University of Southern Queensland

Faculty of Engineering and Surveying

Hydroelectric Generators for Third World Countries

A Dissertation submitted by

Mr Nicholas Burton-Ree

In fulfilment of the requirements of

Mechanical Engineering

November 2013

Bachelor of Mechanical Engineering

Abstract

Today’s society is becoming more pressured to produce renewable energy,as some of the world’s resources are becoming scarcer and the population is increasing. The push to find a new reliable eco-friendly energy source is becoming ever so relevant. Due to the high demand of electricity, the cost of power is expensive and the ability to access the resource is difficult for many poorer areas in the world. These third world areas are in desperate need of power to allow food and medical supplies to be stored, and as a result, distributed in the needed areas.

Papua New Guinea which is located just north of Australia has some of the toughest terrain in the world and is rated high in the top 50 third world nations. It is the perfect location for a hydroelectric system. Micro hydroelectric generators are becoming more and more common in remote locations. The disadvantage to these systems is that specifically designed turbines are expensive and time consuming to design for the location. A solution to this problem is to implement an already designed centrifugal pump as a turbine. At the small cost of efficiency the use of a pump can produce a low cost and reliable energy source.

This unconventional solution has the ability to be applied to poorly developing countries such as Papua New Guinea to help achieve self-sufficient energy production. As a result, it would also have an impact upon improving the health and well-being of all of the local inhabitants.

Disclaimer Page

University of Southern Queensland

Faculty of Engineering and Surveying

ENG 8411 & ENG8412 Research Project

Limitations of Use

The Council of the University of Queensland, its faculty of Engineering and Surveying, and the staff of the University of Queensland, do not accept any responsibility for the truth, accuracy or completeness of the material within or associated with this dissertation.

Persons using this material do at their own risk and not of The Council of the University of Queensland, its staff of The University of Southern Queensland and the faculty of Engineering and Surveying.

This dissertation is an educational designed critique only to satisfy the scope of this exercise and has no validity beyond what is required. This project is to satisfy the pair courses “Research Project” and is to contribute to the completion to the educational requirement of the student’s degree. This Dissertation, the drawings, mechanical components and any other material are set in the appendices and should not be used for any other purpose. If so, they do at their own risk.

Candidates Certification

I certify that the ideas, designs and experimental work, results, analysis and conclusions set out in the dissertation are entirely my own efforts, 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.

Student Name: Nicholas Burton-Ree

Student Number: 0050101614

Signature

Date

Acknowledgements

It is with great pleasure to have the opportunity to thank everyone who helped and supported me throughout the year of working on my project.

I would firstly like to sincerely thank my co-supervisors Les Bowtell and Malcom Gillies. I would not have been able to complete such work without their guidance, knowledge and support throughout this project. They were always there when I had a question or needed help and they were always willing to take the time for me.

On a personal note I would like to thank all of my family and friends who gave me the confidence and strong support to complete the thesis.

Nicholas Burton-Ree

University of Southern Queensland

2013

Contents

List of Tables

List of figures

Abbreviations

PAT	Pump as a Turbine
BEP	Best Efficiency Point
HEC	Hydroelectricity
η	Efficiency
H	Head, m
N	Rotational Speed, rpm
g	Gravitational acceleration, m/s^2
P	Power, W, kW
Q	Volumetric Flow Rate, m^3/s
Q_t	The flow rate of the turbine at best efficiency point
N_t	The turbine running speed
N_p	The rated pump speed
Q_{bep}	The pumps flow rate at the best efficiency point
η_{max}	The pumps maximum efficiency
H_t	The head of the turbine at best efficiency point
N_t	The turbine running speed
H_{bep}	The pumps Head at the best efficiency point
AC	Alternating Current
DC	Direct Current
W	Watts
C_x	Battery capacity, specified for an appropriate discharge rate x, (AH)
E_{tot}	Total design daily energy demand from the d.c, in watt hours (WH)
V_{dc}	Nominal Voltage of the d.c (battery voltage), in vaults (V)
T_{aut}	Number of days of autonomy

DOD_{max} Design maximum depth of discharge of the battery, expressed as a percentage.

Overview of the Dissertation

This dissertation is as organised:

Chapter 1 defines the purpose of the proposed idea of a Small Hydroelectric generator and explains in detail of where the system will be installed. This chapter also investigates the capacity of the generator and briefly outlines the dissertation content.

Chapter 2 is the review of literature relevant to the project. This chapter discusses in detail the information found on topics required for this dissertation and how the information will prove to be beneficial to the design and application of a small hydroelectric generator.

Chapter 3 defines the suitable methodologies for the research and development in designing the hydroelectric generator. This chapter also examines the risks involved with operating the generator. The resources required for this project are also identified.

Chapter 4 details the design of the hydroelectric system. It shows the justification and functions of each component. This chapter contains the theoretical calculations obtained from the literature review and summarises the finalised chosen design. This includes validating the theoretical calculations with the prototype.

Chapter 5 isthe summation of the results found from the test and theoretical calculations. The outcomes of the results are used to finalise the design.

Chapter 6 identifies the work performed and discusses any further research and development that may be required.

Risk Assessments

All of the risks involved in the project were evaluated and taken into serious consideration. To comply with the standards of the University of Southern Queensland, risk assessments were completed for both the physical and theoretical risks. A physical risk was defined as the ability to cause physical harm or damage to a body or object. Theoretical risks were defined as the risks that could damage the dissertation or work produced.

The tables were inserted when the thesis was completed, both lab and project completion assessment were carried out. The outline based on the Risk assessment for the lab operation was used for both.

Chapter 1

1.1 Introduction

Renewable energy is becoming more prominent in society and the understanding for how important it will be in the future is becoming common knowledge. Nowadays, there are many different types of renewable energy available to the public, but are restricted to certain locations because of price and accessibility. The ever so changing climate is making it more difficult to harness the available green energy. However, in particular locations, due to erratic weather, it is has also had the reverse affect and has increased the resources in some countries. As much as droughts are becoming more predominant in countries such as Australia, the wet seasons have become more severe in locations such as North eastern India and Papua New Guinea.

Papua New Guinea is susceptible to climate change. Its inhabitants are spread sparsely throughout the country and it is known to have some of the roughest terrain in the world. It has more than 17,000kms of coastline and 600 islands (Chalapan, Kaluwin, 2000), therefore, making it difficult to supply electricity to many of its inhabitants owing to the severity of the terrain and the separation of the villages. In countries such as Australia, power is distributed across the country as a consequence of several large power stations connected to a national grid. In 2012 Australia's consumption rate was 225 billion kWh (Index mundi - Australian statistics 2013).

Due to Australia's relatively flat topography, it is relatively easy and inexpensive to transmit the power to remote locations. However, unlike Australia, in Papua New Guinea it has proven to be impractical to have one major power station and then attempt to transmit the power across the rugged terrain to each individual village. As a result, only the larger villages have reticulated mains power.

Many of the remote locations in Papua New Guinea use fuel powered generators to gain access to power. Thus, as a result, they have high costs due to poor fuel efficiency, low consistency of power production and the inability to get fuel to many particular locations (Chalapan, Kaluwin 2000). Consistent power production is extremely important for the storage of food and medical supplies. Consequently, if this is not available, then often the site will have to go without because of the inconsistent power supply from fuel generators. The emissions, common fuel and oil spills from each generator are also detrimental to the environment, therefore resulting in a need for a new electrical source.

Hydroelectricity (HEC) is an established energy generation technology that has been used successfully for over one hundred years. HEC is the generation of electricity by harnessing the potential energy of flowing water using a turbine of some sort and converting it into rotational energy. It currently makes up 17% of the world's power production (British Hydropower Association 2011)and is growing due to advancements in technology and availability of parts. Australia has over one hundred hydroelectric plants located in NSW and Tasmania alone (Clean Energy Council 2012).

A generator is then used to produce electricity from the rotational energy and supply it to the power grid. Hydroelectric generation varies in sizes from a small single turbine of 1kW to multiple 700MW. Micro hydroelectric generators are often used to harness the potential power from small streams and creeks. These stations are extremely useful and can be used in remote and rural areas separatedfromthe electrical grid. Micro hydroelectric generator installations have considerable financial and humanitarian benefits.

Small hydroelectric generators became a strong focus after the oil crisis that occurred in the 1970’s as an alternative power source(World Intellectual Property Organization 2011). The costs per kWhr of energy produced by these systems were higher than when compared to a large scale plant and as a result this is a major obstacle for small hydro- electric generators. Components for the micro-hydro plants are relatively expensive and are only supplied from a few companies. Nevertheless, this can be overcome by sourcing equipment from other suppliers who may not be traditionally used for the direct purpose of micro-hydro generation. Therefore, an applied conceptis using a common commercial centrifugal pump as a turbine also known as a PAT.

Using a pump as a turbine is an attractive and feasible alternative to the commercial Pelton wheel. Furthermore, pumps are relatively reliable machines with quite a simple function and operation. Centrifugal pumps are also one of the most common mechanical machines and are readily available 'off the shelf' in many countries. From an economical point of view, it is often stated that the capital payback period of PATs is in the range of 5-500kW over two years or less (Louvian, 1992). However, the decision in using a PAT is influenced by many factors such as, efficiency, cost, availability and potential energy from the site location.

Hence, a small hydroelectric generator using a pump as a turbine should be applicable for the remote locations in Papua New Guinea. The generator could be created using commonly sourced parts.

1.2 Project Aim

The aim of the project is to design a small hydro electric generator using a common centrifugal pump as a turbine and power a small hospital room in the remote location of Papua New Guinea. At the conclusion of the dissertation, the reader will have an understanding of how the pump as a turbine will operate and they will also comprehend how the complete system will be designed and installed in the target area.

The dissertation will highlight the cost effective aspect of using a PAT instead of a purposely designed turbine. The reader should also be able to use the material in this dissertation to gain an understanding of how to select an appropriate pump for varying head and flow rates.

This project involved theoretically testing the use of a centrifugal pump as a turbine and compared the findings to actual testing on the application. The system was designed as a whole and each component was researched in order to justify its use. The dissertation clearly and accurately demonstrates how and why each component was chosen.

The Small hydroelectric generator was to power a small hospital room in a remote location consisting of:

- 1 Medicines Refrigerator
- 5 Lights
- 1 Ceiling Fan

The generator should be able to produce approximately around 6-10kW.hr per day depending on the specific equipment selection. It was expected that the appliances used in the area were not efficient and they had a high power draw.

The hypothesis was firstly, that the use of a pump as a turbine must be proven to be an appropriate application in both cost and power generation.

1.3 Assessment of Consequential effects

Actions taken in the design and testing of this dissertation were completed professionally to ensure the credibility of this project and work ethic was maintained. To do so all aspects were designed to adhere to the code of ethics 2011. The codes of ethics are produced by Engineers Australia to help define the values and principles that shape the decisions made in engineering practice. As a member, it is important to adhere to the code and be accountable for the decisions and actions taken.

1.3.1 Consequential effects and Responsibility

During the design process and analysis of the dissertation, the engineer’s code of ethics must always be followed. This section contains the basic practices of the code that were applied to the completion of this work.

The Institution of Engineers Australia has a strong practice of the four following practices.

1. Demonstrate Integrity
2. Practise Competently
3. Exercise Leadership
4. Promote Sustainability

By following the guidelines on professional conduct as set by engineers Australia 2013, they were not intended by engineers Australia to be interoperated as a full or exhaustive list of the situations and circumstances which may compromise compliance and noncompliance of the code of ethics. The dissertation was completed using judgement, interpretation and balanced decision-making in content.

1.4 Background

Papua New Guinea (PNG) is located north of Australia occupying the eastern half of the island of New Guinea. PNG has some of the roughest terrain in the world and some of the peaks in the central lands reach up to 4,350m (Papua New Guinea Initial National Communication 2000). Many of the smaller islands located near the mainland have high volcanic mountains.

A survey taken in 2010 showed that Papua New Guinea had a population of around 6.7 million in habitants(Australian Department Of Foreign Affairs 013). 87.5% of the population were located in rural areas while the other 12.5% were urban.

Studies have also shown that the annual growth in population for rural areas in PNG is 2.4%, which is .2% greater than the urban growth and was expected to double every 30yrs (Health Service Delivery Profile Papua New Guinea 2012). As a result, demand for power would increase in remote locations as time progresses due to higher population growth.

Although the population is growing at a remarkable rate, the technological advancements and medical supplies struggle to keep up with the ever so increasing population. Medical supplies are only able to be given to villagers in the remote locations on very few occasions and must be used immediately as there are few electric fridges. Consequently, the lack of power throughout the highlands has had many detrimental effects on the country.

PNG has an average rainfall of around 2700mm in the wet season. This had varied by only 15% since 1973 and has had a higher consistency in the highland's central location. Thus fortunately, the rural locations have access to fresh flowing water all year round (Papua New Guinea Initial National Communication 2000).

1.5 Target Area

Papua New Guinea (PNG) has a rough terrain, and a high rainfall throughout the year. There is a lack in power supply across the country, hence making it an appropriate targeted area to design the small hydroelectric generator for operation. The particular location in the highlands was chosen because of its remote positioning and its similarity to other sites around the world, for example parts of Asia and South America. Furthermore, by designing the generator for the highland country in PNG, it allows this project to cover a larger location scope.

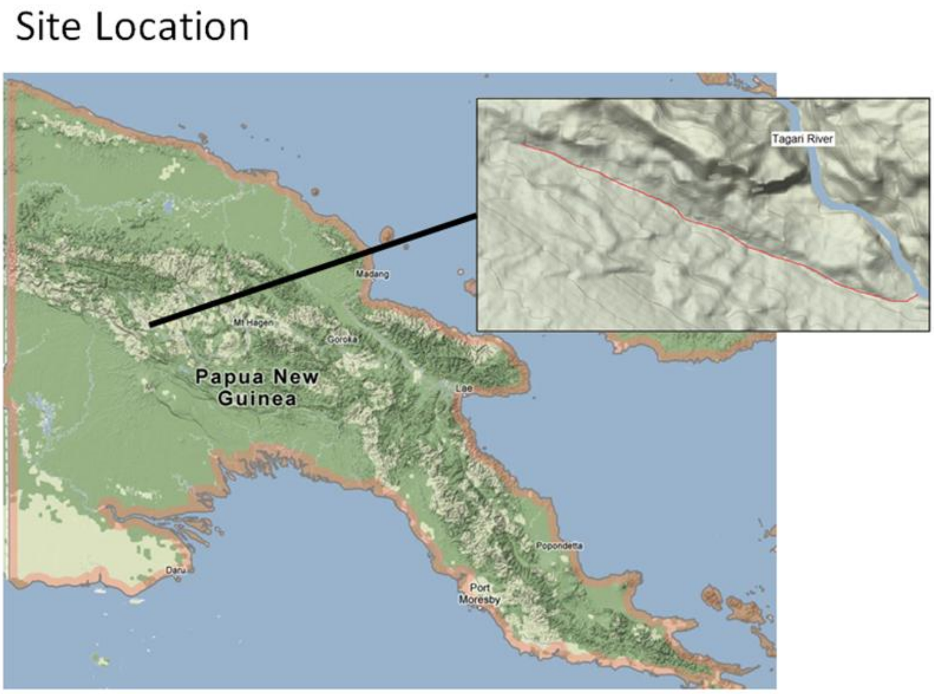


Figure 1: Targeted Site Location (Google Maps, Papua New Guinea 2013)

Figure 1 shows a small gully that is located in the central highlands in Papua New Guinea,this is on the Tagari River. The gully is approximately 6km and has a drop of 600m from the head of the gully to the Tagari River, thus, easily producing the required volume flow and head to power the small hydro electric generator (Google Maps Terrain 2013).

The generator will be designed to be installed on the creek and power a small hospital room located near the gully. Due to the length of the gully, a positive feature would be that it leaves a sufficient amount of room to choose where on the gully the small hydroelectric generator would be installed.

This will be depending on the following factors:

- Village location
- Gully creek flow
- Access to hydro electric generator
- Losses of power transmission lines

More detail of the location is found in chapter five and a runoff analysis is completed. Chapter two reviews the literature around using a centrifugal pump as a turbine.

Chapter 2

2.1 Introduction

The concept of using a centrifugal pump as a turbine is not an original idea. It has been attempted in the past as an alternative application for a turbine. The concept has been deemed successful and under the correct condition, proving to be effective.

The global energy demand is rapidly increasing, particularly in developing countries over the world due to both an increase in population and industrialisation. In order to meet the ever growing demand in power production, new energy sources are required and quickly (Alexandratos,2005), (Bradshaw, 2013),(Fischer, Schrattenholzer, 2001), (Hans-Holger, Popescu, 2000). The purpose of this chapter is to review the literature relating to small scale hydroelectric power and pumps as turbines.

2.2 Third World Countries

Third world is a terminology that arose during the cold war to help define countries that both sided with America and allied states or with the communist bloc (for example the Soviet Union)(Gaddis, 1992),(Haass, 1997). This terminology was then recognised as a way to categorize nations based on three groups:

- Social
- Political
- Economical

Nations that are labelled under the title of third world countries, each have a poor level from at least one of these groups. Within each section, the conditions of being part of a third world country broaden. It is estimated that around 79% of people in the 50 poorest nations have no access to electricity, despite years of industrial developments. In 2012 a study published by scientific America showed the total number of individual people without power is expected to be around 1.5billion people or a quarter of the world’s population (Scientific America, 2013) .

The 1.5 billion is seen as an improvement over the years, but this is not due to the improvement of power supply to people. The improvement is due to the urbanization of areas based at power supply locations. No improvements have been made to develop the infrastructure of power transmission to remote locations, and hence many have moved to the power source. Therefore, the density in specific targeted areas has increased rapidly (Papua New Guinea, Initial National Communication,2000).

This dilemma has two detrimental impacts on the nations affected by this phenomenon:

1. The over-population of the area results in damage to the eco-system. This is due to both pollution and using up the resource available for that specific location. Erosion is also a large problem that causes damage to land, structures and can result in heavy costs. Often erosion occurs when the soil is overloaded or as a consequence of flowing water. Furthermore, poor urbanization frequently results in deficient water control which can be attributed to lack of funding, thus causing the ground to become unstable (Blaikie,1985).

2. The rest of the county is not being used to its possible potential. The resources and space available for society are not used because of the lack of access to electrical power at the location. Subsequently, using the land and space allows less strain on the environmental eco system due to the inhabitants and density of man (Loffler,1977).

2.3 Papua New Guinea

Papua New Guinea is currently showing signs of falling into economical paralysis. This is similar to other locations such as the Solomon Islands. Ever since the nation became independent in 1975, the living conditions have scarcely improved (Australian Geographic 2013). The countries poor finances and unproductive spending have led to the nation having little money, and consequently this has resulted in poor roads, education and health section. Furthermore, roads in rural areas are so poor that access has been denied.

At the same time, population growth in the country is increasing but economic growth is negligible, and hence the country is stagnating as a nation. (Windybank, Manning, 2003). However, the only growth seen by the nation has been in the mining and petroleum sectors due to their large export of their resources.

The greatest concern for Papua New Guinea is the imbalance of the economy, and this has been in existence since independence. The condition of Papua New Guinea has been the result of several different factors. Policies which were implemented were not all beneficial and the governments had failed to correct them. The rural sectors of the country have been restricted, thus this was largely due to the lack of infrastructure and low availability of resources. Consequently, as far as rural villagers were concerned, anecdotal evidence suggested that many believed that their quality of life was now worse than it was 20 years ago (Windybank, Manning, 2003).

It is apparent that funding will go into other sectors before the electrical infrastructure is addressed. Therefore, with the lack of government budgets and the continuous action of urbanisation, the country will continue to struggle. Accordingly, the living conditions of individuals will need to improve instead of declining.

2.4 Small Hydroelectric Generation

Micro Hydroelectric generators allow the production of electricity. This is due to the potential power from flowing water. The systems allow generation to occur in remote and distant locations where often it is too expensive or the country is too rugged for the construction of power transmissions lines (The University of Chicago Press).

“Mini hydro” is a term that can apply to sites ranging from small size schemes that have the ability to power one appliance, up to supplying electricity for a house. Small scale hydroelectric generation is one of the most cost effective and reliable energy technologies available. Hence, small individual hydroelectric generators are becoming quite common. There are multiple companies that provide service in hydro generation and this can vary from 1kW up to 200kW depending on cost and location (D Henderson, 1998).

There are a number of advantages and disadvantages of small scale hydroelectric generation systems.

2.4.1 Advantages

- **Efficient energy source.** It only takes a small amount of flowing water to acquire generation from a correctly installed hydro system.
- **Reliable.** The supply of energy continues compared to other remote power generation systems such as a fuel generator. The greatest draw (peak) is in the winter months when large amounts of energy are being used.
- **Reservoir is not required.** If the system is small enough, the flowing water can be directed into the turbine without any reservoir required. This improves overall cost and results in less impact to the environment.
- **Cost effective.** Once the initial cost of installation is completed, maintenance is relatively cheap and easy. The overall cost will depend on the size and material.
- **Generation into the power grid.** If applicable the generation of power can be transmitted into the power grid. Large power generation companies will buy back the power. This is governed by how much power is generated from the system, what power is being used and on the location in relation to the grid.
- **Power for Third World Countries.** Due to the system being a low cost power generation it is applicable to developing countries where access to power is impractical or impossible (U.S Department of Energy 2001).

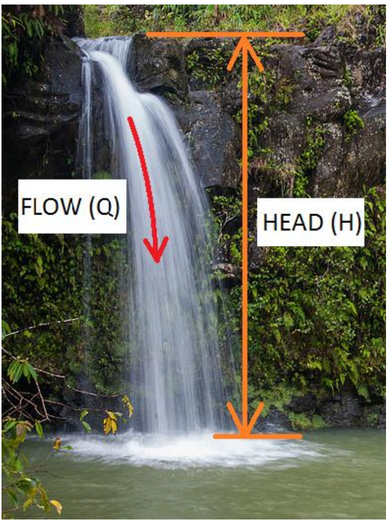
2.4.2 Disadvantages

- **Location limitations.** For the small hydroelectric generator to work it must be installed in a site which meets all of the requirements and factors for successful generation. These requirements and factors are: Small distance from generator to where the power is required (transmission distance), flow rate of the targeted stream, head that can be extracted and the system components of the generator (power storage, generation regulation, piping and possible power inverters).

- **Poor generation in the dry season.** The system relies on water flow for generation. During the dry periods of the year, power generation will be more difficult. Planning and research into the location beforehand is extremely important.
- **Size limitation.** The generator cannot be expanded in the future due to the restrictions of the creek size. Although the water system might be able to be dammed, it is still limited with the floe rate and the incline of the creek.
- **Environmental impact.** Although ecological damage will be minimal due to the small scale of the generator, it still must be considered. Factors such as where and how much of the water will be diverted are important. The smallest possible environmental impact must be taken into account each time (Baxter,1977).

2.5 Basic hydraulic power concepts

Power can be captured whenever a flow of water moves from a high location to a lower location. This change in level is known as the ‘head’ and it is crucial to the ability to produce power with hydro-generation. A flowing creek with a high flow rate does not alone have the ability to produce enough potential energy to power a site. The two conditions that are required for hydroelectric is the flow rate Q, and the head H as seen in Figure 2 below (Wikicommons,2013).



.

