriately licenced and competent to perform task require. • Ensure all operation of plant meets the requirements of SunWater Standard WHS 14 Plant, Equipment, Mobile Plant & Machinery Safety.		
6	**6. Entry into Dissipating Chamber (if applicable).**	• Tripping hazard. • Personal injury. • Injury from sharp objects.	Possible x Critical (Worst Case Hazard - If fell into pit) **= Extreme**	• Ensure correct PPE is worn (e.g. safety helmet, gloves, sun protection, safety boots, protective clothing, eye/ear protection, etc). • All persons working in dissipating chamber are aware of all possible hazards/risks associated with work.		

7	**7. Excavation and Work in Trench (e.g. to insert pig, remove pig stuck within pipeline, etc)** **Refer WMS 8 Excavation Work > 1.5m Deep (as required)**	• Contact with underground services. • Contact with overhead powerlines. • Trench collapse/engulfment. • Person falling into excavation. • Injury caused by contact/accident with machinery. • Environmental harm including noise, air, potential Acid Sulphate soil, and cultural heritage disturbance. • Falling objects. • Inhalation of fumes. • Noise	Possible x Catastrophic (Worst Case Scenario – Trench Collapse. Contact with underground services now unlikely given appropriate steps taken before this one) **= Extreme**	• Onsite Supervisor to direct all excavation works until underground services are located. • No backhoe/excavation machinery activity whilst person(s) in trench. • All persons not involved with the excavation works are excluded from the excavation zone (barrier mesh). • Batter back/shoring/benching implemented as determined by Onsite Supervisor: o Commercially manufactured shoring to be engineer approved. o Determined batter angle must not be more than 45 degrees unless an engineer has approved a greater height in writing. o Once soil excavated, inspect for subtertian water and adjust batter angle to suit conditions. • Machinery meets Australian Standards with regards to safety of operator, registration, etc (eg: roll cage, etc). • Operators of machinery are appropriately licenced. • Machinery is operated at a safe distance from sides of excavation (vibration, weight) and preferably downwind of excavation site to reduce fumes. • Excavated material is placed away from the sides of the excavation. • Ensure workers in vicinity of excavation are wearing appropriate PPE (eye/ear protection, safety footwear, etc). • Re-check air quality prior to entry into pit. • Follow EM22 COP for In-Stream Works if excavating in watercourse. • Follow EM17 Management of Acid Sulphate Soils if lower than 5m AHD. • All persons working in trench are aware of all possible hazards/risks associated with work. • All non-essential equipment/machinery is removed from excavation vicinity as required. • Ensure exhaust fumes cannot be deposited in trench. • Work area is kept clean and clear of falling hazards. • Barricades are installed as necessary. Ladder access/exit equivalent to 1 ladder every 9 metres where a person is working (s179 WHS Regulation). Necessary PPE is worn (eg: safety helmet, safety footwear, protective clothing, sun block, ear protection, eye protection, etc). Ensure pressure is released from both sides of the pig and de-water. Ensure biologically contaminated water is contained as to not contaminate nearby land or waterways.		

8	**8. Ongoing Monitoring**	Loss of control of contaminated water causing environmental impact. Communication breakdown between differing trades (Electrical to Mechanical). Incorrect isolation and powering up procedures.	Likely x Catastrophic (Worst Case hazard – Communication breakdon and power not isolated) **= Extreme**	Where multi-trade complete WHS 25 FI Permit to Work. Ensure all communication equipment is tested prior to use (including battery condition, where applicable). Ensure that a staff member is present at the pig exit point, before the pig is pushed or drawn along the pipeline. Ensure that communications systems are capable of relaying a message to the person in control of the pump or valve that is providing the energy to push or draw the pig along. Ensure that contingencies are planned and capable of reacting in time to divert, halt or control the flow of contaminated water.		
	Removing Spent or Used Pig	Retrieving pig or parts of. Environmental contamination.	Possible x Moderate (Worst case hazard – cuts and abrasions from pig removal) **= Medium**	Monitor the position of pig at all times along the pipeline. Ensure biologically contaminated water is contained as to not contaminate nearby land or waterways. Ensure a staff member is at all times at the exit point of contaminated water so valves can be closed or dirty water can be diverted to holding pond/s, etc.		
9	**Work Completion/ Site Clean Up**.	Retrieving pig or parts of. Environmental contamination.	Possible x Moderate (Worst case hazard – cuts and abrasions from pig removal) **= Medium**			
List additional any additional activities and hazards and risk controls identified and applied during the job and improvements after the work is completed.						

Prepared and reviewed and endorsed by Site Supervisor:
Name: **Signature:** **Date:**

SIGN OFF FOR ALL PERSON INVOLVED IN ANY OF THE ABOVE TASKS (prior to starting the job)

I have completed an induction to the contents of this Work Method Statement and agree to apply the risk controls identified and any additional controls identified during the job.

All persons on site undertaking work (including contractors)			
Name	**Organisation**	**Signature**	**Date**

APPENDIX D

FITTING LOSS FACTORS

(In choosing a value for kinematic viscosity, the average temperature of pipeline irrigation water can be taken as 20°C. This is an average figure between 16°C for river water and an average earth temperature at 1 metre depth (indicated by daily readings at Research Stations thoughout Queensland) of 24°C.)

Fitting losses are commonly expressed in terms of the velocity head:-

$$h_L = K.V^2/2g \qquad \text{........... 4.6}$$

where K = fitting loss factor
and V = smaller diameter velocity

Refer to Table 4.3, Appendix C1 or Reference (10) for recommended values of K.

TABLE 4.3

LOSS FACTORS FOR FITTINGS

ENTRY LOSSES		SUDDEN ENLARGEMENTS	
		Inlet DIA to Outlet DIA	
Sharp-Edged entrance	0.50	4 : 5	0.15
Re-entrant entrance	0.80	3 : 4	0.20
Slightly-Rounded entrance	0.25	2 : 3	0.35
Bellmouthed entrance	0.05	1 : 2	0.60
Footvalve & Strainer	2.50	1 : 3	0.80
Tee-Mainline to Offtake	1.50	1 : 5 and over	1.00
CI-BENDS (Close Radius)		SUDDEN CONTRACTIONS	
		Inlet DIA to Outlet DIA	
22-1/2	0.15	5 : 4	0.15
45	0.30	4 : 3	0.20
90	0.75	3 : 2	0.30
RC BENDS (Elbows)		2 : 1	0.35
22-1/2	0.20	3 : 1	0.45
45	0.40	5 : 1 and over	0.50
90	1.00		
ALL TEES, FLOW ALONG LINE		CONCENTRIC TAPERS	
Equal Tee	0.30		
1/2 < D1/D2 < 1	0.20	Flow to Small End	neg.
		Flow to Large End	
1/3 < D1/D2 < 1/2	0.10	Inlet DIA to Outlet DIA	
		4 : 5	0.03
		3 : 4	0.04
D1/D2 < 1/3	neg.	1 : 2	0.12
GATE VALVES		EXIT LOSSES	
Fully Open	0.25		
25% Closed	0.5	Sudden Enlargement	1.00
50% Closed	3.0	Bellmouth Outlet	0.20
75% Closed	15.0		
		BUTTERFLY VALVES	
		See Appendix C1	

APPENDIX E

STANWELL PIPELINE ANALYSIS & MODELLING

STANWELL PIPELINE

BACK-CALCULATION OF K FOR PIGGING EVENT ON 13TH JULY 2010

Static Head Before Pigging, 12/7/10 (m)	82.95
Static Head After Pigging, 15/7/10 (m)	82.86

Length	K	Volume	ID	Q	Vel	Reynolds Number	Friction	Pipe friction Loss	Fitting Loss	Total Head
(m)	(mm)	ML	(m)	m3/s	(m/s)			(m)		(m)
CALCULATION WITHOUT ASSUMED FITTING LOSS										
28041	**0.474**	24279.26	856	0.937	1.63	1.39E+06	0.01752	77.51	0.00	**160.46**
28041	**0.041**	24279.26	856	1.021	1.77	1.52E+06	0.01214	63.79	0.00	**146.74**
CALCULATION WITH ASSUMED FITTING LOSS						**Fitting Loss**	**3**			
28041	**0.203**	24279.26	856	0.937	1.63	1.39E+06	0.01496	66.15	11.36	**160.46**
28041	**0.020**	24279.26	856	1.021	1.77	1.52E+06	0.01000	52.52	13.49	**146.74**

STANWELL PIPELINE MODELLED K VALUE

DATA ENTRY NUMBER	DATE	PUMP STATION METER (ML)	END METER (ML)	G.Ht RIVER (AHD)	G.Ht STANWELL (AHD)	ENERGY USED (kWh)	MOTOR LOAD (kW)	ENERGY PER ML (kWh/ML)	PUMP NO	RUN TIME	HOURS PER ML (hrs/ML)	AVERAGE SUCTION (m)	AVERAGE DISCHARGE (m)	STATIC HEAD (m)	ACTUAL EFFIC. (%)	AVERAGE VELOCITY (m/s)	PUMP STATION MET FLOW (L/s)	VOLUME (L)	PIPELINE LENGTH (m)	INTERNAL DIAMETER (m)	VELOCITY (m/s)	REYNOLDS NUMBER	TOTAL HEAD (m)	STATIC HEAD (m)	TOTAL FITTING LOSS (m) 3	TOTAL FRICTION LOSS (m)	FRICTION FACTOR	PIPE ROUGHNESS HEIGHT *k* (mm)
1	1/07/2009	27.214	27.059	3.632	86.462	14365	1788.916563	530.9	1&2	8.03	0.297	7.62	167.29	82.83	85.28443508	1.626	941.4	24401.1	28040	856	1.6358	1400266	159.67	82.83	9.98	66.86	0.015	0.204
2	2/07/2009	27.561	27.343	3.639	86.339	14671	1827.023661	536.6	2	8.03	0.294	7.96	167.97	82.7	84.56173986	1.644	953.404	24712.23	28040	856	1.6567	1418121	160.01	82.70	10.24	67.07	0.015	0.179
3	3/07/2009	27.562	27.369	3.616	86.289	14696	1830.136986	537	2	8.03	0.293	7.95	168.01	82.673	84.52456382	1.645	953.438	24713.13	28040	856	1.6567	1418172	160.06	82.67	10.24	67.15	0.015	0.180
4	4/07/2009	82.579	81.829	3.616	86.419	43884	1828.5	536.3	2	24	0.293	7.95	167.95	82.803	84.59824616	1.646	955.775	24773.7	28040	856	1.6608	1421648	160.00	82.80	10.29	66.91	0.015	0.171
5	5/07/2009	82.593	81.902	3.616	86.552	43781	1824.208333	534.6	2	24	0.293	7.94	167.91	82.936	84.85700791	1.647	955.938	24777.9	28040	856	1.6611	1421890	159.97	82.94	10.29	66.74	0.014	0.168
6	6/07/2009	79.342	78.578	3.616	86.678	41998	1818.095238	534.5	1&2	23.1	0.294	7.58	166.86	83.062	84.50335425	1.642	954.089	24729.97	28040	856	1.6579	1419139	159.28	83.06	10.25	65.96	0.014	0.160
7	7/07/2009	27.212	27.055	3.616	86.558	14441	1821.059269	533.8	2	7.93	0.293	7.94	168.18	82.942	85.12586657	1.647	953.202	24706.99	28040	856	1.6563	1417820	160.24	82.94	10.24	67.06	0.015	0.179
8	8/07/2009	27.522	27.388	3.609	86.473	14642	1823.412204	534.6	2	8.03	0.293	7.94	168.09	82.864	84.94292252	1.646	952.055	24677.26	28040	856	1.6543	1416114	160.15	82.86	10.21	67.07	0.015	0.182
9	9/07/2009	27.513	27.294	3.602	86.418	14690	1829.389788	538.2	2	8.03	0.294	7.93	168.22	82.816	84.44854275	1.641	951.743	24669.19	28040	856	1.6538	1415651	160.29	82.82	10.20	67.27	0.015	0.186
10	10/07/2009	27.513	27.324	3.594	86.333	14669	1826.774595	536.9	2	8.03	0.294	7.93	168.44	82.739	84.77859253	1.642	951.743	24669.19	28040	856	1.6538	1415651	160.51	82.74	10.20	67.57	0.015	0.191
11	11/07/2009	82.327	81.672	3.586	86.463	43812	1825.5	536.4	2	24	0.294	7.93	168.36	82.877	84.80198825	1.643	952.859	24698.1	28040	856	1.6557	1417310	160.43	82.88	10.23	67.32	0.015	0.184
12	12/07/2009	82.29	81.722	3.579	86.609	43843	1826.791667	536.5	2	24	0.294	7.92	168.4	83.03	84.820334	1.644	952.431	24687	28040	856	1.6550	1416673	160.48	83.03	10.22	67.23	0.015	0.184
13	13/07/2009	56.622	56.07	3.579	86.635	30161	1825.726392	537.9	2	16.52	0.295	7.91	168.3	83.056	84.54782626	1.638	952.078	24677.87	28040	856	1.6544	1416149	160.39	83.06	10.21	67.12	0.015	0.183
14	14/07/2009	27.439	27.307	3.579	86.55	14669	1826.774595	537.2	2	8.03	0.294	7.91	168.6	82.971	84.8208601	1.641	949.184	24602.84	28040	856	1.6493	1411844	160.69	82.97	10.15	67.57	0.015	0.197
15	15/07/2009	27.424	27.209	3.556	86.506	14617	1820.298879	537.2	2	8.03	0.295	7.9	168.71	82.95	84.88046011	1.635	948.665	24589.39	28040	856	1.6484	1411072	160.81	82.95	10.14	67.72	0.015	0.201
16	16/07/2009	27.432	27.164	3.542	86.419	14664	1826.15193	539.8	2	8.03	0.296	7.88	168.71	82.877	84.47898188	1.633	948.941	24596.56	28040	856	1.6489	1411483	160.83	82.88	10.14	67.81	0.015	0.202
17	17/07/2009	27.428	27.201	3.534	86.333	14637	1822.789539	538.1	2	8.03	0.295	7.88	168.77	82.799	84.78171331	1.635	948.803	24592.98	28040	856	1.6487	1411278	160.89	82.80	10.14	67.95	0.015	0.205
18	18/07/2009	82.113	81.395	3.534	86.462	43789	1824.541667	538	2	24	0.295	7.88	168.67	82.928	84.74851065	1.637	950.382	24633.9	28040	856	1.6514	1413626	160.79	82.93	10.18	67.69	0.015	0.196
19	19/07/2009	82.146	81.391	3.534	86.635	43730	1822.083333	537.3	2	24	0.295	7.87	168.46	83.101	84.75312973	1.637	950.764	24643.8	28040	856	1.6521	1414194	160.59	83.10	10.18	67.31	0.015	0.189
20	20/07/2009	34.233	33.991	3.534	86.592	18257	1820.239282	537.1	2	10.03	0.295	7.87	168.63	83.058	84.86973828	1.636	948.072	24574.04	28040	856	1.6474	1410191	160.76	83.06	10.13	67.58	0.015	0.200
21	21/07/2009	27.396	27.197	3.534	86.549	14654	1824.9066	538.8	2	8.03	0.295	7.87	168.67	83.015	84.62354175	1.635	947.696	24564.28	28040	856	1.6468	1409631	160.80	83.02	10.12	67.67	0.015	0.203
22	22/07/2009	27.391	27.176	3.534	86.462	14681	1828.268991	540.2	2	8.03	0.295	7.87	168.73	82.928	84.43418175	1.634	947.523	24559.8	28040	856	1.6465	1409374	160.86	82.93	10.11	67.82	0.015	0.206
23	23/07/2009	27.39	27.135	3.534	86.333	14676	1827.646326	540.9	2	8.03	0.296	7.85	168.81	82.799	84.38794782	1.631	947.489	24558.9	28040	856	1.6464	1409322	160.96	82.80	10.11	68.05	0.015	0.210
24	24/07/2009	27.342	27.192	3.519	86.288	14666	1826.400996	539.3	2	8.03	0.295	7.86	168.95	82.769	84.69122055	1.634	945.828	24515.87	28040	856	1.6435	1406853	161.09	82.77	10.08	68.24	0.015	0.218
25	25/07/2009	81.423	81.423	3.519	86.406	43825	1826.041667	538.2	2	24	0.295	7.86	168.87	82.887	84.82392501	1.638	942.396	24426.9	28040	856	1.6376	1401747	161.01	82.89	10.01	68.12	0.015	0.225
26	26/07/2009	81.936	81.451	3.517	86.549	43763	1823.458333	537.3	2	24	0.295	7.86	168.83	83.032	84.9521977	1.638	948.333	24580.8	28040	856	1.6479	1410579	160.97	83.03	10.13	67.81	0.015	0.204
27	27/07/2009	47.897	47.36	3.504	86.549	25527	1819.458304	539	2	14.03	0.296	7.84	168.56	83.045	84.55166779	1.629	948.305	24580.07	28040	856	1.6478	1410537	160.72	83.05	10.13	67.54	0.015	0.199
28	28/07/2009	27.345	27.112	3.481	86.462	14649	1824.283935	540.3	2	8.03	0.296	7.83	168.71	82.981	84.42984148	1.63	945.932	24518.56	28040	856	1.6437	1407007	160.88	82.98	10.08	67.82	0.015	0.210
29	29/07/2009	27.239	26.99	3.481	86.419	14606	1818.929016	541.2	2	8.03	0.298	7.82	168.2	82.938	84.03537392	1.622	942.265	24423.51	28040	856	1.6373	1401553	160.38	82.94	10.00	67.44	0.015	0.213
30	30/07/2009	27.318	27.109	3.474	86.333	14642	1823.412204	540.1	2	8.03	0.296	7.81	169.03	82.859	84.63935621	1.629	944.998	24494.35	28040	856	1.6421	1405618	161.22	82.86	10.06	68.30	0.015	0.221
31	31/07/2009	27.275	27.088	3.467	86.25	14612	1815.15528	539.4	1&2	8.05	0.297	7.47	168.32	82.783	84.55293393	1.624	941.166	24395.03	28040	856	1.6354	1399918	160.85	82.78	9.98	68.09	0.015	0.228
32	1/08/2009	80.021	80.021	3.451	86.376	42793	1783.041667	534.8	1	24	0.3	7.15	166.97	82.925	84.74277988	1.609	926.169	24006.3	28040	856	1.6094	1377611	159.82	82.93	9.66	67.23	0.016	0.254
33	2/08/2009	80.569	80.038	3.459	86.513	42733	1780.541667	533.9	1	24	0.3	7.13	167.09	83.054	84.95414629	1.61	932.512	24170.7	28040	856	1.6204	1387045	159.96	83.05	9.80	67.11	0.015	0.233
34	3/08/2009	43.715	43.286	3.458	86.506	23234	1784.485407	536.8	1	13.02	0.301	7.11	167.03	83.048	84.48246764	1.605	932.646	24174.19	28040	856	1.6206	1387246	159.92	83.05	9.80	67.07	0.015	0.232
35	4/08/2009	26.864	26.721	3.451	86.419	14314	1782.56538	535.7	1	8.03	0.301	7.13	167.34	82.968	84.80503818	1.606	929.293	24087.27	28040	856	1.6148	1382258	160.21	82.97	9.73	67.51	0.016	0.250
36	5/08/2009	43.291	42.972	3.451	86.376	23025	1782.120743	535.8	1&2	12.92	0.301	7.47	168.52	82.925	85.22892228	1.605	930.749	24125.02	28040	856	1.6173	1384423	161.05	82.93	9.76	68.37	0.016	0.264
37	6/08/2009	26.835	26.682	3.444	86.289	14276	1777.833126	535	1	8.03	0.301	7.13	167.5	82.845	84.99146382	1.604	928.29	24061.27	28040	856	1.6130	1380765	160.37	82.85	9.71	67.82	0.016	0.260
38	7/08/2009	26.817	26.648	3.444	86.204	14329	1786.658354	537.7	1	8.02	0.301	7.14	167.64	82.76	84.6377507	1.604	928.824	24075.11	28040	856	1.6140	1381560	160.50	82.76	9.72	68.02	0.016	0.262
39	8/08/2009	80.396	79.684	3.451	86.333	42772	1782.166667	536.8	1	24	0.301	7.13	167.58	82.882	84.760133	1.603	930.509	24118.8	28040	856	1.6169	1384067	160.45	82.88	9.75	67.81	0.016	0.253
40	9/08/2009	80.383	79.72	3.429	86.462	42770	1782.083333	536.5	1	24	0.301	7.13	167.56	83.033	84.79182108	1.603	930.359	24114.9	28040	856	1.6166	1383843	160.43	83.03	9.75	67.65	0.016	0.250
41	10/08/2009	47.351	47.048	3.444	86.462	25250	1786.978061	536.7	1	14.13	0.3	7.11	167.44	83.018	84.71004568	1.607	930.86	24127.9	28040	856	1.6175	1384589	160.33	83.02	9.76	67.55	0.015	0.246
42	11/08/2009	32.668	32.668	3.451	86.376	17632	1781.010101	539.7	1	9.9	0.303	7.13	167.68	82.925	84.34738428	1.593	916.611	23758.55	28040	856	1.5927	1363393	160.55	82.93	9.47	68.16	0.016	0.306
43	12/08/2009	25.911	25.695	3.451	86.246	13815	1777.992278	537.7	1	7.77	0.302	7.13	167.5	82.795	84.57873813	1.596	926.319	24010.19	28040	856	1.6096	1377834	160.37	82.80	9.67	67.91	0.016	0.268
44	13/08/2009	57.039	56.548	3.467	86.246	30360	1783.783784	536.9	1	17.02	0.301	7.13	167.54	82.779	84.72025619	1.604	930.915	24129.31	28040	856	1.6176	1384670	160.41	82.78	9.76	67.87	0.016	0.253
45	14/08/2009	26.852	26.671	3.474	86.118	14305	1781.444583	536.4	1	8.03	0.301	7.14	167.52	82.644	84.78948274	1.603	928.878	24076.51	28040	856	1.6141	1381640	160.38	82.64	9.72	68.02	0.016	0.262
46	15/08/2009	74.292	74.292	3.467	86.204	39684	1781.149013	534.2	1	22.28	0.3	7.17	167.52	82.737	85.12084237	1.609	926.242	24008.19	28040	856	1.6095	1377719	160.35	82.74	9.67	67.95	0.016	0.269
47	16/08/2009	60.25	59.566	3.481	86.204	31951	1780	536.4	1	17.95	0.301	7.18	167.4	82.723	84.69758918	1.602	932.374	24167.13	28040	856	1.6201	1386840	160.22	82.72	9.79	67.70	0.015	0.245
48	17/08/2009	57.087	56.391	3.481	86.208	30288	1781.647059	537.1	1	17	0.301	7.18	167.15	82.727	84.45358383	1.601	932.794	24178.02	28040	856	1.6209	1387465	159.97	82.73	9.80	67.44	0.015	0.238
49	18/08/2009	80.732	79.855	3.481	86.341	42814	1783.916667	536.1	1	24	0.301	7.16	167.11	82.86	84.5942595	1.606	934.398	24219.6	28040	856	1.6237	1389851	159.95	82.86	9.84	67.25	0.015	0.230
50	19/08/2009	43.801	43.265	3.481	86.376	23144	1776.208749	534.9	1	13.03	0.301	7.16	167.01	82.895	84.73274333	1.603	933.764	24203.16	28040	856	1.6226	1388908	159.85	82.90	9.82	67.13	0.015	0.230
51	20/08/2009	26.927	26.7	3.497	86.333	14184	1766.37609	531.2	1	8.03	0.301	7.17	167.28	82.836	85.46166226	1.605	931.472	24143.76	28040	856	1.6186	1385499	160.11	82.84	9.77	67.50	0.015	0.244
52	21/08/2009	26.916	26.666	3.481	86.289	14255	1777.431421	534.6	1	8.02	0.301	7.2	167.36	82.808	84.95423876	1.605	932.253	24163.99	28040	856	1.6199	1386660	160.16	82.81	9.79	67.56	0.015	0.243
53	22/08/2009	80.599	80.017	3.504	86.506	42818	1782.597835	535.1	1	24.02	0.3	7.2	167.42	83.002	84.90102897	1.608	932.082	24159.57	28040	856	1.6196	1386406	160.22	83.00	9.79	67.43	0.015	0.240
54	23/08/2009	80.637	80.064	3.504	86.678	42761	1781.708333	534.1	1	24	0.3	7.2	167.24	83.174	84.96857071	1.61	933.299	24191.1	28040	856	1.6217	1388216	160.04	83.17	9.81	67.05	0.015	0.229
55	24/08/2009	22.099	21.982	3.511	86.635	11716	1780.547112	533	1	6.58	0.299	7.21	167.24	83.124	85.13920395	1.612	932.92	24181.28	28040	856	1.6211	1387652	160.03	83.12	9.80	67.10	0.015	0.231
56	25/08/2009	26.937	26.765	3.519	86.567	14312	1782.316314	534.7	1	8.03	0.3	7.21	166.99	83.048	84.72853093	1.609	931.818	24152.73	28040	856	1.6192	1386014	159.78	83.05	9.78	66.95	0.015	0.231
57	26/08/2009	42.59	41.454	3.526	86.592	22207	1795.230396	535.7	1	12.37	0.298	7.1	163.4	83.066	82.73244666	1.618	956.391	24789.65	28040	856	1.6619	1422564	156.30	83.07	10.30	62.93	0.014	0.112
58	27/08/2009	29.436	29.255	3.526	86.526	14638	1829.75	500.4	1	8	0.273	6.74	153.02	83	82.89792324	1.765	1022.08	26492.4	28040	856	1.7760	1520277	146.28	83.00	11.77	51.51	0.010	-0.023
59	28/08/2009	29.552	29.375	3.519	86.506	14659	1825.529265	499	1	8.03	0.273	6.72	152.9	82.987	83.06189355	1.766	1022.28	26497.43	28040	856	1.7764	1520566	146.18	82.99	11.77	51.42	0.010	-0.024
60	29/08/2009	88.427	87.847	3.526	86.679	43780	1822.647794	498.4	1	24.02	0.273	6.75	152.88	83.153	83.14399752	1.765	1022.61	26506.01	28040	856	1.7769	1521058	146.13	83.15	11.78	51.20	0.010	-0.024
61	30/08/2009	35.727	35.628	3.519	86.66	17663	1820.927835	495.8	1	9.7	0.272	6.78	153.02	83.141	83.64374947	1.773	1023.11	26519.01	28040	856	1.7778	1521804	146.24	83.14	11.79	51.31	0.010	-0.024
62	31/08/2009	23.05	22.964	3.534	86.554	11470	1826.433121	499.5	1&2	6.28	0.273	7.18	154.02	83.02	83.36213629	1.765	1019.55	26426.75	28040	856	1.7716	1516510	146.84	83.02	11.71	52.11	0.010	-0.021
63	1/09/2009	29.917	29.713	3.534	86.532	14992	1869.326683	504.6	2	8.02	0.27	7.6	154.53	82.998	82.57293992	1.788	1036.19	26858.15	28040	856	1.8005	1541266	146.93	83.00	12.10	51.84	0.010	-0.026
64	2/09/2009	29.915	29.668	3.534	86.463	14993	1867.123288	505.4	2	8.03	0.271	7.59	154.62	82.929	82.49849503	1.783	1034.83	26822.91	28040	856	1.7982	1539243	147.03	82.93	12.06	52.04	0.010	-0.025
65	3/09/2009	29.903	29.676	3.534	86.419	15001	1868.119552	505.5	2	8.03	0.271	7.6	154.72	82.885	82.52721834	1.784	1034.42	26812.15	28040	856	1.7975	1538626	147.12	82.89	12.05	52.18	0.010	-0.024
66	4/09/2009	29.896	29.692	3.542	86.376	15016	1869.987547	505.7	2	8.03	0.27	7.61	154.78	82.834	82.51726435	1.785	1034.18	26805.88	28040	856	1.7970	1538266	147.17	82.83	12.05	52.29	0.010	-0.024
67	5/09/2009	89.609	88.852	3.549	86.563	44884	1870.166667	505.2	2	24	0.27	7.63	154.78	83.014	82.5992797	1.787	1037.14	26882.7	28040	856	1.8022	1542674	147.15	83.01	12.12	52.02	0.010	-0.026
68	6/09/2009	67.684	67.231	3.549	86.678	33915	1868.595041	504.5	2	18.15	0.27	7.64	154.92	83.129	82.78694653	1.788	1035.87	26849.85	28040	856	1.8000	1540789	147.28	83.13	12.09	52.06	0.010	-0.025
69	7/09/2009	29.393	29.015	3.556	86.594	14729	1864.43038	507.6	2	7.9	0.272	7.65	155.15	83.038	82.39136016	1.773	1033.51	26788.56	28040	856	1.7959	1537272	147.50	83.04	12.03	52.43	0.010	-0.024
70	8/09/2009	29.816	29.595	3.549	86.549	14984	1868.329177	506.3	2	8.02	0.271	7.65	155.23	83	82.65296268	1.781	1032.7	26767.48	28040	856	1.7945	1536062	147.58	83.00	12.01	52.57	0.010	-0.023
71	9/09/2009	29.831	29.561	3.542	86.506	14979	1865.379826	506.7	2	8.03	0.272	7.64	155.27	82.964	82.61354528	1.777	1031.93	26747.6	28040	856	1.7931	1534921	147.63	82.96	12.00	52.67	0.010	-0.022
72	10/09/2009	29.814	29.551	3.542	86.462	14974	1864.757161	506.7	2	8.03	0.272	7.64	155.43	82.92	82.70271018	1.776	1031.34	26732.35	28040	856	1.7921	1534047	147.79	82.92	11.98	52.89	0.010	-0.021
73	11/09/2009	29.811	29.474	3.542	86.419	14985	1866.127024	508.4	2	8.03	0.272	7.65	155.45	82.877	82.43224075	1.772	1031.24	26729.66	28040	856	1.7919	1533892	147.80	82.88	11.98	52.94	0.010	-0.021
74	12/09/2009	89.305	88.449	3.549	86.592	44830	1867.916667	506.8	2	24	0.271	7.67	155.53	83.043	82.72089595	1.779	1033.62	26791.5	28040	856	1.7961	1537441	147.86	83.04	12.04	52.78	0.010	-0.022