Figure 2 Flow Rate and Head (Google Images 2013)

Head represents the total energy available to the turbine. In hydrology it can be defined as the maximum available fall in the vertical direction from upstream to downstream. When a system is installed it is often defined as the distance from the inlet of the system to the turbine. The actual head seen by the turbine will always be less than the maximum head of the site due to losses in the system. This lower measure of head is known as the net head (Hamil,2011). The turbine may also be unable to extract the entire head and therefore a residual head may remain after the water leaves the turbine.

Flow rate (Q)is defined as the volume of water passing per unit of time. The unit may vary from litres per second to $1m^2/sec$ (Engineering Fundamentals, 2011).

Power is defined as the amount of energy consumed per unit of time which is measured in watts (W) (Engineering Fundamentals, 2011).

Hydro generation is the process of turning potential energy into electricity. Through this process it converts the potential energy of water to an equivalent amount of kinetic energy. The water's height which is measure in potential energy is partly converted into kinetic energy which is the speed of the flowing water (Hamil,2011). By balancing the amount of potential and kinetic energy an efficient power generation is plausible. Potential and Kinetic energy are given by:

Kinetic energy (joules) = $\frac{1}{2}mv^2$

Potential energy (joules) = mgh

Where:

- m is the mass of the water (kg)
- g is acceleration due to gravity (9.81m/s^2)
- H is the effective head available (m)
- v is the velocity of the water at the intake of the turbine (m/s)

The intake velocity can be found by $v = \sqrt{(2gH)}$

Turbines convert the energy from the water (Kinetic and Potential) to mechanical shaft power which rotates the generator. The available power is proportional to the product of the head and flow rate (Hamil,2011). Therefore, the power output of hydroelectric systems can be estimated from:

$$P = \eta \rho g Q h$$

Where:

- P is the mechanical power in watts (W) produced at the turbines shaft
- η is the hydraulic efficiency of the turbine
- ρ is the density of the water (1000kg/m^3)
- g is acceleration due to gravity (9.81m/s^2)
- Q is the volume flow rate passing through the turbine (m^3/s)
- H is the effective head available

2.5.1 Capacity factor

Often turbines can be summarized by a capacity factor. This factor is a rating of how hard the system is working.

$$Capacity\ factor\ \% = \frac{Energy\ generated\ per\ year\ (\frac{kWhr}{yr})}{Installed\ capacity\ (kW) * 8760hrs/yr}$$

2.5.2 Energy Output

Energy is defined as work done in a given time (joules)(Engineering Fundamentals, 2011). One form of energy is electricity which has its own set of units (kWhr) where one kWhr is defined as 3600 joules or the electrical supply of 1kW for a period on 1 hour. By using the capacity factor, the estimated energy output can be calculated$Energy\ \left(\frac{kWhr}{yr}\right) = P(kW) * Capacity\ factor * 8760$

2.5.3 Turbines

Turbines are classified under three main categories which also have two sub groups. They are high head, medium head and low head machines. These categories are based on the shape and design of the turbine. The two sub groups are Impulse and Reaction turbines (School of Engineering, 2010).

Impulse turbines use the process of shooting water with a velocity at one specific point on the propeller system (Hamil,2011). The waters velocity forces the blades to rotate. This design of the turbine is the least complex and is commonly used for high head micro hydro-generation systems (U.S Department of Energy,2001). Types of impulse turbines are:

- Pelton Turbine consists of a wheel with split buckets around its rim to catch the water jet.
- Turgo Turbine which is similar to a Pelton wheel but the water is aimed at the blades on an angle to help improve the minimum water needed to run the system.
- Cross flow turbine uses direction blades to ensure that the flow is efficiently directed at the blades. The direction aids also allow the turbine to be hit twice with water jets (U.S Department of Energy,2001).

Reaction Turbines use the oncoming water to generate hydraulic lift forces to create rotation. Reaction turbines are highly efficient and rely greatly on pressure. Often reaction turbines are used for large power generation sites. The distinguishable difference between the reaction and the impulse is that the reaction encases the entire propeller system in water. All reaction turbines also have a draft tube which is the tube where the water is discharged. The draft tube also causes a pressure drop at the discharge area resulting in an improved head and overall efficiency(U.S Department of Energy,2001).

Types of Reaction turbines are:

- Propeller based turbine which is similar to a ship’s drive propeller but under operation in reverse. This style of turbine varies and the design is known to need a high flow rate to ensure the entire propeller is submerged.
- Snail shell turbine directs the flow around the propellers and forces the water to pass through the system. This design is also quite similar to the Kaplan turbine.
- Francis turbine forces the water to flow radially inwards to the centre of the turbine and forcing the turbine to rotate to let the water discharge. Francis turbines are mainly designed for low head situations (U.S Department of Energy,2001).

Small hydroelectric generators have certain advantages and disadvantages that govern the practicality of the hydro system.

2.5.4 Efficiencies

The most significant way to compare turbines is by their relative efficiency. The efficiency is the rating of what power is predicted to get out of a system (Castronuovo, Peas Lopes,). In turbines the value of efficiency is effected by:

- The flow rate
- Head of the water
- Size and design of the turbine

In figure 3 it can be observed what the expected efficiencies would be with certain types of turbines. The Pelton, Kaplan and Cross flow turbines have high efficiency when it is running at low flow. The efficiency of these turbines will be used as a base line of what a normal turbine will produce.

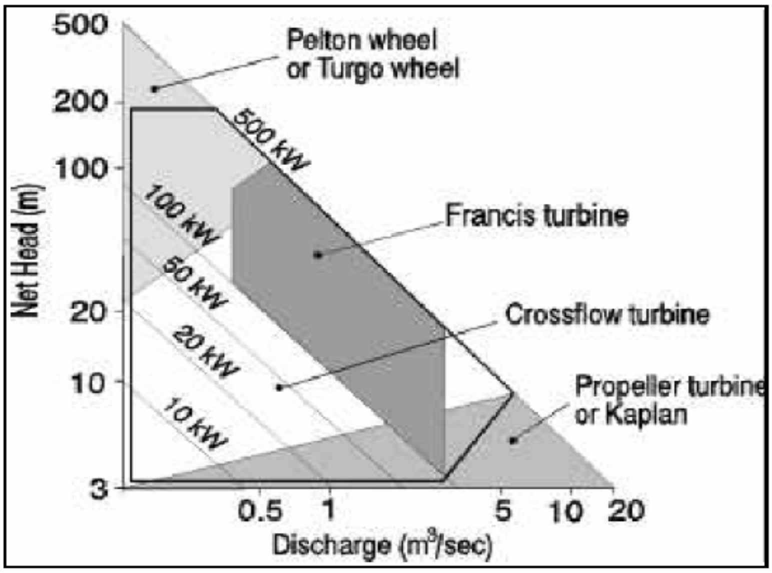


Figure 3Turbine Efficiencies

From figure 4 it can be seen to produce around the 10kw power, therefore a Cross flow turbine would be the most efficient. This also varies with the cost and the instalment conditions.

2.5.5 Economics

With small hydroelectric generation, high head is the most cost effective for projects. High head means that a smaller volume of water is required to produce the given power. It also means that a smaller turbine and overall equipment will be used resulting in a lower cost. These conditions are often found where mountain ranges and steep gullies are good locations to produce high head (U.S Department of Energy,2001).

Due to the high capital costs of the generation system in today's economic system (University of Moratuwa, 2002) a new hydro electric generator system can seem expensive as it can take up to 15yrs before the capital costs can be written off. A system that can last around 50yrs without reinstalment or much maintenance is quite cost effective. However, with the short term quality and product life it is difficult to ensure that the hydroelectric system will have a long running life.

Small hydroelectric generators are often close to the consumer and have more of an effect on the consumer than a coal plant which could be located 200km's away (Schwaiger,K. Pfaundler, M, 2011). As a result, the 'local' benefits are influential to the design and also the losses due to transmission lines are relatively low.

2.5.6 Sustainability and Ecological Impacts

It is important that the hydroelectric generation system when installed fits in with the location and is not detrimental to the community of the environment. This is very important as the most successful designs always look at the areas it will affect and are created to suit the particular environment. Although producing and installing the hydroelectric system can easily be carried out, the proper authorities must look at the proposed project and deem it acceptable. In order to ensure this is done the guidelines from previous hydropower projects have been reviewed.

The 'Situation Report on Hydropower Generation in the Alpine Region Focusing on Small Hydropower' (Schwaiger,K. Pfaundler, 2011) discussed the process of proposing the idea to a society and ensuring the highest success rate for being deemed acceptable by the authorities and community. The highlighted points in the report were:

- Help Develop a common understanding on the topic hydropower.
- Contribute to increase the efficiencies of the facilities and lessen their impact on the aquatic environment and the landscape.
- Support the competent authorities to help accelerate the approval time.
- Help preserve river stretch.
- Strike a strong balance between economic requirements and ecological and landscape needs whilst taking into accounts the social terms.

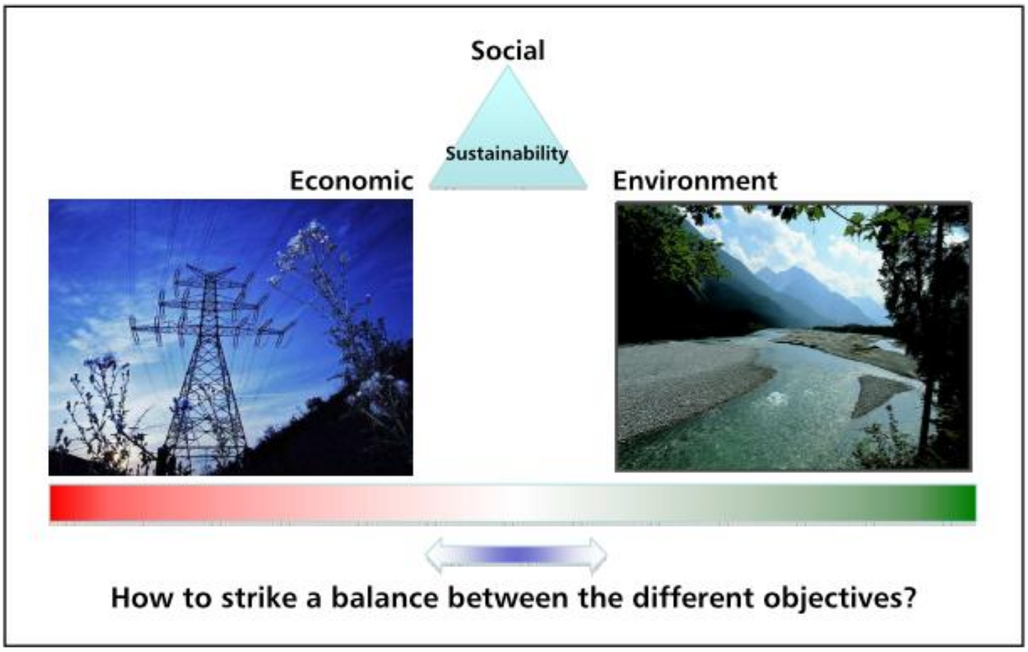


Figure 4Finding the Balance between Objectives

Figure 4 above (Situation Report on Hydropower Generation in the Alpine Region Focusing on Small Hydropower, 2011) demonstrations the area where balance must be found.

2.5.7 Social Benefits

Small hydro power stations have a large impact on the local region. Depending on the location it may disrupt everyday life in installation and operation. In the chosen location (PNG highlands) installation and operation would not affect the everyday life as much as suburban areas, this would be due to the vast low populate rate location. The system must also not contaminate water from the stream. The water must still be usable for drinking, irrigation and for other uses (Schwaiger,K. Pfaundler, 2011).

2.5.8 Environmental Benefits

The most known benefit to the environment is the positive contribution to climate change. The system produces renewable energy and has virtually no emissions. The system must also not affect the landscape and wildlife. Papua New Guinea has a high flooding rate and the system must be designed appropriately. The inlet catchment area for the system must ensure that no downstream damage occurs (Schwaiger,K. Pfaundler, 2011).

Although looking into the ecological and economic effects is not the ultimate goal within the scope of this project, it must be noted that the design must abide by these conditions to be deemed successful. The impact on the environment must always be minimal. Once a system is installed the location must be in a better condition than before the Hydro power was installed (Schwaiger,K. Pfaundler, 2011).

2.6 Pump as a Turbine (PAT)

PAT is the operation of a centrifugal pump being used as a turbine. A small pump as a turbine can be more economical than traditional systems and therefore, when operated in reverse, can have many advantages over the traditional turbine power generation. By using a pump as a turbine costs can be decreased but at the same time, there is the downfall of efficiency. For this concept to prove viable the advantages must out way the losses (Williams, 1995).

Figure 5 illustrates a general visual of the differences with cost and efficiencies with hydro turbines and a PAT.

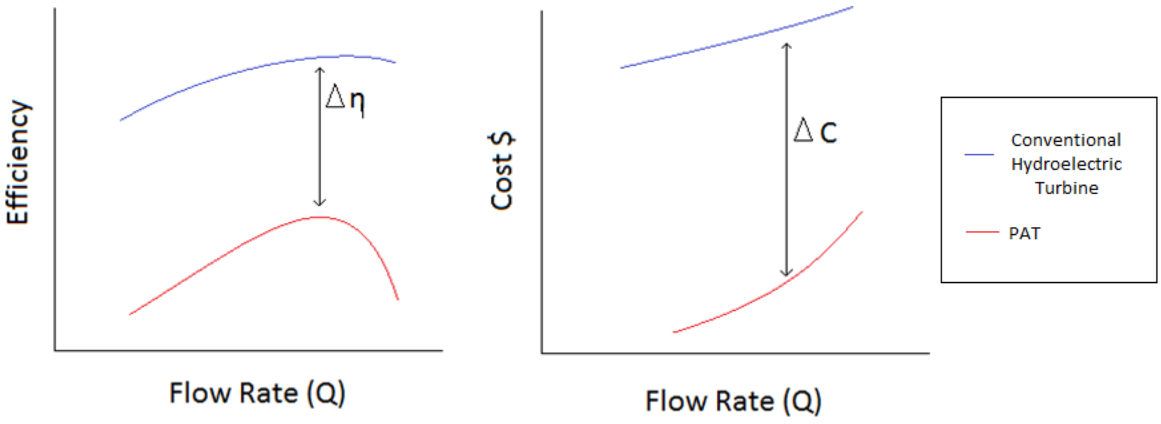


Figure 5Cost vs. Efficiency (Burton-Ree, 2013)

The change in the cost of the hydroelectric generation system must make the project worthwhile. There are more factors that affect the overall analysis of the project. These variables are discussed in more detail in chapter three.

The main focus of cost is on the pump as a turbine compared to a conventional turbine because regardless of what system is chosen, the same piping, weir and pipe inlet will be used.

Some of the advantages of PAT are:

- A wide range of flows and heads available
- Available standards and sizes
- Easy Installation
- Spare parts easy to source
- Fast delivery time
- One of the benefits of using a pump as a turbine is the direct drive instead of a pulley system or gearing.

As a result further advantages are:

- Lower Friction losses
- Less material required
- Increased bearing life
- Low maintenance (no need to tighten belts etc.)

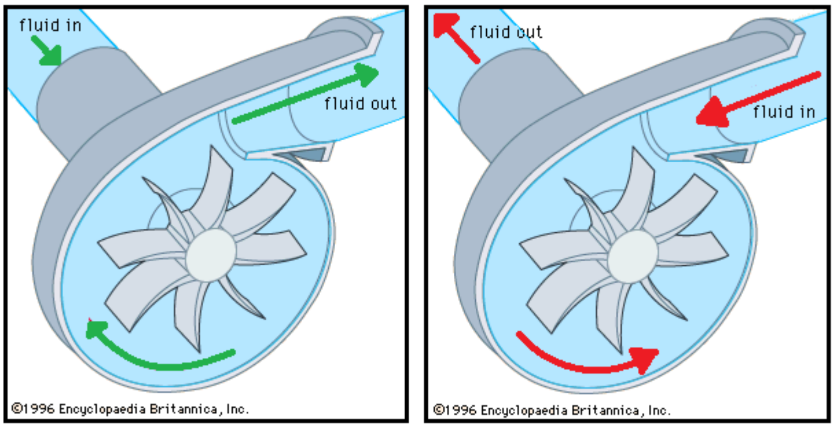
A turbine that is designed for the specific location is fitted with a vane that allows the machine to operate with a large variation of flow rates at a high efficiency. However, when a centrifugal pump is used and run backwards, it is only suitable within a very small range. The pump must be appropriately selected to ensure that it is operating within its optimal efficiency rate. The mathematical relationship used in this dissertation shows how to correctly select the right size pump to ensure it operates in its best efficiency point (BEP) and as a result produces power efficiently (William, 1995).

Pumps have been used for many different operations for many years, but the first use as a turbine is not known. It was not until Thoma and Kittredge (1931) were in the process of evaluating the characteristics of pumps, did they accidentally learn that pumps could very well be used as turbines. From this important discovery, it became a strong interest to many manufacturers. The characteristics of how the pumps operated had been under investigation.

Many different researches investigated the characteristics and predicted the behaviour but only a few examined in detail what would occur. Some of the papers that had been written on the research of pumps, as turbine operations include those, written by Williams (1995), Alatrorre-Frank (1994), Chors(1997) and Paish(2002). Although all of these papers proved to be very informative, they were showing an inconsistency of results when they were compared to each other. One theory is the difference is due to different pump designs tested. This was due mainly to the fact that each test was completed on a different type and size of pump. To ensure the validity of the papers, tests were conducted on a specific prototype. This is covered in more detail in chapter four.

2.6.1 How Does a PAT Operate

A pump as a turbine is relatively self-explanatory. It takes a centrifugal pump and runs the water in reverse. Figure 6 below shows the flow direction under a different operation.



Conventional Pump Operation

PAT Operation

Figure 6 PAT Operation (Burton-Ree, 2013)

The two different operations both rely on two different actions to cause rotation and transferral of energy. When under normal operating conditions, the pumps use its velocity to push the water to the outer casing using the centrifugal force. It then allows the water to exit the casing via the outlet. During PAT operation, however it is quite different. The water is shot in at the outlet and uses its kinetic energy to force the impellor in a rotational manner. The centrifugal force actually disadvantages its operation as a PAT. Furthermore, the water entering with a velocity, in fact wants to stay on the outer casing due to the centrifugal phenomena. Only the increase in pressure makes the water force its way to the centre.

Figure 7 demonstrations that the waters actions are due to these different forces and pressures.

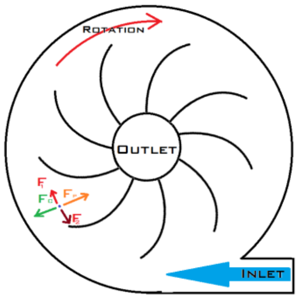


Figure 7Forces within a PAT

It can be seen in figure 7 that in order for the system to work and rotate the impellor, the following statement must be satisfied.

Equation 1

$$F_1 + F_P > F_c + F_2$$

Equation one states that the forces caused by the pressure build up on the edge of the casing, must be greater that the centrifugal force and the force caused by the mass of water flowing into the pump must cause F_1 to be greater thanF_2 . This is only the very basic concept of what occurs is a centrifugal pump as a turbine. Turbulence within the pump causes many more in balances.

2.6.2 Cavitation

Cavitation is the process of the formation of water vapours forming in the liquid due to the change of pressures (Hamil, 2011). These phenomena results in small bubbles of vapour forming that gradually get bigger in the system. The problem is when these large air bubbles are introduced to an increased pressure and as a result the bubbles implode under the pressures. The implosion results in extremely high velocities of water trying to fill the void that had been created by the implosion. These velocities and pressure changes can result in damage to the pump casing and impellor (Hamil, 2011).

To minimise cavitation:

- A generously sized inlet pipe is to be used to minimise velocity.
- Minimise turbulence at the inlet of the pump.
- Use an impellor material that is resistant to cavitation.

2.6.3 Who has done this before

There are currently no documented PAT systems that have available data about them. However, there has been testing and research completed on the characteristics. Pumps as turbines have been tested and analysed by multiple manufacturers and engineers over the years and as a result, it was noticeable that the pumps quality and performance had increased greatly. It was found that the practicality in using a pump as a turbine in 2013,is much greater than 20 years ago (Rawal and Kshirsager, 2007).The higher the operating speed the better the pump will operate as a turbine. Figure 9 displays the PAT's performance for specific speeds.

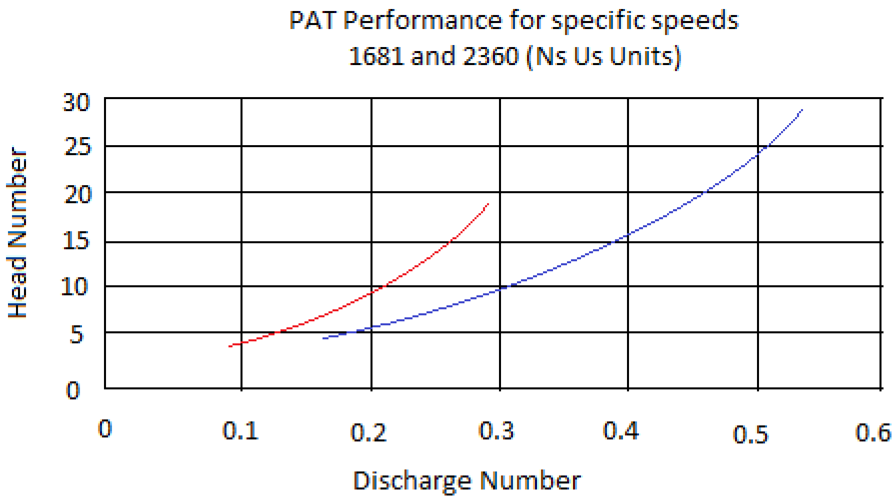


Figure 8Performance for Specific Speeds

It can be seen from figure 8 that it if the head remains the same, it takes a large increase in discharge to reach the increased rpm and vice versa. Currently pumps are built extremely well and have less mechanical resistance, thus allowing a high rpm to be reached. This means that the latest pumps can be acquired and the PAT generation will operate at its best possible efficiency (Rawal and Kshirsager, 2007).

2.7 Mathematical Relationship

2.7.1 Understanding pump performance curves

Before analysing a pump as a turbine, an understanding must first be gained of a pump's normal performance. When examining a pump, as the flow is increased the head produced decreases (Cotton CRC Water Team, 2008). This phenomena means that a relationship can be found between flow rate and head produced. With this relationship a best efficiency point can be found where the greatest flow delivery at the greatest head can be found (Merkley, 2004).

Below figure 9 shows the plotted relationship between flow and head and also how efficiency is shown.

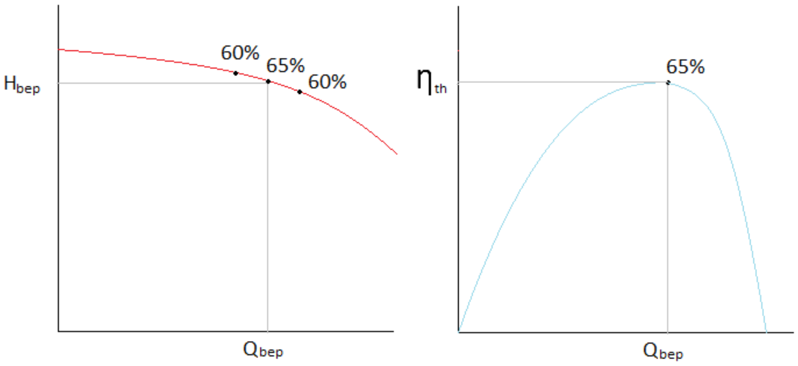


Figure 9 Pump Head vs. Flow and Efficiency Curve (Burton-Ree, 2013)

The BEP is defined as the value when the pump is operating at the maximum efficiency and is known as the best efficiency (Merkley, 2004). These BEP points also exist when using the pump as a turbine. The PAT is to operate under the optimal head and flow rate for the pump modal to be the chosen size. The best efficiency points for pumps under normal operation can be sourced from the pumps manufacturer. The BEPs given in the data sheets are affected by the pump size, not by the flow rate and head (Cotton CRC Water Team, 2008).

Figure 10 demonstrations a data sheet showing the BEP for a Southern Cross model pump.

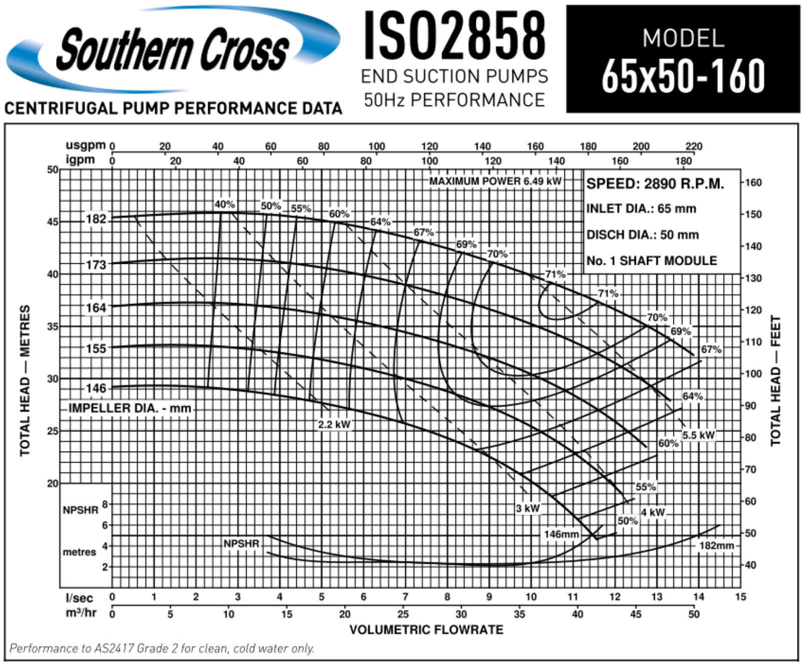


Figure 10 Pump Data Sheet (Southern Cross, 2010)

2.7.2 Pumps as Turbines performance Curves

Pump manufacturers do not normally provide the characteristics curves of their pumps operating as a turbine. Therefore, it is extremely important to establish the relationship between the pumps under normal operating conditions and as a turbine. Pumps as Turbine performance curves are quite different than normal pump operation (Williams, 1995). This is due to the fact that the PAT relies on the head and flow rate available to produce a rotation and as a result gives the PAT what is known as a site limitation. The site limitation is the head that is produced from the incline at the chosen location. Using the site limitation and head and flow rate curve for a turbine the operating points can be found(Cotton CRC Water Team, 2008).

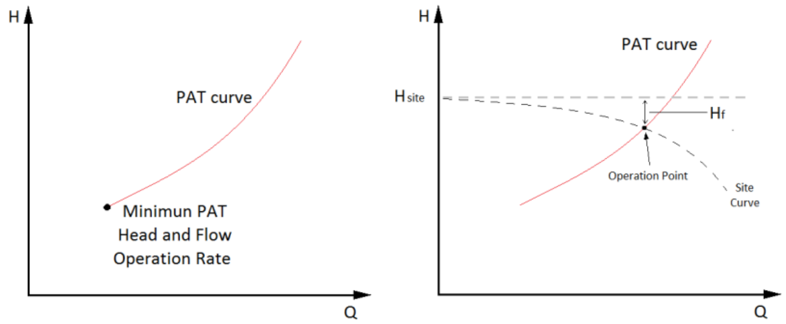


Figure 11 PAT Head and flow and Site and Turbine Curve (Burton-Ree, 2013)

It can be seen from figure 11 that the greater the head and flow the greater the pump will operate as a turbine. But the pump will always be limited to the Head available at the site minus friction losses (Hf) (Williams, 1995). This available head is known as the net head. The speed of the PAT will vary due to the load from the power generation. Therefore as a result, the load is changed and this will affect the PAT curve in relation to head and flow.

2.7.3 Generator Selection

An electric generator uses the concept of turning mechanical power into electrical power. Permanent magnet generation is the most common used power generation system used today (Williams, 1995). It uses the natural phenomena of two magnetic fields passing each other and creating a charge. There are two main types of generator systems that can be chosen. They are:

- Synchronous motor
- Induction motor

Both types of motors are permanent magnet motors which allow power generation when run in reverse. Synchronous motors are AC machines that operate in a steady state meaning that the rotation of the motor is synchronized with the frequency from the current being supplied (Electrical Technology, 2011). A Synchronous generator will operate with the same characteristics as being run as a motor. These motors are often used where specific speeds are required for operation (Williams, 1995).

Induction motors are often used to drive pumps. This is because of their ability to handle sudden changes in speed and they are cheaper than synchronous motors (Williams, 1995). However, the disadvantage of using induction motors is that slip occurs (Electrical Technology, 2011). Synchronous motors run at a fixed speed which is defined as the synchronous speed but induction motors do not. Induction motors run at a slightly lower speed which is known as the slip speed (USQ, 2012).

Equation two and three below show how to calculate the rpm for both types of motor generator speeds are required.

Equation 2

For synchronous generators:

$$N_{s=}\frac{120*f}{P}$$

where P= Number of Poles

f = Frequency (Hz)

N_s =Synchronous speed (rpm)

Equation 3

For Induction generators:

$$N_{ind=}\left(\frac{240*f}{P}\right)-\left(\frac{120}{P}*f\,(1-s)\right)$$

where N_{ind} =Induction as a generator speed

f = Frequency (Hz)

P= Number of Poles

s= Slip which is the small fraction that the motor runs slower than the synchronous speed (.02 to .05)

In 1995 Williams released an academic paper titled ‘Pumps as turbines, A users guide’. Within this paper the selection process for a pump as a turbine was discussed mathematically. The relationship of its operation was found that a PAT could operate similar under normal conditions but require a slightly increased flow rate (Q) and head (H).

The steps taken in the user’s guide to selecting a pump covered the following sections:

1. *Selecting a pump as a turbine for a particular site*
2. *Practical operation of a pump as a turbine*
3. *Design of electrical system*

The three sections within the paper were based on the testing and theoretical application. Through the completion of the theoretical testing of a pumps operation, a mathematical relationship was found to allow an accurate selection of a pump to particular site conditions (Williams, 1995).

The paper stated that the calculations were based on the affinity laws. This related to the following factors:

Flow (Q) is proportional to the speed (N)

Head (H) is proportional to N^2

Power (P) is proportional to N^3

These relationships were then used to calculate the running conditions at the Best Efficiency Point (BEP).

Equation 4

$$Q_t = \frac{N_t}{N_p} * \frac{Q_{bep}}{\eta_{maz}^{0.8}}$$

Where:

Q_t = The flow rate of the turbine at best efficiency point

N_t = The turbine running speed

N_p = The rated pump speed

Q_{bep} = The pumps flow rate at the best efficiency point

η_{max} = The pumps maximum efficiency

And

Equation 5

$$H_t = \left(\frac{N_t}{N_p}\right)^2 * \frac{H_{bep}}{\eta_{maz}^{1.2}}$$

Where:

H_t = The head of the turbine at best efficiency point

N_t = The turbine running speed

N_p = The rated pump speed

H_{bep} = The pumps Head at the best efficiency point

η_{max} = The pumps maximum efficiency

The mathematical relationship was found to be relatively accurate but may vary under operation conditions. All calculations which were made were based on the data sheets available by the pump manufacturer. The paper stated that if the selection of a pump as a turbine was completed according to the guidelines of the paper, then the generation system is plausible and theoretically successful. These formulas are a basis for calculating PAT characteristics and are used later in the dissertation (Williams, 1995).

When ensuring accuracy of mathematical relationships within papers it was noted that each source had completed an experimental verification. To ensure accurate results were maintained within this dissertation an experimental test was completed.

2.7.4 Experimental Setup

An accurate experimental setup of a centrifugal pump as a turbine test was completed in 2007 by Derakhshan and Nourbakhsh. Their test procedure as seen in Figure 12 was to simulate a flow rate and head by using a normal operational pump and circulating water through a centrifugal pump in reverse and collecting data.

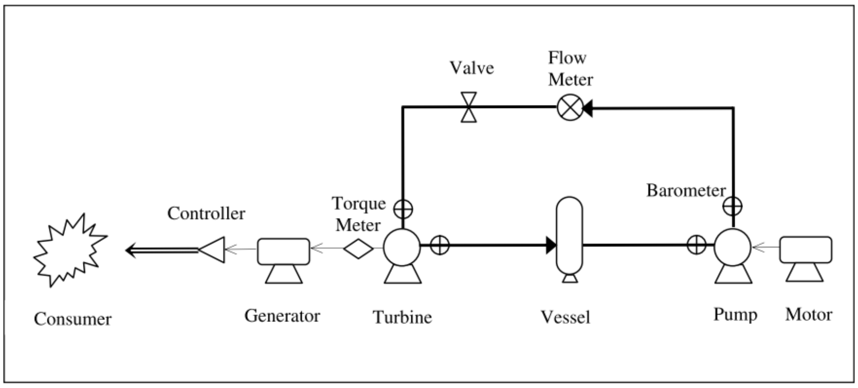
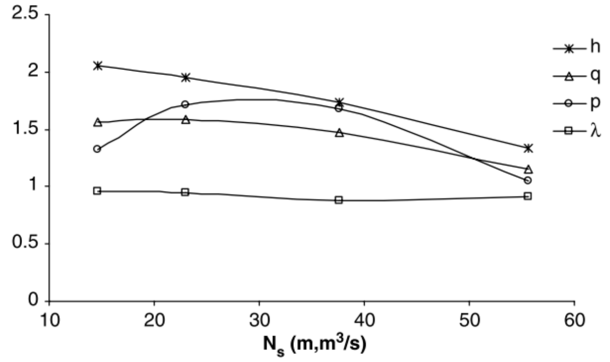


Figure 12Test Experiment (Derakhshan, Anourbakhsh, 2007)

The experiment was completed at multiple speeds (750, 1000, 1500, 3000 rpm) and many dimensionless data points were plotted with the recorded data. The experiment proved successful and showed that low specific speed centrifugal pumps operated at different rpm without any mechanical problems. This meant that smaller size pumps could operate with a large variety of head and flow rates (Derakhshan, Anourbakhsh, 2007).



$$h = \frac{H_{tb}}{H_{pb}},$$

$$q = \frac{Q_{tb}}{Q_{pb}},$$

$$p = \frac{P_{tb}}{P_{pb}},$$

$$\lambda \frac{\eta_{t\,max}}{\eta_{p\,max}}.$$

Figure 13Dimensionless BEP of tested PATs (Derakhshan, Anourbakhsh, 2007)

Figure 13 shows the dimensionless results plotted variables with the specific speed. The results confirm that the application of a PAT is possible and that there are many varying conditions that affect the Best efficiency point of a turbine (Derakhshan, Anourbakhsh, 2007). To verify the finding of this dissertation and to support the mathematics used for the results an experiment has been conducted with a prototype centrifugal pump. More detail of the prototype is in chapter four.

Chapter three explains the methodologies, timelines and resources for the dissertation. Two major components were followed: appropriate project research and theoretical analysis, together with physical testing and practical implementation.

Chapter 3

3.1 Methodologies, Timelines and Resources

To complete this dissertation to an appropriate professional level, resources, deadlines and ways of methodology must be defined. By doing so, it will ensure that each component within this dissertation is completed with appropriate time and attention. It will also ensure that no time was wasted on topics that could be seen as irrelevant or outside of the required scope of this project. Important components or milestones of the topic will be analysed and time restrictions was set accordingly. Hence, a plan of action must always be devised in case of tasks not being completed on time due to unforseen conditions that could hinder the progress. Refer to chapter one and appendix E to review resources required and deadlines set.

3.1.1 Methodology

Methodology is the way in which the project is be undertaken and what steps will be required. By understanding methodology and strategy a plan of action can be created and executed. This allows progress to be taken in the project and still be able to see if the required work is remaining within the scope that was set out in the project aim. Within this project there are two major components:

1. Appropriate project research and theoretical analysis.
2. Physical testing and practical implementation.

Hence, by following the two major components, it minimises the risk of a lack of understanding within the dissertation and as a result improves the quality of the dissertation. The following outlines the method for the project

3.1.2 Research

Previous literature and methods that have been sourced must be researched and analysed. By doing so, this will help ensure that any future progress has not already been completed or is irrelevant. Research also will give a better understanding of the project and as a result will improve the analysed approach and will result in a better dissertation. Broad and specific researching must be used. This approach of research into the topic will make the dissertation more accurate and professional. The research and literature review can be found in chapter two.

3.1.3 Analysed Approach

Once research has been completed and a strong understanding of the topic is apparent, an analysed approach can be devised. Thus, this will ensure that what is to be executed is all still within the scope of the project and will help to minimise time wasted on irrelevant sections.

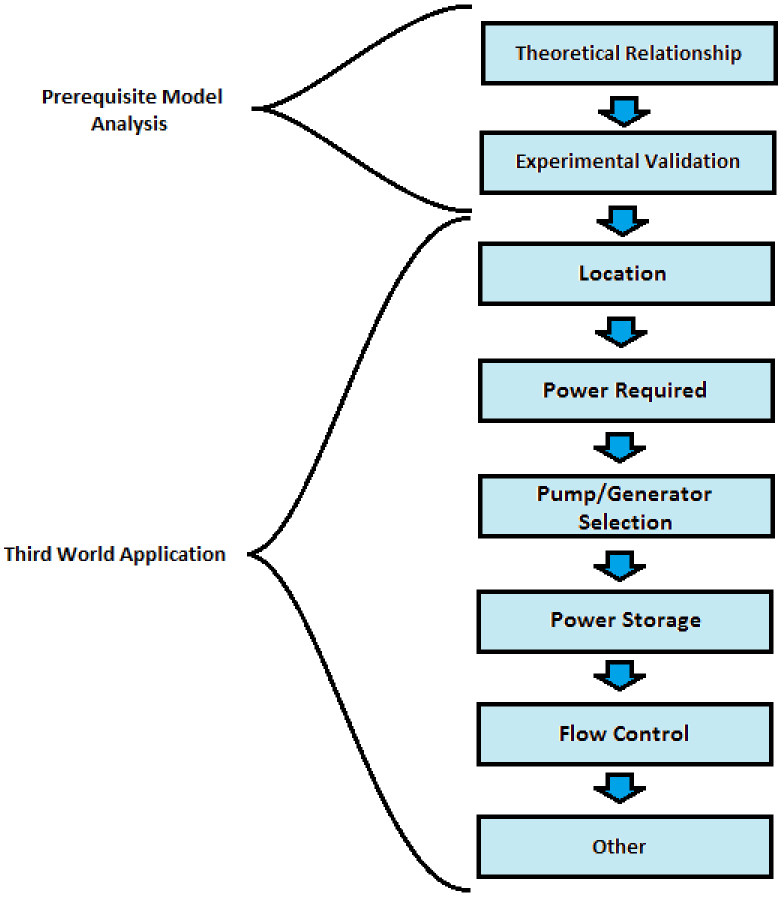


Figure 14Analysis Approach

Figure 14 shows the analysed approach that is used in this dissertation to ensure that the scope is met and to ensure that all appropriate aspects of the project are researched, designed and validated.The Progress map is broken down into two main groups:

- Prerequisite Model Analysis
- Third World Application

3.1.4 Resources

Acquiring resources can often take a long period of time depending on the importance and the original location. To ensure that there was no time wasted over the duration of this project all resources were to be identified early. The resources required would have time frames and deadlines stated to ensure the overall methodology was followed.

The following resources were required:

3.1.4.1 High Volume Centrifugal Pump

This project was based on the operation of a centrifugal pump as a turbine. For the tested prototype a Southern Cross50x32-160 pump, Serial Number 54477 with direct coupling was used. It was connected up to the water system in the Hydraulic labs to simulate head and flow rate. The mechanical operation of the pump was of a responsible manner and all of the operation manuals were to be followed when under normal operation. The operations manual for the Southern Cross 50 x 32-160 model can be found in appendix B.

3.1.4.2 1kW Single phase generator (Prototype)

The single phase 933Watt generator was connected directly to the coupling of the centrifugal pump. Figure 1 shows the centrifugal pump, coupled straight to the Direct Circuit permanent magnet motor. (Southern Cross pump and DC motor sources directly from the University of Southern Queensland).

Figure 15 Hydroelectric Generator Prototype

3.1.4.3 Access to the Hydraulic Labs

The Hydraulic labs located on the NE end of z Block at USQ Toowoomba, was needed to complete testing of the PAT generator system. Access to this resource also included operation of the 15m head tanks and equipment contained in the lab. Appropriate risk assessments for the laboratory use were completed and they can be found in appendix D.

3.1.4.4 Piping and connections (Flanges)

To connect the PAT to the pumping system located in the lab the correct connection was required. The centrifugal pump should have been able to be connected up to the lab system and have sufficient flow. All plumbing were sourced externally to ensure quality under operation.

3.1.4.5 Flow and Torque Meters

To record all findings in detail, the flow of the water at all times should have been able to be recorded. To measure the rotational energy of the centrifugal pumps a torque meter may have been required. It is possible to calculate the torque using calculation but to avoid human error a meter is preferred.

3.1.5 Prerequisite Model Analysis

Prerequisite Model Analysis contains the theoretical relationship and the experimental validation. This section of the dissertation is to be completed before any application to the site could be made. Consequently, this ensures that applied analysis of the site is based on validate mathematical relationships.

3.1.5.1 Theoretical Relationship

The modified mathematical relationships from chapter two must be analysed and applied to the PAT application. Any modifications made to the calculations are noted and justified.

3.1.5.2 Experimental Validation

Before the mathematics could be applied to the site in Papua New Guinea, it must first be validated and the errors must be plotted. This ensures that the results of the project are based on validated evidence. As a result, this improves the accuracy and overall quality of the dissertation.

3.1.6 Third World Application

Once the mathematical background is deemed acceptable, it then can be applied to the site in Papua New Guinea. By following the structure, it ensures that the work applied is completed efficiently and that no sections of the hydroelectric system are missed.

3.1.6.1 Location

This section looks into the specifics of the particular location. The available resources, terrain, population and environmental conditions are looked at in great depth.All environmental conditions must be analysed for the particular location and the hydro electric generator must be designed accordingly. This gives the design of the PAT a base condition and a limitation to operate under. The pump as a turbine must always meet the requirement of the location.

3.1.6.2 Power Required

The power requirement for the small hospital room must be specified. The equipment to be powered and its use must be justified. All equipment must be up to date and be expected to be found in such locations. This section also takes into consideration the transport of the power to specific locations and its losses.

3.1.6.3 Pump and Generator Selection

This section is of extreme importance for the dissertation. If the mathematical relationship is not accurate and not completed in a professional manner, then the whole basis of the dissertation will be incorrect. In order to produce to specific power requirements, an appropriate generator and pump must be used. A cost effective and efficient relationship between the two components must be found. In this section, three main components will be analysed and a justified relationship will be found.

1. Pump as a turbine relationship (PAT)
2. Power Generation and power produced from the flowing water
3. Cost/power production efficiency

3.1.6.4 Power Storage

This section of the design examines whether the power produced needs to be stored to meet peak power use or if it can operate under the maximum load at all times. It also investigates if the power produced needs to be converted from AC to DC. This will be based on generator selection which is also covered in this section. An automatic voltage regulator system will also be studied in more detail. The power storage and output must allow operation of regular appliances. Furthermore, an automated power regulation component will also accommodate for operation error.

3.1.6.5 Flow Control

In order to control the power generation the simplest way is to control the flow. Where the control system is put in place and how it is controlled will be discussed in more detail. All head losses must be accounted for.

3.1.6.6 Other

This section allows room for any unexpected areas of interest. By doing so the methodology does not limit the project to one specific analysis. It also contains the piping analysis for the project.

3.2 Analytical and Experimental Analysis

Before the system can be designed, the mathematical relationship between a centrifugal pump operating under normal conditions and as a turbine must be found and analysed. When a centrifugal pump is run backwards it operates at a lower efficiency and as a result lowers the power production capability. This percentage is to be calculated and applied mathematically to the specific pumps chosen. Therefore, the mathematical relationship must be validated to prove accurate in order to be used for the project's scope.

To validate the theoretical calculations made, an experiment was conducted on a hydroelectric generator using a centrifugal pump as a turbine. The generator system was built specifically for the purpose of this experiment only. The power production under the head and flow rate was not the specific scope of the experiment but the rpm, torque, flow rate and head were closely monitored and compared to the theoretical calculations. This is discussed in great detail in chapter four.

3.2.1 Selecting the PAT

As an understanding of the performance curves for pumps as turbines is comprehended, the mathematical relationship can now be analysed showing how to select the appropriate pump model to operate as a turbine.

When selecting the site, it is limited to a particular head and flow rate and often the minimal value would be selected, for example, the minimal flow rate throughout the entire year. By doing so, the designed hydro electric generator would operate at its maximum efficiency annually. This section examines the calculations required to select the best pump to operate under the particular conditions

The calculations can give the running conditions in terms of head and flow. They also show how to plot the efficiency of a PAT when the running conditions change and how the torque from the load can affect the operating capabilities of the generator. Thus, all of these factors must be taken into consideration when selecting the appropriate pump model.

Chapter four investigates the mathematical and experimental aspects of using a centrifugal pump as a turbine.

Chapter 4

4.1 Prerequisite Modal Analysis

This chapter contains the investigation into the mathematical and experimental aspects of using a centrifugal pump as a turbine. It discusses the applied mathematics found in chapter two and the relationships that have not been analysed in past papers. By doing so, it allows this dissertation to be an improvement on previous analysis. It also discusses the experimental process using the built prototype to validate the findings.

4.2 Theoretical Relationship

In reviewing past papers it was found that the most predominant and accurate relationship between PAT operation and normal operation was by Williams (as discussed in chapter two) who produced a paper called 'Pumps as turbines, A users guide' in 1992. This paper discussed how to select a pump according to the available head (H) and flow rate (Q). Williams discussed how pumps and PAT's both have BEP operating points.

Equation 6Turbine Flow Rate

$$Q_t = \frac{N_t}{N_p} * \frac{Q_{bep}}{\eta_{maz}^{0.8}}$$

Where:

Q_t = The flow rate of the turbine at best efficiency point

N_t = The turbine running speed

N_p = The rated pump speed

Q_{bep} = The pumps flow rate at the best efficiency point

η_{max} = The pumps maximum efficiency

Equation 6 demonstrates that the flow rate of the turbine equals the ratio of the speed of the turbine and the pump multiplied by the flow rate of the pump under normal operation divided by the pumps efficiency. Equation 6can be used to find the required flow rate to operate the PAT at its BEP.