STANWELL PIPELINE MODELLED K VALUE

DATA ENTRY NUMBER	DATE	PUMP STATION METER (ML)	END METER (ML)	G.Ht RIVER (AHD)	G.Ht STANWELL (AHD)	ENERGY USED (kWh)	MOTOR LOAD (kW)	ENERGY PER ML (kWh/ML)	PUMP NO	RUN TIME	HOURS PER ML (hrs/ML)	AVERAGE SUCTION (m)	AVERAGE DISCHARGE (m)	STATIC HEAD (m)	ACTUAL EFFIC. (%)	AVERAGE VELOCITY (m/s)	PUMP STATION METER FLOW (L/s)	VOLUME (L)	PIPELINE LENGTH (m)	INTERNAL DIAMETER (m)	VELOCITY (m/s)	REYNOLDS NUMBER	TOTAL HEAD (m)	STATIC HEAD (m)	TOTAL FITTING LOSS (m) 3	TOTAL FRICTION LOSS (m)	FRICTION FACTOR	PIPE ROUGHNESS HEIGHT k (mm)
75	13/09/2009	49.23	48.86	3.542	86.635	24759	1865.787491	506.7	2	13.27	0.272	7.67	155.84	83.093	82.91268573	1.777	1030.52	26711.08	28040	856	1.7907	1532826	148.17	83.09	11.96	53.11	0.010	-0.021
76	14/09/2009	29.739	29.569	3.542	86.558	14960	1863.013699	505.9	2	8.03	0.272	7.67	155.92	83.016	83.08834054	1.777	1028.75	26665.11	28040	856	1.7876	1530188	148.25	83.02	11.92	53.31	0.010	-0.019
77	15/09/2009	29.75	29.547	3.542	86.506	14968	1864.009963	506.6	2	8.03	0.272	7.67	155.9	82.964	82.97095058	1.776	1029.13	26674.97	28040	856	1.7883	1530754	148.23	82.96	11.93	53.33	0.010	-0.019
78	16/09/2009	29.76	29.488	3.542	86.462	14923	1858.405978	506.1	2	8.03	0.272	7.67	155.9	82.92	83.05497024	1.772	1029.47	26683.94	28040	856	1.7889	1531268	148.23	82.92	11.94	53.37	0.010	-0.019
79	17/09/2009	29.765	29.47	3.549	86.419	14892	1856.857855	505.3	2	8.02	0.272	7.67	155.78	82.87	83.10972202	1.774	1030.93	26721.7	28040	856	1.7914	1533435	148.11	82.87	11.97	53.27	0.010	-0.020
80	18/09/2009	29.788	29.455	3.556	86.347	14913	1857.160648	506.3	2	8.03	0.273	7.68	155.68	82.791	82.88884042	1.77	1030.44	26709.04	28040	856	1.7905	1532709	148.00	82.79	11.96	53.25	0.010	-0.020
81	19/09/2009	89.359	88.319	3.549	86.543	44834	1868.083333	507.6	2	24	0.272	7.68	155.45	82.994	82.54167323	1.776	1034.25	26807.7	28040	856	1.7972	1538370	147.77	82.99	12.05	52.73	0.010	-0.023
82	20/09/2009	89.269	88.233	3.549	86.689	44770	1865.416667	507.4	2	24	0.272	7.69	155.55	83.14	82.62947489	1.774	1033.21	26780.7	28040	856	1.7954	1536821	147.86	83.14	12.03	52.69	0.010	-0.023
83	21/09/2009	27.613	27.183	3.542	86.615	13871	1861.879195	510.3	2	7.45	0.274	7.7	155.7	83.073	82.24162222	1.761	1029.57	26686.39	28040	856	1.7890	1531409	148.00	83.07	11.94	52.99	0.010	-0.021
84	22/09/2009	29.766	29.339	3.549	86.549	14984	1868.329177	510.7	2	8.02	0.273	7.69	155.76	83	82.21005876	1.766	1030.96	26722.59	28040	856	1.7915	1533487	148.07	83.00	11.97	53.10	0.010	-0.021
85	23/09/2009	29.739	29.277	3.542	86.462	14972	1864.508095	511.4	2	8.03	0.274	7.68	155.98	82.92	82.2296127	1.76	1028.75	26665.11	28040	856	1.7876	1530188	148.30	82.92	11.92	53.46	0.010	-0.019
86	24/09/2009	29.705	29.276	3.519	86.419	14983	1865.877958	511.8	2	8.03	0.274	7.68	156.11	82.9	82.23846317	1.76	1027.57	26634.62	28040	856	1.7856	1528438	148.43	82.90	11.90	53.63	0.010	-0.018
87	25/09/2009	29.681	29.305	3.526	86.344	14938	1860.273973	509.7	2	8.03	0.274	7.67	156.29	82.818	82.67360338	1.761	1026.74	26613.1	28040	856	1.7841	1527203	148.62	82.82	11.88	53.93	0.010	-0.016
88	26/09/2009	88.843	87.68	3.534	86.506	44755	1864.791667	510.4	2	24	0.274	7.68	156.47	82.972	82.65574847	1.763	1028.28	26652.9	28040	856	1.7868	1529487	148.79	82.97	11.91	53.91	0.010	-0.017
89	27/09/2009	88.508	87.297	3.504	86.635	44643	1860.125	511.4	2	24	0.275	7.68	157.11	83.131	82.85602299	1.756	1024.4	26552.4	28040	856	1.7800	1523720	149.43	83.13	11.82	54.48	0.010	-0.014
90	28/09/2009	28.746	28.419	3.504	86.592	14585	1857.961783	513.2	2	7.85	0.276	7.67	157.96	83.088	83.03721645	1.747	1017.2	26365.76	28040	856	1.7675	1513009	150.29	83.09	11.66	55.55	0.011	-0.006
91	29/09/2009	26.128	25.947	3.504	86.51	13318	1862.657343	513.3	2	7.15	0.276	7.68	158.21	83.006	83.15943737	1.752	1015.07	26310.71	28040	856	1.7638	1509851	150.53	83.01	11.61	55.92	0.011	-0.003
92	30/09/2009	39.248	39.129	3.497	86.462	20220	1879.182156	516.8	2	10.76	0.275	7.64	155.41	82.965	81.08568885	1.755	1013.22	26262.6	28040	856	1.7606	1507090	147.77	82.97	11.57	53.24	0.010	-0.014
93	1/10/2009	46.58	46.004	3.49	86.46	23703	1859.058824	515.2	1&2	12.75	0.277	7.24	157.6	82.97	82.74941549	1.742	1014.81	26304	28040	856	1.7634	1509465	150.36	82.97	11.60	55.79	0.011	-0.004
94	2/10/2009	28.871	28.528	3.489	86.376	14523	1808.592777	509.1	1	8.03	0.281	6.78	156.51	82.887	83.39963549	1.715	998.72	25886.82	28040	856	1.7354	1485526	149.73	82.89	11.24	55.61	0.011	0.004
95	3/10/2009	86.651	85.483	3.481	86.549	43594	1816.416667	510	1	24	0.281	6.79	156.53	83.068	83.25900253	1.719	1002.91	25995.3	28040	856	1.7427	1491750	149.74	83.07	11.33	55.34	0.011	0.000
96	4/10/2009	86.337	85.257	3.481	86.678	43457	1810.708333	509.7	1	24	0.282	6.8	157.09	83.197	83.60663198	1.715	999.271	25901.1	28040	856	1.7364	1486345	150.29	83.20	11.25	55.84	0.011	0.005
97	5/10/2009	31.018	30.619	3.474	86.626	15654	1805.536332	511.3	1	8.67	0.283	6.82	157.68	83.152	83.67199347	1.705	993.784	25758.89	28040	856	1.7269	1478184	150.86	83.15	11.13	56.58	0.011	0.012
98	6/10/2009	28.658	28.217	3.474	86.549	14501	1808.104738	513.9	1	8.02	0.284	6.82	157.64	83.075	83.21702036	1.698	992.588	25727.88	28040	856	1.7248	1476405	150.82	83.08	11.10	56.65	0.011	0.013
99	7/10/2009	28.611	28.235	3.474	86.462	14489	1806.608479	513.2	1	8.02	0.284	6.82	157.94	82.988	83.50484303	1.699	990.96	25685.69	28040	856	1.7219	1473983	151.12	82.99	11.06	57.07	0.012	0.017
100	8/10/2009	28.543	28.247	3.459	86.376	14472	1804.488778	512.3	1	8.02	0.284	6.82	158.21	82.917	83.78789977	1.7	988.605	25624.64	28040	856	1.7179	1470480	151.39	82.92	11.01	57.46	0.012	0.022
101	9/10/2009	28.526	28.153	3.459	86.289	14470	1801.992528	514	1	8.03	0.285	6.82	158.25	82.83	83.54268153	1.692	986.786	25577.48	28040	856	1.7147	1467774	151.43	82.83	10.97	57.63	0.012	0.024
102	10/10/2009	84.278	84.278	3.459	86.453	43354	1806.416667	514.4	1	24	0.285	6.82	158.58	82.994	83.65322815	1.695	975.44	25283.4	28040	856	1.6950	1450898	151.76	82.99	10.72	58.05	0.012	0.037
103	11/10/2009	85.443	83.973	3.451	86.592	43250	1802.083333	515	1	24	0.286	6.84	159.07	83.141	83.80967258	1.689	988.924	25632.9	28040	856	1.7184	1470954	152.23	83.14	11.02	58.07	0.012	0.026
104	12/10/2009	38.887	38.437	3.451	86.549	19859	1802.087114	516.7	1	11.02	0.287	6.85	159.66	83.098	83.86567042	1.684	980.213	25407.11	28040	856	1.7033	1457997	152.81	83.10	10.82	58.89	0.012	0.039
105	13/10/2009	28.24	27.932	3.467	86.462	14447	1801.371571	517.2	1	8.02	0.287	6.86	159.86	82.995	83.87955753	1.681	978.11	25352.62	28040	856	1.6996	1454870	153.00	83.00	10.78	59.23	0.012	0.044
106	14/10/2009	28.191	28.001	3.459	86.376	14397	1795.137157	514.2	1	8.02	0.286	6.88	160.15	82.917	84.52769646	1.685	976.413	25308.63	28040	856	1.6967	1452346	153.27	82.92	10.74	59.61	0.012	0.049
107	15/10/2009	28.151	27.955	3.451	86.271	14339	1787.905237	512.9	1	8.02	0.287	6.87	160.33	82.82	84.83521507	1.682	975.028	25272.72	28040	856	1.6943	1450285	153.46	82.82	10.71	59.93	0.013	0.054
108	16/10/2009	28.133	27.912	3.451	86.161	14443	1800.872818	517.4	1	8.02	0.287	6.87	160.48	82.71	84.17698643	1.68	974.404	25256.56	28040	856	1.6932	1449358	153.61	82.71	10.70	60.20	0.013	0.057
109	17/10/2009	84.417	83.46	3.444	86.289	43163	1798.458333	517.2	1	24	0.288	6.89	160.42	82.845	84.17833812	1.678	977.049	25325.1	28040	856	1.6978	1453291	153.53	82.85	10.75	59.93	0.012	0.052
110	18/10/2009	84.261	83.328	3.444	86.419	43180	1799.166667	518.2	1	24	0.288	6.9	160.72	82.975	84.17080228	1.676	975.243	25278.3	28040	856	1.6946	1450605	153.82	82.98	10.71	60.13	0.013	0.055
111	19/10/2009	48.671	48.14	3.444	86.45	25006	1796.408046	519.4	1	13.92	0.289	6.91	161.13	83.006	84.18658587	1.669	971.244	25174.66	28040	856	1.6877	1444657	154.22	83.01	10.63	60.59	0.013	0.064
112	20/10/2009	45.67	45.101	3.437	86.419	23506	1805.376344	521.2	1	13.02	0.289	6.88	161.46	82.982	84.10098493	1.672	974.356	25255.3	28040	856	1.6931	1449285	154.58	82.98	10.70	60.90	0.013	0.064
113	21/10/2009	27.977	27.692	3.429	86.333	14413	1797.13217	520.5	1	8.02	0.29	6.9	161.27	82.904	84.1013912	1.667	969.001	25116.51	28040	856	1.6838	1441321	154.37	82.90	10.58	60.89	0.013	0.070
114	22/10/2009	27.953	27.672	3.429	86.212	14408	1796.508728	520.7	1	8.02	0.29	6.9	161.5	82.783	84.19507308	1.665	968.17	25094.96	28040	856	1.6823	1440084	154.60	82.78	10.56	61.26	0.013	0.075
115	23/10/2009	48.853	48.531	3.429	86.161	25206	1797.8602	519.4	1	14.02	0.289	6.88	161.7	82.732	84.52451955	1.671	967.923	25088.56	28040	856	1.6819	1439717	154.82	82.73	10.55	61.53	0.013	0.078
116	24/10/2009	83.831	82.94	3.414	86.246	43191	1799.625	520.7	1	24	0.289	6.88	161.46	82.832	84.17137351	1.668	970.266	25149.3	28040	856	1.6860	1443202	154.58	82.83	10.61	61.14	0.013	0.071
117	25/10/2009	83.693	83	3.407	86.333	43076	1794.833333	519	1	24	0.289	6.88	161.7	82.926	84.58826685	1.669	968.669	25107.9	28040	856	1.6832	1440827	154.82	82.93	10.57	61.32	0.013	0.075
118	26/10/2009	50.817	50.437	3.399	86.373	26222	1799.725463	519.9	1	14.57	0.289	6.86	161.82	82.974	84.51686531	1.671	968.829	25112.04	28040	856	1.6835	1441064	154.96	82.97	10.57	61.41	0.013	0.076
120	27/10/2009	29.112	29.112	3.384	85.988	15078	1838.780488	517.9	2	8.2	0.282	7.69	163.76	82.604	85.44527924	1.714	986.179	25561.76	28040	856	1.7136	1466871	156.07	82.60	10.96	62.51	0.013	0.065
121	28/10/2009	84.911	84.911	3.369	86.08	44259	1844.125	521.2	2	24	0.283	7.66	163.38	82.711	84.71242087	1.708	982.766	25473.3	28040	856	1.7077	1461795	155.72	82.71	10.88	62.13	0.013	0.066
122	29/10/2009	84.779	84.779	3.362	86.21	44254	1843.916667	522	2	24	0.283	7.66	163.6	82.848	84.70979435	1.705	981.238	25433.7	28040	856	1.7051	1459523	155.94	82.85	10.85	62.25	0.013	0.069
123	30/10/2009	84.779	83.681	3.339	86.333	44159	1839.958333	527.7	2	24	0.287	7.65	163.87	82.994	83.94302283	1.683	981.238	25433.7	28040	856	1.7051	1459523	156.22	82.99	10.85	62.38	0.013	0.070
124	31/10/2009	84.333	83.43	3.332	86.462	44110	1837.916667	528.7	2	24	0.288	7.64	164.32	83.13	84.03091415	1.678	976.076	25299.9	28040	856	1.6961	1451845	156.68	83.13	10.73	62.82	0.013	0.081
125	1/11/2009	84.056	83.066	3.302	86.549	44107	1837.791667	531	2	24	0.289	7.63	164.93	83.247	84.00107427	1.671	972.87	25216.8	28040	856	1.6905	1447076	157.30	83.25	10.66	63.39	0.013	0.092
126	2/11/2009	47.944	47.518	3.294	86.506	25235	1832.607117	531.1	2	13.77	0.29	7.61	165.32	83.212	84.20820604	1.666	967.159	25068.76	28040	856	1.6806	1438581	157.71	83.21	10.54	63.96	0.014	0.108
127	3/11/2009	27.973	27.691	3.279	86.376	14727	1833.997509	531.8	2	8.03	0.29	7.6	165.42	83.097	84.1446932	1.664	967.656	25081.64	28040	856	1.6814	1439320	157.82	83.10	10.55	64.17	0.014	0.109
128	4/11/2009	27.945	27.646	3.272	86.246	14715	1834.78803	532.3	2	8.02	0.29	7.58	165.48	82.974	84.11907855	1.664	967.893	25087.78	28040	856	1.6819	1439672	157.90	82.97	10.55	64.37	0.014	0.112
129	5/11/2009	27.907	27.676	3.257	86.118	14701	1830.759651	531.2	2	8.03	0.29	7.58	165.68	82.861	84.39731956	1.664	965.373	25022.47	28040	856	1.6775	1435924	158.10	82.86	10.50	64.74	0.014	0.121
130	6/11/2009	83.653	82.788	3.241	86.22	43975	1832.291667	531.2	2	24	0.29	7.56	165.64	82.979	84.38763379	1.665	968.206	25095.9	28040	856	1.6824	1440138	158.08	82.98	10.56	64.54	0.014	0.113
131	7/11/2009	83.506	82.772	3.219	86.333	43911	1829.625	530.5	2	24	0.29	7.54	165.89	83.114	84.63861122	1.665	966.505	25051.8	28040	856	1.6794	1437607	158.35	83.11	10.52	64.71	0.014	0.118
132	8/11/2009	83.283	82.429	3.211	86.431	43736	1822.333333	530.6	2	24	0.291	7.52	166.13	83.22	84.76408433	1.658	963.924	24984.9	28040	856	1.6750	1433768	158.61	83.22	10.47	64.92	0.014	0.125
133	9/11/2009	45.017	44.623	3.204	86.376	23727	1822.35023	531.7	2	13.02	0.292	7.51	166.44	83.172	84.75438114	1.654	960.424	24894.19	28040	856	1.6689	1428563	158.93	83.17	10.39	65.37	0.014	0.138
134	10/11/2009	27.683	27.498	3.189	86.246	14686	1828.891656	534.1	2	8.03	0.292	7.5	166.68	83.057	84.51356535	1.653	957.624	24821.62	28040	856	1.6640	1424398	159.18	83.06	10.33	65.79	0.014	0.150
135	11/11/2009	39.47	39.181	3.174	86.195	20974	1827.003484	535.3	1&2	11.48	0.293	7.09	166.15	83.021	84.25497809	1.647	955.043	24754.7	28040	856	1.6595	1420558	159.06	83.02	10.28	65.76	0.014	0.155
136	12/11/2009	27.643	27.393	3.167	86.071	14677	1827.770859	535.8	2	8.03	0.293	7.48	166.95	82.904	84.39595598	1.647	956.24	24785.75	28040	856	1.6616	1422340	159.47	82.90	10.30	66.26	0.014	0.160
137	13/11/2009	81.806	81.806	3.151	86.161	43915	1829.791667	536.8	2	24	0.293	7.46	166.91	83.01	84.2242464	1.645	946.829	24541.8	28040	856	1.6453	1408341	159.45	83.01	10.10	66.34	0.015	0.182
138	14/11/2009	82.806	81.849	3.136	86.246	43851	1827.125	535.8	2	24	0.293	7.44	166.95	83.11	84.42326236	1.646	958.403	24841.8	28040	856	1.6654	1425556	159.51	83.11	10.35	66.05	0.014	0.152
139	15/11/2009	82.723	81.605	3.122	86.333	43890	1828.75	537.8	2	24	0.294	7.41	167.05	83.211	84.16533315	1.641	957.442	24816.9	28040	856	1.6637	1424128	159.64	83.21	10.33	66.10	0.014	0.155
140	16/11/2009	82.593	81.448	3.114	86.414	43888	1828.666667	538.8	2	24	0.295	7.37	167.22	83.3	84.11774354	1.638	955.938	24777.9	28040	856	1.6611	1421890	159.85	83.30	10.29	66.26	0.014	0.160
141	17/11/2009	80.478	79.444	3.084	86.462	42439	1789.165261	534.2	1&2	23.72	0.299	6.98	166.4	83.378	84.62118545	1.617	942.454	24428.4	28040	856	1.6377	1401833	159.42	83.38	10.01	66.04	0.015	0.187
142	18/11/2009	81.201	80.061	3.062	86.549	42831	1784.625	535	1	24	0.3	6.59	165.56	83.487	84.25938982	1.61	939.826	24360.3	28040	856	1.6331	1397925	158.97	83.49	9.95	65.53	0.015	0.184
143	19/11/2009	27.047	26.819	3.054	86.416	14353	1787.422167	535.2	1&2	8.03	0.299	6.94	167	83.362	84.80531028	1.612	935.623	24251.36	28040	856	1.6258	1391674	160.06	83.36	9.86	66.84	0.015	0.219
144	20/11/2009	82.434	81.437	3.046	86.462	43803	1825.125	537.9	2	24	0.295	7.32	167.32	83.416	84.34866883	1.638	954.097	24730.2	28040	856	1.6579	1419152	160.00	83.42	10.26	66.33	0.014	0.165
145	21/11/2009	82.217	81.202	3.024	86.549	43735	1822.291667	538.6	2	24	0.296	7.28	167.56	83.525	84.38344824	1.633	951.586	24665.1	28040	856	1.6535	1415416	160.28	83.53	10.20	66.55	0.015	0.174
146	22/11/2009	81.954	80.836	3.009	86.592	43747	1822.791667	541.2	2	24	0.297	7.26	167.95	83.583	84.19488911	1.626	948.542	24586.2	28040	856	1.6482	1410889	160.69	83.58	10.14	66.97	0.015	0.188
147	23/11/2009	81.737	80.664	2.994	86.678	43726	1821.916667	542.1	2	24	0.298	7.24	168.24	83.684	84.21825124	1.622	946.03	24521.1	28040	856	1.6439	1407153	161.00	83.68	10.08	67.23	0.015	0.199
148	24/11/2009	23.521	23.378	2.987	86.514	12587	1816.305916	538.4	2	6.93	0.296	7.22	168.77	83.527	85.08096829	1.628	942.801	24437.4	28040	856	1.6383	1402350	161.55	83.53	10.01	68.01	0.015	0.222
149	25/11/2009	27.215	26.99	2.987	86.376	14538	1812.718204	538.6	2	8.02	0.297	7.23	168.48	83.389	84.88643266	1.624	942.609	24432.42	28040	856	1.6379	1402064	161.25	83.39	10.01	67.85	0.015	0.219

STANWELL PIPELINE MODELLED K VALUE

DATA ENTRY NUMBER	DATE	PUMP STATION METER (ML)	END METER (ML)	G.Ht RIVER (AHD)	G.Ht STANWELL (AHD)	ENERGY USED (kWh)	MOTOR LOAD (kW)	ENERGY PER ML (kWh/ML)	PUMP NO	RUN TIME	HOURS PER ML (hrs/ML)	AVERAGE SUCTION (m)	AVERAGE DISCHARGE (m)	STATIC HEAD (m)	ACTUAL EFFIC. (%)	AVERAGE VELOCITY (m/s)	PUMP STATION ME FLOW (L/s)	VOLUME (L)	PIPELINE LENGTH (m)	INTERNAL DIAMETER (m)	VELOCITY (m/s)	REYNOLDS NUMBER	TOTAL HEAD (m)	STATIC HEAD (m)	TOTAL FITTING LOSS (m) 3	TOTAL FRICTION LOSS (m)	FRICTION FACTOR	PIPE ROUGHNESS HEIGHT k (mm)
150	26/11/2009	27.197	27.025	2.964	86.246	14556	1812.702366	538.6	2	8.03	0.297	7.22	168.69	83.282	85.00722525	1.624	940.812	24385.85	28040	856	1.6348	1399392	161.47	83.28	9.97	68.22	0.015	0.231
151	27/11/2009	81.343	80.491	2.949	86.289	43503	1812.625	540.5	2	24	0.298	7.21	168.85	83.34	84.80418738	1.619	941.47	24402.9	28040	856	1.6359	1400370	161.64	83.34	9.99	68.31	0.015	0.231
152	28/11/2009	80.978	80.104	2.934	86.376	43354	1806.416667	541.2	2	24	0.3	7.16	169.34	83.442	84.96942228	1.611	937.245	24293.4	28040	856	1.6286	1394086	162.18	83.44	9.90	68.84	0.016	0.254
153	29/11/2009	80.578	79.814	2.919	86.419	43325	1805.208333	542.8	2	24	0.301	7.11	169.91	83.5	85.04234856	1.605	932.616	24173.4	28040	856	1.6206	1387200	162.80	83.50	9.80	69.50	0.016	0.283
154	30/11/2009	80.228	79.367	2.911	86.506	43268	1802.833333	545.2	2	24	0.302	7.01	170.34	83.595	84.95314185	1.596	928.565	24068.4	28040	856	1.6135	1381175	163.33	83.60	9.71	70.02	0.016	0.308
155	1/12/2009	80.228	79.095	2.889	86.549	43238	1801.583333	546.7	2	24	0.303	6.94	170.87	83.66	85.03196426	1.591	928.565	24068.4	28040	856	1.6135	1381175	163.93	83.66	9.71	70.56	0.016	0.321
156	2/12/2009	26.577	26.39	2.882	86.417	14417	1795.392279	546.3	2	8.03	0.304	6.91	171.14	83.535	85.2427249	1.586	919.365	23829.94	28040	856	1.5975	1367490	164.23	83.54	9.52	71.17	0.017	0.372
157	3/12/2009	61.464	60.875	2.866	86.419	33252	1804.23223	546.2	2	18.43	0.303	6.9	170.52	83.553	84.93719805	1.594	926.388	24011.98	28040	856	1.6097	1377937	163.62	83.55	9.67	70.40	0.016	0.325
158	4/12/2009	79.803	78.949	2.852	86.506	43246	1801.916667	547.8	2	24	0.304	6.87	170.91	83.654	84.91624659	1.588	923.646	23940.9	28040	856	1.6050	1373858	164.04	83.65	9.61	70.78	0.016	0.345
159	5/12/2009	79.422	78.627	2.836	86.592	43147	1797.791667	548.8	2	24	0.305	6.85	171.5	83.756	85.07915646	1.581	919.236	23826.6	28040	856	1.5973	1367299	164.65	83.76	9.52	71.37	0.017	0.378
160	6/12/2009	79.261	78.366	2.822	86.635	43014	1792.25	548.9	2	24	0.306	6.84	171.79	83.813	85.21391299	1.576	917.373	23778.3	28040	856	1.5941	1364527	164.95	83.81	9.48	71.66	0.017	0.394
161	7/12/2009	40.654	40.588	2.806	86.549	22170	1799.512987	546.2	1&2	12.32	0.304	6.5	166.07	83.743	82.83684376	1.59	916.622	23758.83	28040	856	1.5928	1363410	159.57	83.74	9.47	66.36	0.016	0.264
162	8/12/2009	72.164	71.556	2.784	86.563	35895	1829.510703	501.6	1&2	19.62	0.274	6.09	152.33	83.779	82.6644186	1.76	1021.69	26482.2	28040	856	1.7753	1519692	146.24	83.78	11.76	50.70	0.010	-0.026
163	9/12/2009	81.679	81.679	2.776	86.636	40439	1821.576577	495.1	1	22.2	0.272	5.75	151.7	83.86	83.59002271	1.776	1022.01	26490.49	28040	856	1.7759	1520167	145.95	83.86	11.77	50.32	0.010	-0.027
164	10/12/2009	58.092	58.092	2.747	86.549	28735	1829.089752	494.6	1	15.71	0.27	5.75	152.06	83.802	83.8724785	1.785	1027.16	26623.96	28040	856	1.7848	1527826	146.31	83.80	11.89	50.62	0.010	-0.027
165	11/12/2009	88.175	88.175	2.731	86.659	43633	1818.041667	494.8	1	24	0.272	5.74	152.41	83.928	84.0450279	1.773	1020.54	26452.5	28040	856	1.7733	1517987	146.67	83.93	11.73	51.01	0.010	-0.024
166	12/12/2009	52.599	52.599	2.717	86.627	26036	1832.230823	495	1	14.21	0.27	5.76	152.8	83.91	84.23237733	1.787	1028.21	26651.15	28040	856	1.7867	1529387	147.04	83.91	11.91	51.22	0.010	-0.026
167	13/12/2009	40.3	40.3	2.709	86.549	19990	1815.622162	496	1	11.01	0.273	5.75	153.08	83.84	84.22165675	1.767	1016.75	26354.22	28040	856	1.7668	1512347	147.33	83.84	11.65	51.84	0.010	-0.021
168	14/12/2009	31.493	31.493	2.687	86.43	15686	1813.410405	498.1	1&2	8.65	0.275	6.2	154.47	83.743	84.41030111	1.757	1011.34	26213.83	28040	856	1.7573	1504291	148.27	83.74	11.52	53.00	0.010	-0.015
169	15/12/2009	31.438	30.963	2.679	86.316	15703	1813.279446	507.2	1	8.66	0.28	5.75	153.72	83.637	82.73216993	1.726	1008.4	26137.83	28040	856	1.7523	1499930	147.97	83.64	11.46	52.88	0.010	-0.014
170	16/12/2009	29.164	28.603	2.671	86.183	14564	1815.9601	509.2	1	8.02	0.28	5.75	153.98	83.512	82.54815366	1.721	1010.11	26182.14	28040	856	1.7552	1502473	148.23	83.51	11.49	53.22	0.010	-0.013
171	17/12/2009	69.012	67.617	2.657	86.226	34565	1813.483736	511.2	1	19.06	0.282	5.72	154.15	83.569	82.33440739	1.712	1005.77	26069.59	28040	856	1.7477	1496014	148.43	83.57	11.40	53.46	0.010	-0.010
172	18/12/2009	50.626	47.954	2.641	86.243	24609	1809.485294	513.2	1	13.6	0.284	5.71	154.47	83.602	82.19726776	1.702	1034.03	26802	28040	856	1.7968	1538043	148.76	83.60	12.05	53.11	0.010	-0.022
173	19/12/2009	42.768	40.635	2.641	86.222	20655	1808.669002	508.3	1	11.42	0.281	5.7	155.08	83.581	83.33124288	1.717	1040.28	26964.06	28040	856	1.8076	1547343	149.38	83.58	12.19	53.61	0.010	-0.022
174	20/12/2009	86.431	84.835	2.626	86.35	43404	1808.5	511.6	1	24	0.283	5.69	155.74	83.724	83.16137255	1.706	1000.36	25929.3	28040	856	1.7383	1487963	150.05	83.72	11.27	55.05	0.011	0.000
175	21/12/2009	85.642	84.016	2.619	86.469	43329	1805.375	515.7	1	24	0.286	5.71	157.25	83.85	83.32032539	1.69	991.227	25692.6	28040	856	1.7224	1474380	151.54	83.85	11.07	56.62	0.011	0.014
176	22/12/2009	49.628	48.73	2.604	86.451	25276	1796.44634	518.7	1	14.07	0.289	5.74	158.54	83.847	83.53178431	1.672	979.784	25395.99	28040	856	1.7025	1457359	152.80	83.85	10.81	58.14	0.012	0.034
177	23/12/2009	28.393	27.901	2.604	86.355	14468	1792.812887	518.5	1	8.07	0.289	5.78	158.72	83.751	83.63204074	1.669	977.317	25332.04	28040	856	1.6982	1453689	152.94	83.75	10.76	58.43	0.012	0.038
178	24/12/2009	28.25	27.809	2.589	86.277	14360	1795	516.4	1	8	0.288	5.76	158.7	83.688	83.98318821	1.678	980.903	25425	28040	856	1.7045	1459024	152.94	83.69	10.84	58.41	0.012	0.035
179	25/12/2009	84.826	83.431	2.596	86.454	43101	1795.875	516.6	1	24	0.288	5.7	158.72	83.858	83.99020469	1.678	981.782	25447.8	28040	856	1.7060	1460332	153.02	83.86	10.86	58.30	0.012	0.033
180	26/12/2009	84.206	83.019	2.589	86.637	42998	1790.09159	517.9	1	24.02	0.289	5.7	159.74	84.048	84.33407617	1.668	973.795	25240.77	28040	856	1.6921	1448451	154.04	84.05	10.68	59.31	0.012	0.049
181	27/12/2009	39.62	39.062	2.664	86.637	20440	1792.982456	523.3	1	11.4	0.292	5.75	161.03	83.973	84.14521919	1.654	965.4	25023.16	28040	856	1.6775	1435964	155.28	83.97	10.50	60.81	0.013	0.074
182	28/12/2009	27.355	27.019	2.799	86.567	14094	1788.57868	521.6	1	7.88	0.292	5.94	161.21	83.768	84.40397431	1.655	964.291	24994.42	28040	856	1.6756	1434314	155.27	83.77	10.48	61.03	0.013	0.078
183	29/12/2009	27.223	26.98	3.144	86.53	14157	1829.069767	524.7	1&2	7.74	0.287	6.53	162.14	83.386	84.0908138	1.682	976.995	25323.72	28040	856	1.6977	1453212	155.61	83.39	10.75	61.47	0.013	0.066
184	30/12/2009	28.307	28.005	3.204	86.452	14685	1828.767123	524.4	1&2	8.03	0.287	6.96	162.27	83.248	83.98493401	1.683	979.21	25381.12	28040	856	1.7015	1456506	155.31	83.25	10.80	61.26	0.013	0.061
185	31/12/2009	27.936	27.653	3.227	86.393	14335	1791.875	518.4	1	8	0.289	6.49	160.97	83.166	84.5000871	1.668	970	25142.4	28040	856	1.6855	1442806	154.48	83.17	10.60	60.71	0.013	0.067
186	1/01/2010	82.869	81.85	3.414	86.527	42606	1775.25	520.5	1	24	0.293	6.7	158.76	83.113	82.83297247	1.646	959.132	24860.7	28040	856	1.6666	1426641	152.06	83.11	10.36	58.58	0.013	0.059
187	2/01/2010	81.698	80.653	3.602	86.635	42227	1759.458333	523.6	1	24	0.298	7	156.92	83.033	81.1951729	1.622	945.579	24509.4	28040	856	1.6431	1406482	149.92	83.03	10.07	56.81	0.013	0.057
188	3/01/2010	44.355	43.834	3.759	86.611	22942	1762.058372	523.4	1	13.02	0.297	7.13	157.72	82.852	81.5861239	1.625	946.301	24528.11	28040	856	1.6443	1407555	150.59	82.85	10.09	57.65	0.013	0.064
189	4/01/2010	28.011	27.719	3.774	86.509	14370	1796.25	518.4	1	8	0.289	7.09	161.21	82.735	84.29855498	1.672	972.604	25209.9	28040	856	1.6900	1446680	154.12	82.74	10.66	60.73	0.013	0.064
190	5/01/2010	28.033	27.711	3.737	86.407	14365	1795.625	518.4	1	8	0.289	7.06	161.13	82.67	84.27620872	1.672	973.368	25229.7	28040	856	1.6914	1447816	154.07	82.67	10.67	60.73	0.013	0.063
191	6/01/2010	28.013	27.726	3.789	86.318	14355	1794.375	517.7	1	8	0.289	7.06	161.19	82.529	84.41342854	1.673	972.674	25211.7	28040	856	1.6902	1446783	154.13	82.53	10.66	60.94	0.013	0.066
192	7/01/2010	27.992	27.719	3.774	86.228	14336	1792	517.2	1	8	0.289	7.12	161.31	82.454	84.53686029	1.672	971.944	25192.8	28040	856	1.6889	1445699	154.19	82.45	10.64	61.09	0.013	0.068
193	8/01/2010	84.183	83.141	3.707	86.336	43094	1795.583333	518.3	1	24	0.289	6.99	161.17	82.629	84.34645168	1.672	974.34	25254.9	28040	856	1.6931	1449262	154.18	82.63	10.69	60.86	0.013	0.063
194	9/01/2010	84.035	83.036	3.744	86.447	43054	1793.916667	518.5	1	24	0.289	6.94	161.33	82.703	84.43303886	1.67	972.627	25210.5	28040	856	1.6901	1446714	154.39	82.70	10.66	61.03	0.013	0.067
195	10/01/2010	83.77	82.857	3.796	86.54	43107	1796.125	520.3	1	24	0.29	7.01	161.72	82.744	84.32185088	1.666	969.56	25131	28040	856	1.6848	1442152	154.71	82.74	10.59	61.38	0.013	0.074
196	11/01/2010	83.55	82.696	3.796	86.657	43068	1794.5	520.8	1	24	0.29	7.03	162.05	82.861	84.40299758	1.663	967.014	25065	28040	856	1.6803	1438365	155.02	82.86	10.53	61.62	0.013	0.080
197	12/01/2010	42.37	41.876	3.737	86.609	21879	1793.360656	522.5	1	12.2	0.291	7.01	162.21	82.872	84.23057768	1.657	964.709	25005.25	28040	856	1.6763	1434936	155.20	82.87	10.48	61.84	0.013	0.086
198	13/01/2010	27.813	27.51	3.804	86.53	14305	1788.125	520	1	8	0.291	7	161.97	82.726	84.50661399	1.66	965.729	25031.7	28040	856	1.6781	1436454	154.97	82.73	10.51	61.74	0.013	0.083
199	14/01/2010	39.422	38.973	3.729	86.508	20309	1797.256637	521.1	1&2	11.3	0.29	7.52	163.25	82.779	84.73989488	1.665	969.076	25118.44	28040	856	1.6839	1441432	155.73	82.78	10.58	62.37	0.013	0.086
200	15/01/2010	84.823	83.723	3.759	86.64	43953	1831.375	525	2	24	0.287	7.81	163.81	82.881	84.25994989	1.684	981.748	25446.9	28040	856	1.7059	1460280	156.00	82.88	10.86	62.26	0.013	0.068
201	16/01/2010	51.531	50.894	3.707	86.652	26513	1797.491525	520.9	1&2	14.75	0.29	7.38	163.02	82.945	84.7167478	1.665	970.452	25154.12	28040	856	1.6863	1443479	155.64	82.95	10.61	62.09	0.013	0.081
202	17/01/2010	24.436	24.153	3.691	86.591	12555	1785.917496	519.8	1	7.03	0.291	7.04	162.23	82.9	84.65613503	1.658	965.544	25026.91	28040	856	1.6778	1436179	155.19	82.90	10.50	61.79	0.013	0.084
203	18/01/2010	27.773	27.449	3.714	86.502	14291	1786.375	520.6	1	8	0.291	6.97	162.4	82.788	84.65236473	1.656	964.34	24995.7	28040	856	1.6757	1434388	155.43	82.79	10.48	62.17	0.013	0.090
204	19/01/2010	29.38	28.568	3.707	86.432	15159	1787.617925	530.6	1	8.48	0.297	6.94	162.38	82.725	83.06391781	1.626	962.395	24945.28	28040	856	1.6723	1431495	155.44	82.73	10.43	62.28	0.013	0.094
205	20/01/2010	27.735	27.37	3.721	86.351	14288	1786	522	1	8	0.292	6.89	162.36	82.63	84.44817993	1.651	963.021	24961.5	28040	856	1.6734	1432425	155.47	82.63	10.45	62.39	0.013	0.095
206	21/01/2010	27.695	27.358	3.759	86.262	14285	1790.100251	522.2	1	7.98	0.292	6.91	162.44	82.503	84.46146536	1.655	964.042	24987.97	28040	856	1.6752	1433944	155.53	82.50	10.47	62.56	0.013	0.095
207	22/01/2010	83.368	82.117	3.804	86.395	42934	1787.427144	522.8	1	24.02	0.293	6.92	162.36	82.591	84.3014122	1.65	964.104	24989.58	28040	856	1.6753	1434037	155.44	82.59	10.47	62.38	0.013	0.093
208	23/01/2010	83.207	82.122	3.714	86.508	42814	1783.916667	521.3	1	24	0.292	6.86	162.33	82.794	84.55915821	1.652	963.044	24962.1	28040	856	1.6734	1432460	155.47	82.79	10.45	62.23	0.013	0.093
209	24/01/2010	82.85	81.892	3.766	86.576	43132	1819.915612	526.7	1&2	23.7	0.289	7.22	163.34	82.81	84.05058941	1.668	971.05	25169.62	28040	856	1.6873	1444369	156.12	82.81	10.62	62.69	0.013	0.087
210	25/01/2010	45.527	44.985	3.789	86.512	23823	1828.319263	529.6	1&2	13.03	0.29	7.36	163.77	82.723	83.74832496	1.666	970.559	25156.9	28040	856	1.6865	1443639	156.41	82.72	10.61	63.07	0.013	0.092
211	26/01/2010	27.648	27.336	3.721	86.362	14300	1787.5	523.1	1	8	0.293	7.07	162.54	82.641	84.27249779	1.649	960	24883.2	28040	856	1.6681	1427932	155.47	82.64	10.38	62.45	0.013	0.100
212	27/01/2010	27.648	27.648	3.721	86.224	14564	1791.389914	526.8	1	8.13	0.294	6.81	162.48	82.503	83.79697001	1.641	944.649	24485.31	28040	856	1.6415	1405099	155.67	82.50	10.05	63.11	0.014	0.135
213	28/01/2010	27.669	27.33	3.789	86.091	14313	1789.125	523.7	1	8	0.293	6.85	162.42	82.302	84.23161964	1.649	960.729	24902.1	28040	856	1.6694	1429017	155.57	82.30	10.40	62.87	0.014	0.104
214	29/01/2010	83.304	82.177	3.812	86.193	42954	1789.75	522.7	1	24	0.292	6.85	162.29	82.381	84.32372764	1.653	964.167	24991.2	28040	856	1.6754	1434130	155.44	82.38	10.47	62.59	0.013	0.095
215	30/01/2010	83.259	82.118	3.864	86.336	42914	1788.083333	522.6	1	24	0.292	6.86	162.33	82.472	84.35800581	1.651	963.646	24977.7	28040	856	1.6745	1433355	155.47	82.47	10.46	62.54	0.013	0.096
216	31/01/2010	62.088	61.396	3.917	86.481	32385	1806.190742	527.5	1&2	17.93	0.292	6.07	161.66	82.564	83.64080351	1.653	961.889	24932.16	28040	856	1.6714	1430742	155.59	82.56	10.42	62.60	0.013	0.099
218	1/02/2010	27.812	27.617	4.044	86.516	14385	1791.407223	520.9	1	8.03	0.291	7.25	161.87	82.472	84.17296822	1.66	962.087	24937.29	28040	856	1.6718	1431036	154.62	82.47	10.43	61.72	0.013	0.088
219	2/02/2010	27.836	27.642	4.337	86.427	14324	1790.5	518.2	1	8	0.289	7.17	161.68	82.09	84.54775539	1.668	966.528	25052.4	28040	856	1.6795	1437642	154.51	82.09	10.52	61.90	0.013	0.084
220	3/02/2010	27.836	27.648	4.134	86.314	14323	1790.375	518	1	8	0.289	7.45	161.5	82.18	84.32022776	1.668	966.528	25052.4	28040	856	1.6795	1437642	154.05	82.18	10.52	61.35	0.013	0.078
221	4/02/2010	82.863	82.107	4.531	86.435	42713	1799.957859	520.2	1&2	23.73	0.289	8.73	161.33	81.904	83.17924646	1.67	969.975	25141.74	28040	856	1.6855	1442769	152.60	81.90	10.60	60.10	0.013	0.061
222	5/02/2010	84.756	83.95	4.532	86.43	43895	1828.958333	522.9	2	24	0.286	8.67	160.21	81.898	82.18134968	1.688	980.972	25426.8	28040	856	1.7046	1459127	151.54	81.90	10.84	58.80	0.012	0.038
223	6/02/2010	84.425	83.629	5.176	86.696	43809	1825.375	523.8	2	24	0.287	8.74	160.07	81.52	81.91415118	1.682	977.141	25327.5	28040	856	1.6979	1453429	151.33	81.52	10.76	59.05	0.012	0.044
224	7/02/2010	28.207	27.951	5.124	86.586	14640	1827.715356	523.8	1&2	8.01	0.287	8.65	160.78	81.462	82.3590784	1.684	978.187	25354.61	28040	856	1.6997	1454984	152.13	81.46	10.78	59.89	0.012	0.050

STANWELL PIPELINE MODELLED K VALUE

DATA ENTRY NUMBER	DATE	PUMP STATION METER (ML)	END METER (ML)	G.Ht RIVER (AHD)	G.Ht STANWELL (AHD)	ENERGY USED (kWh)	MOTOR LOAD (kW)	ENERGY PER ML (kWh/ML)	PUMP NO	RUN TIME	HOURS PER ML (hrs/ML)	AVERAGE SUCTION (m)	AVERAGE DISCHARGE (m)	STATIC HEAD (m)	ACTUAL EFFIC. (%)	AVERAGE VELOCITY (m/s)	PUMP STATION METER FLOW (L/s)	PUMP STATION METER VOLUME (L)	PIPELINE LENGTH (m)	INTERNAL DIAMETER (m)	VELOCITY (m/s)	REYNOLDS NUMBER	TOTAL HEAD (m)	STATIC HEAD (m)	TOTAL FITTING LOSS (m) 3	TOTAL FRICTION LOSS (m)	FRICTION FACTOR	PIPE ROUGHNESS HEIGHT *k* (mm)
225	8/02/2010	28.259	28.005	4.426	86.473	14384	1798	513.6	1	8	0.286	8.22	160.91	82.047	84.29597479	1.69	981.215	25433.1	28040	856	1.7050	1459488	152.69	82.05	10.85	59.80	0.012	0.046
226	9/02/2010	28.218	27.95	4.134	86.376	14366	1795.75	514	1	8	0.286	7.6	160.54	82.242	84.37375459	1.686	979.792	25396.2	28040	856	1.7025	1457371	152.94	82.24	10.81	59.88	0.012	0.048
227	10/02/2010	28.195	27.926	4.164	86.279	14363	1795.375	514.3	1	8	0.286	7.4	160.35	82.115	84.32442607	1.685	978.993	25375.5	28040	856	1.7011	1456183	152.95	82.12	10.80	60.04	0.012	0.050
228	11/02/2010	84.818	83.791	4.172	86.434	43131	1797.125	514.7	1	24	0.286	7.42	160.33	82.262	84.23335013	1.685	981.69	25445.4	28040	856	1.7058	1460194	152.91	82.26	10.86	59.79	0.012	0.046
229	12/02/2010	84.782	83.725	4.179	86.588	43019	1792.458333	513.8	1	24	0.287	7.35	160.23	82.409	84.36957452	1.684	981.273	25434.6	28040	856	1.7051	1459575	152.88	82.41	10.85	59.62	0.012	0.045
230	13/02/2010	62.437	61.544	4.194	86.648	31790	1796.045198	516.5	1	17.7	0.288	7.35	160.29	82.454	83.95694299	1.678	979.865	25398.1	28040	856	1.7027	1457480	152.94	82.45	10.82	59.67	0.012	0.046
231	14/02/2010	28.211	27.883	4.216	86.62	14355	1794.375	514.8	1	8	0.287	7.42	160.52	82.404	84.3241228	1.682	979.549	25389.9	28040	856	1.7021	1457009	153.10	82.40	10.81	59.89	0.012	0.049
232	15/02/2010	28.165	27.905	4.209	86.57	14359	1794.875	514.6	1	8	0.287	7.5	160.76	82.361	84.45531615	1.684	977.951	25348.5	28040	856	1.6993	1454634	153.26	82.36	10.77	60.12	0.012	0.052
233	16/02/2010	28.144	27.891	4.232	86.572	14348	1793.5	514.4	1	8	0.287	7.51	160.8	82.34	84.49419669	1.683	977.222	25329.6	28040	856	1.6981	1453549	153.29	82.34	10.76	60.19	0.013	0.054
234	17/02/2010	28.147	27.909	4.216	86.53	14333	1791.625	513.6	1	8	0.287	7.58	160.84	82.314	84.62064581	1.684	977.326	25332.3	28040	856	1.6983	1453704	153.26	82.31	10.76	60.19	0.012	0.054
235	18/02/2010	84.51	83.663	4.299	86.701	43027	1792.791667	514.3	1	24	0.287	7.58	160.44	82.402	84.28039487	1.683	978.125	25353	28040	856	1.6996	1454892	152.86	82.40	10.78	59.68	0.012	0.048
236	19/02/2010	43.938	43.938	4.539	86.696	22374	1792.788462	509.2	1	12.48	0.284	7.77	160.5	82.157	85.04745889	1.699	977.965	25348.85	28040	856	1.6994	1454653	152.73	82.16	10.77	59.80	0.012	0.049
237	20/02/2010	19.206	19.058	4.809	86.585	9817	1797.985348	515.1	1&2	5.46	0.286	8.5	162	81.776	84.49815978	1.685	977.106	25326.59	28040	856	1.6979	1453377	153.50	81.78	10.76	60.97	0.013	0.061
238	21/02/2010	28.55	28.334	5.184	86.469	14709	1836.329588	519.1	1&2	8.01	0.283	8.9	161.9	81.285	83.57117568	1.707	990.082	25662.92	28040	856	1.7204	1472677	153.00	81.29	11.04	60.67	0.012	0.045
239	22/02/2010	28.019	27.802	5.559	86.356	14327	1790.875	515.3	1	8	0.288	8.77	160.31	80.797	83.38508974	1.677	972.882	25217.1	28040	856	1.6905	1447093	151.54	80.80	10.66	60.08	0.013	0.057
240	23/02/2010	28.061	27.842	5.859	86.255	14322	1790.25	514.4	1	8	0.287	9.1	160.42	80.396	83.41294059	1.68	974.34	25254.9	28040	856	1.6931	1449262	151.32	80.40	10.69	60.23	0.013	0.057
241	24/02/2010	28.092	28.092	6.136	86.169	14363	1795.375	511.3	1	8	0.285	9.34	161.56	80.033	84.42081807	1.695	975.417	25282.8	28040	856	1.6949	1450863	152.22	80.03	10.72	61.47	0.013	0.068
242	25/02/2010	85.344	84.449	6.249	86.308	43129	1797.041667	510.7	1	24	0.284	9.64	161.66	80.059	84.40461443	1.698	987.778	25603.2	28040	856	1.7164	1469250	152.02	80.06	10.99	60.97	0.012	0.050
243	26/02/2010	85.437	84.537	6.25	86.31	43089	1795.375	509.7	1	24	0.284	9.64	161.65	80.06	84.56544042	1.7	988.854	25631.1	28040	856	1.7183	1470851	152.01	80.06	11.02	60.93	0.012	0.048
244	27/02/2010	60.44	59.845	6.414	86.467	30512	1794.823529	509.9	1	17	0.284	9.74	161.82	80.053	84.58038135	1.699	987.582	25598.12	28040	856	1.7161	1468958	152.08	80.05	10.99	61.04	0.012	0.050
245	28/02/2010	28.408	28.144	5.582	86.38	14360	1795	510.2	1	8	0.284	9.79	161.82	80.798	84.48916483	1.698	986.389	25567.2	28040	856	1.7140	1467184	152.03	80.80	10.96	60.27	0.012	0.045
246	1/03/2010	51.776	51.347	5.332	86.369	26426	1819.972452	514.7	1&2	14.52	0.283	10.12	162.78	81.037	84.11031151	1.707	990.511	25674.05	28040	856	1.7212	1473315	152.66	81.04	11.05	60.57	0.012	0.043
247	2/03/2010	32.373	32.091	4.72	86.283	16579	1835.991141	516.6	1&2	9.03	0.281	9.92	162.84	81.563	83.93238185	1.715	995.847	25812.36	28040	856	1.7304	1481252	152.92	81.56	11.17	60.18	0.012	0.035
248	3/03/2010	28.74	28.472	4.636	86.198	14761	1840.523691	518.4	2	8.02	0.282	9.01	162.85	81.562	84.14180136	1.714	995.428	25801.5	28040	856	1.7297	1480629	153.84	81.56	11.16	61.12	0.012	0.043
249	4/03/2010	85.744	84.725	4.082	86.344	43978	1832.416667	519.1	2	24	0.283	8.82	162.85	82.262	84.14372952	1.704	992.407	25723.2	28040	856	1.7245	1476136	154.03	82.26	11.10	60.67	0.012	0.042
250	5/03/2010	85.744	84.725	3.692	86.49	43978	1832.416667	519.1	2	24	0.283	8.82	162.85	82.798	84.14372952	1.704	992.407	25723.2	28040	856	1.7245	1476136	154.03	82.80	11.10	60.14	0.012	0.038
251	6/03/2010	86.693	86.693	3.752	86.635	43024	1815.35865	496.3	1&2	23.7	0.273	8.57	162.73	82.883	88.08161889	1.766	1016.09	26337.11	28040	856	1.7656	1511366	154.16	82.88	11.63	59.65	0.011	0.016
252	7/03/2010	45.802	45.22	3.892	86.64	23352	1793.548387	516.4	1&2	13.02	0.288	8.58	162.4	82.748	84.4616619	1.676	977.172	25328.29	28040	856	1.6980	1453474	153.82	82.75	10.76	60.31	0.013	0.055
253	8/03/2010	28.498	27.89	4.282	86.542	14707	1836.0799	527.3	1&2	8.01	0.287	8.8	163	82.26	82.91806047	1.681	988.279	25616.18	28040	856	1.7173	1469995	154.20	82.26	11.00	60.94	0.012	0.049
254	9/03/2010	28.155	27.887	5.304	86.462	14386	1798.25	515.9	1&2	8	0.287	9.02	163.3	81.158	84.8030965	1.683	977.604	25339.5	28040	856	1.6987	1454117	154.28	81.16	10.77	62.36	0.013	0.074
255	10/03/2010	44.824	44.824	5.544	86.521	23151	1834.469097	516.5	2	12.62	0.282	9.71	163.81	80.977	84.60262391	1.714	986.617	25573.12	28040	856	1.7144	1467524	154.10	80.98	10.97	62.16	0.013	0.062
256	11/03/2010	84.055	84.055	5.777	86.584	43140	1817.95196	513.2	1&2	23.73	0.282	9.5	162.92	80.807	84.76288492	1.71	983.928	25503.41	28040	856	1.7097	1463523	153.42	80.81	10.91	61.71	0.013	0.060
257	12/03/2010	84.291	84.291	5.979	86.623	42973	1790.541667	509.8	1	24	0.285	9.26	161.78	80.644	84.83062541	1.695	975.59	25287.3	28040	856	1.6952	1451122	152.52	80.64	10.72	61.15	0.013	0.065
258	13/03/2010	32.169	32.169	6.084	86.671	16459	1792.91939	511.6	1&2	9.18	0.285	9.88	163.08	80.587	84.90499099	1.691	973.402	25230.59	28040	856	1.6914	1447867	153.20	80.59	10.67	61.94	0.013	0.075
259	14/03/2010	28.487	28.168	4.899	86.573	14711	1832.004981	522.3	2	8.03	0.285	10.49	164.32	81.674	83.52090587	1.693	985.437	25542.52	28040	856	1.7123	1465767	153.83	81.67	10.94	61.22	0.013	0.054
260	15/03/2010	28.485	28.165	4.992	86.486	14717	1835.037406	522.5	2	8.02	0.285	10.43	164.52	81.494	83.61905599	1.695	986.596	25572.57	28040	856	1.7144	1467492	154.09	81.49	10.97	61.63	0.013	0.057
261	16/03/2010	28.441	28.068	4.902	86.346	14738	1835.367372	525.1	2	8.03	0.286	9.95	164.38	81.444	83.39594352	1.687	983.845	25501.27	28040	856	1.7096	1463400	154.43	81.44	10.90	62.08	0.013	0.064
262	17/03/2010	28.314	28.314	4.5	86.221	14721	1833.250311	519.9	2	8.03	0.284	9.14	164.03	81.721	84.47488987	1.702	979.452	25387.4	28040	856	1.7019	1456866	154.89	81.72	10.81	62.36	0.013	0.072
263	18/03/2010	84.421	84.421	4.693	86.45	44004	1833.5	521.2	2	24	0.284	8.29	163.36	81.757	84.35803649	1.698	977.095	25326.3	28040	856	1.6979	1453360	155.07	81.76	10.76	62.56	0.013	0.077
264	19/03/2010	84.223	84.223	4.88	86.59	43905	1829.375	521.3	2	24	0.285	8.26	163.07	81.71	84.20852793	1.694	974.803	25266.9	28040	856	1.6939	1449951	154.81	81.71	10.71	62.39	0.013	0.078
265	20/03/2010	28.799	28.465	5.274	86.832	15101	1834.872418	530.5	2	8.23	0.289	8.7	163.15	81.558	82.55316583	1.669	972.02	25194.75	28040	856	1.6890	1445811	154.45	81.56	10.64	62.25	0.013	0.080
266	21/03/2010	25.207	24.99	5.499	86.747	13083	1829.79021	523.5	2	7.15	0.286	10.28	165.21	81.248	83.91406793	1.687	979.293	25383.27	28040	856	1.7017	1456629	154.93	81.25	10.80	62.88	0.013	0.078
267	22/03/2010	27.74	27.444	4.471	86.654	14457	1834.64467	526.8	2	7.88	0.287	9.28	164.87	82.183	83.75124079	1.681	977.862	25346.19	28040	856	1.6992	1454501	155.59	82.18	10.77	62.63	0.013	0.077
268	23/03/2010	28.151	27.902	3.774	86.568	14708	1831.631382	527.1	2	8.03	0.288	8.85	164.44	82.794	83.69581321	1.677	973.813	25241.25	28040	856	1.6921	1448479	155.59	82.79	10.68	62.11	0.013	0.077
269	24/03/2010	28.164	27.893	3.849	86.483	14735	1834.993773	528.3	2	8.03	0.288	8.43	164.76	82.634	83.91271134	1.677	974.263	25252.9	28040	856	1.6929	1449148	156.33	82.63	10.69	63.00	0.013	0.086
270	25/03/2010	84.166	83.213	3.872	86.634	43962	1831.75	528.3	2	24	0.288	8.54	164.34	82.762	83.62218868	1.674	974.144	25249.8	28040	856	1.6927	1448970	155.80	82.76	10.69	62.35	0.013	0.079
271	26/03/2010	61.598	60.941	4.232	86.702	32291	1824.350282	529.9	2	17.7	0.29	8.72	163.11	82.47	82.62045616	1.662	966.698	25056.81	28040	856	1.6798	1437895	154.39	82.47	10.53	61.39	0.013	0.078
272	27/03/2010	27.347	27.02	4.539	86.607	14333	1814.303797	530.5	2	7.9	0.292	9.11	163.42	82.068	82.48645787	1.651	961.568	24923.85	28040	856	1.6709	1430265	154.31	82.07	10.42	61.83	0.013	0.090
273	28/03/2010	26.296	26.071	4.54	86.524	13909	1794.709677	533.5	1&2	7.75	0.297	8.75	162.16	81.984	81.53719967	1.624	942.509	24429.83	28040	856	1.6378	1401916	153.41	81.98	10.01	61.42	0.014	0.115
274	29/03/2010	29.981	29.981	4.445	86.473	15722	1780.520951	524.4	1&2	8.83	0.295	8.59	157.05	82.028	80.27644249	1.639	943.155	24446.57	28040	856	1.6389	1402876	148.46	82.03	10.02	56.41	0.013	0.055
275	30/03/2010	27.639	27.376	4.337	86.422	14309	1788.625	522.7	1	8	0.292	7.44	163.27	82.085	84.53802911	1.652	959.688	24875.1	28040	856	1.6676	1427467	155.83	82.09	10.38	63.37	0.014	0.112
276	31/03/2010	27.639	27.334	4.239	86.366	14306	1788.25	523.4	1	8	0.293	7.19	163.23	82.127	84.5398067	1.649	959.688	24875.1	28040	856	1.6676	1427467	156.04	82.13	10.38	63.54	0.014	0.114
277	1/04/2010	82.993	81.959	4.224	86.524	42869	1786.208333	523.1	1	24	0.293	7.14	163.15	82.3	84.57579217	1.648	960.567	24897.9	28040	856	1.6691	1428776	156.01	82.30	10.39	63.32	0.014	0.110
278	2/04/2010	83.025	81.944	4.179	86.684	42840	1785	522.8	1	24	0.293	7.14	163.13	82.505	84.60670758	1.648	960.938	24907.5	28040	856	1.6698	1429327	155.99	82.51	10.40	63.08	0.014	0.106
279	3/04/2010	33.922	33.538	4.172	86.657	17539	1784.231943	523	1	9.83	0.293	7.11	163.13	82.485	84.59660712	1.647	958.574	24846.23	28040	856	1.6657	1425810	156.02	82.49	10.35	63.18	0.014	0.112
280	4/04/2010	27.576	27.266	4.209	86.582	14274	1784.25	523.5	1	8	0.293	7.12	163.27	82.373	84.57812751	1.645	957.5	24818.4	28040	856	1.6638	1424214	156.32	82.37	10.33	63.45	0.014	0.117
281	5/04/2010	27.561	27.231	4.194	86.512	14302	1787.75	525.2	1	8	0.294	7.15	163.32	82.318	84.31498483	1.643	956.979	24804.9	28040	856	1.6629	1423439	156.17	82.32	10.32	63.53	0.014	0.119
282	6/04/2010	27.558	27.558	4.179	86.437	14288	1786	518.5	1	8	0.29	7.14	163.38	82.258	85.44936191	1.663	956.875	24802.2	28040	856	1.6627	1423284	156.24	82.26	10.31	63.67	0.014	0.121
283	7/04/2010	27.553	27.211	3.751	86.478	14287	1785.875	525	1	8	0.294	7.12	163.44	82.727	84.42252618	1.642	956.701	24797.7	28040	856	1.6624	1423026	156.32	82.73	10.31	63.28	0.014	0.116
284	8/04/2010	82.871	81.643	3.783	86.478	42891	1787.125	525.3	1	24	0.294	7.13	163.42	82.695	84.35761902	1.642	959.155	24861.3	28040	856	1.6667	1426675	156.29	82.70	10.36	63.23	0.014	0.111
285	9/04/2010	82.873	81.708	3.796	86.613	42793	1783.041667	523.7	1	24	0.294	7.17	163.44	82.817	84.60729261	1.643	959.178	24861.9	28040	856	1.6667	1426710	156.27	82.82	10.36	63.09	0.014	0.109
286	10/04/2010	44.829	44.227	3.789	86.585	23211	1785.461538	524.8	1	13	0.294	7.17	163.5	82.796	84.46490484	1.642	957.885	24828.37	28040	856	1.6645	1424786	156.33	82.80	10.34	63.20	0.014	0.113
287	11/04/2010	27.567	27.181	3.773	86.523	14271	1788.345865	525	1	7.98	0.294	7.16	163.42	82.75	84.39159281	1.644	959.586	24872.48	28040	856	1.6674	1427317	156.26	82.75	10.37	63.14	0.014	0.109
288	12/04/2010	27.931	27.67	3.77	86.449	14525	1788.793103	524.9	1&2	8.12	0.293	7.58	165.06	82.679	85.06653902	1.645	955.494	24766.4	28040	856	1.6603	1421230	157.48	82.68	10.29	64.52	0.014	0.135
289	13/04/2010	31.785	31.405	3.77	86.398	16692	1824.262295	531.5	1&2	9.15	0.291	7.66	164.98	82.628	83.92951218	1.657	964.936	25011.15	28040	856	1.6767	1435275	157.32	82.63	10.49	64.20	0.014	0.114
290	14/04/2010	28.005	27.635	3.817	86.335	14702	1833.167082	532	2	8.02	0.29	8.08	165.64	82.518	83.97874151	1.663	969.971	25141.65	28040	856	1.6855	1442763	157.56	82.52	10.60	64.44	0.014	0.109
291	15/04/2010	84.091	82.772	3.787	86.466	43989	1832.875	531.4	2	24	0.29	8.09	165.54	82.679	84.00833247	1.665	973.275	25227.3	28040	856	1.6912	1447679	157.45	82.68	10.67	64.10	0.013	0.100
292	16/04/2010	84.09	82.763	3.704	86.598	43919	1829.958333	530.7	2	24	0.29	8.06	165.46	82.894	84.10636219	1.664	973.264	25227	28040	856	1.6912	1447661	157.40	82.89	10.67	63.83	0.013	0.097
293	17/04/2010	59.588	58.636	3.749	86.633	31219	1833.176747	532.4	2	17.03	0.29	8.01	165.44	82.884	83.84423052	1.662	971.945	25192.81	28040	856	1.6889	1445699	157.43	82.88	10.64	63.90	0.013	0.099
294	18/04/2010	26.759	26.419	3.789	86.548	13971	1809.715026	528.8	1&2	7.72	0.292	7.65	164.5	82.759	84.1034371	1.652	962.831	24956.58	28040	856	1.6731	1432143	156.85	82.76	10.44	63.65	0.014	0.111
295	19/04/2010	27.554	27.21	3.729	86.459	14350	1789.276808	527.4	1&2	8.02	0.295	7.59	164.74	82.73	84.49506911	1.638	954.35	24736.76	28040	856	1.6583	1419529	157.15	82.73	10.26	64.16	0.014	0.132
296	20/04/2010	27.937	27.559	3.729	86.369	14665	1830.836454	532.1	1&2	8.01	0.291	7.55	164.65	82.64	83.71396496	1.661	968.824	25111.91	28040	856	1.6835	1441057	157.10	82.64	10.57	63.89	0.014	0.104
297	21/04/2010	27.515	27.086	3.766	86.283	14283	1785.375	527.3	1	8	0.295	7.1	163.17	82.517	83.92381307	1.634	955.382	24763.5	28040	856	1.6601	1421063	156.07	82.52	10.28	63.27	0.014	0.118
298	22/04/2010	82.689	81.383	3.804	86.425	42901	1787.541667	527.1	1	24	0.295	7.14	163.25	82.621	83.97255022	1.637	957.049	24806.7	28040	856	1.6630	1423542	156.11	82.62	10.32	63.17	0.014	0.114