Equation 7 Turbine Head

$$H_t = \left(\frac{N_t}{N_p}\right)^2 * \frac{H_{bep}}{\eta_{maz}^{1.2}}$$

H_t = The head of the turbine at best efficiency point

N_t = The turbine running speed

N_p = The rated pump speed

H_{bep} = The pumps Head at the best efficiency point

η_{max} = The pumps maximum efficiency

Equation 7 gives the head required to have the PAT operate at the best efficiency point. By using the two calculations with the given data of the pump it can deduce if the PAT will operate efficiently for the specific location conditions (Head and Flow rate). These formulas can be rearranged to show the characteristics if you use a PAT far off its best efficiency points.

If the operation speed of the pump as a turbine is known, then the above equations can be used with data easily accessible from the pump manufacturing company. To find the RPM required by the PAT the power generation must be briefly examined.

4.2.1 Power Generation

By knowing the generation rpm it can be used as a bench mark for the PAT to operate. In chapter five under power required, the generator size in discussed in detail.

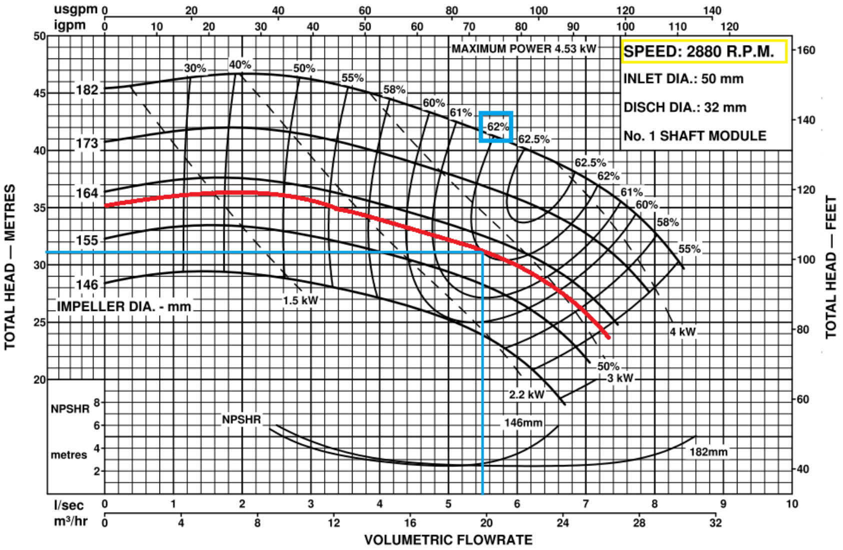
4.2.2 Calculations at 15m

To allow validation, the theoretical calculations at the 15m head must be calculated. Knowing that the pump as a turbine operates at 1410 RPM when the system is completely open, is the starting rpm value.

4.3 First Test

Matlab 2013 was used to simulate the head (H) and Flow rates (Q). In Figure 16 the underlined sections are where the different operation specs for the pump were put in. Using the data tables sourced from the pumps manufacturers, the data spec sheet shown in figure 16 below highlights the chosen pumps best efficiency points under normal operation. Documents are also attached in appendix B.

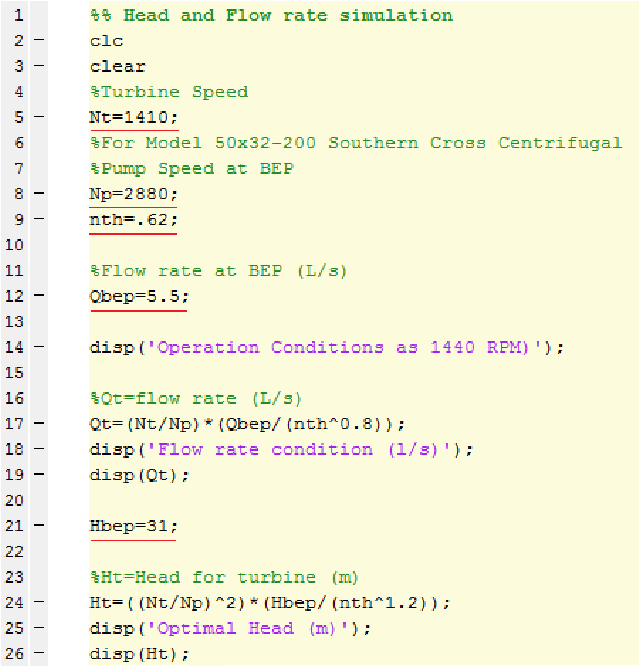
Knowing the pumps nominal diameter of 6.375 inch or 162mm the red performance line was used. It can be seen that at 2880 RPM the pump can operate at a maximum efficiency of 62% with a head flow of 31 meter and a flow rate of 5.5 L/second.



Performance to AS2417 Grade 2 for clean, cold water only.

Figure 16 50-32-160 performance data

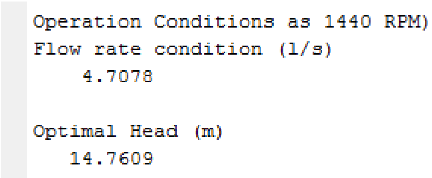
To compare to the experimental prototype, the maximum RPM gained from the experiment was plugged into the Matlab program. This RPM is the speed that the turbine operated at in the experiment. More detail on the experiment is further in this chapter. By doing so, the code then calculates what flow and head is required to reach that speed. If the mathematical relationship is correct then the head and flow rate for both the experiment and code should be similar. The head and flow rate to reach the 62% maximum efficiency was used.



```
%% Head and Flow rate simulation
clc
clear
%Turbine Speed
Nt=1410;
%For Model 50x32-200 Southern Cross Centrifugal
%Pump Speed at BEP
Np=2880;
nth=.62;

%Flow rate at BEP (L/s)
Qbep=5.5;

disp('Operation Conditions as 1440 RPM)');

%Qt=flow rate (L/s)
Qt=(Nt/Np)*(Qbep/(nth^0.8));
disp('Flow rate condition (l/s)');
disp(Qt);

Hbep=31;

%Ht=Head for turbine (m)
Ht=((Nt/Np)^2)*(Hbep/(nth^1.2));
disp('Optimal Head (m)');
disp(Ht);
```

Figure 17Simulation Code for Prototype Pump

The code shown in figure 17 output for the following conditions in figure 18:



```
Operation Conditions as 1440 RPM)
Flow rate condition (l/s)
    4.7078

Optimal Head (m)
   14.7609
```

Figure 18Matlab Output

This code was then run for a total of three times at the following different turbine RPM’s:

- 1410 RPM
- 1000 RPM
- 700 RPM

The results from the simulation are plotted further, under section 4.8.1.

4.4 Pump as a Turbine Prototype

This chapter contains the testing of the prototype that was purpose built for this dissertation. Before analysis can begin, the mathematical relationships described in chapter two must be validated. If not, the results and system design would prove to be inaccurate and deem this dissertation invalid. This chapter describes the testing set up based on previous prototypes and shows the overall results of how the mathematics are accurate and viable. All testing was completed at the University Of Southern Queensland (USQ) under the guidance and supervision of Malcolm Gillies and Les Bowetell.

4.5 Previous Prototypes and Experiments

The mathematics can be validated by either a physical experiment or through computation analysis such as a model created in Ansys. Both forms of experimental validation have been described in previous research on PAT’s. It was found that although computational modelling analysis is very accurate in ideal situations, when applied to real life scenarios it was found that errors occurred due to real life imperfections (Rawel and Kshirsager, 2007). Due to this finding, a physical testing is the most accurate way to validate the mathematical relationships of a pump as a turbine.

In previous prototypes (described in chapter two) a complete setup of a mini hydro power plant had been installed. The systems contained the three basic components of a hydro plant:

- Pump as a turbine
- Generator (Power Production)
- Flow Control

In these previous studies, to simulate the head (H) and flow rate (Q) the system was connected up to another separate pump. This separate pump was able to change speed and as a result was able to simulate multiple heights. The pump as a turbine was a centrifugal pump driving an alternating current permanent magnet motor. The flow control was achieved using a series of valves and barometer to ensure accurate readings. The specific type of centrifugal pump used was not specified and as a result the mathematical relationship in this dissertation could not be validated without a relative error.

4.6 Resources Available

The prototype can only be designed to the limitation of the resources on hand. The goal of the prototype is to validate mathematical relationships whilst remaining in the budget of the dissertation. The USQ’s hydraulics labs have a 15m head tank that can produce a flow rate up to 17m/s. The system flows through a 10 inch piping system before it is reduced down to 2 inch gate valve. The tank is hooked up to a recirculating system that pumps the water back into the 15m head tank. This allows testing to be completed without a time restraint due to lack of water.

4.7 Prototype

The prototype was built to contain the three main components used in previous testing. It had to produce power from the potential energy of water available at the USQ hydraulic lab. The design schematics of the prototype are shown in figure 19.

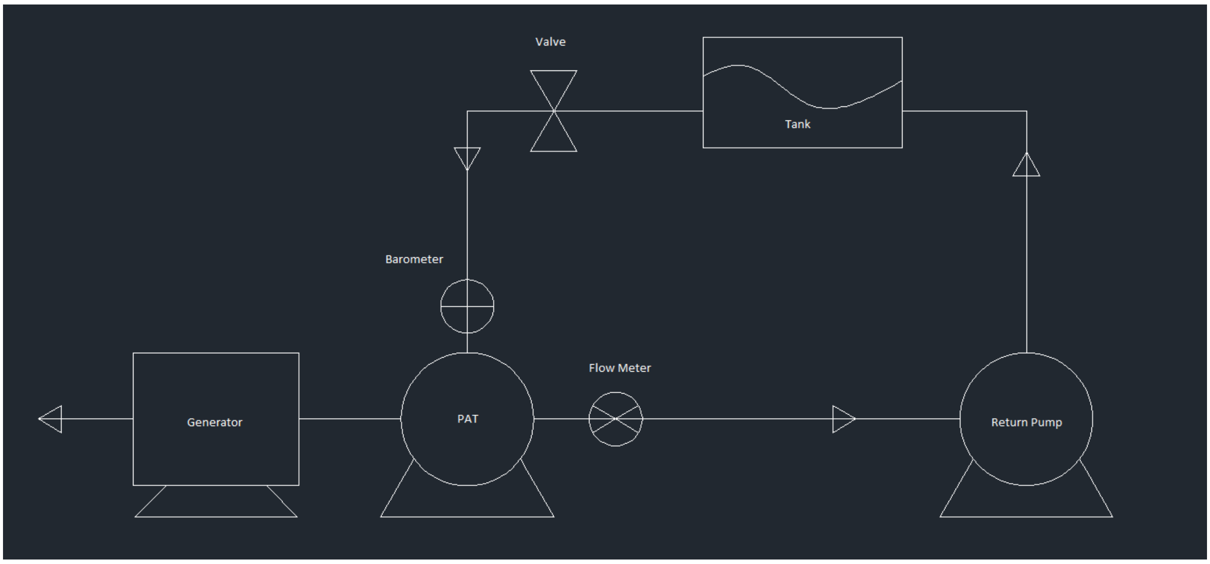


Figure 19Prototype Schematics

The prototype was then built from available resources. It contained;

- Southern Cross Centrifugal Pump (Model 50-32-160) Sourced from USQ's hydraulics lab
- 1.25hp Direct Current permanent magnet motor (Honeywell)
- Plumbing connections
- Bourdon Gauge
- Flow Meter (Model Elster Q4000 EM flow meter)
- Taco meter

The Pump as a turbine was directly coupled to the permanent magnet motor and appropriate guards were built to ensure safety during testing. A 1 meter length of 1 inch piping was used to connect the control valve to the PAT system. It is to be noted that the inlet of the pump is 32mm. This reduction smaller then the inlet to the pipe is not optimal as it causes a head loss and increase in turbulence. Figure 20 shows the built prototype with the appropriate guards and pressure meters.

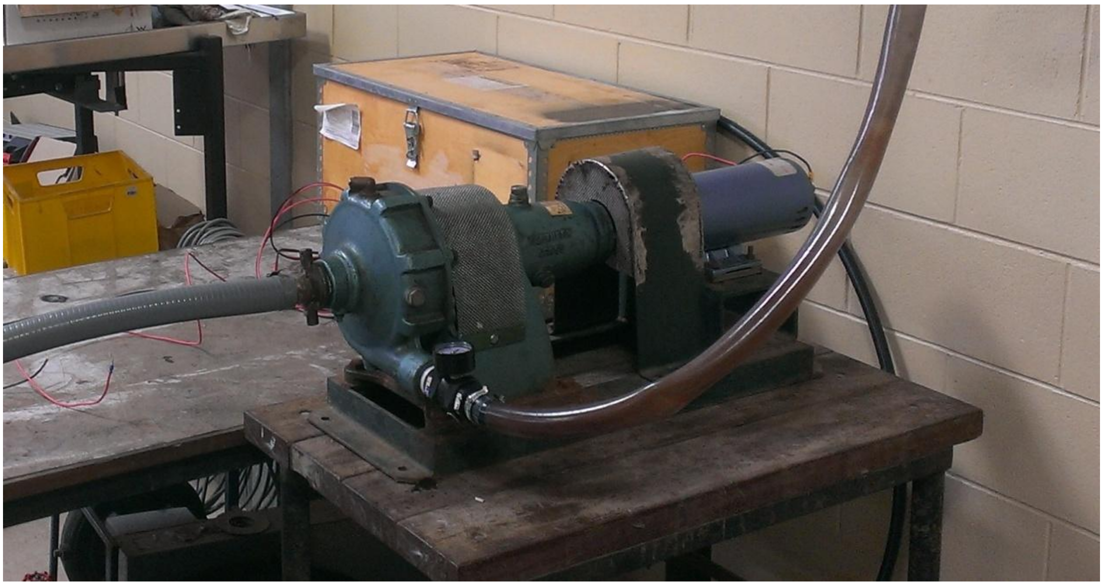


Figure 20 Prototype PAT Generator

The pump (50-32-160) used a prototype which had a nominal impellor diameter of 6.375 inches or 161.93mm (figure 20). Using the data gathered off the pump, the specification data sheet was sourced from the manufacturers Southern Cross. This data is used in section B to gain a simulation result based on the specific pump model.

4.7.1 Load Simulation

In order for the hydroelectric generator to simulate usage in a real life application, a simulation load must be applied. This was done by using a wind resistor with a volt and amp meter. As the wind resistor was wound up, it increased the resistance in the circuit and as a result, increased the simulated load.

This relationship is based on the fundamentals of electrical principles:

$$V = IR$$

Where:

V = Volts (V)

I = Current (Amps)

R = Resistance (ohms)

Figure 21 shows the Volt meter, Amp meter and wind resistor connected to the system.

Before the prototype was tested the appropriate risk assessments and safety procedures were followed. The risk assessments are attached in appendix D. It was ensured that appropriate PPE equipment was worn at all times and the appropriate supervisors were privy to the knowledge of my testing procedure.

4.7.2 Testing procedure

The prototype was then connected up to the water system at USQ. Figure 21 shows the general layout of the testing system in more detail.

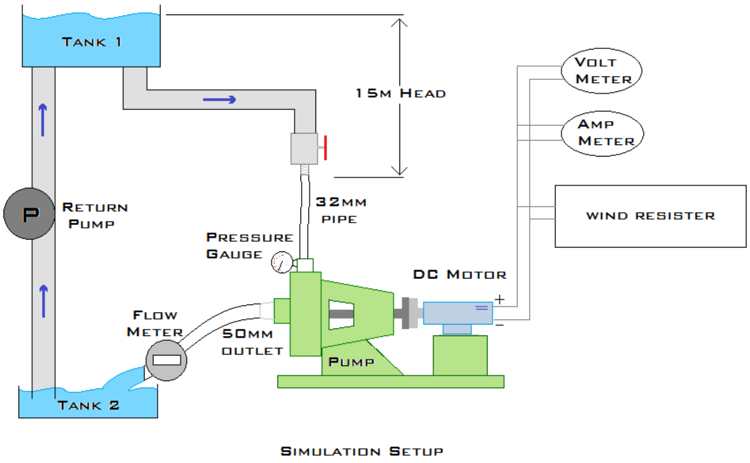


Figure 21 Experimental Setup

4.8 Test One

The first test is to compare to the mathematical results at a15 meters head.

1. The prototype was set up for the experiment. The Southern Cross pump prototype was connected up to the 15 meter head water system using a one meter length of 1 inch plastic piping. At the inlet of the PAT was a 15kpa pressure gauge to measure the dynamic pressures. The inlet had an expansion in diameter from 1 inch to $1\frac{1}{4}$ inch. This expansion was noted due to its effect on head. The outlet is than connected up to a flow meter. The water then is allowed to flow into the hydraulic labs drainage system.
   The permanent magnet motor is connected up to the wind resistor, volte and amp meter.
2. The water valve was opened completely to reach maximum RPM. No load was applied. Using the correct equipment, the following was recorded at maximum speed:
   - Rotations per minute (RPM)
   - Flow Rate (m^3/hr)
   - Pressure (Pa)
3. The test was completed 3 times at different RPM (1410,1000,700)

4.8.1 Results

Table 1 Test one results

RPM		**Prototype**
1410	Head (m)	14.7
	Flow Rate (l/s)	4.1
1000	Head (m)	7.8
	Flow Rate (l/s)	2.8
700	Head (m)	4.2
	Flow Rate (l/s)	1.9

4.9 Testing Validation Results and Discussion

4.9.1 Test One

After plotting the results of the theoretical vs. the experimental, it can be seen from figure 22 and table 5 below, that the results are similar. It can be seen that the error percentage is increased as the pump operates at a slower RPM. This is because the further the pump operates away from is best efficiency the larger error value.

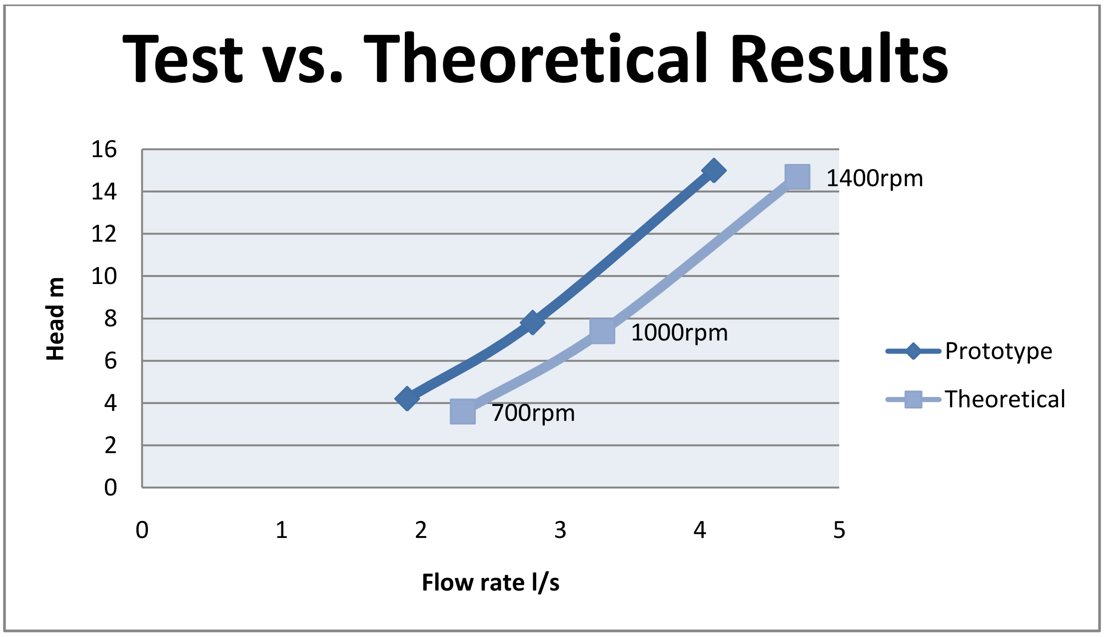


Figure 22Test vs. Theoretical

Table 2 Error between theoretical and experiment

RPM		Prototype	Theoretical	Error %
1410	Head (m)	15	14.7	2
	Flow Rate (l/s)	4.1	4.7	12.8
1000	Head (m)	7.8	7.4	5.1
	Flow Rate (l/s)	2.8	3.3	15.2
700	Head (m)	4.2	3.6	14.3
	Flow Rate (l/s)	1.9	2.2	17.4

It can be seen from the results that the prototype operates at a higher head and a lower flow rate is achieved. This is due to the imperfections within the pump and the system (hosing reductions and expansions). When the pump was sourced from USQ it was not in peak condition. It had rusted and ceased due to no maintenance. Although the pump was restored to an operational condition, in real life BEP would be lower than the data sheet stated from the manufacturer due to the wear of the pump.

Chapter five explains the step by step process on how each component of the hydroelectric system was chosen. It also justifies this process by implementing the methodology previously in chapter three.

Chapter 5

This chapter covers the details of the hydroelectric pump system and shows the implementation of the project at the selected location. Within this chapter, there is a step by step process on how each component of the hydroelectric system was chosen and justified by implementing the methodology in chapter three.

5.1 Location

The location chosen for the hydroelectric generator is positioned in the highlands of Papua New Guinea. The location was chosen for its ideal conditions for rainfall and a need for electricity generation in remote locations, as discussed earlier in chapter two.

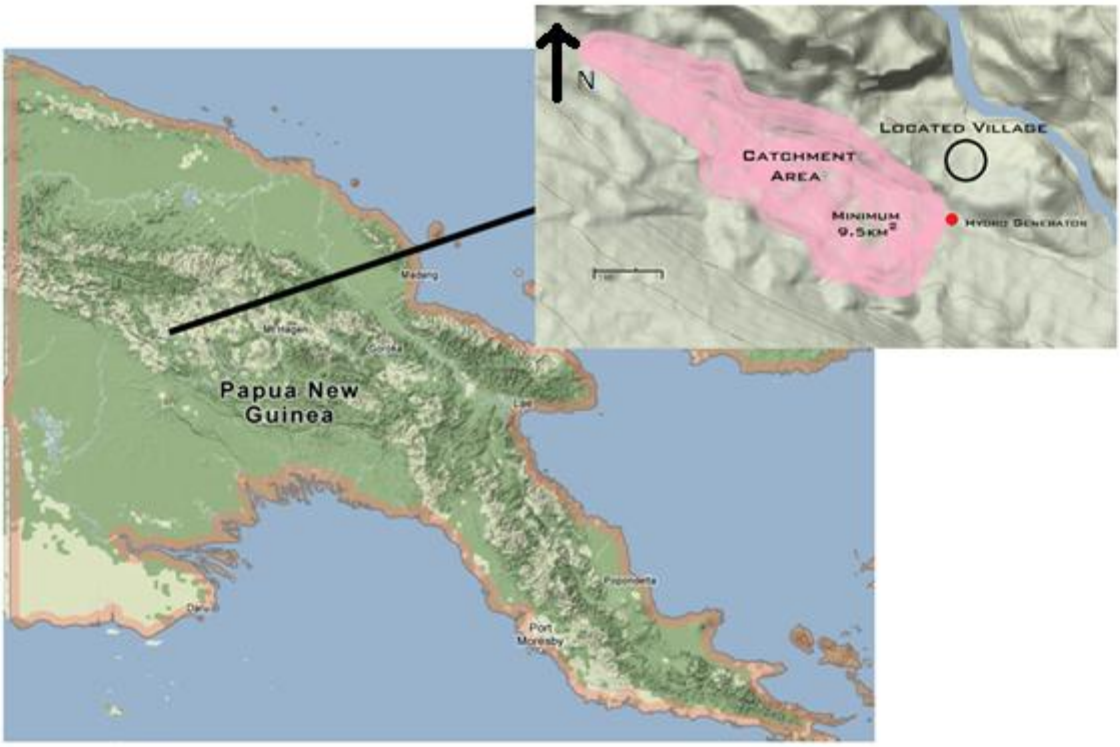


Figure 23Site Location

The location is a small creek that flows into the Tagari River. Using Google maps and terrain analysis, it was acceptable to assume that the catchment area was around 9.5km^2 minimum. A smaller catchment area was used because this gave room for improvement to be made if required. The pink in figure 23 shows the plotted area.