STANWELL PIPELINE MODELLED K VALUE

DATA ENTRY NUMBER	DATE	PUMP STATION METER (ML)	END METER (ML)	G.Ht RIVER (AHD)	G.Ht STANWELL (AHD)	ENERGY USED (kWh)	MOTOR LOAD (kW)	ENERGY PER ML (kWh/ML)	PUMP NO	RUN TIME	HOURS PER ML (hrs/ML)	AVERAGE SUCTION (m)	AVERAGE DISCHARGE (m)	STATIC HEAD (m)	ACTUAL EFFIC. (%)	AVERAGE VELOCITY (m/s)	PUMP STATION METER FLOW (L/s)	PUMP STATION METER VOLUME (L)	PIPELINE LENGTH (m)	INTERNAL DIAMETER (m)	VELOCITY (m/s)	REYNOLDS NUMBER	TOTAL HEAD (m)	STATIC HEAD (m)	TOTAL FITTING LOSS (m) 3	TOTAL FRICTION LOSS (m)	FRICTION FACTOR	PIPE ROUGHNESS HEIGHT k (mm)
299	23/04/2010	82.629	81.333	3.804	86.571	42850	1785.416667	526.8	1	24	0.295	7.15	163.36	82.767	84.07466341	1.636	956.354	24788.7	28040	856	1.6618	1422509	156.21	82.77	10.30	63.14	0.014	0.115
300	24/04/2010	43.974	43.974	3.729	86.565	23208	1785.230769	527.8	1	13	0.296	7.1	163.38	82.836	83.9657165	1.633	939.615	24354.83	28040	856	1.6327	1397612	156.28	82.84	9.95	63.50	0.014	0.151
301	25/04/2010	24.476	24.085	3.797	86.478	12654	1777.247191	525.4	1	7.12	0.296	7.07	163.34	82.681	84.34022827	1.633	954.9	24751.01	28040	856	1.6593	1420346	156.27	82.68	10.27	63.32	0.014	0.120
303	26/04/2010	20.07	19.423	3.787	86.183	10240	1787.085515	527.2	1	5.73	0.295	7.2	163.95	82.396	84.30711782	1.636	972.949	25218.85	28040	856	1.6906	1447194	156.75	82.40	10.66	63.69	0.013	0.095
304	27/04/2010	82.811	81.316	3.734	86.323	43034	1793.083333	529.2	1	24	0.295	7.24	163.62	82.589	83.78877478	1.635	958.461	24843.3	28040	856	1.6655	1425643	156.38	82.59	10.35	63.44	0.014	0.115
305	28/04/2010	82.697	81.274	3.696	86.443	42902	1787.583333	527.9	1	24	0.295	7.17	163.72	82.747	84.09448349	1.635	957.141	24809.1	28040	856	1.6632	1423680	156.55	82.75	10.32	63.48	0.014	0.118
306	29/04/2010	82.666	81.193	3.719	86.575	42845	1785.208333	527.7	1	24	0.296	7.2	163.83	82.856	84.16542653	1.633	956.782	24799.8	28040	856	1.6626	1423146	156.63	82.86	10.31	63.46	0.014	0.118
307	30/04/2010	77.811	76.332	3.727	86.695	40344	1785.132743	528.5	1	22.6	0.296	7.11	163.81	82.968	84.06922085	1.63	956.379	24789.35	28040	856	1.6619	1422546	156.70	82.97	10.30	63.43	0.014	0.119
308	1/05/2010	24.515	24.088	3.72	86.602	12739	1786.676017	528.9	1&2	7.13	0.296	7.55	165.27	82.882	84.56536209	1.631	955.08	24755.68	28040	856	1.6596	1420614	157.72	82.88	10.28	64.56	0.014	0.137
309	2/05/2010	27.939	27.428	3.728	86.523	14710	1834.164589	536.3	2	8.02	0.292	8.05	166.03	82.795	83.52642949	1.651	967.685	25082.39	28040	856	1.6815	1439363	157.98	82.80	10.55	64.64	0.014	0.115
310	3/05/2010	27.928	27.415	3.707	86.421	14686	1831.17207	535.7	2	8.02	0.293	8.04	166.13	82.714	83.68150171	1.65	967.304	25072.52	28040	856	1.6808	1438796	158.09	82.71	10.54	64.83	0.014	0.118
311	4/05/2010	32.244	31.685	3.691	86.36	16989	1824.81203	536.2	1&2	9.31	0.294	7.57	165.39	82.669	83.46190124	1.643	962.048	24936.28	28040	856	1.6717	1430978	157.82	82.67	10.43	64.72	0.014	0.126
312	5/05/2010	83.531	81.864	3.744	86.482	43909	1829.541667	536.4	2	24	0.293	8.03	165.83	82.738	83.42318237	1.646	966.794	25059.3	28040	856	1.6800	1438038	157.80	82.74	10.53	64.53	0.014	0.115
313	6/05/2010	81.822	80.129	3.766	86.598	43434	1809.75	542.1	2	24	0.3	8.16	162.64	82.832	80.81137495	1.611	947.014	24546.6	28040	856	1.6456	1408616	154.48	82.83	10.10	61.54	0.014	0.109
314	7/05/2010	58.407	57.257	3.707	86.632	30853	1820.235988	538.9	2	16.95	0.296	8.05	164.79	82.925	82.48051652	1.63	957.178	24810.05	28040	856	1.6632	1423735	156.74	82.93	10.32	63.49	0.014	0.118
315	8/05/2010	27.891	27.379	3.789	86.552	14686	1831.17207	536.4	2	8.02	0.293	8.03	166.19	82.763	83.60861969	1.648	966.022	25039.3	28040	856	1.6786	1436890	158.16	82.76	10.51	64.88	0.014	0.121
316	9/05/2010	27.882	27.379	3.707	86.445	14678	1827.895392	536.1	2	8.03	0.293	8.1	166.34	82.738	83.69650288	1.646	964.508	25000.05	28040	856	1.6760	1434638	158.24	82.74	10.48	65.02	0.014	0.126
317	10/05/2010	27.993	27.5	3.729	86.385	14797	1833.581165	538.1	2	8.07	0.293	8.01	166.38	82.656	83.45882694	1.645	963.548	24975.17	28040	856	1.6743	1433210	158.37	82.66	10.46	65.25	0.014	0.131
318	11/05/2010	27.962	27.509	3.751	86.324	14708	1827.080745	534.7	2	8.05	0.293	8.05	166.48	82.573	84.02314704	1.649	964.872	25009.49	28040	856	1.6766	1435179	158.43	82.57	10.49	65.37	0.014	0.130
319	12/05/2010	83.486	81.995	3.691	86.48	43892	1828.833333	535.3	2	24	0.293	8.02	166.36	82.789	83.87508624	1.649	966.273	25045.8	28040	856	1.6790	1437263	158.34	82.79	10.52	65.03	0.014	0.123
320	13/05/2010	83.533	82.049	3.766	86.62	43921	1830.041667	535.3	2	24	0.293	8.04	166.32	82.854	83.84312437	1.65	966.817	25059.9	28040	856	1.6800	1438072	158.28	82.85	10.53	64.90	0.014	0.120
321	14/05/2010	67.806	66.547	3.766	86.709	35712	1829.508197	536.6	2	19.52	0.293	8.09	166.38	82.943	83.63886438	1.646	964.908	25010.41	28040	856	1.6767	1435232	158.29	82.94	10.49	64.86	0.014	0.123
322	15/05/2010	25.549	25.109	3.691	86.629	13463	1831.70068	536.2	2	7.35	0.293	8.04	166.32	82.938	83.70549172	1.649	965.571	25027.59	28040	856	1.6778	1436218	158.28	82.94	10.50	64.84	0.014	0.121
323	16/05/2010	27.921	27.1	3.714	86.524	14724	1833.62391	543.3	2	8.03	0.296	7.98	166.11	82.81	82.5273866	1.629	965.857	25035.02	28040	856	1.6783	1436644	158.13	82.81	10.51	64.81	0.014	0.121
324	17/05/2010	27.935	27.458	3.789	86.446	14682	1828.393524	534.7	2	8.03	0.292	8.03	166.11	82.657	83.83028597	1.65	966.341	25047.57	28040	856	1.6792	1437365	158.08	82.66	10.52	64.90	0.014	0.121
325	18/05/2010	27.895	27.413	3.744	86.394	14693	1829.763387	536	2	8.03	0.293	8.09	166.32	82.65	83.70959775	1.648	964.958	25011.71	28040	856	1.6768	1435307	158.23	82.65	10.49	65.09	0.014	0.126
326	19/05/2010	83.233	81.989	3.691	86.554	43946	1831.083333	536	2	24	0.293	8.03	166.81	82.863	83.99866332	1.649	963.345	24969.9	28040	856	1.6740	1432908	158.78	82.86	10.45	65.46	0.014	0.134
327	20/05/2010	82.959	81.513	3.744	86.711	43784	1824.333333	537.1	2	24	0.294	8.06	167.42	82.967	84.12616715	1.639	960.174	24887.7	28040	856	1.6684	1428190	159.36	82.97	10.39	66.01	0.014	0.148
328	21/05/2010	27.611	27.194	3.789	86.641	14629	1817.267081	537.9	2	8.05	0.296	8.11	168.11	82.852	84.33712176	1.631	952.761	24695.55	28040	856	1.6556	1417164	160.00	82.85	10.23	66.92	0.015	0.178
329	22/05/2010	27.529	27.062	3.729	86.586	14614	1819.92528	540	2	8.03	0.297	8.06	168.63	82.857	84.31319239	1.627	952.297	24683.54	28040	856	1.6548	1416474	160.57	82.86	10.22	67.50	0.015	0.189
330	23/05/2010	27.429	27.018	3.73	86.59	14630	1821.917808	541.5	2	8.03	0.297	8.04	168.81	82.86	84.18878123	1.624	948.838	24593.87	28040	856	1.6487	1411329	160.77	82.86	10.14	67.77	0.015	0.202
331	24/05/2010	27.365	26.966	3.744	86.475	14614	1815.403727	541.9	2	8.05	0.299	8.1	169.26	82.731	84.3228012	1.617	944.272	24475.53	28040	856	1.6408	1404538	161.16	82.73	10.05	68.38	0.015	0.225
332	25/05/2010	27.365	26.966	3.789	86.38	14621	1820.797011	542.2	2	8.03	0.298	8.1	169.26	82.591	84.28243052	1.621	946.624	24536.49	28040	856	1.6449	1408036	161.16	82.59	10.10	68.47	0.015	0.220
333	26/05/2010	81.79	80.455	3.707	86.564	43643	1818.458333	542.5	2	24	0.298	8.11	169.32	82.857	84.26956662	1.618	946.644	24537	28040	856	1.6449	1408065	161.21	82.86	10.10	68.26	0.015	0.216
334	27/05/2010	82.229	80.841	3.707	86.704	43677	1819.875	540.3	2	24	0.297	8.05	168.6	82.997	84.26156589	1.626	951.725	24668.7	28040	856	1.6538	1415623	160.55	83.00	10.20	67.35	0.015	0.187
335	28/05/2010	26.306	25.873	3.744	86.634	13958	1817.447917	539.5	2	7.68	0.297	8.09	168.5	82.89	84.31316119	1.626	951.461	24661.88	28040	856	1.6533	1415231	160.41	82.89	10.20	67.32	0.015	0.188
336	29/05/2010	27.508	27.054	3.75	86.63	14645	1819.254658	541.3	2	8.05	0.298	8.09	168.5	82.88	84.02603835	1.622	949.206	24603.43	28040	856	1.6494	1411877	160.41	82.88	10.15	67.38	0.015	0.194
337	30/05/2010	27.528	27.016	3.691	86.501	14643	1823.536737	542	2	8.03	0.297	8.11	168.44	82.81	83.87762353	1.624	952.262	24682.64	28040	856	1.6547	1416423	160.33	82.81	10.22	67.30	0.015	0.185
338	31/05/2010	27.528	27.052	3.714	86.442	14640	1823.163138	541.2	2	8.03	0.297	8.02	168.38	82.728	84.02232388	1.626	952.262	24682.64	28040	856	1.6547	1416423	160.36	82.73	10.22	67.42	0.015	0.187
339	1/06/2010	27.509	27.004	3.744	86.377	14636	1822.665006	542	1&2	8.03	0.297	7.67	167.49	82.633	83.61364656	1.623	951.605	24665.6	28040	856	1.6536	1415445	159.82	82.63	10.20	66.99	0.015	0.182
340	2/06/2010	81.558	79.934	3.789	86.528	42729	1780.375	534.6	1	24	0.3	7.29	165.77	82.739	84.06662633	1.608	943.958	24467.4	28040	856	1.6403	1404071	158.48	82.74	10.04	65.70	0.015	0.178
341	3/06/2010	81.735	80.182	3.766	86.662	42731	1780.458333	532.9	1	24	0.299	7.29	165.42	82.896	84.13727434	1.613	946.007	24520.5	28040	856	1.6438	1407119	158.13	82.90	10.08	65.15	0.014	0.164
342	4/06/2010	47.189	46.309	3.721	86.68	24698	1783.249097	533.3	1	13.85	0.299	7.25	165.19	82.959	83.97230794	1.614	946.43	24531.47	28040	856	1.6446	1407748	157.94	82.96	10.09	64.89	0.014	0.159
343	5/06/2010	26.846	26.307	3.707	86.599	14074	1786.040609	535	1	7.88	0.3	7.23	165.68	82.892	83.98202864	1.611	946.348	24529.34	28040	856	1.6444	1407626	158.45	82.89	10.09	65.47	0.015	0.168
344	6/06/2010	27.203	26.74	3.707	86.544	14269	1783.625	533.6	1	8	0.299	7.2	165.44	82.837	84.08615203	1.613	944.549	24482.7	28040	856	1.6413	1404949	158.24	82.84	10.05	65.35	0.015	0.170
345	7/06/2010	27.293	26.842	3.71	86.54	14313	1778.012422	533.2	1	8.05	0.3	7.21	165.62	82.83	84.23782291	1.609	941.787	24411.13	28040	856	1.6365	1400842	158.41	82.83	9.99	65.59	0.015	0.181
346	8/06/2010	27.358	26.875	3.751	86.4	14311	1777.763975	532.5	1	8.05	0.3	7.24	165.75	82.649	84.40642312	1.611	944.03	24469.27	28040	856	1.6404	1404178	158.51	82.65	10.04	65.82	0.015	0.179
347	9/06/2010	81.55	80.284	3.766	86.526	42660	1777.5	531.4	1	24	0.299	7.27	165.83	82.76	84.61398083	1.615	943.866	24465	28040	856	1.6401	1403934	158.56	82.76	10.04	65.76	0.015	0.179
348	10/06/2010	81.521	80.217	3.789	86.68	42677	1778.208333	532	1	24	0.299	7.3	165.91	82.891	84.53633932	1.613	943.53	24456.3	28040	856	1.6395	1403434	158.61	82.89	10.03	65.69	0.015	0.178
349	11/06/2010	37.671	37.099	3.759	86.67	19818	1782.194245	534.2	1&2	11.12	0.3	7.68	167.48	82.911	84.82414558	1.61	941.022	24391.29	28040	856	1.6352	1399704	159.80	82.91	9.98	66.91	0.015	0.206
350	12/06/2010	24.493	24.164	3.71	86.41	12995	1822.580645	537.8	2	7.13	0.295	8.07	168.28	82.7	84.47389181	1.636	954.223	24733.46	28040	856	1.6581	1419340	160.21	82.70	10.26	67.25	0.015	0.180
351	13/06/2010	27.01	26.512	3.699	86.539	14400	1827.411168	543.2	2	7.88	0.297	8.02	168.54	82.84	83.80105565	1.624	952.129	24679.19	28040	856	1.6545	1416225	160.52	82.84	10.21	67.47	0.015	0.188
352	14/06/2010	27.49	27.021	3.707	86.488	14662	1821.36646	542.6	2	8.05	0.298	8.02	168.4	82.781	83.81056162	1.62	948.585	24587.33	28040	856	1.6483	1410954	160.38	82.78	10.14	67.46	0.015	0.197
353	15/06/2010	27.432	26.962	3.713	86.401	14619	1816.024845	542.2	1&2	8.05	0.299	7.74	167.59	82.688	83.59636977	1.617	946.584	24535.45	28040	856	1.6448	1407977	159.85	82.69	10.09	67.07	0.015	0.195
354	16/06/2010	81.12	79.723	3.752	86.567	42709	1779.541667	535.7	1	24	0.301	7.34	166.51	82.815	84.24920003	1.603	938.889	24336	28040	856	1.6315	1396531	159.17	82.82	9.93	66.42	0.015	0.202
355	17/06/2010	81.05	79.65	3.768	86.62	42669	1777.875	535.7	1	24	0.301	7.33	166.62	82.852	84.31448023	1.602	938.079	24315	28040	856	1.6301	1395326	159.29	82.85	9.91	66.52	0.015	0.206
356	18/06/2010	23.187	22.858	3.71	86.49	12258	1776.521739	536.3	1	6.9	0.302	7.34	166.99	82.78	84.41660337	1.599	933.454	24195.13	28040	856	1.6220	1388447	159.65	82.78	9.82	67.05	0.015	0.229
357	19/06/2010	27	26.56	3.759	86.576	14240	1775.561097	536.1	1	8.02	0.302	7.33	166.79	82.817	84.33545272	1.598	935.162	24239.4	28040	856	1.6250	1390988	159.46	82.82	9.85	66.79	0.015	0.219
358	20/06/2010	26.982	26.567	3.721	86.488	14288	1781.546135	537.8	1&2	8.02	0.302	7.69	168.31	82.767	84.68588594	1.599	934.539	24223.24	28040	856	1.6239	1390060	160.62	82.77	9.84	68.01	0.015	0.245
359	21/06/2010	27.391	26.952	3.699	86.435	14642	1823.412204	543.3	2	8.03	0.298	8.05	169.05	82.736	84.03434337	1.62	947.523	24559.8	28040	856	1.6465	1409374	161.00	82.74	10.11	68.15	0.015	0.212
360	22/06/2010	27.378	27.378	3.707	86.391	14619	1820.547945	534	2	8.03	0.293	8.03	169.16	82.684	85.56591515	1.646	947.073	24548.14	28040	856	1.6457	1408705	161.13	82.68	10.10	68.34	0.015	0.217
361	23/06/2010	81.953	81.953	3.729	86.61	43665	1819.375	532.8	2	24	0.293	8.06	169.16	82.881	85.73680028	1.648	948.53	24585.9	28040	856	1.6482	1410872	161.10	82.88	10.14	68.08	0.015	0.208
362	24/06/2010	81.985	81.985	3.751	86.67	43635	1818.125	532.2	2	24	0.293	8.09	169.12	82.919	85.79195274	1.649	948.9	24595.5	28040	856	1.6489	1411422	161.03	82.92	10.14	67.97	0.015	0.205
363	25/06/2010	31.432	31.432	3.774	86.59	16765	1808.522114	533.4	1&2	9.27	0.295	7.71	168.27	82.816	85.3583786	1.637	941.867	24413.2	28040	856	1.6366	1400961	160.56	82.82	9.99	67.75	0.015	0.219
364	26/06/2010	26.162	25.819	3.789	86.48	13855	1778.562259	536.6	1&2	7.79	0.302	7.8	168.04	82.691	84.67284712	1.6	932.891	24180.54	28040	856	1.6210	1387610	160.24	82.69	9.80	67.74	0.015	0.244
365	27/06/2010	26.954	26.51	3.759	86.381	14271	1779.426434	538.3	1	8.02	0.303	7.31	167.05	82.622	84.14132392	1.595	933.569	24198.1	28040	856	1.6222	1388618	159.74	82.62	9.82	67.30	0.015	0.233
366	28/06/2010	33.005	32.609	3.721	86.326	17607	1787.51269	539.9	1&2	9.85	0.302	7.68	168.33	82.605	84.36711258	1.598	930.767	24125.48	28040	856	1.6173	1384450	160.65	82.61	9.76	68.29	0.016	0.262
367	29/06/2010	27.36	26.921	3.707	86.248	14621	1820.797011	543.1	2	8.03	0.298	8.05	169.14	82.541	84.10523563	1.618	946.451	24532	28040	856	1.6446	1407779	161.09	82.54	10.09	68.46	0.015	0.221
368	30/06/2010	80.649	79.511	3.707	86.388	42945	1808.972199	540.1	1&2	23.74	0.299	7.63	167.88	82.681	84.13040626	1.617	943.66	24459.68	28040	856	1.6398	1403628	160.25	82.68	10.03	67.54	0.015	0.211
369	1/07/2010	80.622	79.385	3.714	86.552	42563	1773.458333	536.2	1	24	0.302	7.2	166.32	82.838	84.1533342	1.597	933.125	24186.6	28040	856	1.6214	1387958	159.12	82.84	9.81	66.47	0.015	0.218
370	2/07/2010	80.7	79.498	3.737	86.677	42751	1781.291667	537.8	1	24	0.302	7.2	166.26	82.94	83.87088826	1.599	934.028	24210	28040	856	1.6230	1389300	159.06	82.94	9.83	66.29	0.015	0.213
371	3/07/2010	25.983	25.677	3.741	86.68	13826	1784	538.5	1&2	7.75	0.302	7.65	168.27	82.939	84.58389685	1.599	931.29	24139.05	28040	856	1.6183	1385229	160.62	82.94	9.77	67.91	0.016	0.253
372	4/07/2010	29.168	28.805	3.766	86.483	15476	1782.949309	537.3	1&2	8.68	0.301	7.66	168.23	82.717	84.74496513	1.602	933.436	24194.65	28040	856	1.6220	1388420	160.57	82.72	9.82	68.04	0.015	0.249
373	5/07/2010	27.422	27.025	3.789	86.456	14673	1827.272727	542.9	2	8.03	0.297	8.09	168.95	82.667	84.01081326	1.624	948.596	24587.6	28040	856	1.6483	1410969	160.86	82.67	10.14	68.06	0.015	0.208

STANWELL PIPELINE MODELLED K VALUE

DATA ENTRY NUMBER	DATE	PUMP STATION METER (ML)	END METER (ML)	G.Ht RIVER (AHD)	G.Ht STANWELL (AHD)	ENERGY USED (kWh)	MOTOR LOAD (kW)	ENERGY PER ML (kWh/ML)	PUMP NO	RUN TIME	HOURS PER ML (hrs/ML)	AVERAGE SUCTION (m)	AVERAGE DISCHARGE (m)	STATIC HEAD (m)	ACTUAL EFFIC. (%)	AVERAGE VELOCITY (m/s)	PUMP STATION MET FLOW (L/s)	VOLUME (L)	PIPELINE LENGTH (m)	INTERNAL DIAMETER (m)	VELOCITY (m/s)	REYNOLDS NUMBER	TOTAL HEAD (m)	STATIC HEAD (m)	TOTAL FITTING LOSS (m) 3	TOTAL FRICTION LOSS (m)	FRICTION FACTOR	PIPE ROUGHNESS HEIGHT *k* (mm)
374	6/07/2010	27.418	26.913	3.766	86.403	14653	1824.782067	544.5	2	8.03	0.298	8.1	169.01	82.637	83.80287847	1.618	948.457	24584.01	28040	856	1.6481	1410763	160.91	82.64	10.13	68.14	0.015	0.209
375	7/07/2010	81.07	79.901	3.699	86.563	43147	1817.481045	540	1&2	23.74	0.297	7.62	167.81	82.864	84.11575568	1.625	948.587	24587.36	28040	856	1.6483	1410955	160.19	82.86	10.14	67.19	0.015	0.192
376	8/07/2010	81.002	79.786	3.707	86.715	42700	1779.166667	535.2	1	24	0.301	7.17	166.56	83.008	84.45011158	1.605	937.523	24300.6	28040	856	1.6291	1394499	159.39	83.01	9.90	66.48	0.015	0.207
377	9/07/2010	29.073	28.683	3.721	86.665	15356	1775.260116	535.4	1&2	8.65	0.302	7.62	168.34	82.944	85.12492311	1.601	933.622	24199.49	28040	856	1.6223	1388697	160.72	82.94	9.82	67.96	0.015	0.247
378	10/07/2010	41.572	39.953	3.729	86.665	21643	1796.099585	541.7	1	12.05	0.302	7.05	163.36	82.936	81.81991771	1.6	958.322	24839.7	28040	856	1.6652	1425436	156.31	82.94	10.35	63.03	0.014	0.110

APPENDIX F

OPERATOR QUESTIONNAIRES

DISCUSSION / OUTCOMES

ENG4111/2 Research Project Operator Questionnaire

Date:	21/06/2010
Time:	11:15
Organisation:	SunWater
Pipeline Name:	Awoonga-Callide Pipeline
Pipeline Location:	Bundaberg, Queensland
Pipeline Age:	24 years
Operator/s:	John Barber

Discussion / Outcomes	
Item 1	How many years experience do you have in the operation of water pipelines, specifically in pipeline pigging?
30 years	
Item 2	How often do you pig the pipeline?
Whenever the efficiency spreadsheet says to.	
Item 3	Do you have long-sections of the pipeline and General Arrangements of the swabs that we could access?
Pipeline Length = 54km	
Pipeline Diameter = 450mm	
Flow Rate = 89 ML/day OR 1.0 m3/s	
Item 4	How do you know when to pig the pipeline?
An efficiency spreadsheet has been produced that compares the electricity costs used by the	
Pump stations against the amount of water being pumped. When the cost of electricity	
Immediately after pigging (unfouled) rises to a an accumulated cost of electricity caused by	
decrease in performance equals the approximate cost of a pigging event, then pigging is	
Warranted and performed as soon as possible. The spreadsheet calculates this.	
The operator enters power bills at the pump station and flow meter readings (total volume).	

Discussion / Outcomes	
Item 5	What factors delay on onset pigging in your opinion?
Temperature main factor. Biofilm growth slows during winter.	
Item 6	Can you report any evidence of increases in hydraulic performance of the pipeline after pigging?
Yes. Pipeline increases in capacity from 78-84ML/day to 89ML/day.	
Unit Energy of pump decreases from 800kW.hrs/ML to 710kW.hrs/ML.	
Item 7	Can you report any evidence of decreases in hydraulic performance of the pipeline before or without pigging?
The Unit Energy increases which means it costs more money to pump each ML of water.	
Item 7	Any other comments?
There are 3 sections of the Awoonga-Callide Pipeline. One section cannot be pigged.	
This is the Wooderson Pump Station section.	
A disc-pig is more efficient at cleaning than a foam swab however concerned about the	
damage the disc pig causes to internal concrete lining of pipes.	

DISCUSSION / OUTCOMES

ENG4111/2 Research Project Operator Questionnaire

Date:	10/06/2010
Time:	15:30
Organisation:	BMA Coal
Pipeline Name:	Bingegang Pipeline
Pipeline Location:	Middlemount, Queensland
Pipeline Age:	35 years
Operator/s:	Rob Alford

Discussion / Outcomes	
Item 1	How many years experience do you have in the operation of water pipelines, specifically in pipeline pigging?
20 years	
Item 2	How often do you pig the pipeline?
Every 2 years	
Item 3	Do you have long-sections of the pipeline and General Arrangements of the swabs that we could access?
Pipeline Length = 150km	
Pipeline Diameter = 450mm	
Flow Rate = Unknown	
Item 4	How do you know when to pig the pipeline?
Look at the pump performance, capacity and head pressure.	
As a general rule once every two years.	

Discussion / Outcomes	
Item 5	What factors delay on onset pigging in your opinion?
Varies depending on weather and time of year.	
During the drought didn't have to pig as much because of the cleaner water.	
Floods reduce the demand on the pipeline so the biofilm has a chance to grow.	
Item 6	Can you report any evidence of increases in hydraulic performance of the pipeline after pigging?
Yes. A 9% increase in capacity.	
Item 7	Can you report any evidence of decreases in hydraulic performance of the pipeline before or without pigging?
The internal lining is damaged after pigging occurs.	
Item 8	Any other comments?
Use a high density foam device. Swab pits located every 4 km. So there are approximately	
38 swab structures. Do 8km a day. A nearby pipeline, Bedford, had no swab pits so had	
some installed. Witness improvement in all pipelines he pigs.	
Once pulled an air valve off Bingegang and it had a 20mm bore hole due to growth out of	
80mm. Due to Manganese in water.	

DISCUSSION / OUTCOMES

ENG4111/2 Research Project Operator Questionnaire

Date:	13/08/2010
Time:	13:25
Organisation:	SunWater
Pipeline Name:	Burdekin-Moranbah Pipeline
Pipeline Location:	Collinsville – Moranbah, Queensland
Pipeline Age:	4 years
Operator/s:	Tony Buckingham and Geoff Renton

Discussion / Outcomes	
Item 1	How many years experience do you have in the operation of water pipelines, specifically in pipeline pigging?
More than 30 years between the two operators.	
Item 2	How often do you pig the pipeline?
0 times. Never been pigged.	
Item 3	Do you have long-sections of the pipeline and General Arrangements of the swabs that we could access?
Pipeline Length = 218km	
Pipeline Diameter = 750mm	
Flow Rate = 17,000 ML/annum OR 0.54m3/s	
Item 4	How do you know when to pig the pipeline?
N/A	

Discussion / Outcomes	
Item 5	What factors delay on onset pigging in your opinion?
N/A	
Item 6	Can you report any evidence of increases in hydraulic performance of the pipeline after pigging?
N/A	
Item 7	Can you report any evidence of decreases in hydraulic performance of the pipeline before or without pigging?
N/A	
Item 7	Any other comments?
The inside lining of the pipeline seems to have no growth on it whatsoever. Therefore	
It seems pigging may not be an issue and the swab structures may never be used.	
There are 13 swab structures.	

DISCUSSION / OUTCOMES

ENG4111/2 Research Project Operator Questionnaire

Date: 13/08/2010

Time: 13:35

Organisation: SunWater

Pipeline Name: Eastern Extension Pipeline

Pipeline Location: Moranbah, Queensland

Pipeline Age: 5 years

Operator/s: Geoff Renton

Discussion / Outcomes	
Item 1	How many years experience do you have in the operation of water pipelines, specifically in pipeline pigging?
15 years	
Item 2	How often do you pig the pipeline?
0 times. Never been pigged.	
Item 3	Do you have long-sections of the pipeline and General Arrangements of the swabs that we could access?
Pipeline Length = 47km	
Pipeline Diameter = 450mm	
Flow Rate = 7,000 ML/annum OR 0.23m3/s	
Item 4	How do you know when to pig the pipeline?
N/A	

Discussion / Outcomes	
Item 5	What factors delay on onset pigging in your opinion?
N/A	
Item 6	Can you report any evidence of increases in hydraulic performance of the pipeline after pigging?
N/A	
Item 7	Can you report any evidence of decreases in hydraulic performance of the pipeline before or without pigging?
N/A	
Item 7	Any other comments?
No evidence of growth on walls. Should never be pigged.	
There are 5 swab structures.	

DISCUSSION / OUTCOMES

ENG4111/2 Research Project Operator Questionnaire

Date: 13/08/2010

Time: 13:30

Organisation: SunWater

Pipeline Name: Eungella-Moranbah Pipeline

Pipeline Location: Eungella – Moranbah, Queensland

Pipeline Age: 14 years

Operator/s: Tony Buckingham and Geoff Renton

Discussion / Outcomes	
Item 1	How many years experience do you have in the operation of water pipelines, specifically in pipeline pigging?
More than 30 years between the two operators.	
Item 2	How often do you pig the pipeline?
0 times. Never been pigged.	
Item 3	Do you have long-sections of the pipeline and General Arrangements of the swabs that we could access?
Pipeline Length = 122km	
Pipeline Diameter = 600mm	
Flow Rate = 15,000 ML/annum OR 0.48m3/s	
Item 4	How do you know when to pig the pipeline?
N/A	

Discussion / Outcomes	
Item 5	What factors delay on onset pigging in your opinion?
N/A	
Item 6	Can you report any evidence of increases in hydraulic performance of the pipeline after pigging?
N/A	
Item 7	Can you report any evidence of decreases in hydraulic performance of the pipeline before or without pigging?
N/A	
Item 7	Any other comments?
Internal walls exposed during maintenance shows no evidence of any kind of growth.	
It is unlikely swab structures installed will never be used. There are 8 of them.	

DISCUSSION / OUTCOMES

ENG4111/2 Research Project Operator Questionnaire

Date: 26/7/2010

Time: 3:30pm

Organisation: Water-Corp – Western Australia

Pipeline Name: Perth to Kalgoorlie Pipeline

Pipeline Location: Perth

Pipeline Age: 107 years

Operator/s: Scott Miller

Discussion / Outcomes	
Item 1	How many years experience do you have in the operation of water pipelines, specifically in pipeline pigging?
11 years	
Item 2	How often do you pig the pipeline?
Never been pigged in 107 years	
Item 3	Do you have long-sections of the pipeline and General Arrangements of the swabs that we could access?
Pipeline Length = 550km	
Pipeline Diameter = 800mm	
Flow Rate = Varies	
Item 4	How do you know when to pig the pipeline?
N/A	

Discussion / Outcomes	
Item 5	What factors delay on onset pigging in your opinion?
The pipeline has treated water therefore the pipeline does not seem to foul and thus never gets pigged.	
Item 6	Can you report any evidence of increases in hydraulic performance of the pipeline after pigging?
N/A	
Item 7	Can you report any evidence of decreases in hydraulic performance of the pipeline before or without pigging?
There is a small layer of biofilm, of less than 1mm in thickness. Flow is not affected.	
Sometimes they have to pull out bends to release sediment build up but rarely.	
The entire 550km of 107 year old pipeline is above ground.	
Item 7	Any other comments?
Should never be pigged.	
The entire 550km of 107 year old pipeline is above ground in excessive heat of Kalgoorlie.	

DISCUSSION / OUTCOMES

ENG4111/2 Research Project Operator Questionnaire

Date: 13/08/2010

Time: 13:45

Organisation: SunWater

Pipeline Name: Newlands Pipeline (Bowen River)

Pipeline Location: Collinsville, Queensland

Pipeline Age: 27 years

Operator/s: Tony Buckingham

Discussion / Outcomes	
Item 1	How many years experience do you have in the operation of water pipelines, specifically in pipeline pigging?
15 years.	
Item 2	How often do you pig the pipeline?
Once every ten years. Last done in 2010.	
Item 3	Do you have long-sections of the pipeline and General Arrangements of the swabs that we could access?
Pipeline Length = 54km	
Pipeline Diameter = 450mm	
Flow Rate = 0.12L/s	
Item 4	How do you know when to pig the pipeline?
This year was the first time it was done in ten years. There is no methodology into	
Calculating when the pipeline should be pigged. Decided to do it.	

Discussion / Outcomes	
Item 5	What factors delay on onset pigging in your opinion?
Unknown.	
Item 6	Can you report any evidence of increases in hydraulic performance of the pipeline after pigging?
The flow rate went from 106L/s to 112L/s Amp's drawn by pumps were similar when	
Comparing the power usage before pigging to after pigging.	
The same amount of head pressure was read downstream of the pump before and after pigging	
Therefore no increase in hydraulic performance	
Item 7	Can you report any evidence of decreases in hydraulic performance of the pipeline before or without pigging?
No not really. Hard to measure. Pre-November 2009 the differential head pressure	
Gauge was not reliable.	
Item 7	Any other comments?
Used a red Kriss-Kross pig which is high density foam.	
Took 3 days of to pig 57km of pipe. 24 hours per day with 2 crews doing 12 hour shifts.	
Decreased the flow to 0.5m/s.	
Approximately 1 pipe every 1.5km. Not large pits.	

DISCUSSION / OUTCOMES

ENG4111/2 Research Project Operator Questionnaire

Date:	28/7/2010
Time:	11:30am
Organisation:	Water-Corp – Western Australia
Pipeline Name:	Perth Collector Bore Main
Pipeline Location:	Perth
Pipeline Age:	40 years
Operator/s:	Merzuk Hodzic

Discussion / Outcomes	
Item 1	How many years experience do you have in the operation of water pipelines, specifically in pipeline pigging?
30 years	
Item 2	How often do you pig the pipeline?
Once a Year	
Item 3	Do you have long-sections of the pipeline and General Arrangements of the swabs that we could access?
Pipeline Length = 10km	
Pipeline Diameter = 600mm	
Flow Rate = 60ML/day OR 0.7m3/s	
Item 4	How do you know when to pig the pipeline?
It is just done as part of the annual shutdown. Annual shutdown lasts 2 weeks every July.	

Discussion / Outcomes	
Item 5	What factors delay on onset pigging in your opinion?
The more the pipeline is used the less build up within the pipeline.	
The build up is caused by an iron concentration in the bore water.	
The artesian bores cause less build up and only require pigging every ten years.	
The superficial bores have an iron concentrate between 7 to 21 mg/l and are pigged between	
One and three times a year.	
Item 6	Can you report any evidence of increases in hydraulic performance of the pipeline after pigging?
The flow increases from 47ML/day to 60ML/day after pigging.	
Item 7	Can you report any evidence of decreases in hydraulic performance of the pipeline before or without pigging?
The more the pipelines are used the cleaner the internal lining is. So during wet season	
the pipelines wall lining does grow.	
Item 7	Any other comments?
In pipelines with 90 degree bends, swabs that are 0.5m long are used.	
In pipelines with bends less than 90 degrees have 1m long bends used.	
Due to iron bacteria reduction in pipe diameter is 50mm. Up to 75mm after 2 years.	
One pipe section was left for 5 years and went from diameter of 200mm to 50mm. Had to	
Pressure jet to clean.	

DISCUSSION / OUTCOMES

ENG4111/2 Research Project Operator Questionnaire

Date: 10/06/2010

Time: 14:00

Organisation: SunWater

Pipeline Name: Stanwell Pipeline

Pipeline Location: Rockhampton, Queensland

Pipeline Age: 18 years

Operator/s: Jim Barry

Discussion / Outcomes	
Item 1	How many years experience do you have in the operation of water pipelines, specifically in pipeline pigging?
20 years	
Item 2	How often do you pig the pipeline?
Once per year.	
Item 3	Do you have long-sections of the pipeline and General Arrangements of the swabs that we could access?
Pipeline Length = 28km	
Pipeline Diameter = 900mm	
Flow Rate = 13,000 ML/annum OR 0.9m3/s	
Item 4	How do you know when to pig the pipeline?
Keep a spreadsheet file number 08-006624/001. Works off flowmeters, barrage level	
Storage level, energy used by pumps, Discharge pressures. It evaluates cost of pumping.	
There is a contract agreement to provide 915L/s to Stanwell Power Station.	

Discussion / Outcomes	
Item 5	What factors delay on onset pigging in your opinion?
Temperature and water quality.	
When the flood occurred to an upstream mine (photos were posted all over internet) the	
water that came downstream from that must have had something in it. Had to pig 3 times	
that year.	
Item 6	Can you report any evidence of increases in hydraulic performance of the pipeline after pigging?
Yes. A 10% increase in capacity.	
When there seems to be high sediment in the water it seems to "sandblast" the wall lining.	
Item 7	Can you report any evidence of decreases in hydraulic performance of the pipeline before or without pigging?
Consumer offtakes are affected because of build up.	
Item 7	Any other comments?
Definitely need facilities for Stanwell pipeline.	
There are 3 of them.	
Use a plastic disc pig. Used to use high density foam but had to swab 3 times per year	
when using swabs compared to once per year with disc pig.	
The disc pig tends to damage the internal lining of the pipeline.	

DISCUSSION / OUTCOMES

ENG4111/2 Research Project Operator Questionnaire

Date:	13/08/2010
Time:	13:40
Organisation:	SunWater
Pipeline Name:	Southern Extension Pipeline
Pipeline Location:	Moranbah, Queensland
Pipeline Age:	4 years
Operator/s:	Geoff Renton

Discussion / Outcomes	
Item 1	How many years experience do you have in the operation of water pipelines, specifically in pipeline pigging?
15 years	
Item 2	How often do you pig the pipeline?
0 times. Never been pigged.	
Item 3	Do you have long-sections of the pipeline and General Arrangements of the swabs that we could access?
Pipeline Length = 70km	
Pipeline Diameter = 450mm	
Flow Rate = 3,000 ML/annum OR 0.09m3/s	
Item 4	How do you know when to pig the pipeline?
N/A	

Discussion / Outcomes	
Item 5	What factors delay on onset pigging in your opinion?
N/A	
Item 6	Can you report any evidence of increases in hydraulic performance of the pipeline after pigging?
N/A	
Item 7	Can you report any evidence of decreases in hydraulic performance of the pipeline before or without pigging?
N/A	
Item 7	Any other comments?
No evidence of growth on walls. Should never be pigged.	
There are 5 swab structures.	

APPENDIX G

PIGGING PROCEDURE & STRUCTURE COST ESTIMATES

GENERIC COST ESTIMATE FOR INSTALLATION OF A SWABBING STRUCTURE

Cost Estimate to install permanent pipework for catching and launching pipeline pigs. Based on the assumption that the pit is as per drawing 92029 and at current (2010) rates for labour, plant and materials. This does not include design and construction contractor overheads which can be in order of 50% to 70% of the construction price.

Description	Quantity	Unit	Rate	Total
Personnel & Plant				
Supervisor	14	day	$1,000.00	$14,000.00
Labour				
Concreter (2 off)	4	day	$1,600.00	$6,400.00
Formsetters (2 off)	6	day	$1,600.00	$9,600.00
Fitter (2 off)	4	day	$1,600.00	$6,400.00
Fitter (2 off)	2	day	$1,600.00	$3,200.00
Excavator Hire	4	day	$1,300.00	$5,200.00
Crane Hire (assumed without dogman)	2	day	$1,300.00	$2,600.00
Vehicle Hire (1 off)	14	day	$150.00	$2,100.00
Materials				
32 Mpa Concrete (assumed < 50km cartage and 2 loads)	60.0	m3	$500.00	$30,000.00
Reinforcement	7.0	tonne	$1,800.00	$12,600.00
Formwork	1.0	Lump Sum	$5,000.00	$5,000.00
Upstream Reducer Thrust Pipe	1	each	$15,000.00	$15,000.00
Downstream Reducer Thrust Pipe	1	each	$12,000.00	$12,000.00
Removable Spool Piece Pipe	1	each	$12,000.00	$12,000.00
1200-900 Diameter Reducer Piece	1	each	$12,000.00	$12,000.00
900 Diameter Sluice Valve and Actuator	1	each	$35,000.00	$35,000.00
1200 Diameter Straubb Couplings	2	each	$7,500.00	$15,000.00
Walkway Grates (Overhead and inside Pit)	45.0	m2	$200.00	$9,000.00
Walkway Support Frames	1	Lump Sum	$2,500.00	$2,500.00
By-Pass Valve and Pipework	1	Lump Sum	$5,000.00	$5,000.00
Air Valve and Pipework	1	Lump Sum	$1,500.00	$1,500.00
Ladders	1	Lump Sum	$2,500.00	$2,500.00
Drainage Pipework and Outlet Headwall	1	Lump Sum	$7,500.00	$7,500.00
Bolts/Anchors for Pipework, Walkways and Ladders	300	each	$15.00	$4,500.00
Miscellaneous	1	Lump Sum	$5,000.00	$5,000.00
Accommodation				
7 persons including food (labourers and supervisor)	14	day	$1,250.00	$17,500.00
1 person including food (crane driver and excavator driver)	4	day	$175.00	$700.00
CONTINGENCIES @ 15%				$38,070.00
TOTAL				**$291,870.00**

Reinforcement Mass Caclulations

N16 bar mostly throughout at 200 centres	=	1.6	kg/m
Side Walls (9.5m) = 9.5m/0.2m*4.0m long each * 2 layers * 2 sides	=	776	m
Side Walls (4.0m) = 4.0m/0.2m*9.5m long each * 2 layers * 2 sides	=	798	m
End Walls (3.9m) = 3.9m/0.2m*4.0m long each * 2 layers * 2 sides	=	328	m
End Walls (4.0m) = 4.0m/0.2m*3.9m long each * 2 layers * 2 sides	=	327.6	m
Floor (9.5m) = 9.5m/0.2m*3.9m long each * 2 layers	=	378.3	m
Floor (3.9m) = 3.9m/0.2m*9.5m long each * 2 layers	=	389.5	m
End Walls 1000 thick area (2.75m)	=	230.1	m
End Walls 1000 thick area (3.9m)	=	225.5	m
TOTAL LENGTH OF N16 BAR	=	3453	m
Add 25% for N24 L bars etc	=	4316.25	m
Total Mass of Reinforcement	=	6906	kg

28/10/2010

GENERIC COST ESTIMATE FOR PIGGING OF A PIPELINE

Cost Estimate to pig a pipeline based on experience of pigging Stanwell Pipeline, Rockhampton. Based on pigging 25km of pipeline in one day. If pipeline is greater than this length add extra days to DAY 2, accommodation and vehicle hire costs as require

Description	Quantity	Unit	Rate	Total
DAY 1 - Travel and preparation				
Personnel & Plant				
Travel, Preparation of Pig and Paperwork (5 men)	1	day	$4,800.00	$4,800.00
Materials				
New discs for Pig	1	Lump Sum	$500.00	$500.00
DAY 2 - Pig Pipeline				
Personnel & Plant				
Labour				
Consumer Offtake valve opener/closer	1	day	$960.00	$960.00
Scour opener/closer	1	day	$960.00	$960.00
Electrician	1	day	$960.00	$960.00
Extra staff required for Confined Space requirements (2 men)	1	day	$1,920.00	$1,920.00
Crane Hire (assumed without dogman)	1	day	$1,300.00	$1,300.00
DAY 3 - Travel Home				
Personnel & Plant				
Debrief, Data extraction and travel home	0.5	day	$4,800.00	$2,400.00
MISCELLANEOUS				
Accommodation - 5 persons including food	2	day	$900.00	$1,800.00
Vehicle Hire (3 off)	3	day	$450.00	$1,350.00
CONTINGENCIES @ 15%				$2,542.50
TOTAL				**$19,492.50**

APPENDIX H

PIPELINE OPTIMISATION SPREADSHEET

DICL/MSCL Rising Main Optimisation Worksheet

Note:	
	DICL Data
	MSCL Data

Data Input (from Analysis Worksheet)

Annual Volume	10,000	Ml	i - Interest per period	0.08	
Cost/ML/m	0.60		n - number of periods	20	years
Static Lift	50	m	a	0.102	
Pump Cost constant	5,000	$			
Length	20,000	m			
k	2.00	mm			
Flow	0.39	m^3/s =			
Fitting factor	3	km			

Minimum Cost = $ 16,902,887

Nominal Diameter (mm)	ID (m)	Vel (m/s)	Reynolds Number	Friction	Pipe friction Loss	Fitting Loss	Surge EL (m)	Pressure Rating	PN 20 Length (m)	Pressure Rating	PN 35 Length (m)	Lift	NPV Power ($)	Pump Cost ($)	Total Rising Main Capital Cost ($)	Total Cost ($)	$M	Surge>Class
2000	2.13	0.11	2.31E+05	0.02079	0.12	0.04	65	-135	20000	-285	0	50.15	$ 2,954,487	$ 96,747	$ 50,994,581	$ 54,045,815	54.0	
1800	1.80	0.15	2.73E+05	0.02130	0.28	0.07	65	-135	20000	-285	0	50.35	$ 2,966,085	$ 97,127	$ 43,226,902	$ 46,290,113	46.3	
1750	1.72	0.17	2.86E+05	0.02146	0.35	0.08	66	-134	20000	-284	0	50.44	$ 2,971,209	$ 97,294	$ 41,373,439	$ 44,441,942	44.4	
1500	1.47	0.23	3.35E+05	0.02206	0.80	0.16	66	-134	20000	-284	0	50.95	$ 3,001,695	$ 98,293	$ 29,429,632	$ 32,529,620	32.5	
1200	1.26	0.31	3.90E+05	0.02275	1.78	0.29	68	-132	20000	-282	0	52.07	$ 3,067,405	$ 100,444	$ 23,709,670	$ 26,877,519	26.9	
1000	1.04	0.45	4.71E+05	0.02369	4.72	0.62	72	-128	20000	-278	0	55.34	$ 3,260,257	$ 106,759	$ 18,382,490	$ 21,749,506	21.7	
900	0.90	0.61	5.47E+05	0.02453	10.33	1.13	80	-120	20000	-270	0	61.47	$ 3,620,952	$ 118,571	$ 15,868,505	$ 19,608,028	19.6	
800	0.80	0.77	6.15E+05	0.02524	19.07	1.81	92	-108	20000	-258	0	70.88	$ 4,175,266	$ 136,722	$ 13,462,860	$ 17,774,849	17.8	
750	0.75	0.88	6.58E+05	0.02568	27.34	2.38	104	-96	20000	-246	0	79.72	$ 4,696,446	$ 153,788	$ 12,052,653	**$ 16,902,887**	16.9	
600	0.60	1.36	8.19E+05	0.02719	86.02	5.69	184	-16	20000	-166	0	141.71	$ 8,348,196	$ 273,367	$ 9,482,584	$ 18,104,147	18.1	
500	0.50	1.96	9.82E+05	0.02860	225.09	11.81	373	173	0	23	20000	286.90	$ 16,900,962	$ 553,434	$ 7,830,521	$ 25,284,916	25.3	**Do not use**
450	0.45	2.43	1.09E+06	0.02947	392.82	18.00	599	399	0	249	20000	460.81	$ 27,146,048	$ 888,916	$ 6,289,719	$ 34,324,683	34.3	**Do not use**
375	0.38	3.49	1.31E+06	0.03109	1031.22	37.31	1454	1254	0	1104	20000	1118.53	$ 65,891,336	$ 2,157,658	$ 5,116,889	$ 73,165,882	73.2	**Do not use**
300	0.30	5.46	1.64E+06	0.03328	3369.02	91.10	4563	4363	0	4213	20000	3510.12	$ 206,777,000	$ 6,771,057	$ 3,834,243	$ 217,382,300	217.4	**Do not use**
250	0.25	7.86	1.96E+06	0.03527	8882.38	188.90	11858	11658	0	11508	20000	9121.29	$ 537,324,908	$ 17,595,077	$ 3,287,419	$ 558,207,405	558.2	**Do not use**
225	0.23	9.70	2.18E+06	0.03650	15567.55	287.92	20677	20477	0	20327	20000	15905.47	$ 936,973,281	$ 30,681,841	$ 2,985,129	$ 970,640,251	970.6	**Do not use**
200	0.20	12.28	2.46E+06	0.03795	29173.24	461.19	38590	38390	0	38240	20000	29684.43	$ 1,748,676,861	$ 57,261,639	$ 2,655,129	$ 1,808,593,629	1808.6	**Do not use**
150	0.15	21.83	3.27E+06	0.04191	135760.56	1457.60	178449	178249	0	178099	20000	137268.16	$ 8,086,314,266	$ 264,791,978	$ 1,754,967	$ 8,352,861,212	8352.9	**Do not use**
100	0.10	49.12	4.91E+06	0.04866	1196815.87	7379.08	1565518	1565318	0	1565168	20000	1204244.96	$ 70,940,726,974	$ 2,323,003,388	$ 1,393,312	$ 73,265,123,674	73265.1	**Do not use**

Scenario A

Multi Option Rising Main Spreadsheet

This spreadsheet is only intended for the preliminary sizing/costing purposes

Input

Hydraulics

Parameter		Units	Comment
Q - Flow	0.385802469	m3/s	= 33.33 ML/d
V - Volume/an	10,000	ML/yr	
L-Length	20,000	m	
Static Lift	50	m	
f - Surge Factor	1.3		

Pipe Parameters

Parameter	Pipe Material			Units
	PE	RC	DICL	
k	0.03	0.30	2.00	mm
Fitting Factor	3	3	3	/km

Cost

Item	Cost	Units
NPV Power	0.60	$ ML/m
Pump Cost Constant	5,000.00	$
i - Interest per period	8.00%	
n - number of periods	20	years

Output

	PE			RC			DICL/MSCL			
Ø	Rising Main Costs ($)	NPV Power ($)	Total ($)*	Rising Main Costs ($)	NPV Power ($)	Total ($)*	Rising Main Costs ($)	NPV Power ($)	Total ($)*	Ø
2400										2400
2100										2100
2000	61,740,267	2,957,478	64,794,589				50,994,581	2,954,487	54,045,815	2000
1800	50,504,777	2,964,982	53,566,850				43,226,902	2,966,085	46,290,113	1800
1750							41,373,439	2,971,209	44,441,942	1750
1600	40,347,374	2,979,135	43,424,063							1600
1500							29,429,632	3,001,695	32,529,620	1500
1400	31,177,937	3,008,090	34,284,529							1400
1200	23,758,547	3,073,871	26,933,074				23,709,670	3,067,405	26,877,519	1200
1050										1050
1000	15,461,330	3,248,196	18,815,890				18,382,490	3,260,257	21,749,506	1000
900	13,183,102	3,444,372	**16,740,262**				15,868,505	3,620,952	19,608,028	900
800							13,462,860	4,175,266	17,774,849	800
750							12,052,653	4,696,446	**16,902,887**	750
710										710
630										630
600							9,482,584	8,348,196	18,104,147	600
560										560
525										525
500										500
450										450
400										400
375										375
355										355
315										315
300										300
280										280
250										250
225										225
200										200
180										180
160										160
140										140
110										110
50										50

APPENDIX I

MARGINAL COST ESTIMATOR

PUMPED PIPELINE COST ANALYSIS WORKSHEETS = LENGTH OF 2,000m

Fitting Loss **3**

Static Head **50** m

Swab Ops $20,000/ann

Capital 300000

Length	K	Volume	ID	Q	Vel	Reynolds Number	Friction	Pipe friction Loss	Fitting Loss	Total Head	Pipe Supply & Install Cost	Marginal Pump Cost	NPV Power Cost		Total Cost
(m)	(mm)	ML/ann	(m)	m3/s	(m/s)			(m)	(m)	(m)					
2000	0.3	1800	300	0.069	0.98	2.95E+05	0.02078	6.81	0.30	57.11	$ 337,398		$ 616,780		$ 954,179
2000	2	1800	300	0.069	0.98	2.95E+05	0.03360	11.02	0.30	61.31	$ 337,398	$ 100,000	$ 662,187		$ 1,099,585
														Marginal Cost	**$ 145,407**
2000	0.3	5000	450	0.193	1.21	5.46E+05	0.01869	6.23	0.45	56.68	$ 525,825		$ 1,700,394		$ 2,226,219
2000	2	5000	450	0.193	1.21	5.46E+05	0.02960	9.86	0.45	60.31	$ 525,825	$ 100,000	$ 1,809,434		$ 2,435,260
														Marginal Cost	**$ 209,041**
2000	0.3	10000	750	0.386	0.87	6.55E+05	0.01689	1.75	0.23	51.98	$ 1,207,816		$ 3,119,056		$ 4,326,872
2000	2	10000	750	0.386	0.87	6.55E+05	0.02565	2.66	0.23	52.89	$ 1,207,816	$ 100,000	$ 3,173,495		$ 4,481,311
														Marginal Cost	**$ 154,440**
2000	0.3	15000	800	0.579	1.15	9.21E+05	0.01646	2.78	0.41	53.18	$ 1,346,286		$ 4,786,625		$ 6,132,911
2000	2	15000	800	0.579	1.15	9.21E+05	0.02513	4.24	0.41	54.65	$ 1,346,286	$ 100,000	$ 4,918,406		$ 6,364,692
														Marginal Cost	**$ 231,781**
2000	0.3	20000	900	0.772	1.21	1.09E+06	0.01601	2.67	0.45	53.12	$ 1,586,851		$ 6,374,089		$ 7,960,939
2000	2	20000	900	0.772	1.21	1.09E+06	0.02432	4.05	0.45	54.50	$ 1,586,851	$ 100,000	$ 6,540,302		$ 8,227,153
														Marginal Cost	**$ 266,214**
2000	0.3	30000	1000	1.157	1.47	1.47E+06	0.01555	3.44	0.66	54.11	$ 1,838,249		$ 9,738,992		$ 11,577,241
2000	2	30000	1000	1.157	1.47	1.47E+06	0.02361	5.23	0.66	55.89	$ 1,838,249	$ 100,000	$ 10,060,329		$ 11,998,578
														Marginal Cost	**$ 421,337**

PUMPED PIPELINE COST ANALYSIS WORKSHEETS = LENGTH OF 5,000m

Fitting Loss **3**

Static Head **50** m

Swab Ops $20,000/ann

Capital 300000

Length	K	Volume	ID	Q	Vel	Reynolds Number	Friction	Pipe friction Loss	Fitting Loss	Total Head	Pipe Supply & Install Cost	Marginal Pump Cost	NPV Power Cost		Total Cost
(m)	(mm)	ML/ann	(m)	m3/s	(m/s)			(m)	(m)	(m)					
5000	0.3	1800	300	0.069	0.98	2.95E+05	0.02078	17.04	0.74	67.77	$ 843,496		$ 731,950		$ 1,575,446
5000	2	1800	300	0.069	0.98	2.95E+05	0.03360	27.55	0.74	78.28	$ 843,496	$ 100,000	$ 845,467		$ 1,788,963
														Marginal Cost	**$ 213,517**
5000	0.3	5000	450	0.193	1.21	5.46E+05	0.01869	15.57	1.12	66.70	$ 1,314,563		$ 2,000,984		$ 3,315,547
5000	2	5000	450	0.193	1.21	5.46E+05	0.02960	24.66	1.12	75.79	$ 1,314,563	$ 100,000	$ 2,273,586		$ 3,688,149
														Marginal Cost	**$ 372,602**
5000	0.3	10000	750	0.386	0.87	6.55E+05	0.01689	4.38	0.58	54.96	$ 3,019,540		$ 3,297,639		$ 6,317,179
5000	2	10000	750	0.386	0.87	6.55E+05	0.02565	6.65	0.58	57.23	$ 3,019,540	$ 100,000	$ 3,433,738		$ 6,553,278
														Marginal Cost	**$ 236,099**
5000	0.3	15000	800	0.579	1.15	9.21E+05	0.01646	6.95	1.01	57.96	$ 3,365,715		$ 5,216,562		$ 8,582,277
5000	2	15000	800	0.579	1.15	9.21E+05	0.02513	10.61	1.01	61.62	$ 3,365,715	$ 100,000	$ 5,546,015		$ 9,011,730
														Marginal Cost	**$ 429,453**
5000	0.3	20000	900	0.772	1.21	1.09E+06	0.01601	6.67	1.12	57.79	$ 3,967,126		$ 6,935,221		$ 10,902,348
5000	2	20000	900	0.772	1.21	1.09E+06	0.02432	10.13	1.12	61.26	$ 3,967,126	$ 100,000	$ 7,350,756		$ 11,417,882
														Marginal Cost	**$ 515,535**
5000	0.3	30000	1000	1.157	1.47	1.47E+06	0.01555	8.60	1.66	60.26	$ 4,595,622		$ 10,847,481		$ 15,443,103
5000	2	30000	1000	1.157	1.47	1.47E+06	0.02361	13.07	1.66	64.73	$ 4,595,622	$ 100,000	$ 11,650,824		$ 16,346,446
														Marginal Cost	**$ 903,343**

PUMPED PIPELINE COST ANALYSIS WORKSHEETS = LENGTH OF 10,000m

Fitting Loss **3**

Static Head **50** m

Swab Ops $20,000/ann

Capital 300000

Length	**K**	**Volume**	**ID**	**Q**	**Vel**	**Reynolds Number**	**Friction**	**Pipe friction Loss**	**Fitting Loss**	**Total Head**	**Pipe Supply & Install Cost**	**Marginal Pump Cost**	**NPV Power Cost**		**Total Cost**
(m)	**(mm)**	**ML/ann**	**(m)**	**m3/s**	**(m/s)**			**(m)**	**(m)**	**(m)**					
10000	0.3	1800	300	0.069	0.98	2.95E+05	0.02078	34.07	1.48	85.55	$ 1,686,992		$ 923,901		$ 2,610,893
10000	2	1800	300	0.069	0.98	2.95E+05	0.03360	55.09	1.48	106.57	$ 1,686,992	$ 100,000	$ 1,150,934		$ 2,937,926
														Marginal Cost	**$ 327,033**
10000	0.3	5000	450	0.193	1.21	5.46E+05	0.01869	31.15	2.25	83.40	$ 2,629,127		$ 2,501,968		$ 5,131,095
10000	2	5000	450	0.193	1.21	5.46E+05	0.02960	49.32	2.25	101.57	$ 2,629,127	$ 100,000	$ 3,047,171		$ 5,776,298
														Marginal Cost	**$ 645,203**
10000	0.3	10000	600	0.386	1.36	8.19E+05	0.01743	27.56	2.85	80.41	$ 4,754,302		$ 4,824,670		$ 9,578,972
10000	2	10000	600	0.386	1.36	8.19E+05	0.02719	43.01	2.85	95.86	$ 4,754,302	$ 100,000	$ 5,751,411		$ 10,605,713
														Marginal Cost	**$ 1,026,741**
10000	0.3	15000	800	0.579	1.15	9.21E+05	0.01646	13.90	2.03	65.92	$ 6,731,430		$ 5,933,124		$ 12,664,554
10000	2	15000	800	0.579	1.15	9.21E+05	0.02513	21.22	2.03	73.24	$ 6,731,430	$ 100,000	$ 6,592,030		$ 13,423,460
														Marginal Cost	**$ 758,906**
10000	0.3	20000	900	0.772	1.21	1.09E+06	0.01601	13.34	2.25	65.59	$ 7,934,253		$ 7,870,443		$ 15,804,695
10000	2	20000	900	0.772	1.21	1.09E+06	0.02432	20.26	2.25	72.51	$ 7,934,253	$ 100,000	$ 8,701,512		$ 16,735,765
														Marginal Cost	**$ 931,070**
10000	0.3	30000	1000	1.157	1.47	1.47E+06	0.01555	17.21	3.32	70.53	$ 9,191,245		$ 12,694,962		$ 21,886,207
10000	2	30000	1000	1.157	1.47	1.47E+06	0.02361	26.13	3.32	79.45	$ 9,191,245	$ 100,000	$ 14,301,647		$ 23,592,892
														Marginal Cost	**$ 1,706,685**