The pink area has an average incline of 12 degrees. This angle allows water flow to be at a high rate in such a short distance and it will also help to minimise material costs when considering the pipe selection.

5.1.1 General Geographical analysis

Creek gradient - 12^0

South-west gradient - 11^0

North-east gradient - 11^0

It can be seen from figure 23 that a hypothetical village has been positioned on the crest of the hill to the north east of the catchment area. By doing so it allowed a physical goal to be reached by the end of the dissertation. Ways of power transmission are looked into further in this chapter and are discussed in detail.

The Highlands of Papua New Guineas have a rich soil and are covered in a thick natural shrubbery. Due to the incline of the location, minimum soil damage must occur when installation is being carried out. This is to avoid possible soil erosion and future landslides which could the damage system completely.

Due to Papua New Guinea’s unpredictable weather, the system must be installed with the consideration of:

- Flooding – It must be positioned so if it floods no damage would occur
- Can be accessed relatively easily
- Ease of installation

Before the system design could begin the expected water flow rate had to be calculated. The most commonly used methods to determine peak discharge is the rational method and Manning’s kinematic process. These two methods have the ability to calculate the ground absorption rate and predict the flow rate from the catchment area.

The rational method is:

$$Q = (C) * (i) * (A)$$

Where:

$Q =$ Peak rate of runoff in cubic feet per second (cbs)

$C =$ Runoff coefficient (dimensionless unit)

$i =$ Average intensity of rainfall in inches per hour (in/hr)

$A =$ The catchment area in acres (ac)

The units in the formula were kept in imperial until a final solution was calculated. This was because the tables and graphs which were used to find values, were in imperial measure.

5.1.2 Area

The first step to calculating the runoff was to determine the area (A). The information used in drainage area was:

- The land use – The highlands are not used for anything in particular due to the remote location and difficult access. The thick natural coverage is taken into consideration.
- The soil in the highlands has been recorded as clay like soil. This influences the run off coefficient.
- The incline of 12degree on average is taken into consideration.

Using simple geometry the catchment area in figure 24 was calculated to be a minimum 9.5km^2.

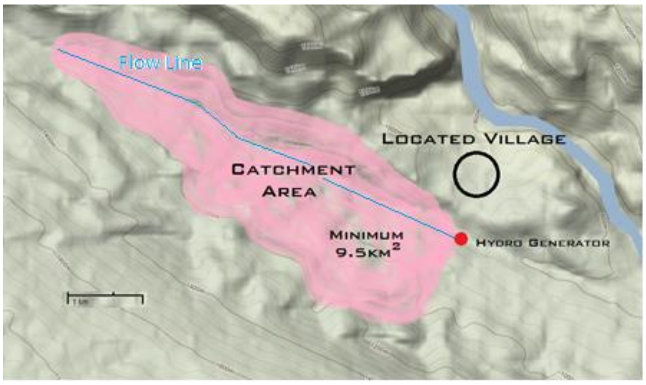


Figure 24Catchment Area

5.1.3 Runoff Coefficient

The next process was in finding the flow rate, this was to find the runoff coefficient. The runoff coefficient is a dimensionless decimal value that is used to represent the runoff to rainfall ratio. It takes into consideration the predicted infiltration, evaporation and ground storage. Using Table F in the appendix it was found that:

Steep woodlands with sandy soil C = 0.25

5.1.4 Rainfall Intensity

The rainfall intensity (Tc) was then calculated in minutes using the rational formula involving three factors:

- Average rainfall occurrence
- Intensity and duration of the selected rainfall occurrence
- The average rainfall intensity time Tc (time concentration)

Tc is found using the Manning's kinematic process. This process allowed the time for the water to run off the catchment area to be calculated. This method took into consideration the slope, soil composition and natural shrubbery. The time concentration was found using the following equation:

$$Tc = \frac{0.007(nL)^{0.8}}{(P_2)^{0.5} * (S)^{0.4}}$$

Where:

n =Mannings roughness coefficient

L =Length of flow line (Ft)

S = Given Slope (decimal value)

P_2 = 24hr Rainfall average (inches)

The calculated Tc (30hrs) value was then used with ‘Rainfall Intensity Factor – Frequency duration chart’ in appendix F. Using the table was 0.25 inches per hour every 24hrs. $P_2$was found using the Papua New Guinea Initial Communication – Under the united Nations Framework Convention on Climate Change report (2000).

5.2 Peak Discharge

With the found values, the peak discharge was then calculated using the rational method.

$$Q = (C) * (i) * (A)$$

$$Q = (0.25) * (0.1) * (2347.5)$$

$$Q = 58.68cbs = 1.67m^3/s$$

Therefore, using the rational method it was found that the average peak discharge would be approximately 1.67 m^3/s. This flow rate is expected under the weather conditions of Papua New Guinea and considering the size of such a large catchment area.

With such a large flow rate it allows more room in the pump selection process. The available head is quite large but due to observation of the location it is seen that the incline of the catchment area drastically climbs approximately at the 50m head point. Due to this geographical limit the head available will only be 40m. If 40m did not prove to be a sufficient head then the hydroelectric system could have been moved down stream, but by doing so, it increases the flooding and moves the system further away from the village.

5.3 Power Required

As stated earlier in the dissertation (chapter one) the PAT hydroelectric generator is required to power a small hospital room that was position in the centre of the local Papua New Guinea village discussed in 5.1 Location. The hospital room consist of:

- 1 Bar Refrigerator to be used for medical storage
- 5 lights
- 1 Ceiling Fan

To approximate the power required to run each appliance, an average of six across each appliance is taken. Due to the remote location of the site it is viable to assume that the appliance is not top of the line and the equipment could have a high power draw.

5.3.1 Type of Generator

The type of generation system greatly affects the performance of the hydroelectric generation capability. There are two types of generator:

- Alternating Current (AC)
- Direct Current (DC)

Alternating current generators are more commonly used when an electrical grid fails. Nearly all everyday appliances are powered by AC. AC generators must be able to operate at a constant speed to produce a stable AC. If they are overloaded the system will shut down. An automatic frequency regulator is used to ensure that the current does not become unstable.

Direct Current generators produce a smooth supply directly into batteries or inverters where they can then be turned into AC. DC generators are not reliant on speed regulation. As most appliances operate on AC, DC generators require conversion. This can be avoided by using DC powered appliances.

Table 3Advantages and disadvantages of AC

Advantage	Disadvantage

• Transmits better over long distances than DC **• Most Appliances are AC.**	**• Any changes in RPM significantly the power quality.** **• Have a high voltage and can cause serious harm or death** **• The generator must operate at maximum speed at all time** **• Automatic frequency regulator is required**

Table 4Advantages and disadvantages of DC

Advantage	Disadvantage
• Low DC generators produce that produce less than 50 volts require minimum Safety regulation **• DC size is not important when connected to battery system.** **• RPM speed doesn't greatly affect power stability.** **• By using a storage system the generator does not have to produce the peak load**	**• Poor transmission over long distances** **• Need an inverter if required to power AC appliances.**

By analysing the advantages and disadvantages of both DC and AC generators the chosen system will be Direct Current. Due to the shortage of skilled operators, safety is the greatest importance for the system. The transmission of power is approximately 40m and losses will be minimal due to it short distance. Due to the possible irregularities in RPM from the PAT, a DC will be optimal due to its ability to handle fluctuations and speed and still produce a stable power source.

5.3.2 DC power source

In order for the system to operate at maximum efficiency the fewer components the better. Due to the system having a limited power production from the PAT it will be difficult to produce a high voltage and will have difficulty reaching peak load.

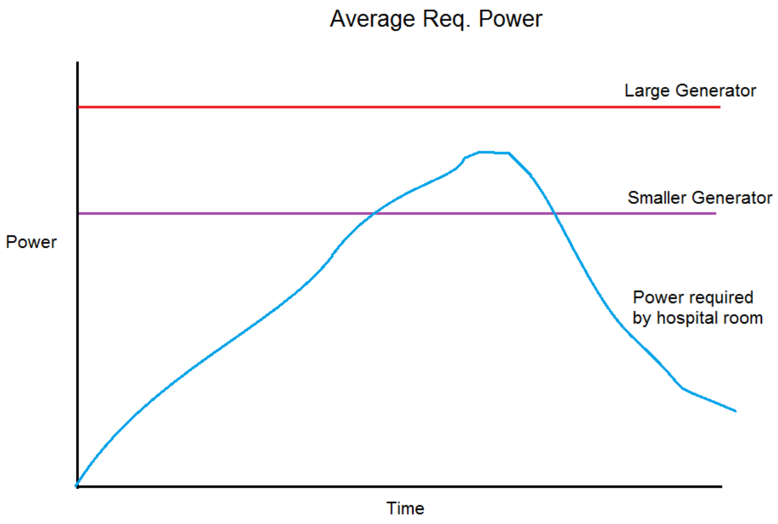


Figure 25Average power required (Burton-Ree, 2013)

By avoiding an AC inverter it allows the DC based system to operate at maximum efficiency and safety. As a result, a storage system will be used to allow the required power to be met without the generator running at peak ability as seen in figure 25. This will allow a smaller generator to be used but it limits the appliances to being DC.

Table 5 DC Storage system advantage and disadvantages

Advantage	Disadvantage
• Smaller Generator required • Less component's in the system, resulting in less losses overall • Generator is not required to run at peak • Low maintenance • Safe for operation	• Only DC powered appliances can be used • The batteries mean the overall size of the system will be increased.

The battery bank will also allow the hydroelectric system to be turned off when maintenance is required and it will still be able to power the appliances.

5.3.3 DC appliances

In order to avoid the requirement for conversion to AC current, all appliances will have to be DC. These appliances can be sourced like any regular appliance have similar power requirements and to start the motors like a regular AC motor. Often the appliance has its own DC to AC converter. The focus on the appliances is the starting period for the motor. If all components that are connected up to the system draw the maximum power simultaneously the battery bank must be able to power them.

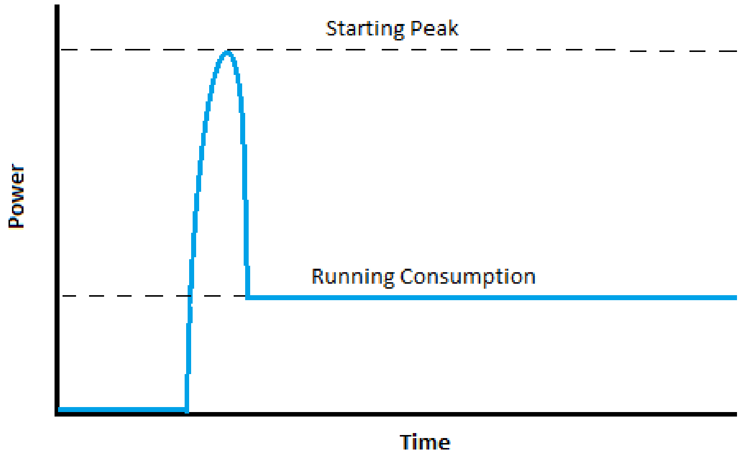


Figure 26Starting behaviour of electric motors (Burton-Ree, 2013)

It can be seen from figure 26 that the power consumption is greatest whilst the motor is starting. The maximum draw will be the total starting peaks of all the appliances.

5.3.4 Refrigerator

Research into general mobile refrigerators, the Danfoss BD-Series will be analysed. It is a common sized compressor often used for small trucks and caravan use. The model is easily capable of acting as a medicine fridge. The refrigerator is designed by Danfoss to have a long term operation life.

Refrigerator Specs:

- Can operate of a DC 12 or 24 volt

- Operates with a permanent magnet motor
- Cut in current of 6 Amps
- Resistance of 3 windings of 14.0 Ohms
- Has a peak start of 144 W

To ensure no under calculations are made, the daily energy demand is calculated using the peak. It is also assumed that the fridge operates at 24hs. The refrigerator uses 144W.

5.3.5 Lighting

Incandescent light bulbs are becoming fewer and harder to acquire. Today what can be found on the shelf is the new energy efficient fluorescent lighting. The hospital room lighting will be assumed to contain five 30w fluorescent lights. This lighting wattage is higher than what could be bought in the store but ensures room for a variety of light bulbs to be used.

The peak start up for lighting is not required as it is minimal. The lighting uses 150W.

5.3.6 Ceiling fan

One ceiling fan would be required for the room. Research into Direct Current power ceiling fans found that an average wattage of 40 watts would be required. A Regent DC motor ceiling fan will be used. The model has a 40 watt fan motor. According to AS/NZS 4509.2.2010 the surge factor for ceiling fans are rated 2.5 times the average watt rating.

Therefore the ceiling fan uses 100W.

5.4 Total power

The total power is when all the appliances are used at the one time. The system must be able to accommodate for this peak. Table 8 shows the total real power required.

Table 6Real power required (W)

Appliance	Number used	Peak Watts
Medicine Fridge	1	144
Lights	5	150
Ceiling fan	1	100
Total	7	394

5.5 Battery Sizing and Selection

When selecting batteries for stand-alone systems, they should be a type suitable for the particular operating conditions. The following factors should be considered:

- Maintenance
- Self-discharge
- Energy efficiency
- Ease and safety of installation and operation
- Size

The Australian standards of stand-alone power systems AS/NZS 4509.2.2010 specifies that the battery capacity should be chosen according to the following:

Equation 8 Calculating Battery Capacity

$$C_x = \frac{E_{tot}}{V_{dc}} * \frac{T_{aut}}{DOD_{max}}$$

Where

C_x = battery capacity, specified for an appropriate discharge rate x, (AH)

E_{tot} = Total design daily energy demand from the d.c, in watt hours (WH)

V_{dc} = Nominal Voltage of the d.c (battery voltage), in vaults (V)

T_{aut} = Number of days of autonomy (number of days to support the load without switching the generator on

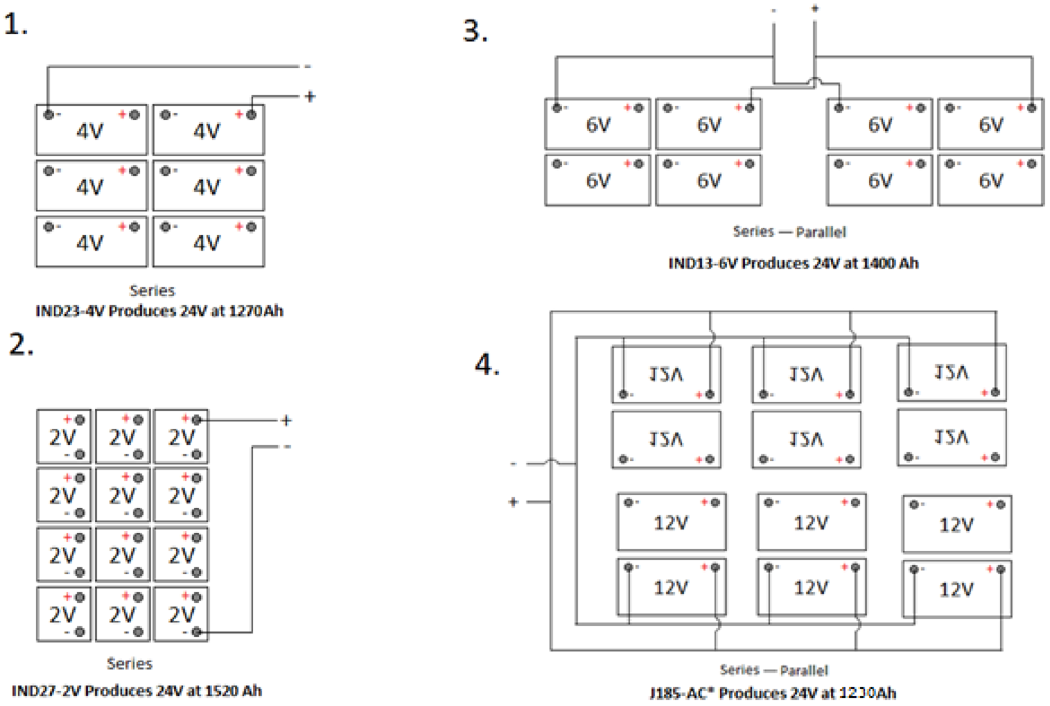
DOD_{max} = Design maximum depth of discharge of the battery, expressed as a percentage.

For selecting a suitable number of days of autonomy the AS/NZS 4509.2.2010 was used. In appendix G states that a system operating on 100% hydro generation should have autonomy of T_{aut} = 1.5.

The DC appliances are designed to operate better on 24V systems, and therefore it will operate on 24V.

Normal car batteries could be used for the system but the DOD for the cycle life is low and as a result, the AmpHr required is quite high. Car batteries have a poor efficiency when required to have large cycles applied. To avoid having a large battery bank, specially designed batteries for renewable energy will be used. There are many manufacturers of renewable energy batteries. Trojan is one of the companies who has a reliable power storage. Due to the extent of battery specification data and variety, a Trojan battery system will be used. The selected Trojan batteries have a design of 2800 cycles with a DOD of %50. Therefore, the battery capacity is 1182 Ah.

Referring to appendix XX Product specification guide for Trojan batteries there are multiple battery sizes that could accommodate. It can be seen in figure 27 that the storage system could be made up of the following battery layouts that can produce the required Volts and AmpHr to power the appliances. Due to the Australian standard of T_{aut} = 1.5 days, each must be able to produce the 36-AmpHr rate.



Series
IND23-4V Produces 24V at 1270Ah

Series
IND27-2V Produces 24V at 1520 Ah

Series — Parallel
IND13-6V Produces 24V at 1400 Ah

Series — Parallel
J185-AC* Produces 24V at 1230Ah

Figure 27Available Battery arrangements

All of the four possible arrangements can produce the requirements for the system. System 4 is advised for use for the following purposes.

- If one cell fails the system can still produce the required Amphr.
- If one battery is to fail and no more batteries are at hand a car battery can be installed for use.
- Although the batteries as a system are larger, the 12V batteries are smaller.
- If a cell was to fail it will still produce the required output.

5.5.1 Battery Charging and Selection

The Australian standards AS/NZS 4509.2.2010 state that the battery should be charged at the following rate:

$$I_{bc} = 0.1 * C_{10}$$

Where:

I_{bc} = Maximum charge current of the battery charger, in Amperes (A)

C_{10} = 10hr rate capacity of the battery, in Ampere hours (AH)

By using the C_{10} given in the product specification guide in appendix G the maximum charging rate for the selected D.C battery bank is 1129 Ah.

5.5.2 Regulator Sizing and Selection

To ensure that the generators voltage does not go over this limit a regulator is used. The function of a regulator is to control the flow of current from the generator into the batteries. Due to the deep cycle design of the Trojan batteries, a regulator with the Low Voltage feature will be used. This feature monitors the battery level and will disconnect if the voltage is so low it could cause long term damage to the batteries. This will help to ensure that the batteries have a long service life. Regulators do not require much maintenance and will only often have to be checked that corrosion has not occurred.

5.5.3 Fuse Control

The system needs to have an over current protection to ensure that damage does not occur to either the batteries or the appliances running off the system. Over current often occurs because of two main issues:

- Lightning strike
- Incorrect connections

Over current from the generator is not an issue as the regulator should stop too much current from passing. Due to the batteries floating (batteries not earthed) in the system, circuit breaker fuses will be installed at the positive and negative terminals.

5.6 Schematics

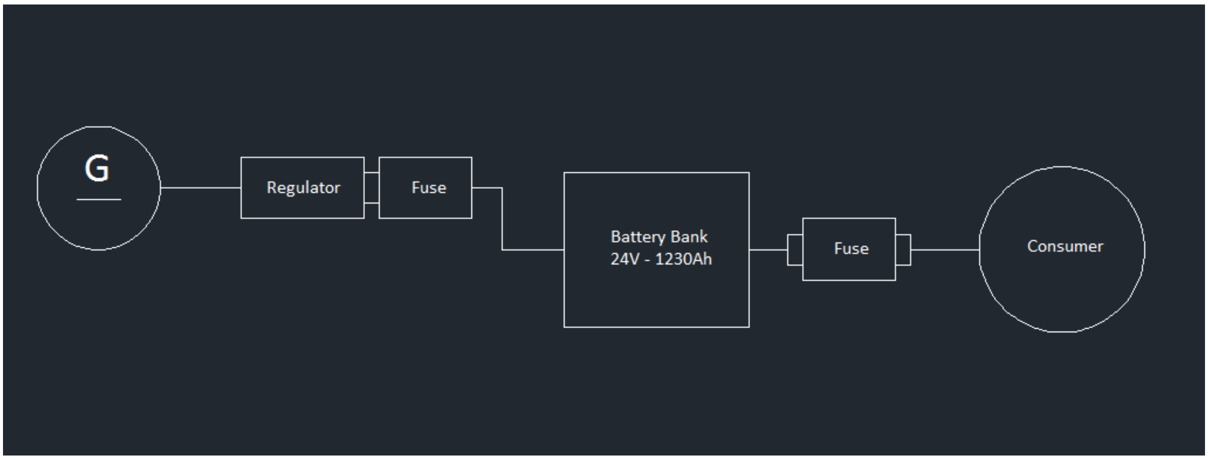


Figure 28Battery Schematics

Figure 28 displays the schematics of the D.C generator to the consumer. Fuse systems will be connected at both ends of the battery bank. By doing so, it will ensure that if either end of the system is overloaded the battery system would not be damaged.

5.7 Transmission Lines

Once the power has been produced the electricity must then be transmitted to the village. The transmission lines are required to;

- Have minimum transmission losses
- Travel across the shortest distance
- Have a high safety
- Require minimum maintenance

As seen in figure 29 the village is 800m north east of the turbine and 40 meters vertically above. To work out the transmission line distance simple trigonometry was used. On site analysis would require surveying to ensure accurate measurement. To accommodate for this error a 10% error addition factor is added on.