PUMPED PIPELINE COST ANALYSIS WORKSHEETS = LENGTH OF 20,000m

Fitting Loss **3**

Static Head **50** m

Swab Ops $20,000/ann

Capital 300000

Length	**K**	**Volume**	**ID**	**Q**	**Vel**	**Reynolds Number**	**Friction**	**Pipe friction Loss**	**Fitting Loss**	**Total Head**	**Pipe Supply & Install Cost**	**Marginal Pump Cost**	**NPV Power Cost**		**Total Cost**
(m)	**(mm)**	**ML/ann**	**(m)**	**m3/s**	**(m/s)**			**(m)**	**(m)**	**(m)**					
20000	0.3	1800	300	0.069	0.98	2.95E+05	0.02078	68.14	2.95	121.09	$ 3,373,984		$ 1,307,802		$ 4,681,786
20000	2	1800	300	0.069	0.98	2.95E+05	0.03360	110.18	2.95	163.14	$ 3,373,984	$ 100,000	$ 1,761,868		$ 5,235,852
														Marginal Cost	**$ 554,066**
20000	0.3	5000	450	0.193	1.21	5.46E+05	0.01869	62.30	4.50	116.80	$ 5,258,254		$ 3,503,935		$ 8,762,189
20000	2	5000	450	0.193	1.21	5.46E+05	0.02960	98.65	4.50	153.14	$ 5,258,254	$ 100,000	$ 4,594,342		$ 9,952,596
														Marginal Cost	**$ 1,190,407**
20000	0.3	10000	750	0.386	0.87	6.55E+05	0.01689	17.51	2.33	69.84	$ 12,078,160		$ 4,190,557		$ 16,268,717
20000	2	10000	750	0.386	0.87	6.55E+05	0.02565	26.58	2.33	78.92	$ 12,078,160	$ 100,000	$ 4,734,953		$ 16,913,113
														Marginal Cost	**$ 644,396**
20000	0.3	15000	800	0.579	1.15	9.21E+05	0.01646	27.79	4.05	81.85	$ 13,462,860		$ 7,366,247		$ 20,829,108
20000	2	15000	800	0.579	1.15	9.21E+05	0.02513	42.44	4.05	96.49	$ 13,462,860	$ 100,000	$ 8,684,060		$ 22,246,920
														Marginal Cost	**$ 1,417,812**
20000	0.3	20000	900	0.772	1.21	1.09E+06	0.01601	26.68	4.50	81.17	$ 15,868,505		$ 9,740,885		$ 25,609,390
20000	2	20000	900	0.772	1.21	1.09E+06	0.02432	40.53	4.50	95.03	$ 15,868,505	$ 100,000	$ 11,403,024		$ 27,371,530
														Marginal Cost	**$ 1,762,139**
20000	0.3	30000	1000	1.157	1.47	1.47E+06	0.01555	34.41	6.64	91.06	$ 18,382,490		$ 16,389,924		$ 34,772,414
20000	2	30000	1000	1.157	1.47	1.47E+06	0.02361	52.27	6.64	108.91	$ 18,382,490	$ 100,000	$ 19,603,295		$ 38,085,784
														Marginal Cost	**$ 3,313,370**

PUMPED PIPELINE COST ANALYSIS WORKSHEETS = LENGTH OF 50,000m

Fitting Loss **3**

Static Head **50** m

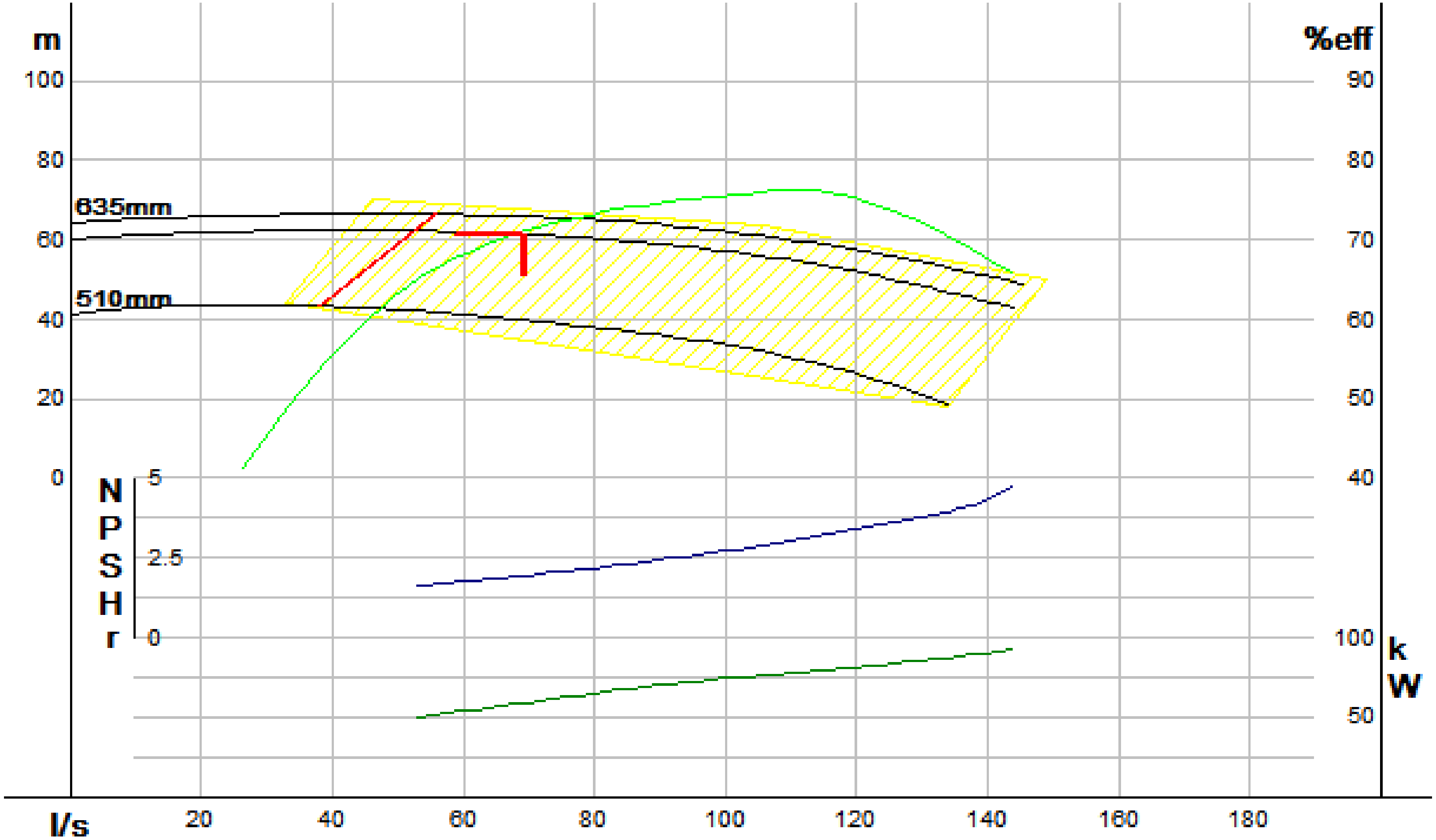
Swab Ops $20,000/ann

Capital 300000

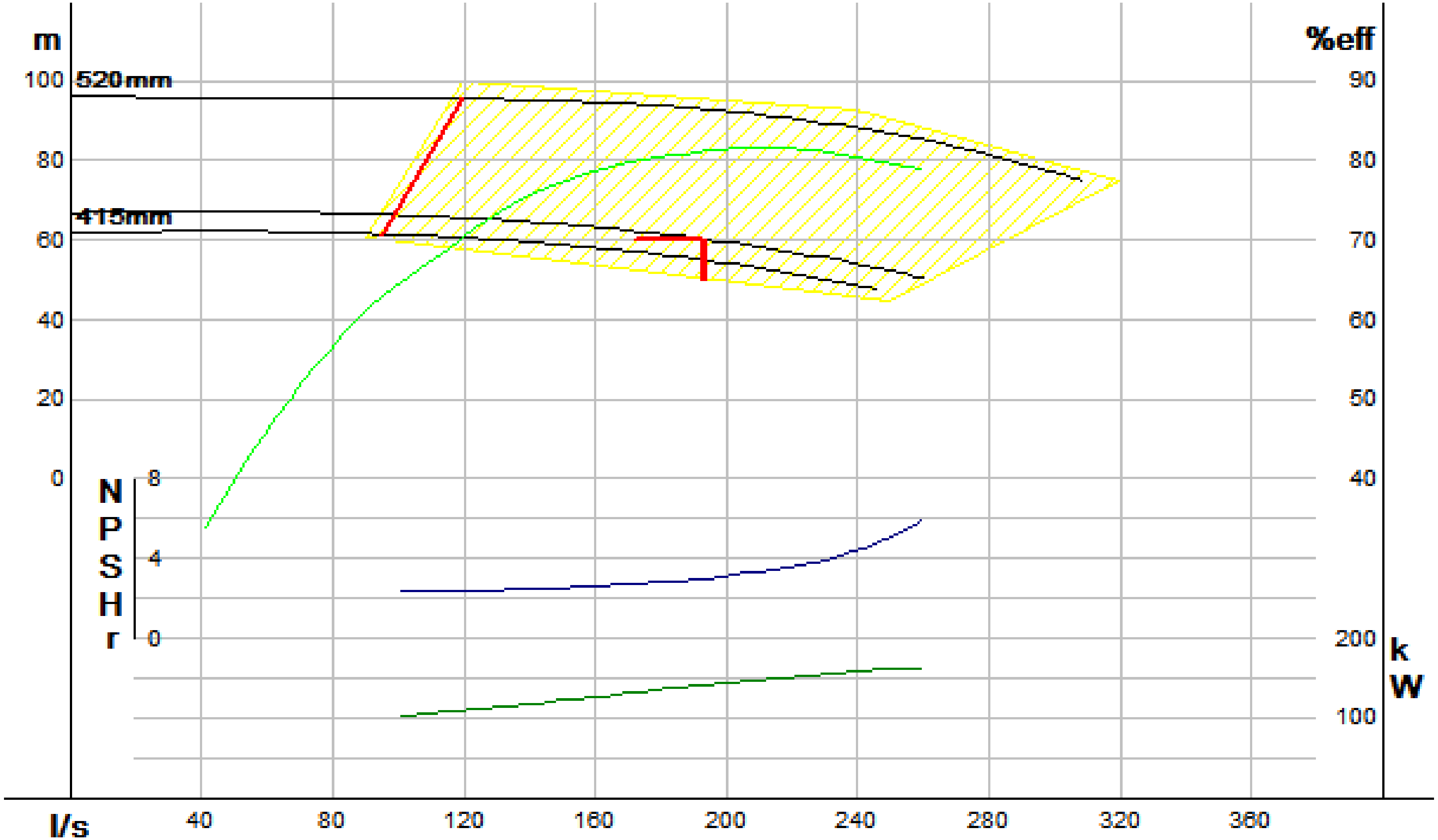
Length	K	Volume	ID	Q	Vel	Reynolds Number	Friction	Pipe friction Loss	Fitting Loss	Total Head	Pipe Supply & Install Cost	Marginal Pump Cost	NPV Power Cost		Total Cost
(m)	(mm)	ML/ann	(m)	m3/s	(m/s)			(m)	(m)	(m)					
50000	0.3	1800	300	0.069	0.98	2.95E+05	0.02078	170.35	7.38	227.73	$ 8,434,960		$ 2,459,504		$ 10,894,464
50000	2	1800	300	0.069	0.98	2.95E+05	0.03360	275.46	7.38	332.84	$ 8,434,960	$ 100,000	$ 3,594,670		$ 12,129,630
														Marginal Cost	**$ 1,235,166**
50000	0.3	5000	450	0.193	1.21	5.46E+05	0.01869	155.75	11.25	216.99	$ 13,145,635		$ 6,509,838		$ 19,655,473
50000	2	5000	450	0.193	1.21	5.46E+05	0.02960	246.61	11.25	307.86	$ 13,145,635	$ 100,000	$ 9,235,855		$ 22,481,490
														Marginal Cost	**$ 2,826,017**
50000	0.3	10000	750	0.386	0.87	6.55E+05	0.01689	43.78	5.83	99.61	$ 30,195,401		$ 5,976,392		$ 36,171,793
50000	2	10000	750	0.386	0.87	6.55E+05	0.02565	66.46	5.83	122.29	$ 30,195,401	$ 100,000	$ 7,337,383		$ 37,632,784
														Marginal Cost	**$ 1,460,990**
50000	0.3	15000	800	0.579	1.15	9.21E+05	0.01646	69.48	10.13	129.62	$ 33,657,150		$ 11,665,619		$ 45,322,769
50000	2	15000	800	0.579	1.15	9.21E+05	0.02513	106.09	10.13	166.22	$ 33,657,150	$ 100,000	$ 14,960,149		$ 48,717,299
														Marginal Cost	**$ 3,394,531**
50000	0.3	20000	900	0.772	1.21	1.09E+06	0.01601	66.69	11.25	127.94	$ 39,671,263		$ 15,352,213		$ 55,023,476
50000	2	20000	900	0.772	1.21	1.09E+06	0.02432	101.32	11.25	162.56	$ 39,671,263	$ 100,000	$ 19,507,561		$ 59,278,824
														Marginal Cost	**$ 4,255,348**
50000	0.3	30000	1000	1.157	1.47	1.47E+06	0.01555	86.03	16.60	152.64	$ 45,956,224		$ 27,474,810		$ 73,431,034
50000	2	30000	1000	1.157	1.47	1.47E+06	0.02361	130.67	16.60	197.27	$ 45,956,224	$ 100,000	$ 35,508,236		$ 81,564,460
														Marginal Cost	**$ 8,133,426**

APPENDIX J

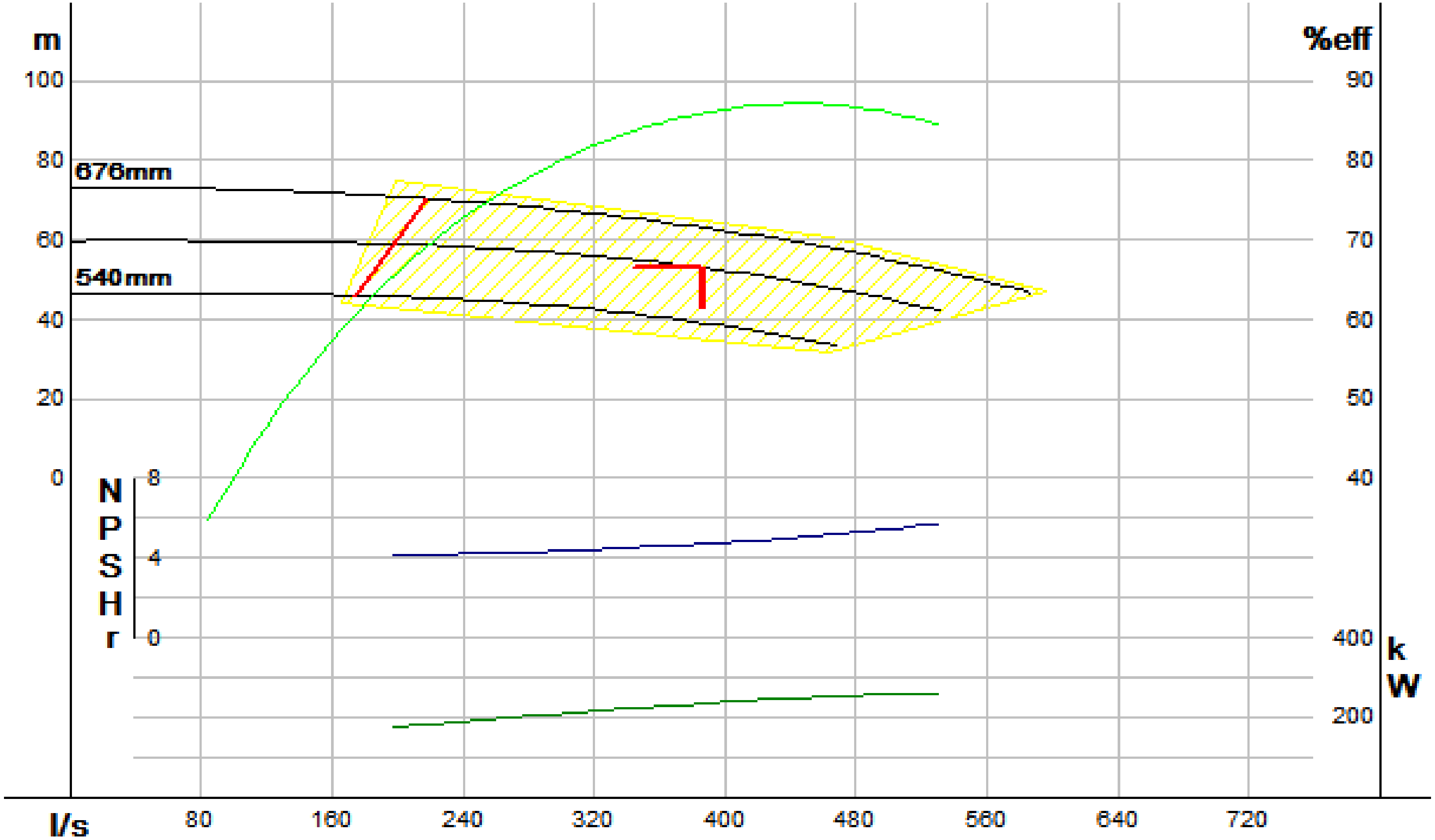
PUMP CURVES



PUMP CURVE - LENGTH = 2,000m, V=1800ML/ANNUM



PUMP CURVE - LENGTH = 2,000m, V=5,000ML/ANNUM



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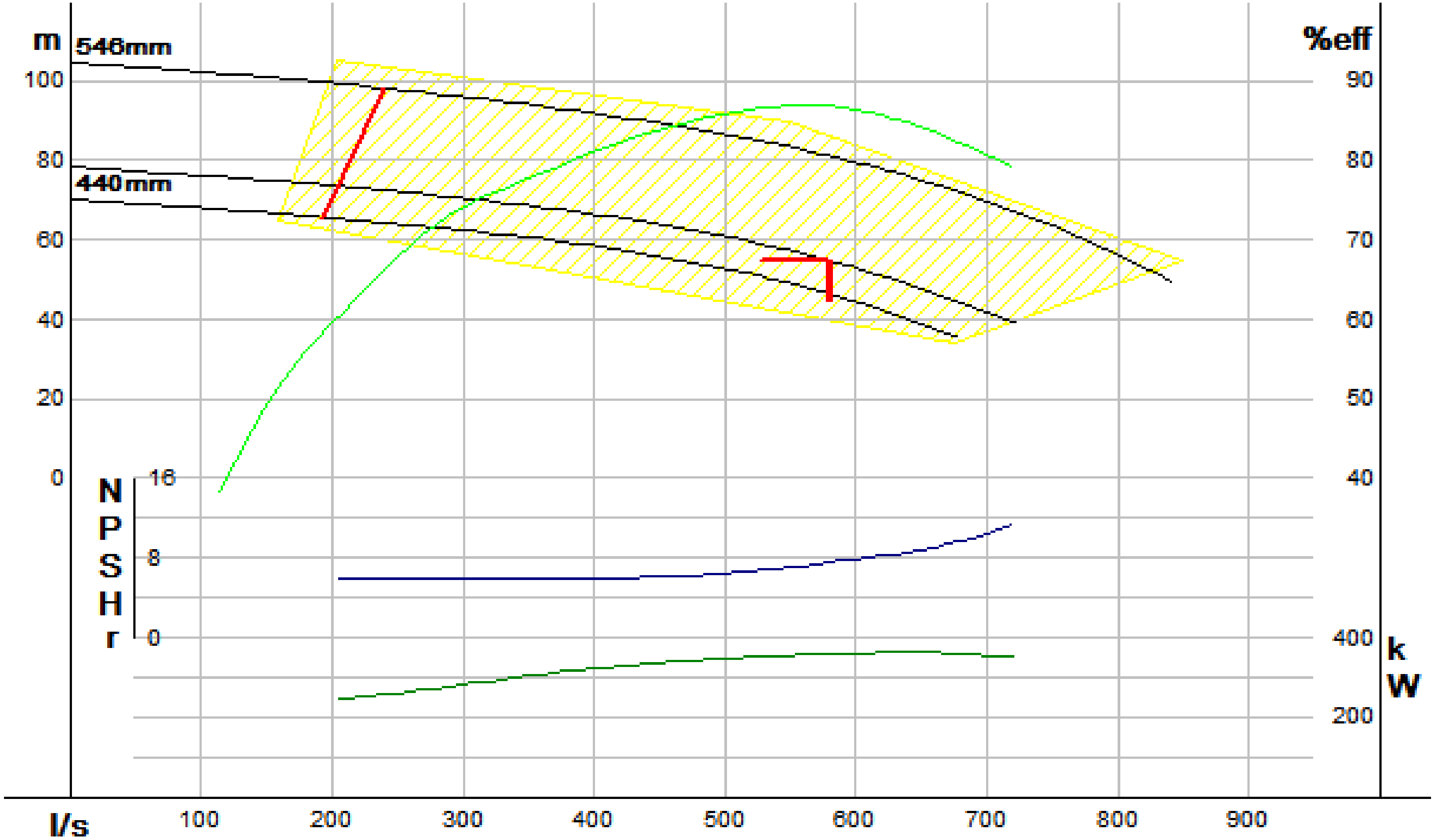

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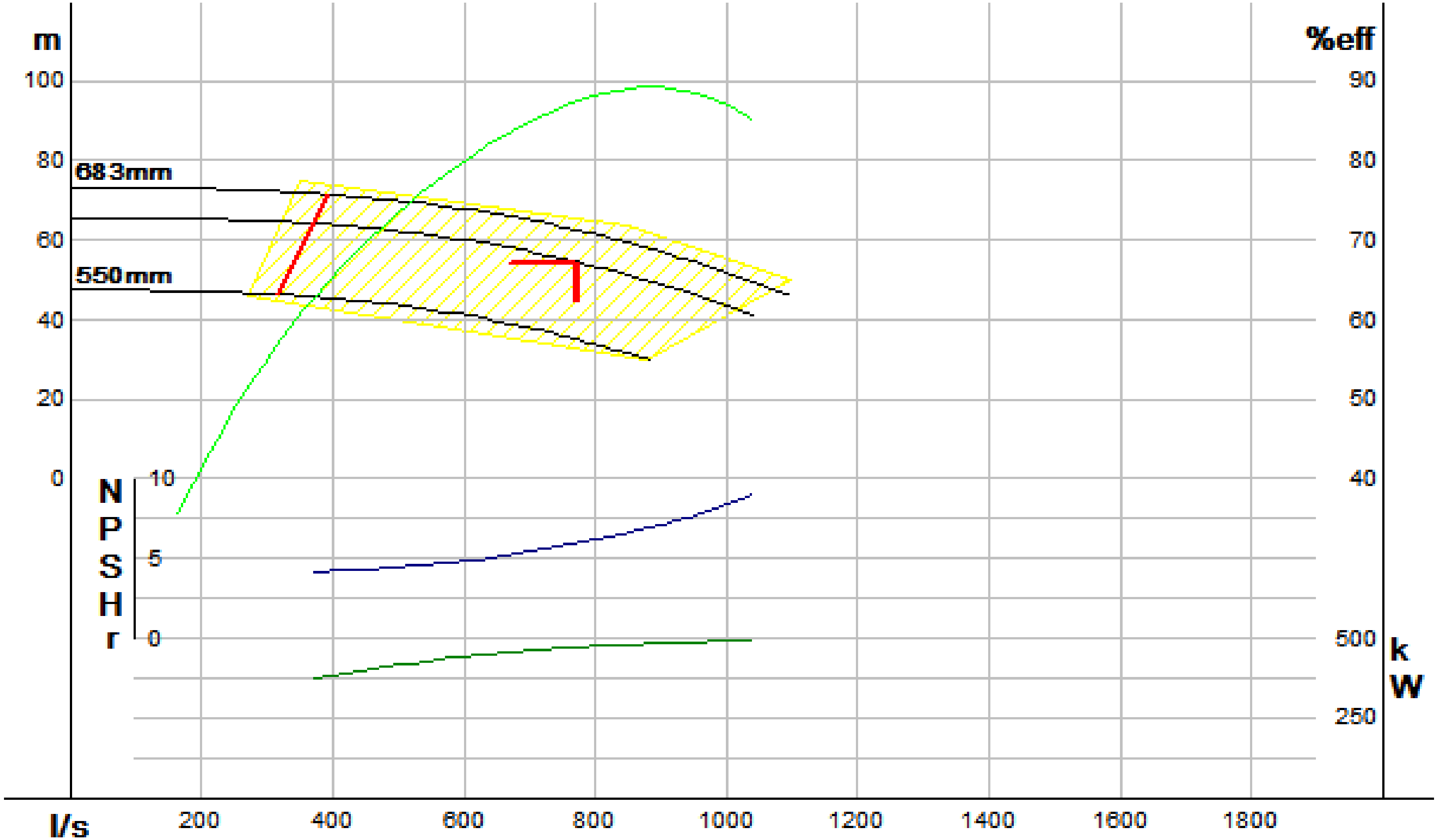

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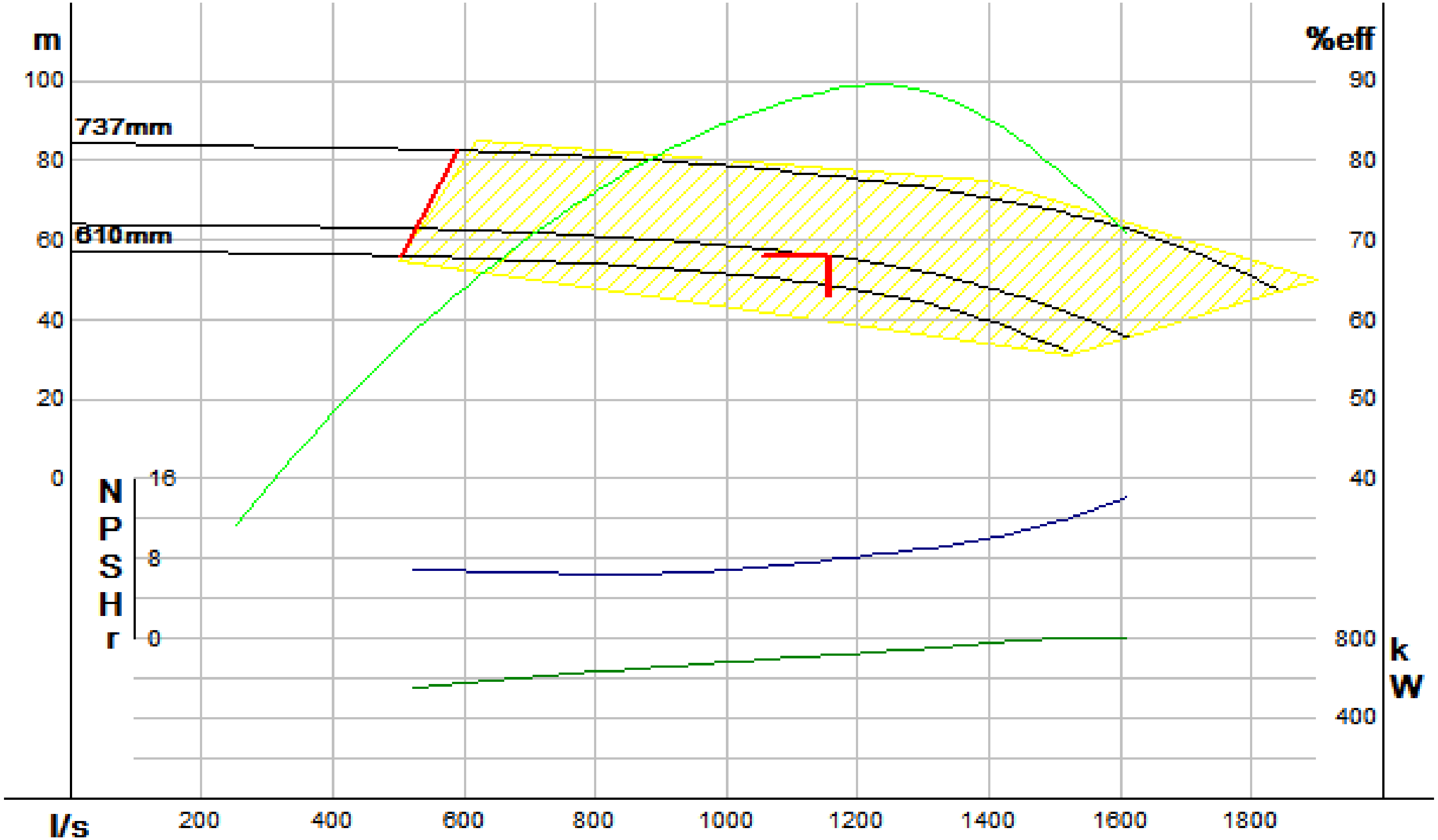

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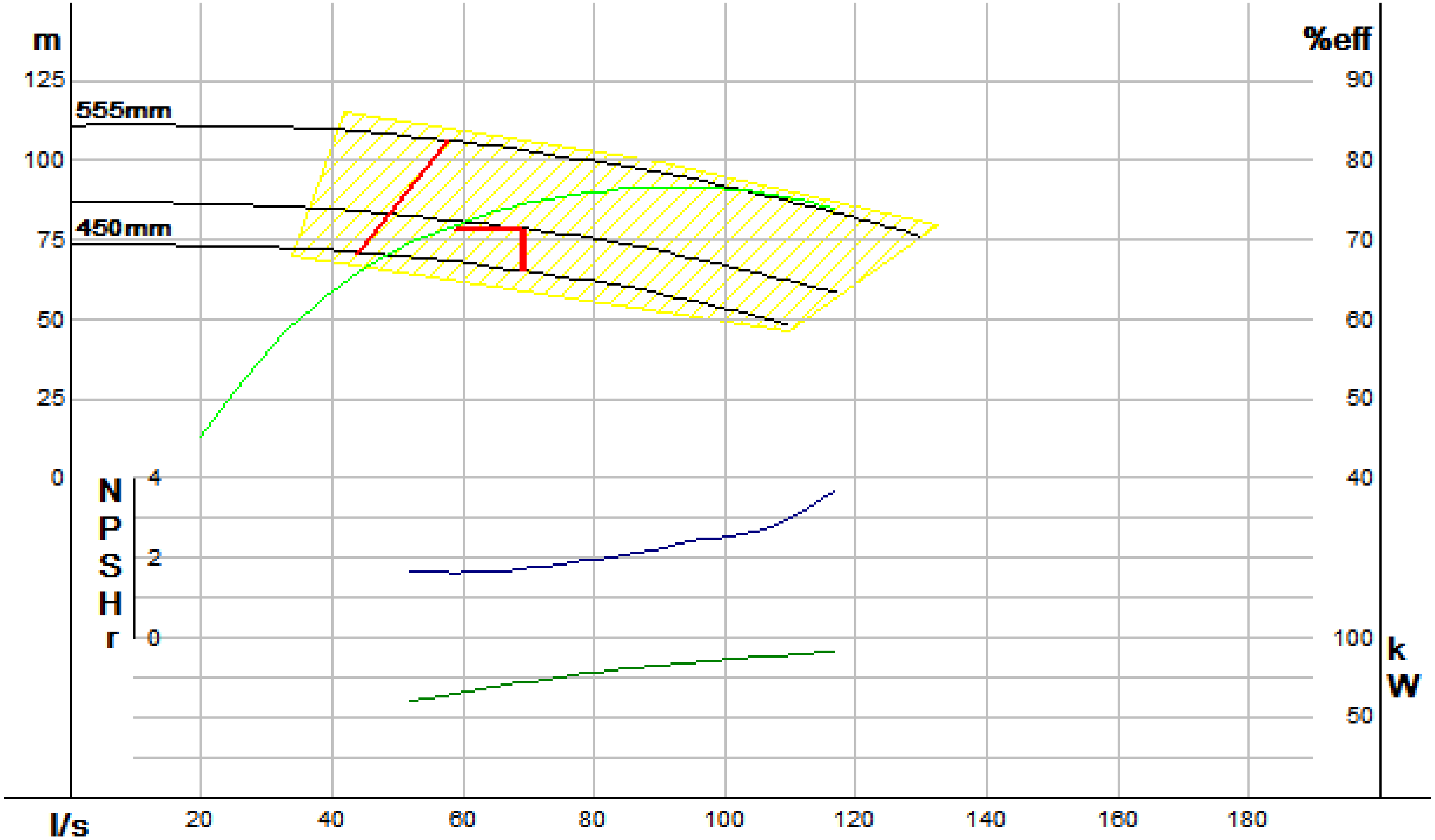