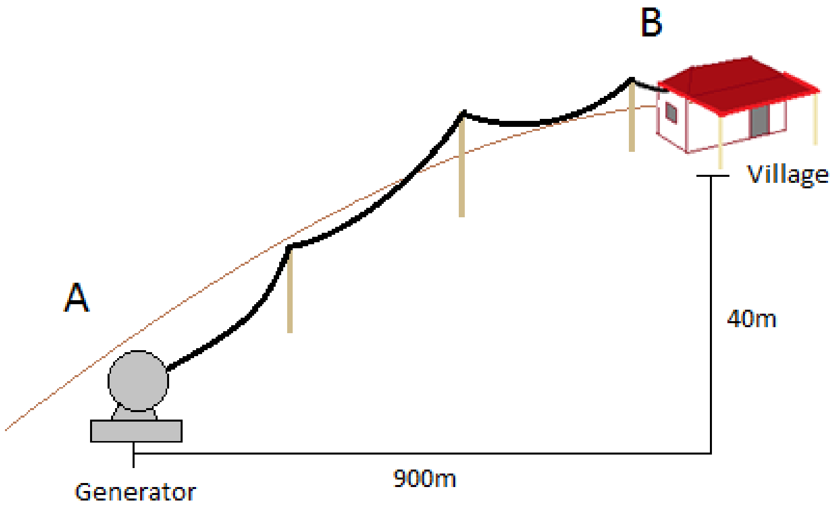


Figure 29Transmission line

The transmission line distance between A and B is calculated to be 990 meters including the 10% error addition factor. The transmission line is designed to be up on wooden polls to prolong line life and ensure that the lines do not affect the living conditions of the locals. Having them suspended will also allow the minimum distance to be taken as the lines will hang over any obstacles in the path.

5.8 Efficiency Losses

It is expected that the power system will have losses when travelling from A to B. The following factors affect the losses:

- Diameter of the lines
- Material Properties
- Distance required to be transmitted
- LVDC current transmitted (LVDC)

The ability to calculate the exact losses without knowing all these factors is difficult. It is advised that when source the transmission lines the power factor losses is requested and implemented into the design.

5.9 Generator Selection

From section 5.5.1 Battery charging and selection it was found that the generator is to produce a maximum current of 1129Ahs. In order to have an efficient generator it must operate just under the maximum current of 1129Ahs. Depending on the system design, the generator only has to produce the charging compactly. Due to the battery being able to handle higher than the maximum requirement to run the system and the appliance running time is not 24hrs a large charge is not required. Therefore the watts required can be calculated by:

Equation 8

$$W_m = V * (A_{Max} / 10hrs)$$

Where

W_m = Watts (W)

V = Volts of the battery system (V)

A_{max} = Ampere (A)

Using equation 8 the maximum watts required to produce the ampere limit is 2,709.6W or 3.6hp. If the generator produces over this limit the regulator is designed to protect the system. The most efficient generation is just below the limit.

By charging just below the limit it will charge the batteries in the shortest time. The generators maximum RPM should produce wattage just under the power limit.

Before the appropriate generator was chosen different types were analysed.

Two main types of generators are:

- Synchronous motor
- Induction motor
- Permanent magnet motor or otherwise known as an electromagnetically excited motor

All three types of motors are capable of producing power. Induction motors have slip when operating. Slip is when the motor runs slightly lower than synchronous speed which means it has to operate at a higher rpm to produce the Synchronous motor produces AC power and as a result when operating as a generator without an inverter it would not work on this particular system. Due to simplicity and the system required to run on D.C a permanent magnet motor will be used:

- High Efficiency
- High Torque and Power Density
- More compact in size
- Very low maintenance

A 5hp, shunt permanent magnet motor will be used as a generator. This selection was based on product detail's supplied from local motor suppliers. The motor is required to operate at 2300rpm. Selection can vary to location specifics.

5.10 System Analysis

5.10.1 Weir and intake

The weir is where the water is built up from the stream to allow a smooth intake to the piping of the hydroelectric system. Due to the environmental sensitivity of this project, the weir is to have minimal impact to the streams flow soil build up. The weir must be designed to the following conditions:

- Minimal environmental impact
- Easy to install
- Easy to maintain
- Minimum cost
- Have minimum sediment build up

After analysing the location conditions the weir will be built with a concrete/sand mixture. It will stand 1.5 meters high and have a width of 7.4m. This size will allow a large pool of water to back up for a length of 10m as seen below. This allows maximum time for sediment to settle before reaching the inlet. Figure 30 shows the design of the weir. The weir design is a permanent structure with a release gate in the centre.

The release gate was installed so that when the sediment builds up and becomes too great, this would affect the systems intake. Consequently, it could just be opened and this process would allow it to be cleaned through natural flow.

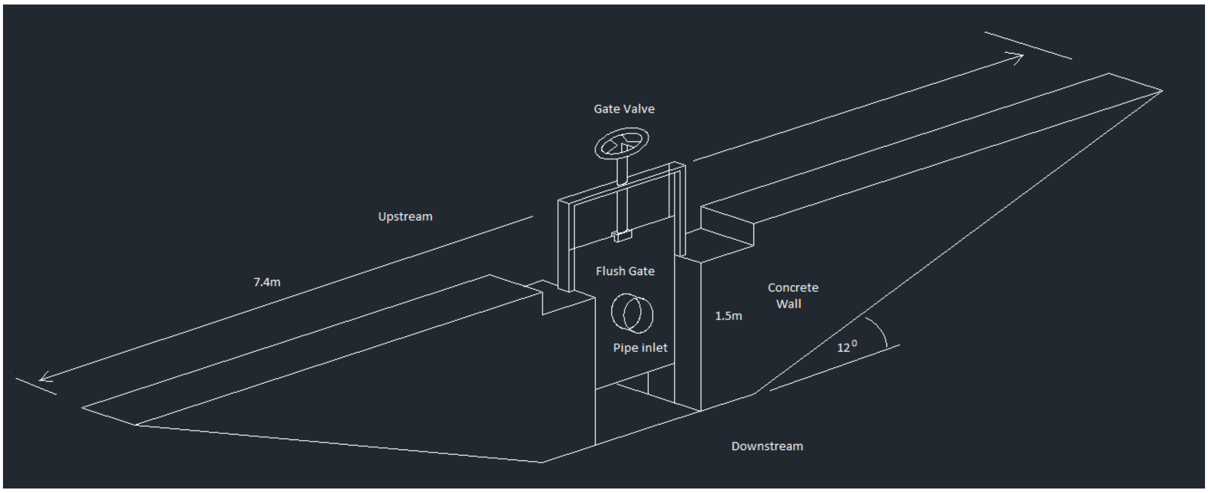


Figure 30Weir Design

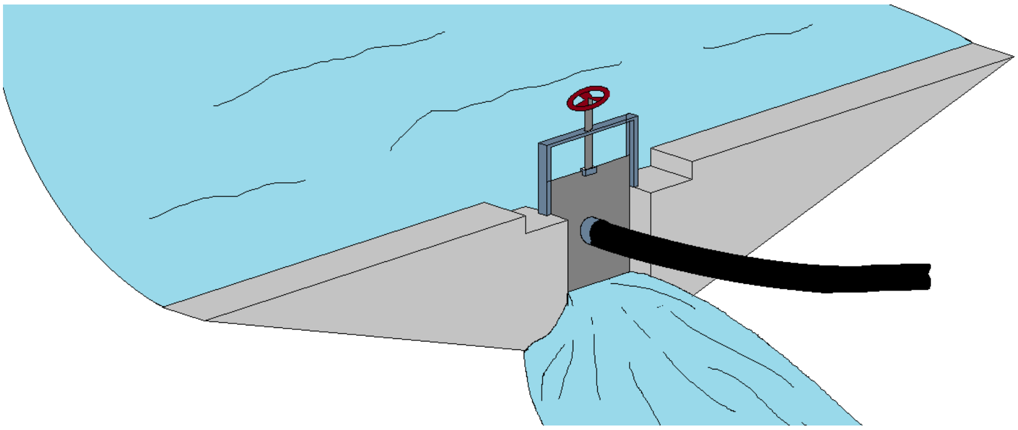


Figure 31Weir Concept

The weir will cause a maximum of 7.5 meters back up of water where it is then to overflow under normal operation. Figure 31 above shows the weir with its gates slightly open. The weir could be left to operate in this mode in high rainfall conditions. By doing so it will allow any dirt or sediment to flow through the weir and not become caught.

The concept of a plain straight wall was the chosen design because of the simplicity and minimization of cost of this model.

5.10.2 Pipe inlet

The pipe inlet positioned at the weir must not allow contaminants to come down the piping and into the PAT. This could cause damage to the pump and lower the efficiency of the system. A filtration system is required as it is easier to replace a filter than it is to replace a PAT. The filtration system used could be purchased directly from the same place where the pump was sourced from. Inlet suction filters are used every day for pumping out of the dirty water sources, see figure 32. By sourcing an already available part it is cheaper and easier to replace.

Figure 32Suction Filter

5.10.3 Piping

The piping is required to transport the volume of water to the inlet of the PAT system with:

- Minimum Turbulence
- Minimum Friction resistance
- Low maintenance
- Low cost

A six inch diameter pipe was chosen as it causes minimum turbulence. The smaller diameter of the piping to the system, the lower the dynamic pressure will be at the end. Although, further investigation of diameters would prove to be more cost effective.

However, as stated in chapter two ‘the main focus of cost is on the pump as a turbine compared to a conventional turbine because regardless of what system is chosen the same piping, weir and pipe inlet will be used’. The easiest to source detailed information on, is the pipe diameter and it is also the most common size to find.

5.10.4 Pipe Materials

Before a piping material could be chosen, different types must be analysed. All prices calculated were on average for a 6 inch diameter.

Table 7 Pipe Materials

Pipe Materials		
Pipe Material	Description	Cost (analyses Sep 2013)
Cast Iron Piping	Cast iron piping is often used for transporting properties that has pressure and can be created to have minimum corrosive behaviour and improve friction loss. Although it is a good material it is not often used anymore.	$14.85 per meter on average
Ductile Iron Piping	Often used to transport water and has a protective lining to stop corrosive ability. This design of pipe was directly developed from cast iron and often exceeds it 100yr life use.	$29.36 per meter on average
PVC piping	PVC is the third most widely produced plastic, often used because of cost/property effectiveness for appropriate installations. It is a brittle material and can be damaged easily. Also is easy to source due to its high production rate. Piping would also require excavation to ensure protection.	$9.00 per meter on average
Flexible PVC piping	Often is used for low pressure system. It can tear easily and the design of the pipe is rough and causes high turbulence.	$10.00 per meter on average
Poly Pipe (Polyethylene Pipe)	Poly pipe is a common produce piping that is used in the agricultural community due to its flexibility and toughness. It is durable piping material that is produced in a range of diameter.	$13.00 per meter on average

It can be seen from above in table 9 that the poly pipe is the best decision, but before it can be chosen, a decision on the weight matrix must be used to ensure validity of chosen pipe.

Table 8 Weighted Pipe Selection process

Weight	Cost X 3	Maintenance X 1	corrosion resistance X 2	accessibility X 3	installation X 2	turbulence factor X 3	total	ranking
Cast Iron	4	3	3	1	1	4	38	3
Ductile Iron	1	5	3	3	1	4	37	5
PVC	5	1	4	3	2	4	49	2
Flexi PVC	4	1	4	2	4	1	38	4
Poly Pipe	4	4	4	5	5	4	61	1

Considering the pipe materials in table 9 and the weighting matrix 10, the best material based on costs and property behaviour is Poly Pipe (Polyethylene Pipe) with a total score of 61. Instillation will be easier with this material as it is flexible and will be forgiving in the tough terrain of the Papua New Guinea highlands. Six inch diameter sections will also be light enough for people to transport down the hill from the village or Tagari River to the site location.

5.10.5 Flow Control

In order to ensure that the electrical generation is at a constant rate and the pump does not operate at a speed that could lower the expected operation life, a flow control system must be installed. The easiest way to obtain this is, is with a flow control valve. Although the system could be controlled by an automated system it would require higher maintenance, cost and it would not be as durable in the environmental conditions of Papua New Guinea.

The flow control system is required to ensure:

- Minimum turbulence is maintained
- Flow adjustment must be easy and accurate. (no movement in opening)
- Cost effective

Two control valves will be used: Firstly, installed at the weir to allow the inlet to be closed and turned off in case of maintenance and floods. Secondly, installed just before the inlet of the pump. From the PAT analysis and piping selection the diameters are inlet 1 = 6 inch and 2 = $1\frac{1}{4}$ inch. Flow control could be obtained by the valve at the weir but it would require a patron to walk to the weir every time an adjustment is required. In an emergency where immediate control is required this would prove to an inefficient option.

5.10.5 Flow control valves

Before a particular flow control system could be chosen, the different types were analysed. K values were sourced from ‘Friction Losses in pipe fitting’ found.

Table 9 Valve Analysis

Valve analysis					
Valve type	Description	$ Cost (1.25') Average	$ Cost (6') Average	k value (1.25')	k value (6')
Ball valve	When fully open they have minimum turbulent affects. Due to the small turning control of the valve (one quarter open to close) it is difficult to have an accurate flow rate control.	55	300	0.08	0.5
Gate valve	The gate valve or also known as the sluice valve uses a plate system to cut the water off. It has a more accurate flow control due to the closing rate. It is a bulkier and has a large turbulence factor when it isn't completely open.	95	750	0.18	0.10
Angle valve	Angle valve allow for an accurate flow control but can cause a high turbulence in the flow depending on the particular design of the valve.	78	1000	1.21	0.83
Butterfly valve	The butterfly wafer valve is quite often used to regulate and control flow. The wafer model uses a tightly fitted seal to stop a back flow in pressure. The opening and closing mechanism allows the valve to be opened at a slow and consistent rate. The butterfly wafer valve also known as the quarter turn valve. When the valve is almost completely shut is causes a high turbulence factor.	N/A	250	0.86	0.68

Before the head losses could be calculated, the flow rate is to be calculated. The piping investigated - as a system states that v in must equal v out.

Therefore, using the following equation the flow rate due to gravity was calculated:

$$v = \sqrt{2gh}$$

v =Flow rate (m/s)

g =Gravity (m/s^2)

h =Head (40m)

Therefore

$$v = 28.014 m/s$$

Using the K values from table 10 the head loss percentage for each valve was calculated using the following equation and put into table 11 :

$$h_l(\%) = ((K * \frac{v^2}{2g})/h) * 100$$

Where:

K = Loss Coefficient

v =Flow rate (m/s)

g =Gravity (m/s^2)

Table 10 Percentage Head Loss

Head Loss		
Valve type	Head loss 1.25' (hL) %	Head loss 6' (hL) %
Ball valve	8	5
Gate valve	18	10
Angle valve	121	83
Butterfly valve	68	68

In considering table 12, it can be seen that the smallest head loss for the pump inlet and weir flow control valve is the ball valve. By using a Valve weighing matrix, a selection was made considering extra variables. The valves together will have an 8% head loss at the 40 meters and a 10% loss at the .75 meter thereby, resulting in a combined loss of 3.28 meters.

Table 11 Valve Decision Matrix

Valve type	**Availability**	**Head Loss**	**Cost**	**Flow Control**	**Total**	**Rank**
Weight	**x 1**	**x 3**	**x 2**	**x 3**		
1.25 Inch						
Ball valve	3	5	6	3	39	1
Gate Valve	3	4	4	5	38	2
Angle Valve	3	1	1	3	17	4
Butterfly Valve	1	2	N/A	4	19	3
6 Inch						
Ball valve	3	5	6	2	36	2
Gate Valve	3	4	4	5	38	1
Angle Valve	2	2	1	3	19	4
Butterfly Valve	3	2	5	4	31	3

Table 13 above, demonstrates that for the $1\frac{1}{4}$ inch pump inlet the best valve is a Ball valve. The gate and ball valve are very close in total weight and either can really be chosen. The N/A was used for the butterfly valve because it is often difficult to get a butterfly valve under 2 inches. For the 6 inch weir inlet the Gate valve is the chosen mechanism. This is not only the lowest head loss available it is also the second cheapest viable option.

5.11 Pump as a Turbine Selection

The pump selection for turbine operation is based on the following aspects:

- Head available
- flow rate available
- Required generator speed

From previous analysis of the location in section 5.1 location, the available head is 40m due to rough terrain. This includes losses from the selected valves and piping. Due to such a large piping diameter flow available is not a limitation. Its maximum reduction will be at the inlet of the pump. The flow rate for each pump is calculated from the head required. It was also analysed in section 5.9 that the pump must operate at 2300 rpm to produce the required the most efficient charging amperage.

5.11.1 Matlab Analysis

Matlab is a commonly used program to analyse numerical problems efficiently and accurately. It can be applied to the pump selection process. Knowing that the head and flow calculations can be used due to its validation in section 4.9 they can be inserted into the program. Knowing:

Equation 9

$$H_t = \left(\frac{N_t}{N_p}\right)^2 * \frac{H_{bep}}{\eta_{maz}^{1.2}}$$

Where;

H_t = The head of the turbine at best efficiency point

N_t = The turbine running speed

N_p = The rated pump speed

H_{bep} = The pumps Head at the best efficiency point

η_{max} = The pumps maximum efficiency

And

Equation 10

$$Q_t = \frac{N_t}{N_p} * \frac{Q_{bep}}{\eta_{maz}^{0.8}}$$

Where;

Q_t = The flow rate of the turbine at best efficiency point

N_t = The turbine running speed

N_p = The rated pump speed

Q_{bep} = The pumps flow rate at the best efficiency point

η_{max} = The pumps maximum efficiency

Figure 33 below shows the process of the Matlab programming used. The centrifugal pump data which is found in appendix B was input into the pump model A component. Using the program it was analysed against the site requirement conditions, where it was then output depending if true or false was satisfied with the site conditions. The resultant output was then given a statement to allow it to be identified before it was output into the command window.

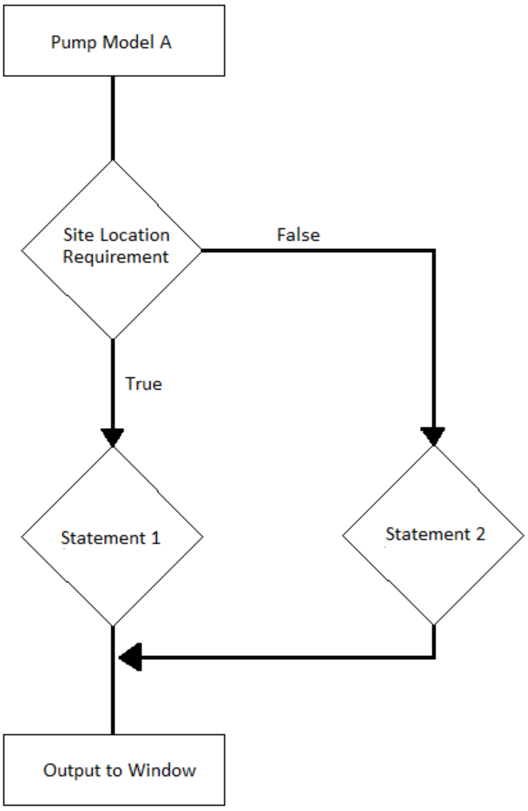


Figure 33 Matlab Process

This process was then applied to 13 different pump models. All pumps analysed are manufactured by Southern Cross to ensure similarity to the mathematical analysis and validation in chapter four. This was to ensure that unpredicted error was kept to a minimum. The coding is found in appendix C.

5.12 Results

The results from the code are in table 14. Each head calculated is when the pump as a turbine is operating at its maximum efficiency point at 2300 rpm.

Table 12 Head Required for Pump Model

Pump Model	Head at BEP (m)
50x32-146	30
50x32-160 Prototype	35
50x32-182	45
50x32-182	55
50x32-228	84
65x50-146	27
65x50-182	37
65x40-182	45
65x40-228	72
65x40-222	79
65x40-278	124
65x40-274	140
65x40-342	216

Before the results were analysed against the site requirement it produced the Head required for each pump to operate at 2300 rpm. Pump model 50x32-160 is the model used in the built prototype. Figure 34 is the plotted results after being analysed against the site requirements.

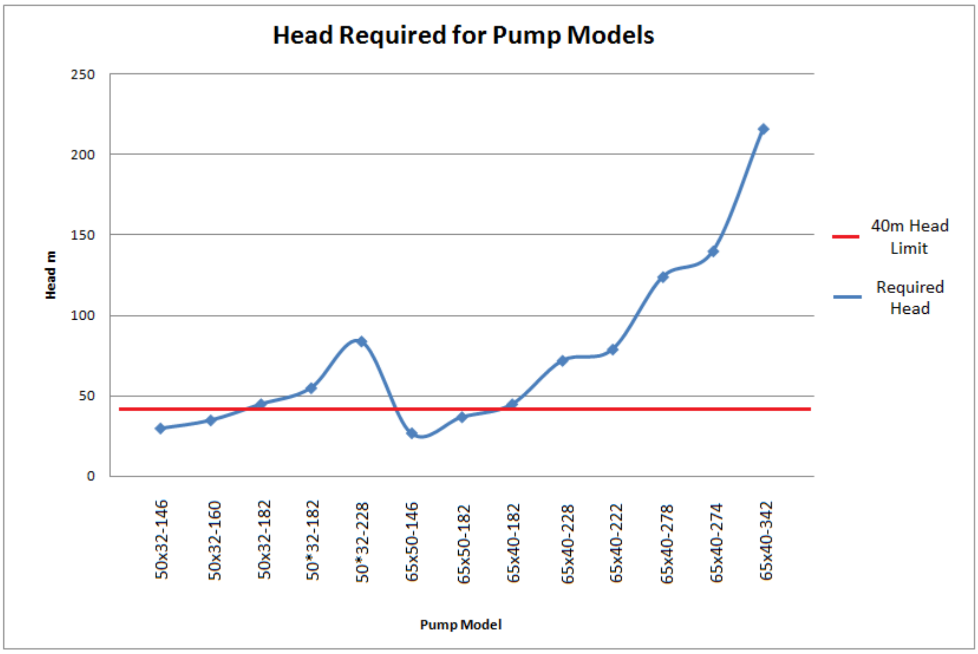


Figure 34 Head Required for Pump Models

The red line in figure 34 is the site limitation. Any pump that is plotted above the limit would not be able to operate under the conditions of the sites location. There were 4 pumps deemed acceptable to operate as a PAT. They are:

1. Centrifugal pump model 50x32-146

2. Centrifugal pump model 50x32-160

3. Centrifugal pump model 65x50-146

4. Centrifugal pump model 65x50-182

To select which of these for pumps the flow rate must be taken into consideration. The pump with the minimum flow rate would be rated higher during the selection process because:

- Require smaller fittings
- Smaller control valves
- Lower cost

Using equation 9 and the pump model conditions found using the manufacturer's data sheets found in appendix B the following flow rates (Q) were calculated:

Table 13 Required Flow Rate

Pump Model	Flow Rate (l/s)
50x32-146	6
50x32-160 Prototype	6.4
65x50-146	7.6
65x50-182	10.9

From table 15 it can be seen that the minimum flow rate required is model 50x32-146. The required flow rate between model 50x32-146 and model 50x32-160 in minimal. Either can be chosen.

The maximum flow rate available can be calculated using the following equation:

Equation 11

$$Q = vA$$

Where

Q =Volumetric Flow Rate (m^3/s)

v = is the velocity of the water at the intake of the turbine (m/s)

A = Area of the pump Inlet (m^3)

The volumetric flow rate calculated in equation 11 only works in idea situations with no losses. A more accurate description would be the 40m head is converted into;

- Friction loss in supply line, both outlet and inlet
- Minor losses in the supply line
- The amount of head extracted by the pump

- Kinetic energy left in the water after passing through the system

The excel spreadsheet sourced is found in appendix E can be used to calculate the flow rate. Therefore model 50x32-(146-160) has a maximum flow rate of $7.6l/s$ and for model 65x50-(146-182) the maximum flow rate is $11l/s$. It can be seen from the flow rate at the site is extremely high and as a result the inlet control valve will not have to be completely open to reach the rpm. The flow rate is not expected to be this high from the site conditions due to imperfections in the system (Head losses).

Before selection of the particular pump can be made the efficiencies and cost of each available pump must be looked at. By selecting the pump with the greatest efficiency at the available head it will operate at its peak performance.

Efficiencies of PAT performance

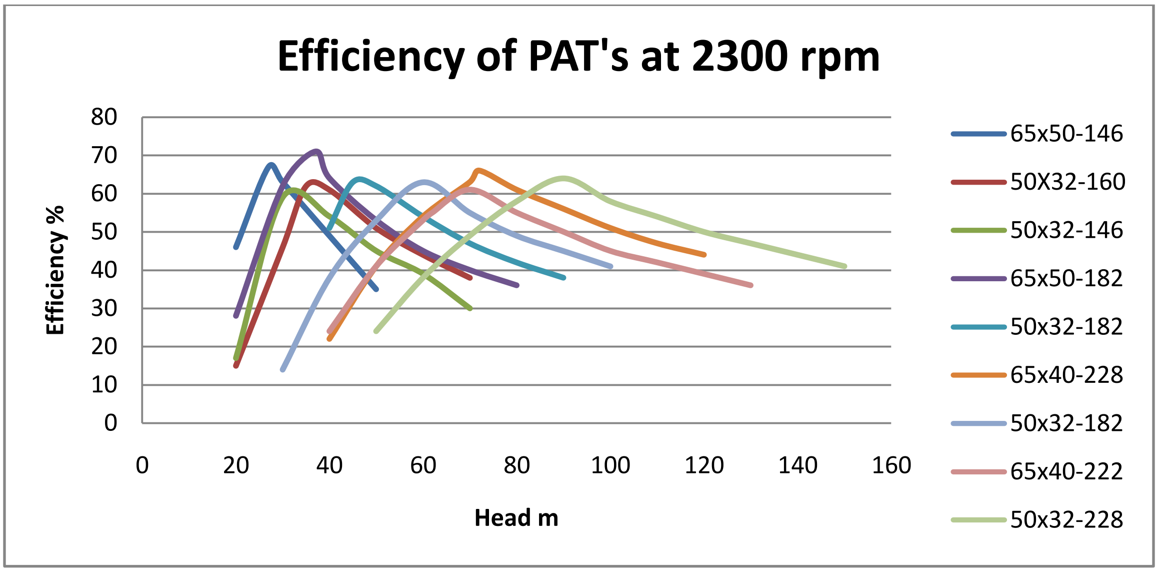


Figure 35 PAT efficiencies

Figure 35 shows the efficiencies for the different models against head (m). It can be seen that 65x50-182 has the greatest efficiency 71%. Using a weighted matrix method the 4 available pumps were analysed. Figure 35 was generated by running the Matlab code attached in appendix C. Each pump was run through the simulation at 2300rpm and the efficiencies were plotted.

Table 14 Pump Analysis

Pump Model	Head Required at BEP	Flow Rate Required	Efficiency	Cost	Total	Ranking
Weight	x2	x1	x2	x3		
50x32-146	4	4	4	1	23	2
50x32-160	3	4	4	1	21	3
65x50-146	4	4	5	1	23	2
65x50-182	4	3	6	1	26	1

It can be seen from table 17 that the optimal pump to operate as the selected PAT is model 65x50-182 at a new cost of $1411 including GST. The prices were sourced directly Pentair Southern Cross. This company manufactures and sells the selected model. Prices may vary from different sources.

Characteristics of the selected PAT

Below in figure 36 this shows how the efficiency behaves against different head for 65x32-182.

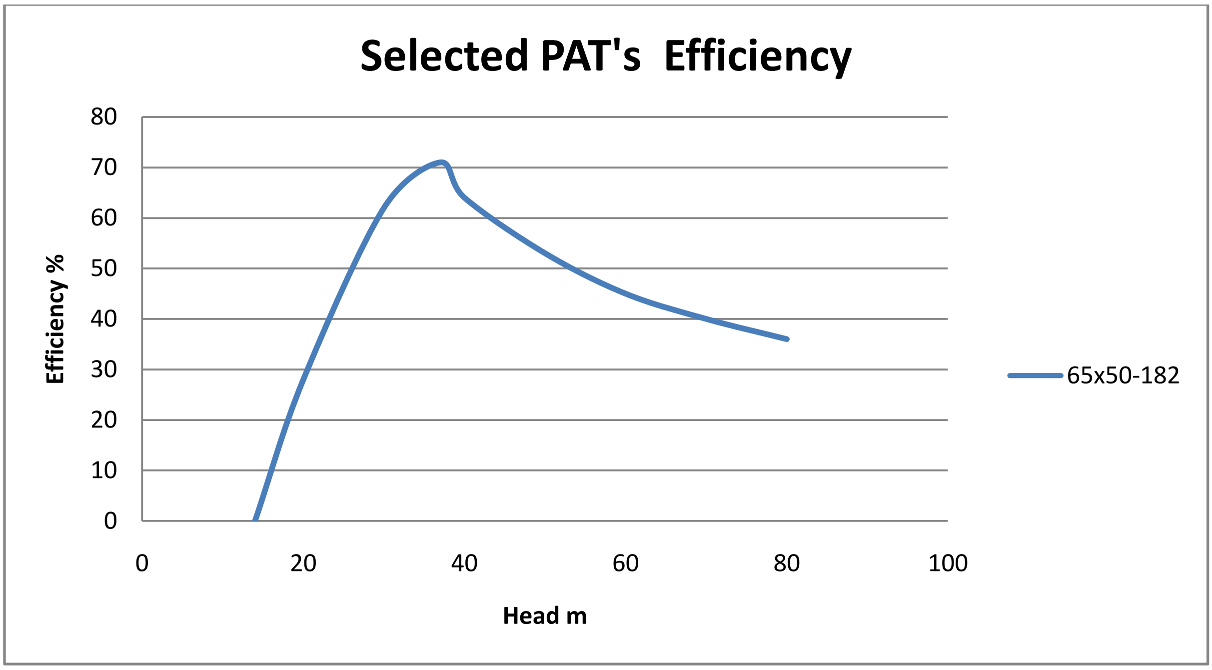


Figure 36 PAT Efficiency

By rearranging the mathematical relationship (equation 7) it can be seen that the maximum efficiency reached by the PAT is 71% at 37 meters. It was also found that if the flow drops below 14.8 meters head the PAT will cease operating. Although the efficiency does drop after 37 meters it does not mean that the speed of the PAT slows as the head efficiency decreases. It means that the requirement of head and flow to increase the speed is even greater per unit of water.

5.12.1 Cost

The cost of using a large pump due to the loss in efficiency compared to an average turbine is greatly compensated by the large reduction in cost due to the pump mass production. It was found that the reduction in cost using a PAT instead of conventional turbines makes then more economical than conventional machines. The cost for the selected PAT is $1411 including GST. This price was sourced from Southern Cross pump manufactures located in Australia. It is to be noted that the costs can vary due to the pumps source and condition. By selecting a new pump less error is to occur from the theoretical analysis due to its operating condition.

Chapter six will present the conclusions of this study.

Chapter 6

6.1 Conclusion and further work

The purpose of this dissertation was to investigate the use of a pump used as a turbine for a small hydroelectric generation system. The work was also created to show the reader what aspects are to be analysed in a hydroelectric system for a specific location. The research and analysis of the project was found to prove that the PAT's use was viable. It was found that a pump would operate at a lower efficiency than a specifically designed turbine, but economically better due to:

- Availability of centrifugal pumps
- Ease of installation
- Cost efficiency
- Reliability
- Ease of replacement
- Mass Manufacturing

In section 5.12 results, it was found that the maximum efficiency for the selected pumps was 71% at 37m. Thus, meaning that the pump operates at approximately 15% less than a specifically designed turbine.

By building the prototype and testing it under flow conditions, the PAT showed that the mathematics based in the literature review where validated and deemed accurate. The experiment also showed that the further the system operates outside of the operation range, the more the system becomes inaccurate. It was found by testing the prototype on a 15m head, that it was operating at its minimum limit, resulting in the data having a level of error that could be deemed influential. By building the prototype, it proved that the ease and minimal time was required to produce a hydroelectric generation system.

Small hydro electric generators are restricted because of the condition that they must be specifically designed and built to for the chosen location. This is not only costly but also time consuming, often resulting in the small hydroelectric system being deemed impractical. From the dissertation it was found that a pump analysed correctly for the location could prove to be successful.

Although pumps are limited to small variations of head and flow available, unlike the specifically designed turbine, the abundance of the different models manufactured allowed a broad selection at different best operating points (BEP's).

As a pump as a turbine operation was analysed, it was found that depending on the conditions of the pump itself and how accurate the pump’s data sheet was, it greatly affected the head at its best efficiency point (Hbep). As the larger pump sizes were analysed, its operation was found to vary from what was expected. It was found that this occurrence was from inaccurate analysis of the pumps data sheet at higher heads and flow rates. If the manufacturer produces poor quality data sheets, then error is expected and results could be deemed as inaccurate.

The analysis of the site location proved to be a process that could be completed theoretically but it was found due to unknown variables, that it will always be inaccurate when designing systems. The small hydroelectric plant was designed to produce more than what the average power draw would be expected. By doing so this allowed for head and power losses that were under calculated and also allowed the system to be modified for future expansion. If the variables were known, then this power production factor analysis could be done much more accurately.

Due to the expected lack of skilled operators in the chosen location, the system also had to be designed to cater for this occurrence. Therefore, if an incident or incorrect operation of the plant was to occur, there would not be any injuries and a cease of power production would be a result from the action. As well, by operating the system on a low voltage direct current (LVDC) system, the chance of a fatal electrocution was drastically dropped. The hydroelectric generation system for third world countries would also operate under low maintenance and low running cost. The use of a pump also means that operation errors would not be as costly. This was due to the economical benefits of a pump as a turbine (PAT) and as a result of the maintenance which was not frequently required as a specifically built system was applied.

The use of a PAT in a small hydroelectric system in third world countries is not only viable but economically better for smaller systems. It is my conclusion, from the analysis of the system and research in the literature that it is better to sacrifice the efficiency of a turbine for the ease and readily available pump.

A small power production at a cheaper price is healthier for countries in immediate need of a small power production than having no power at all.

6.2 Further Work

6.2.1 PAT performance prediction

It was found in chapter five that the larger the PAT the more inaccurate the theoretical analysis became. It is predicted that this occurs due to the possible limitation of the PAT application. Although the prediction of the PAT system was validated using the centrifugal PAT built prototype shown in figure 20 (p.64) further testing is required at higher applications.

It is suggested that another prototype would be built where the head could be greatly varied at an accurate rate. Hence, the limit would then be predicted when a limit of data tolerance was found. Consequently, by doing so, it would allow the identification of the threshold when a specifically designed turbine becomes not only more efficient but more economical. The overall process of a PAT system application would become more efficient and practical. Pumps as turbine systems are not the common choice of hydroelectric generation due to the lack of understanding in the system behaviour of its operation. Further analysis would also allow more information to be readily available for future hydroelectric generator installations and the builder would be less hesitant in selecting an economical PAT system.

6.2.2 Torque available as a PAT

Although the dissertation does look at the operation of different pump models as turbine it was noted that research into the behaviour of torque was lightly touched upon. The relationship of the torque produced by a centrifugal pump under normal operation needs to be related to PAT operation. Although the torque can be calculated from the generator, this cannot be done during a site analysis with limited information. The built prototype (P.6) Figure 20 would be modified with a dynamometer.

6.2.3 Pump as a Turbine information readily available

As discussed earlier, the greatest limitation of a PAT system is the lack of information and how to apply the system to a particular location in order to allow optimal information during selection. By producing more detailed reports and examples of application such as in chapter five in this dissertation, this concept of PAT applications would thus seem less complicated and therefore, as a result would be considered more often as a renewable energy source for third world countries.

Appendix A

Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG 4111/4112 Research Project

PROJECT SPECIFICATION

FOR:	Nicholas Burton-Ree
TOPIC:	Hydroelectric Generator for Third World Countries
SUPERVISORS:	Les Bowtell and Malcolm Gillies
ENROLMENT:	ENG 4111 – S1, D, 2013

ENG 4112 – S2, D, 2013

PROJECT AIM: The aim of this project is to design a cheap and simple electric generator that can be powered by a small creek or stream and have the capability to produce enough power to run small appliances.

SPONSORSHIP: UNIVERSITY OF SOUTHERN QUEENSLAND

PROGRAMME: (Issue A, 13 March 2013)

Research into small scale hydroelectric generators

Set design specifications.

- The Generator will be designed to power a small room with a variety of electrical appliances such as a hospital room which would be expected to need lighting, refrigeration system and at least one fan. This would require approximately around 6000kw/hr.

-A power storage system will be investigated.

-A control limit will be set to manage the speed at which the hydroelectric generator will run during operation.

Analyse field data gathered from a creek that would be expected to have similarities in flow and size rate to my targeted areas. This includes the possibility of floods.

Research into petrol/diesel motor generators and find the requirements for the equipment to produce an output and look into possible design modifications.

Research and testing into gearing system. Find the correct balance between rotations per minute and torque.

Create mechanical designs and simulate the operation due to the tested flow rate.

Analyse final design and test if it meet the design speciation's set earlier.

Submit academic dissertation

As Time Permits

Look into the ability of having different generator sizes and different water wheel designs to use on different sizes of water flow.

Build the designed hydroelectric generator.

AGREED Nicholas Burton-Ree

Date: 27 / 03/ 2013

Malcolm Gillies (supervisor)	Les Bowtell (supervisor)
Date: 27 / 03/ 2013	Date: 27 / 03/ 2013

Examiner/Co-examiner:

Appendix B

Pump Performance Sheets

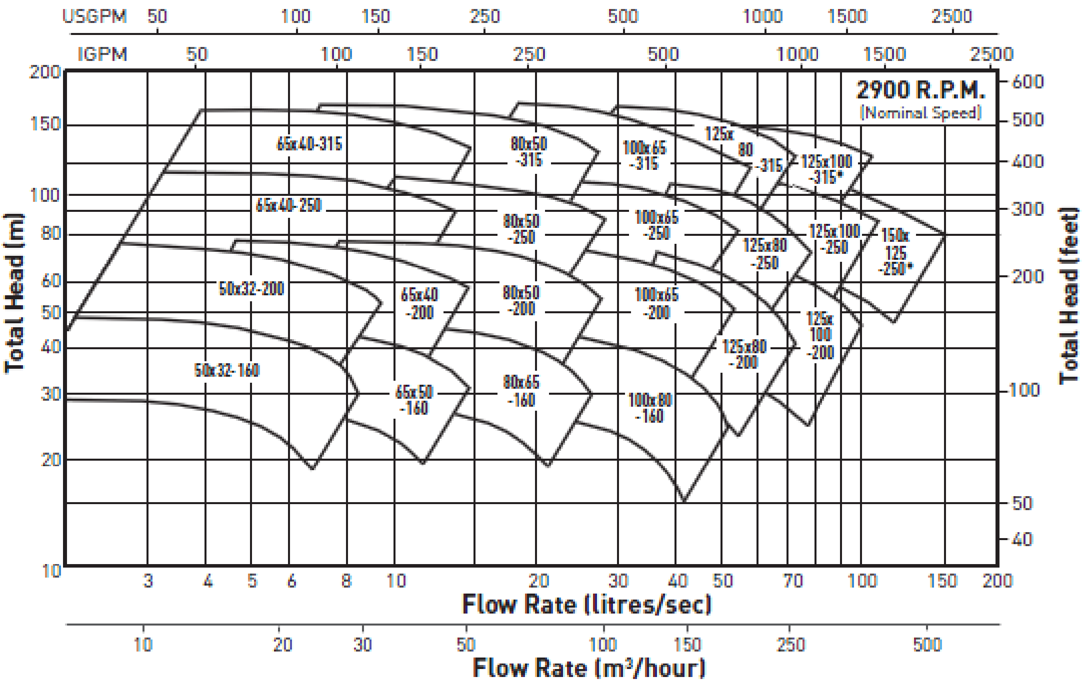
Southern Cross

CENTRIFUGAL PUMP PERFORMANCE DATA

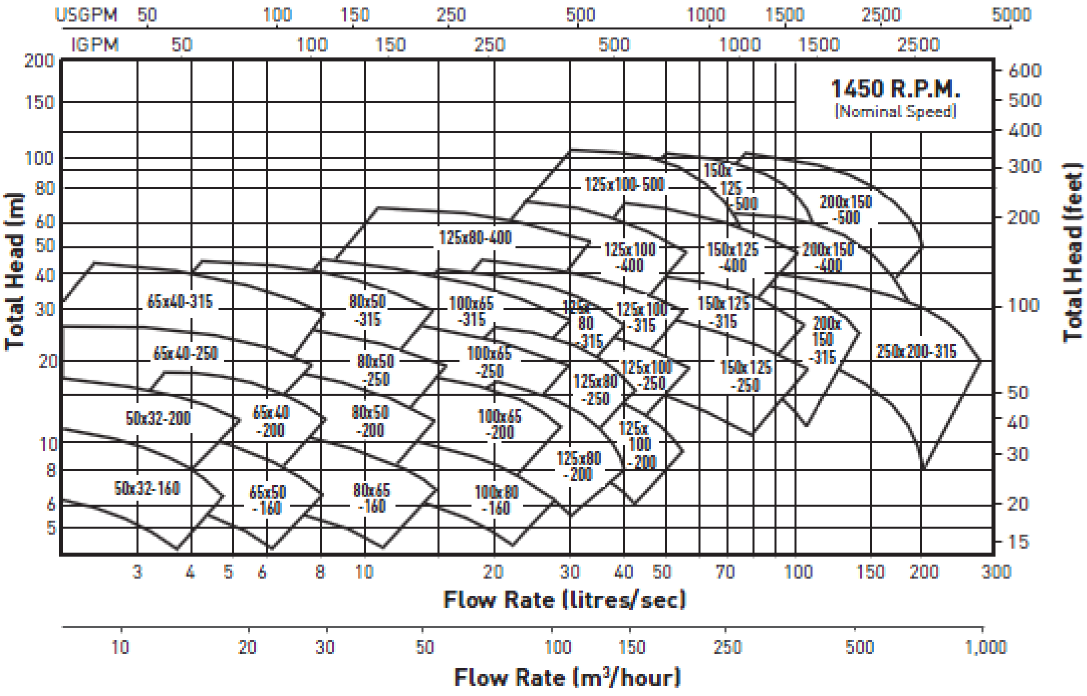
ISO2858

END SUCTION PUMPS
50Hz PERFORMANCE

SELECTION CHART
1450/2900 R.P.M.



* ISO-PRO Pumps (ISO5199 Standard) required to operate these models (125x100-315 & 150x125-250) at 2 pole speed.



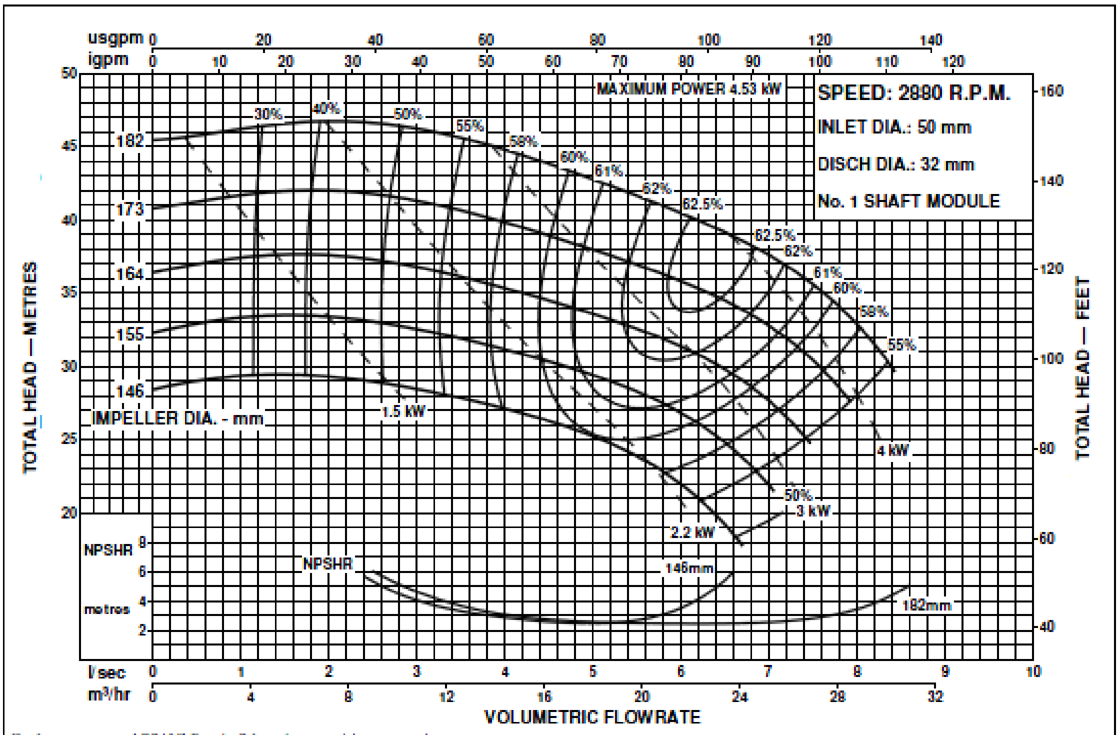
PENTAIR

Southern Cross

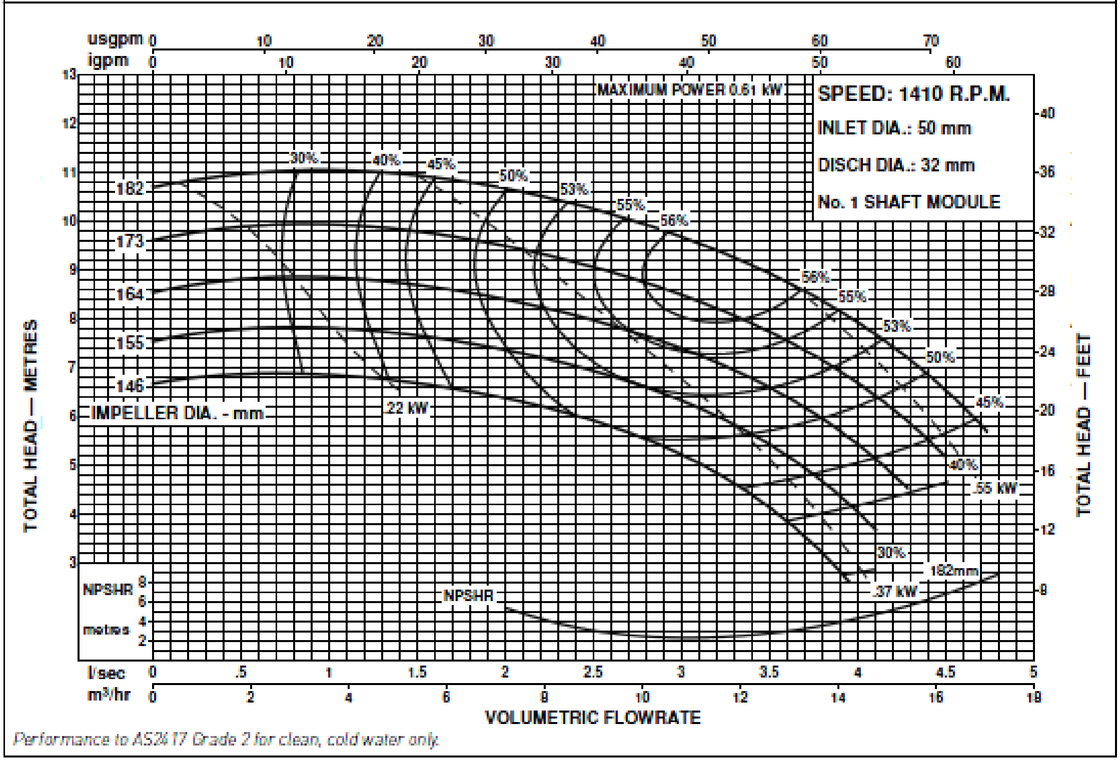
CENTRIFUGAL PUMP PERFORMANCE DATA

ISO2858
END SUCTION PUMPS
50Hz PERFORMANCE

MODEL
50x32-160



Performance to AS2417 Grade 2 for clean, cold water only.