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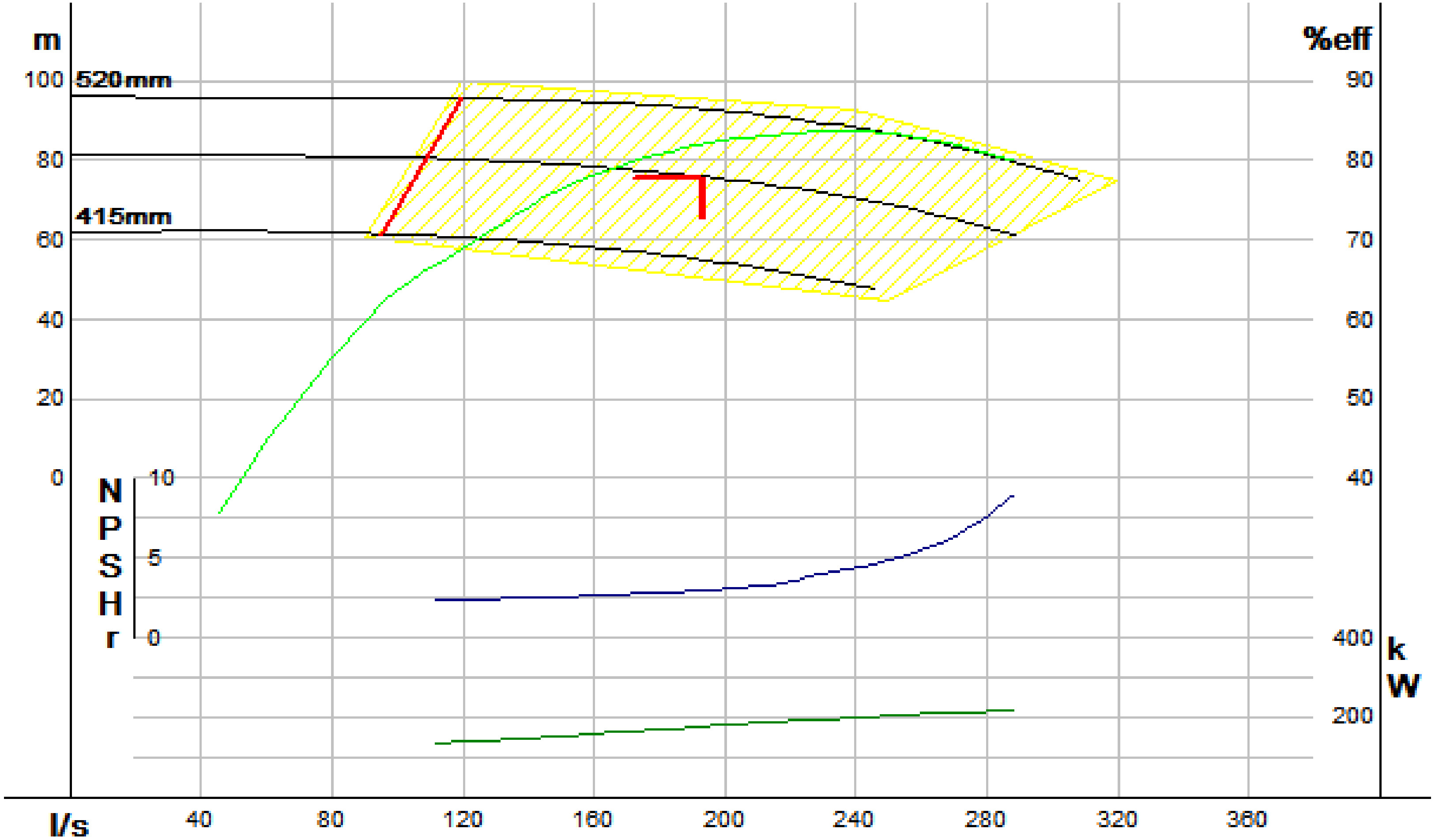

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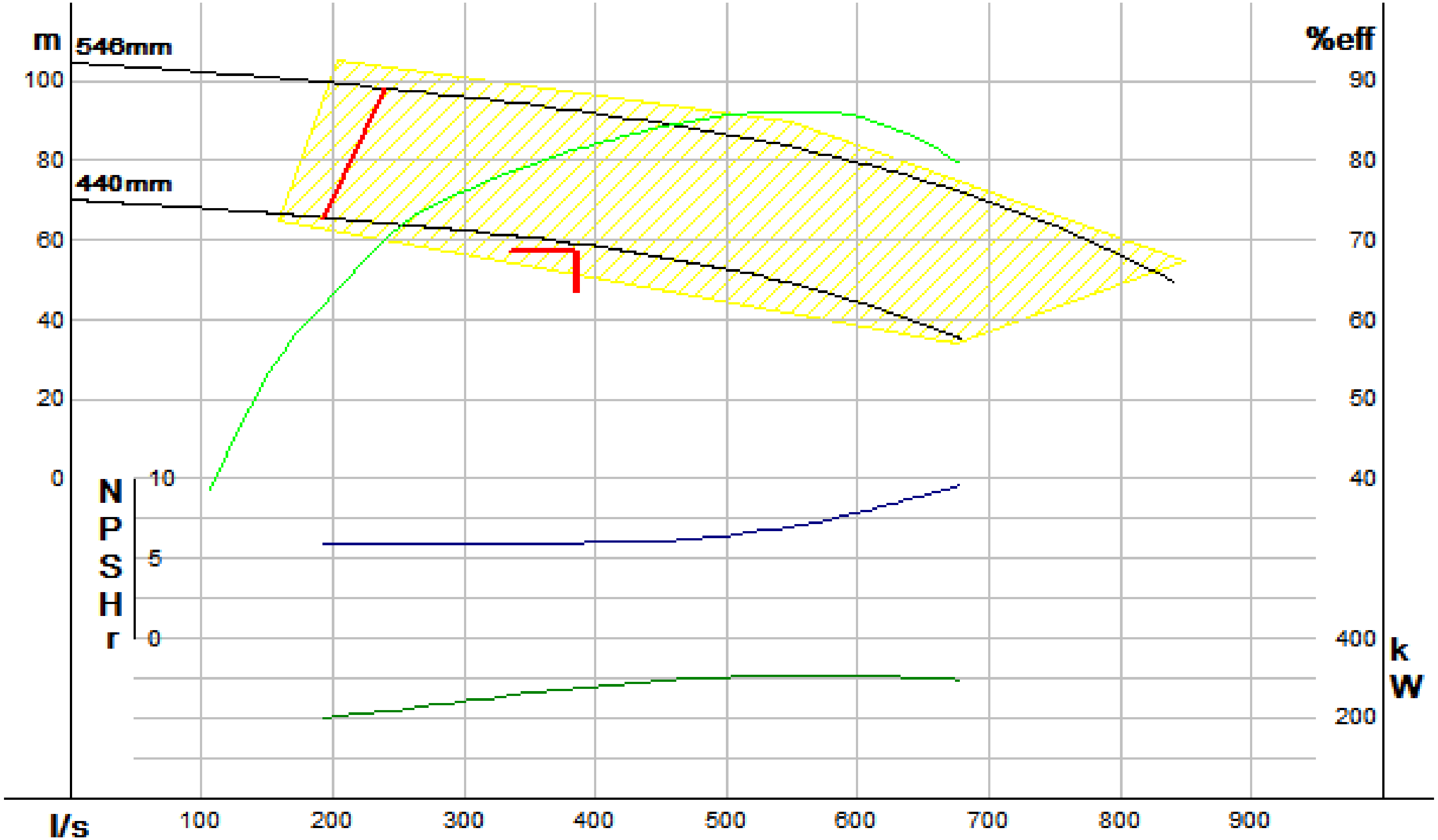

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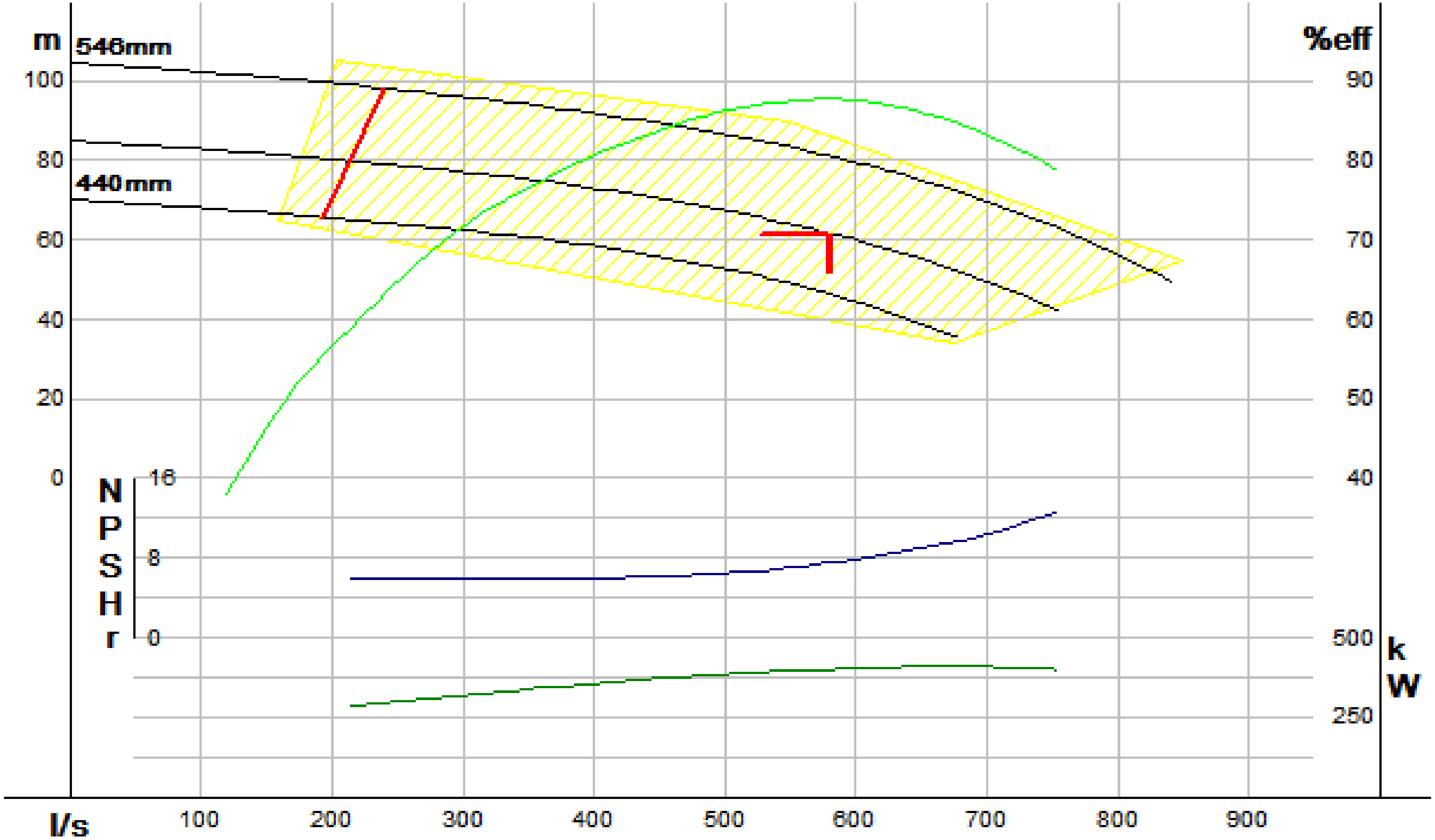

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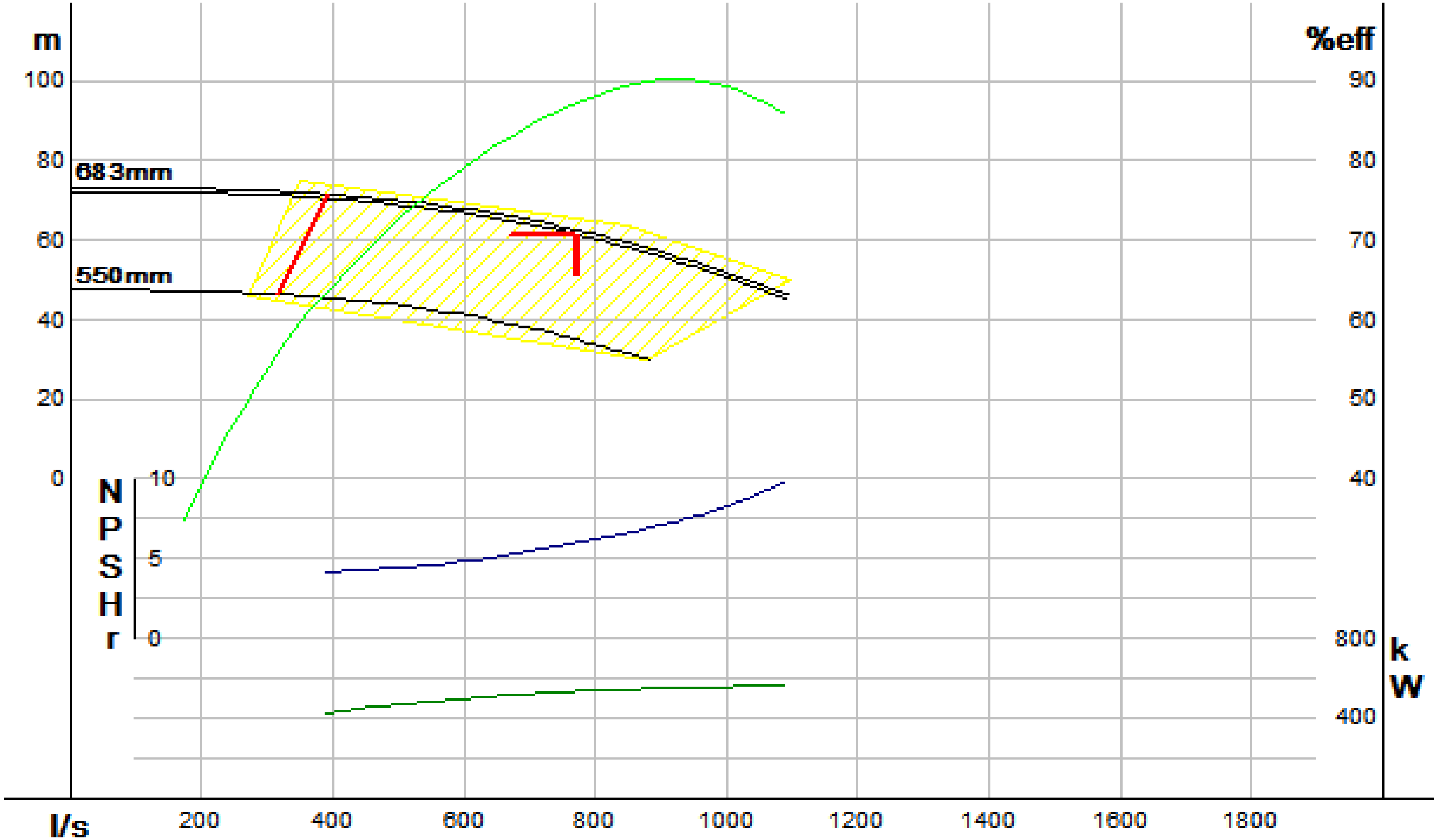

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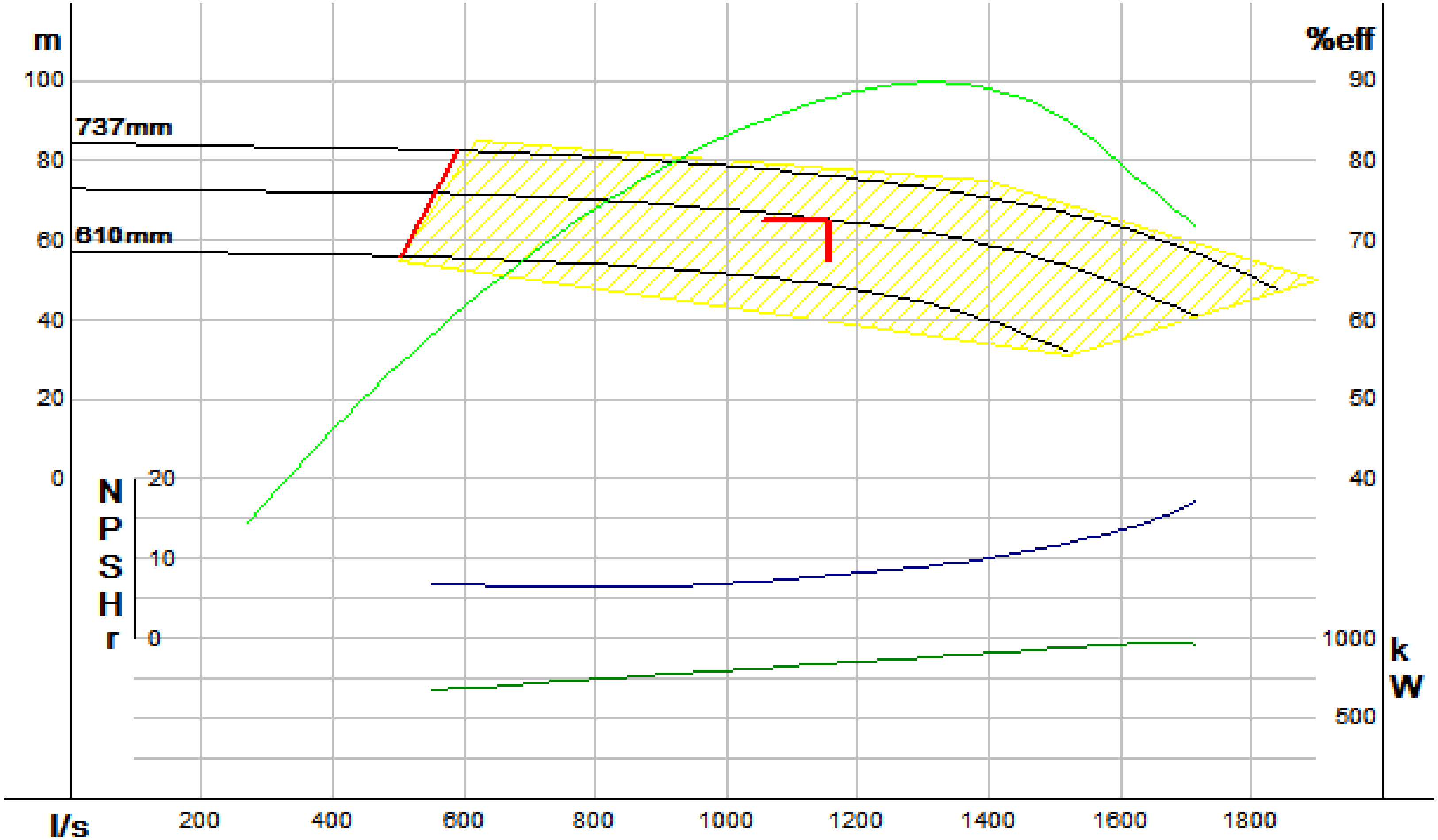

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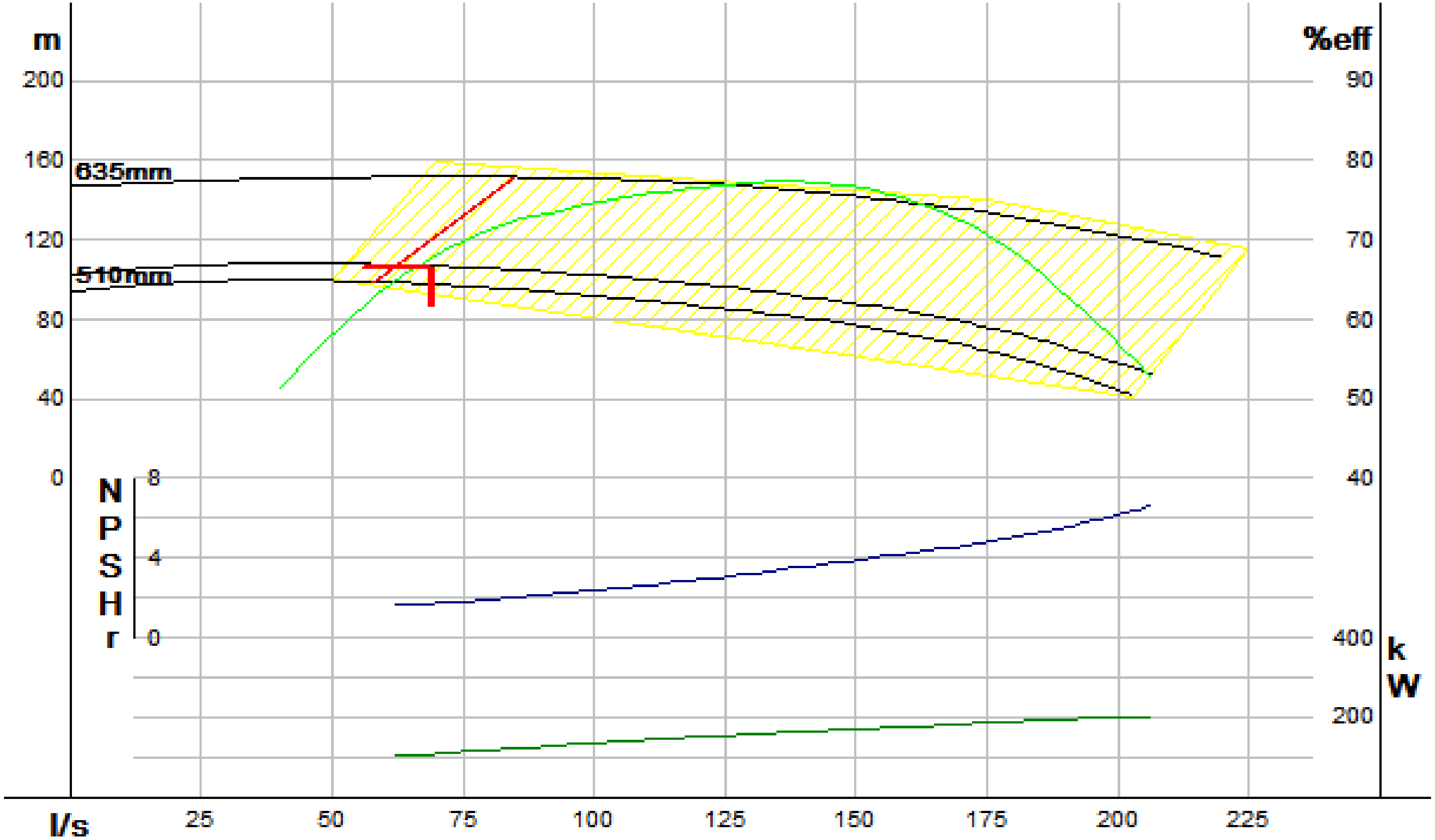

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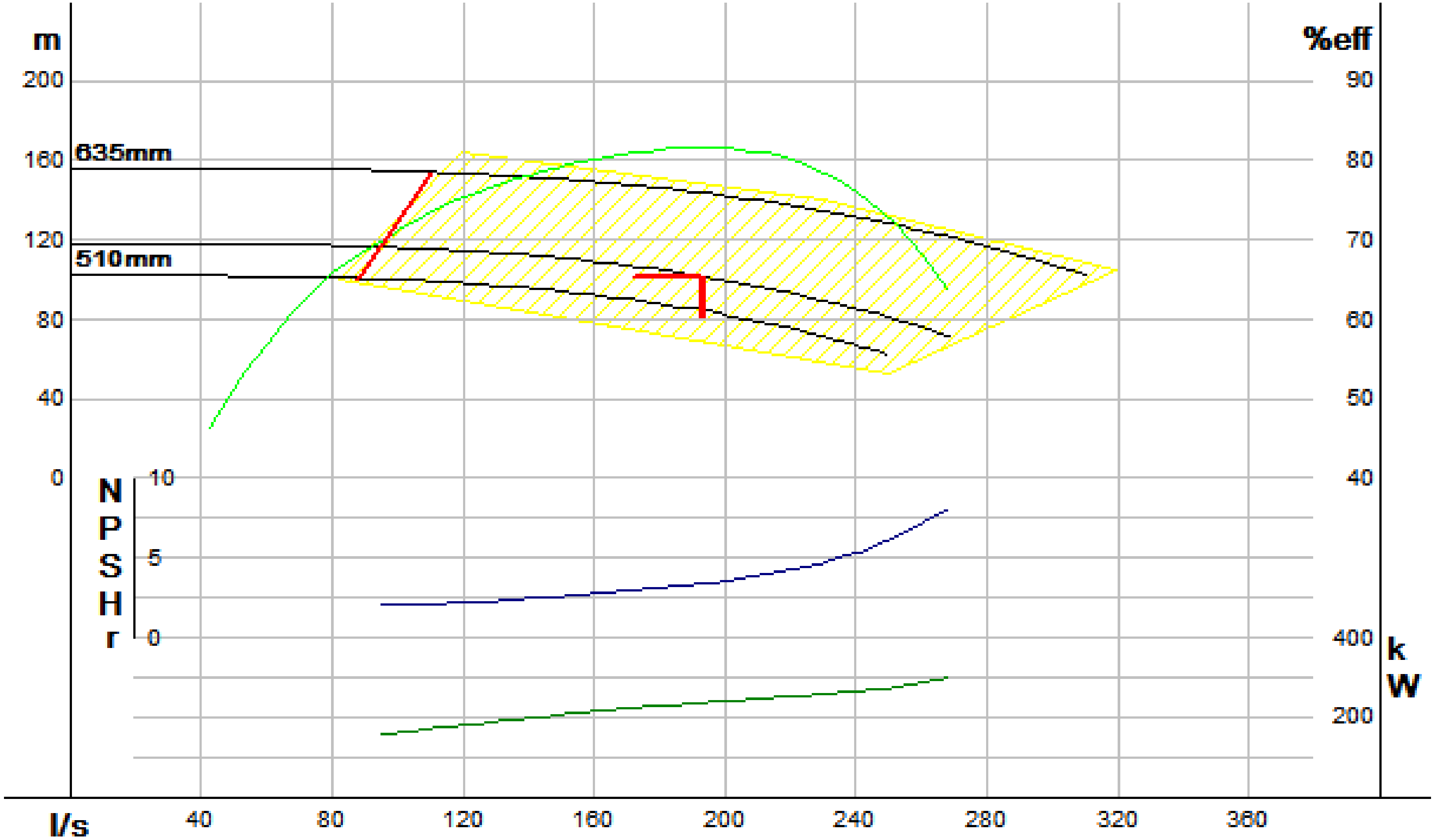

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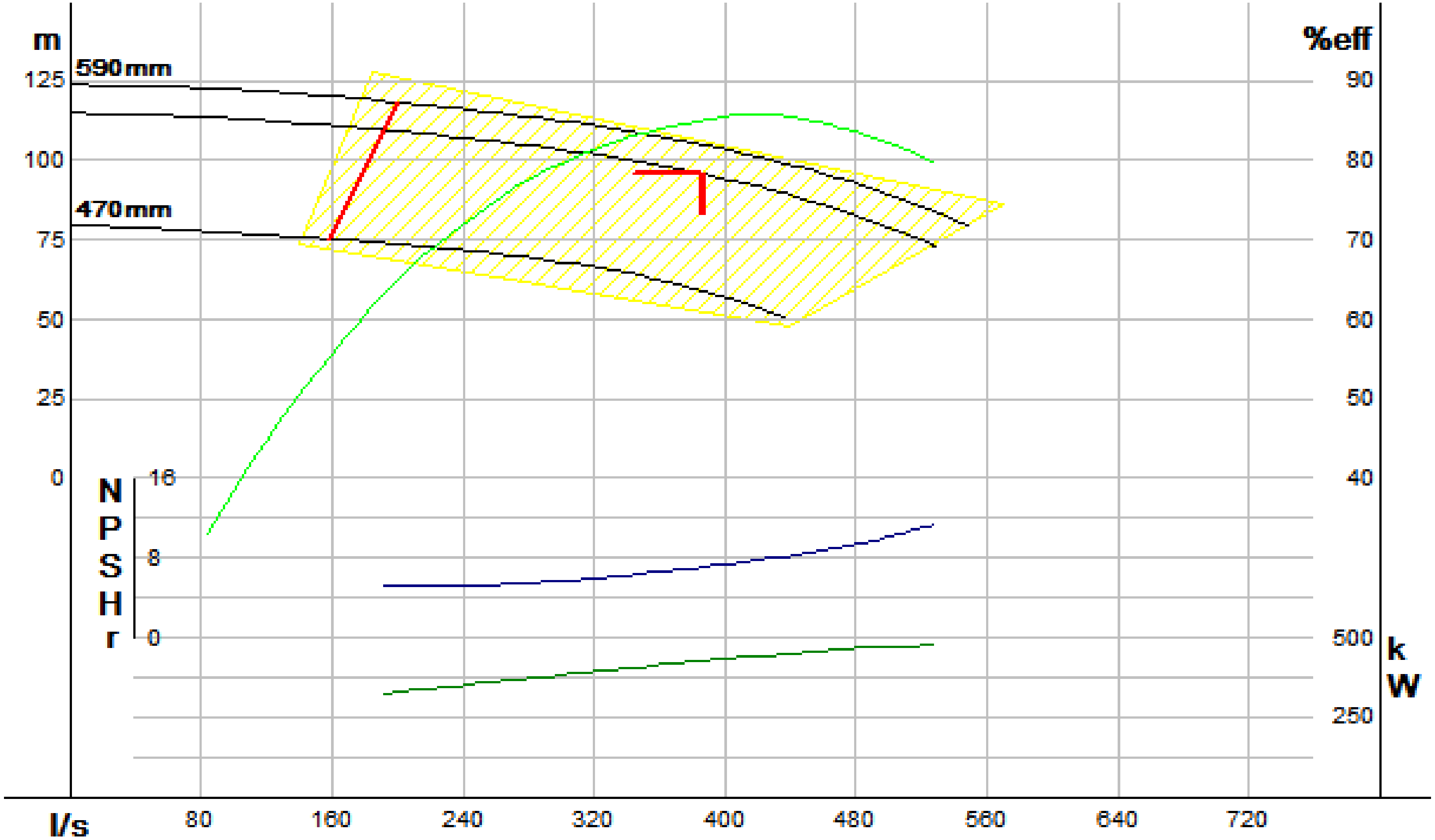

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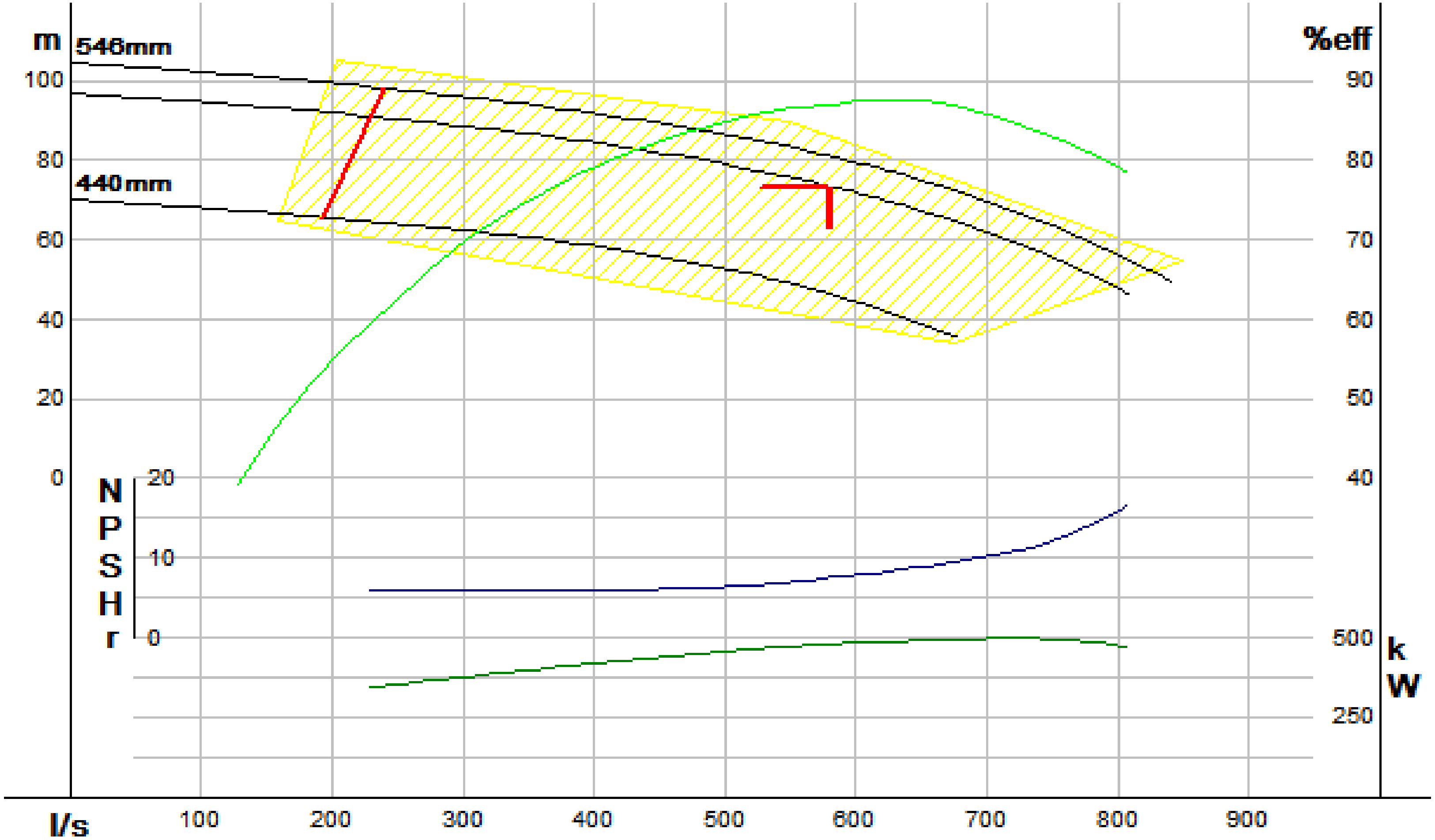

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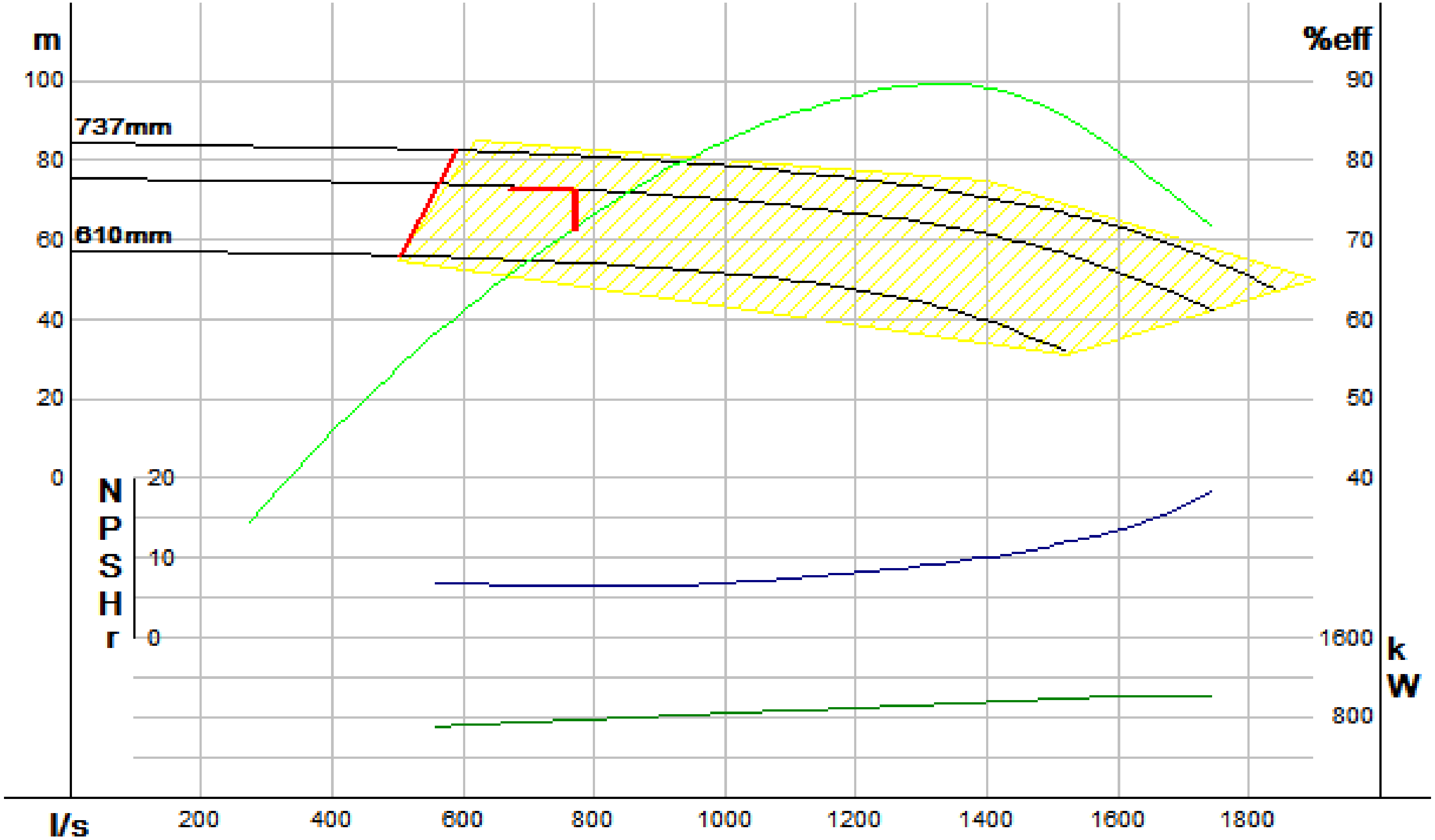

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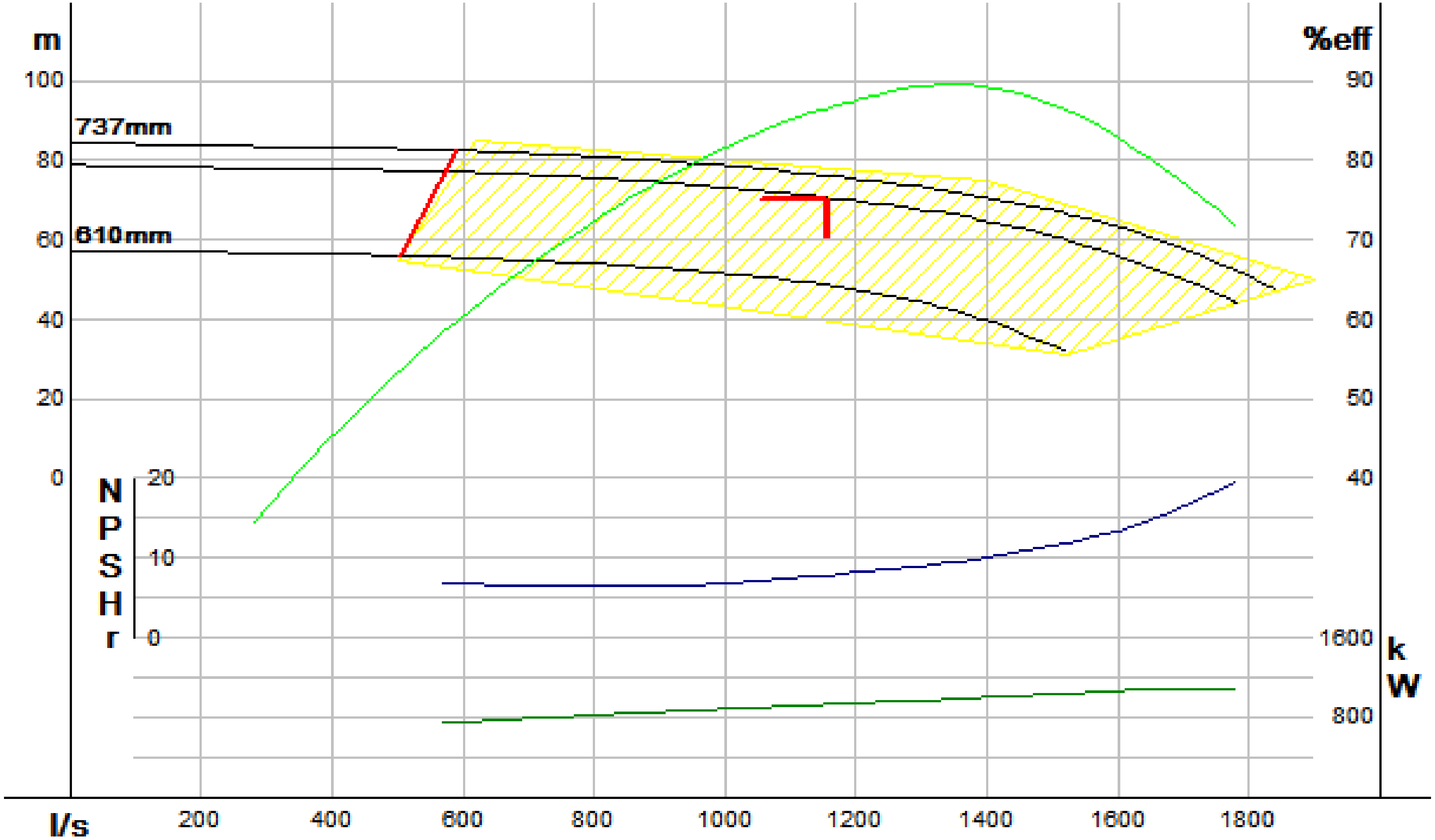

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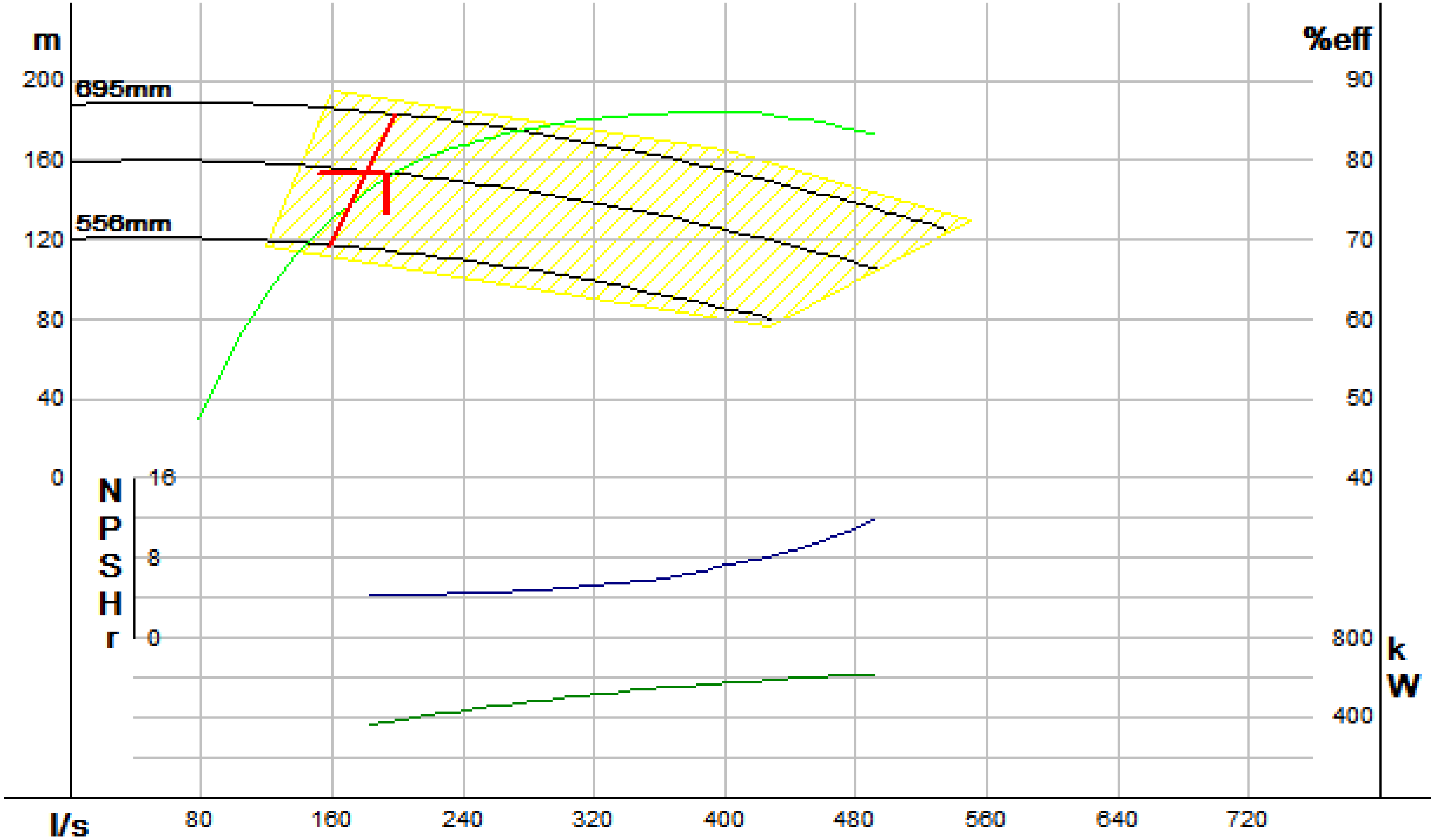

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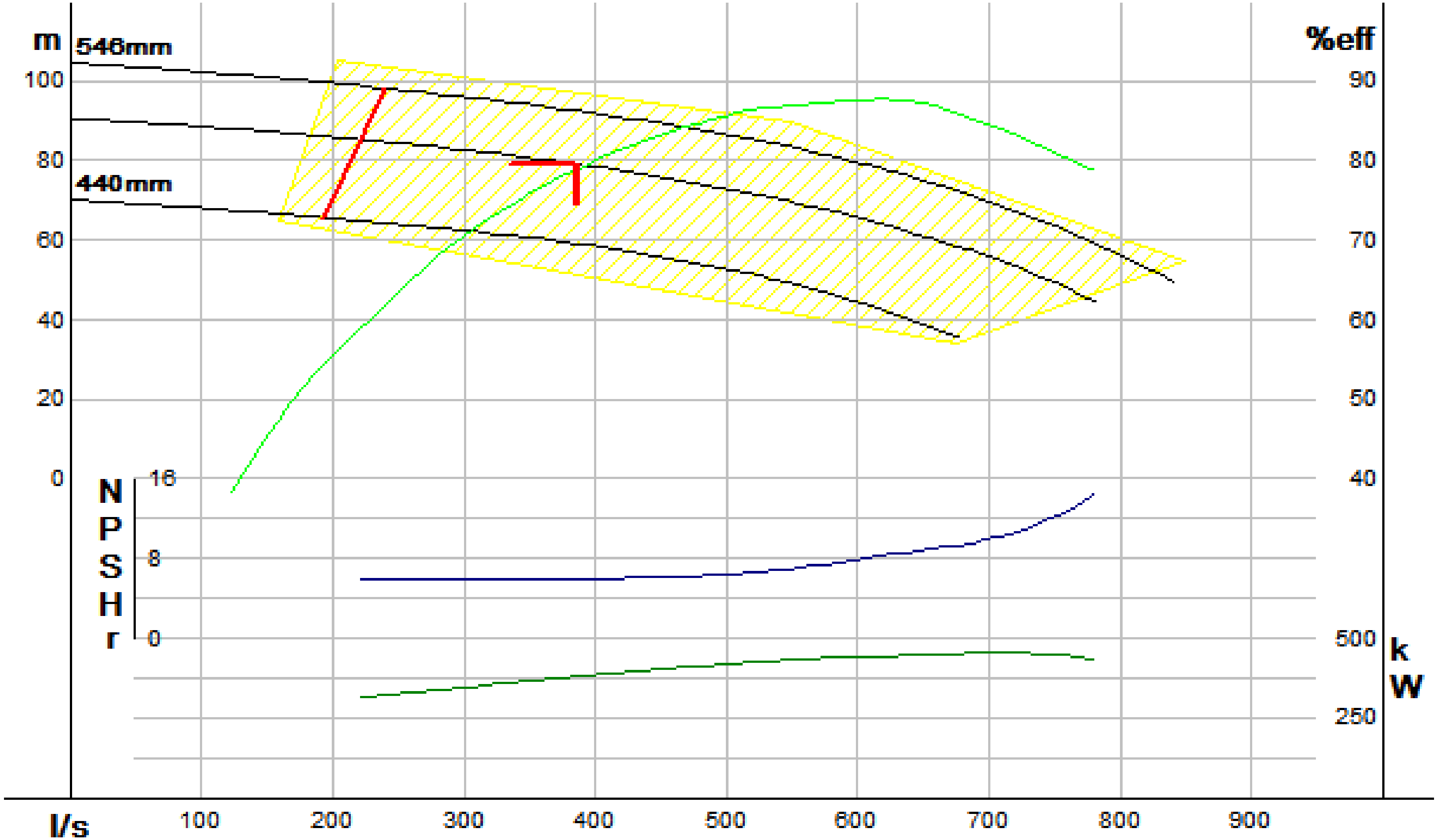

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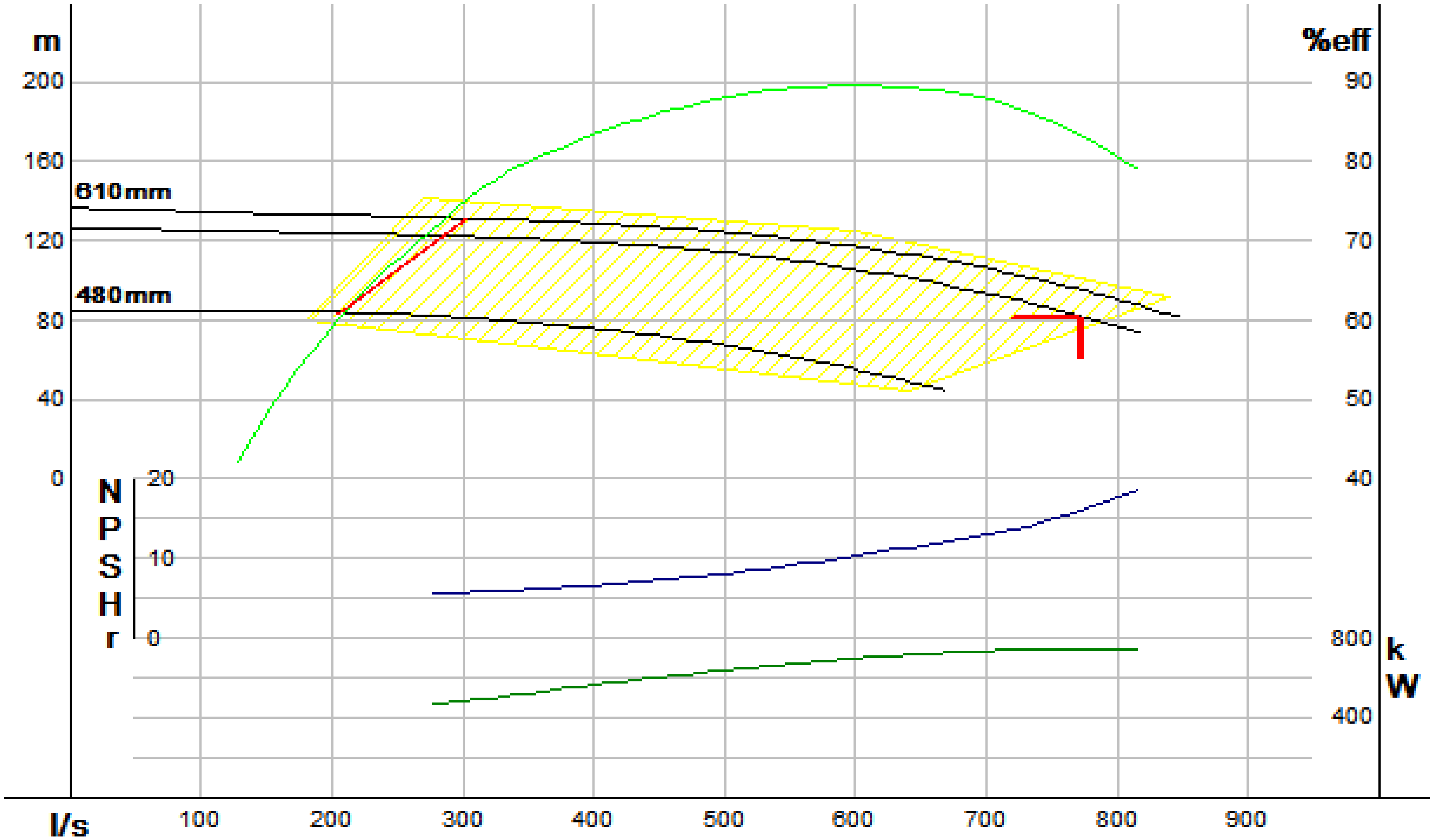

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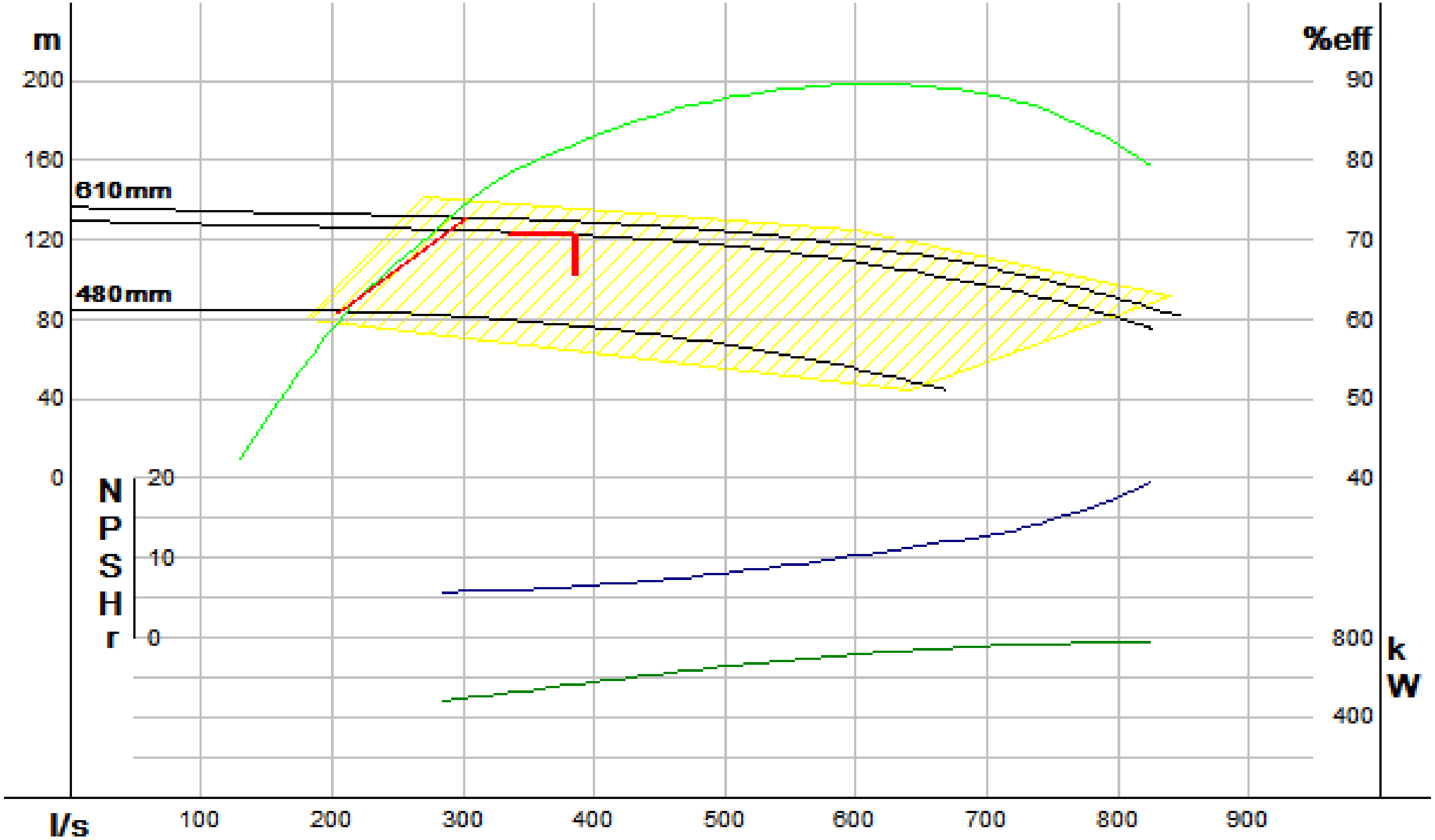

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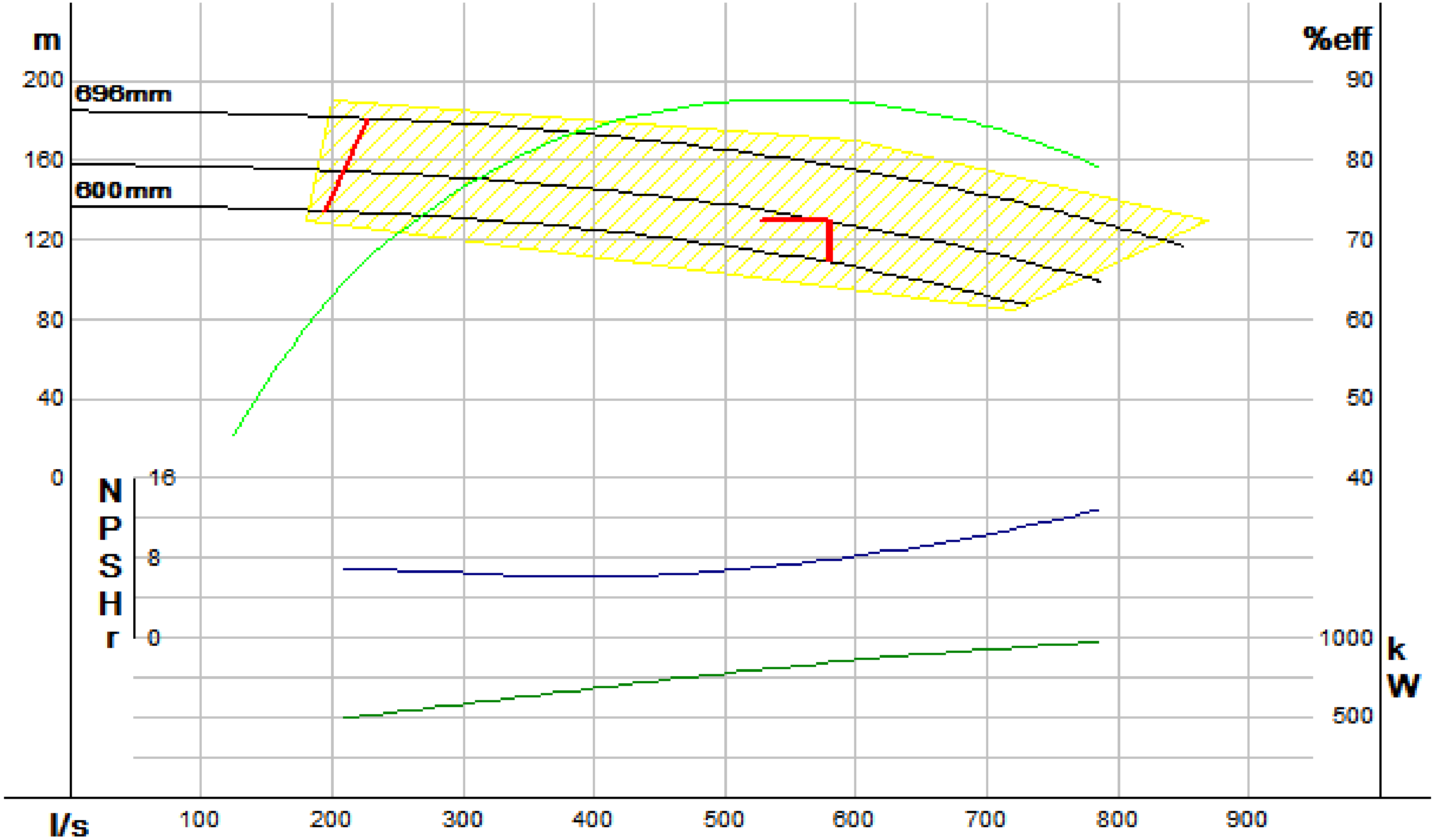

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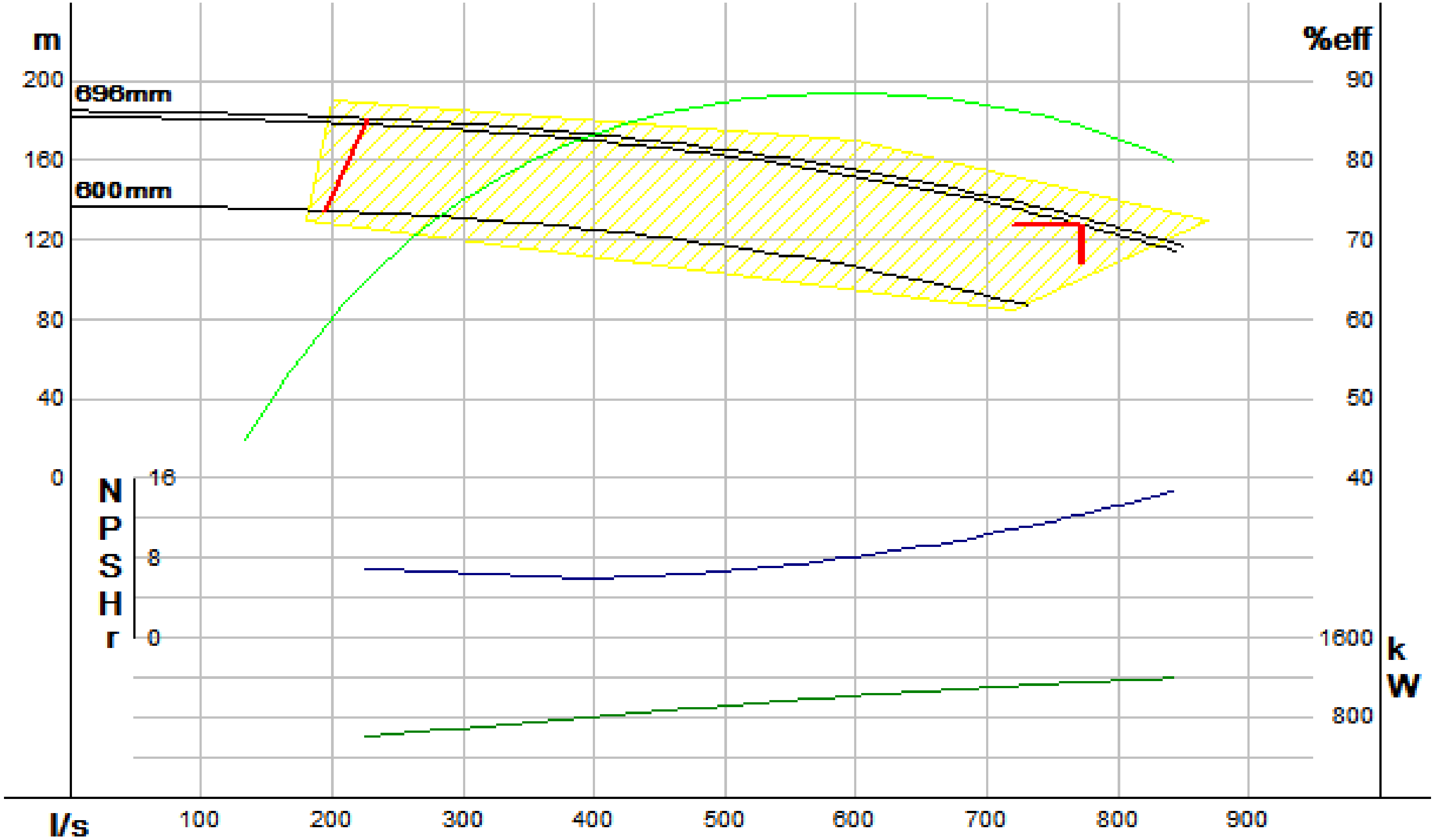

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