Performance to AS2417 Grade 2 for clean, cold water only.

PENTAIR

Southern Cross

CENTRIFUGAL PUMP PERFORMANCE DATA

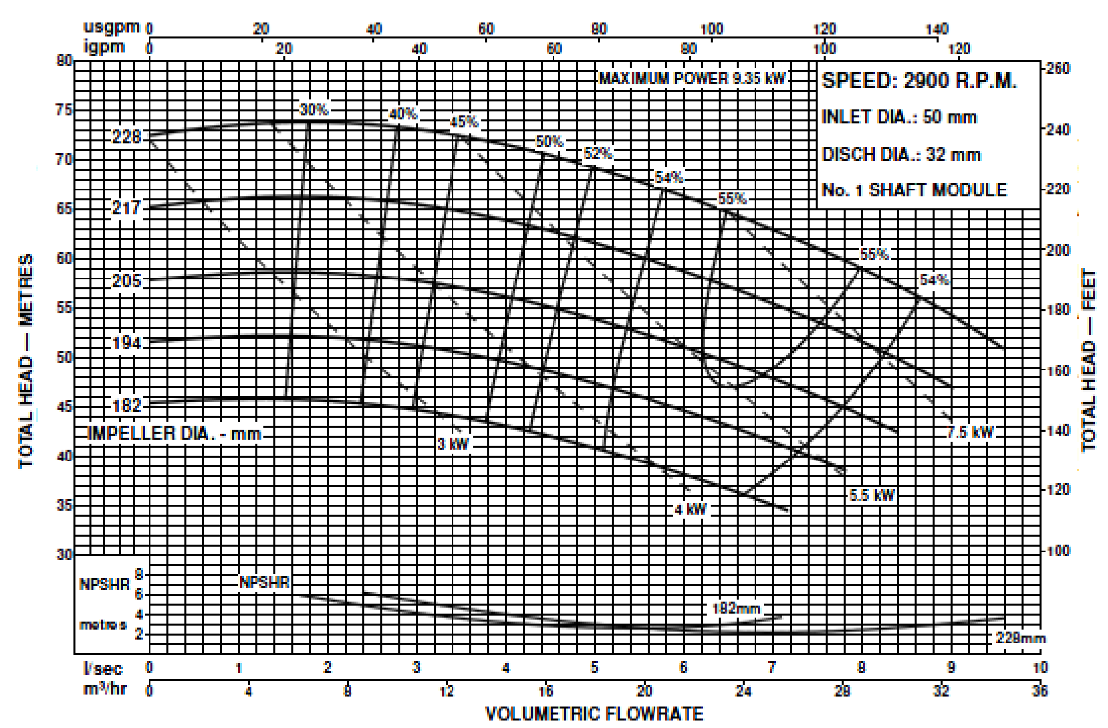
ISO2858

END SUCTION PUMPS

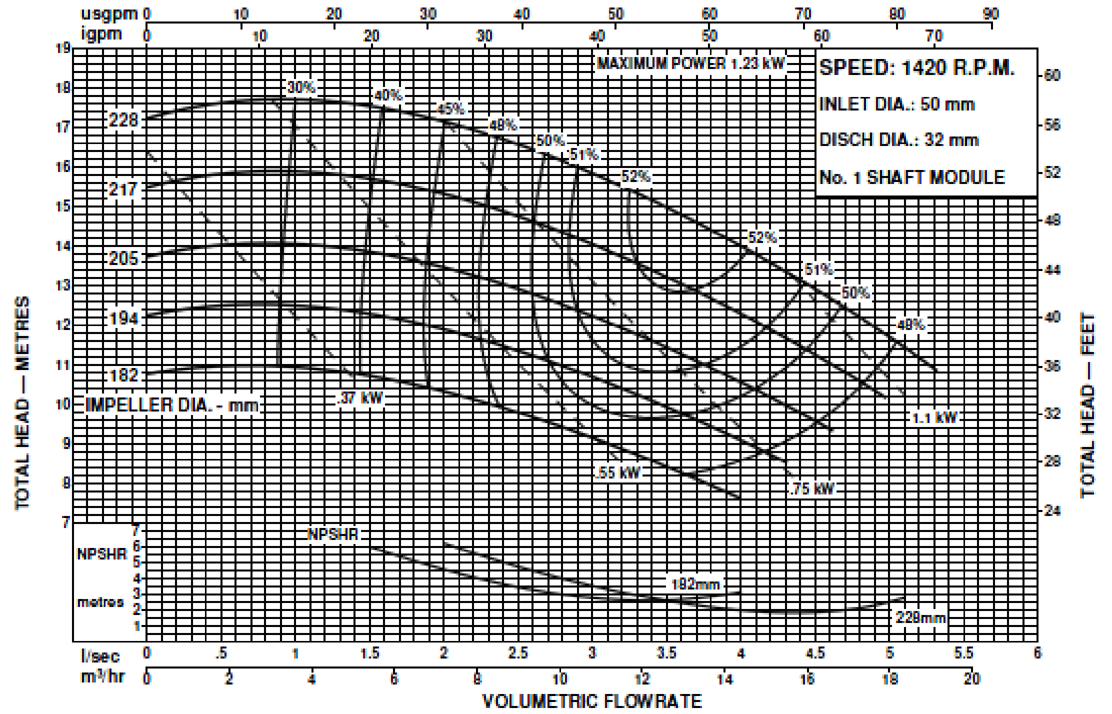
50Hz PERFORMANCE

MODEL

50x32-200



Performance to AS2417 Grade 2 for clean, cold water only.



Performance to AS2417 Grade 2 for clean, cold water only.

PENTAIR

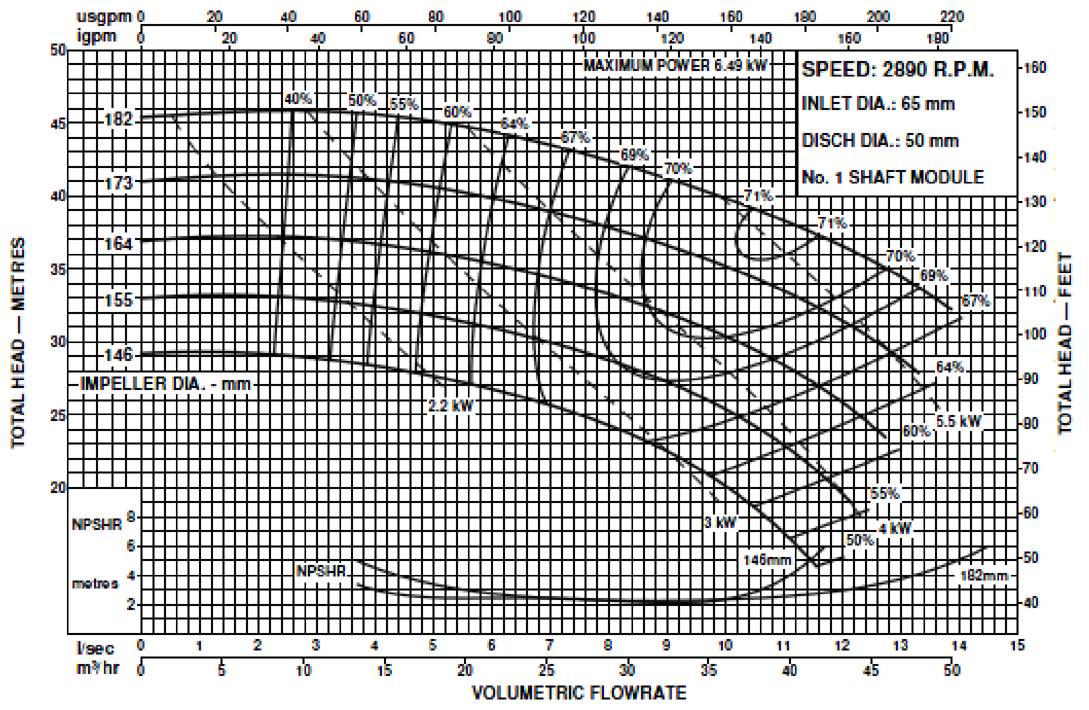
Southern Cross

CENTRIFUGAL PUMP PERFORMANCE DATA

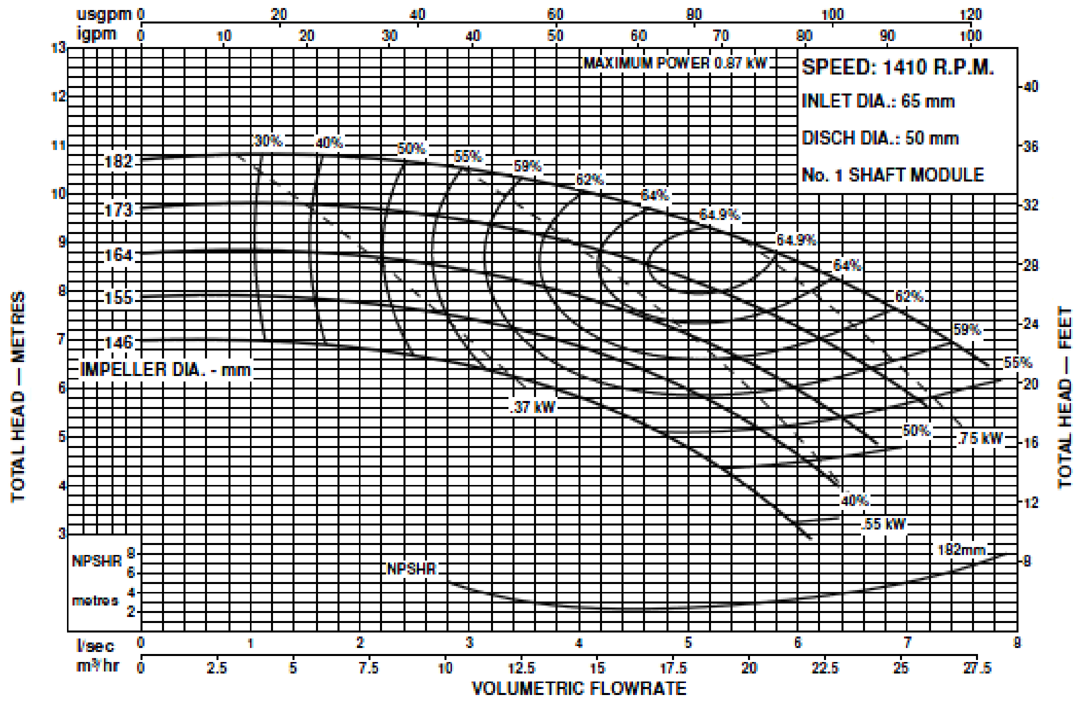
ISO2858

END SUCTION PUMPS
50Hz PERFORMANCE

MODEL
65x50-160



Performance to AS2417 Grade 2 for clean, cold water only.



Performance to AS2417 Grade 2 for clean, cold water only.

PENTAIR

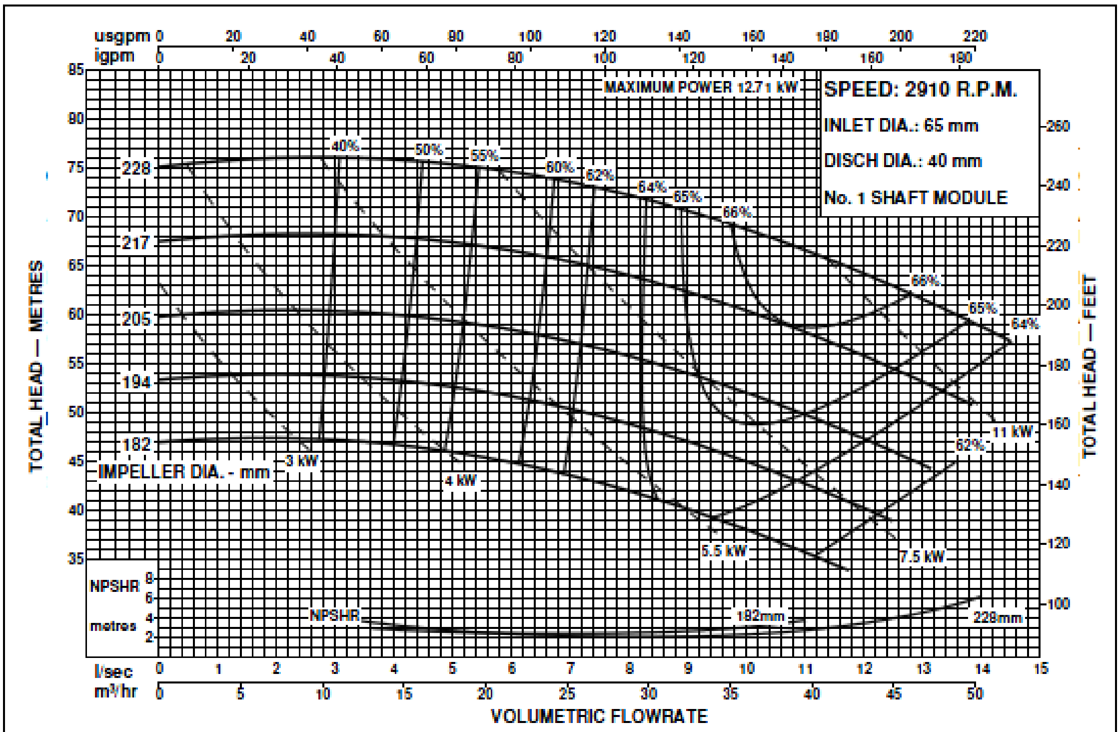
Southern Cross

CENTRIFUGAL PUMP PERFORMANCE DATA

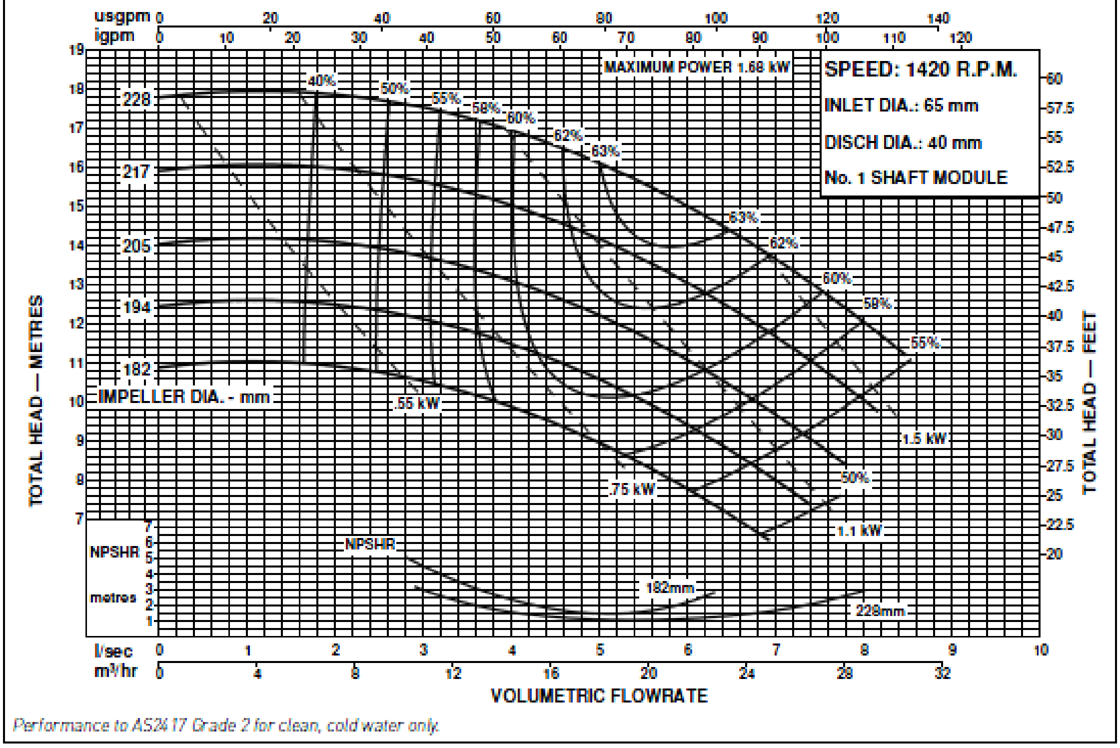
ISO2858

END SUCTION PUMPS
50Hz PERFORMANCE

MODEL
65x40-200



Performance to AS2417 Grade 2 for clean, cold water only.



Performance to AS2417 Grade 2 for clean, cold water only.

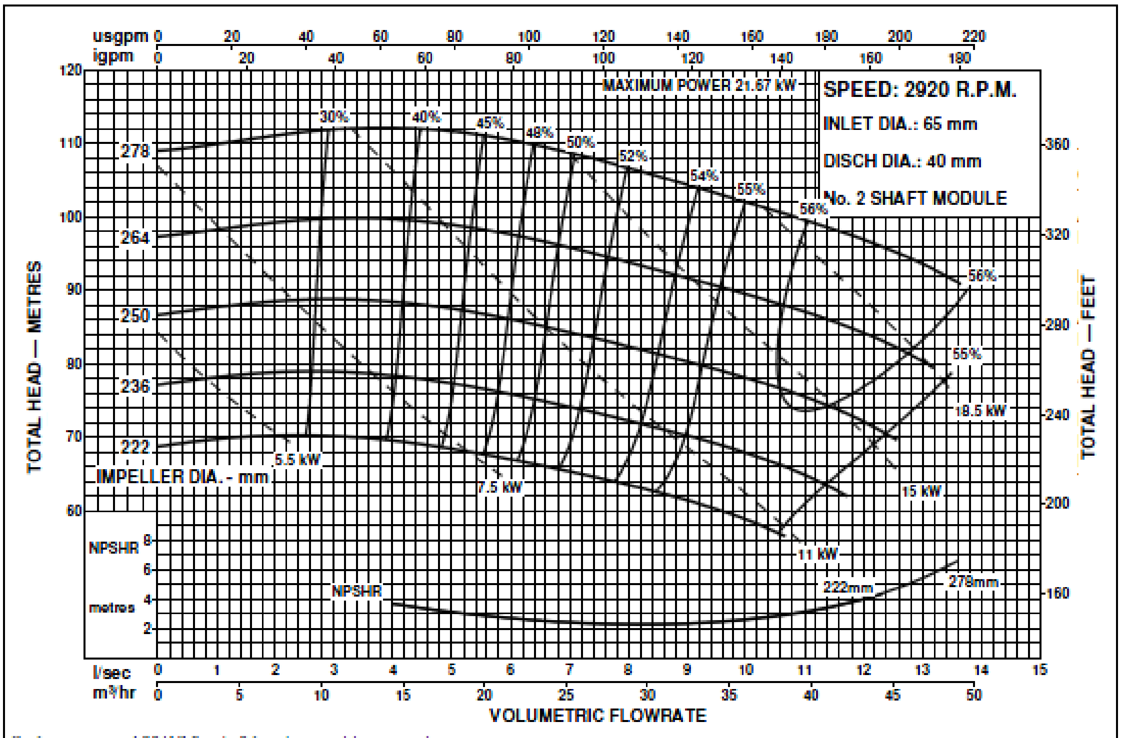
PENTAIR

Southern Cross

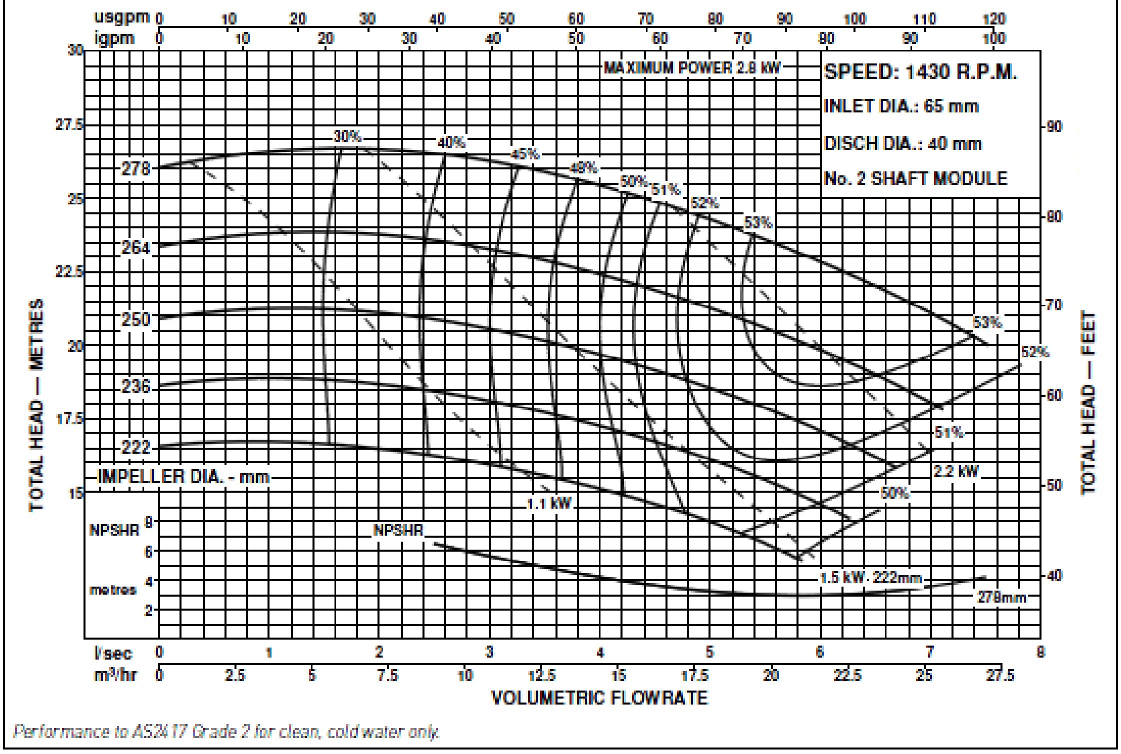
ISO2858
END SUCTION PUMPS
50Hz PERFORMANCE

MODEL
65x40-250

CENTRIFUGAL PUMP PERFORMANCE DATA



Performance to AS2417 Grade 2 for clean, cold water only.



Performance to AS2417 Grade 2 for clean, cold water only.

PENTAIR

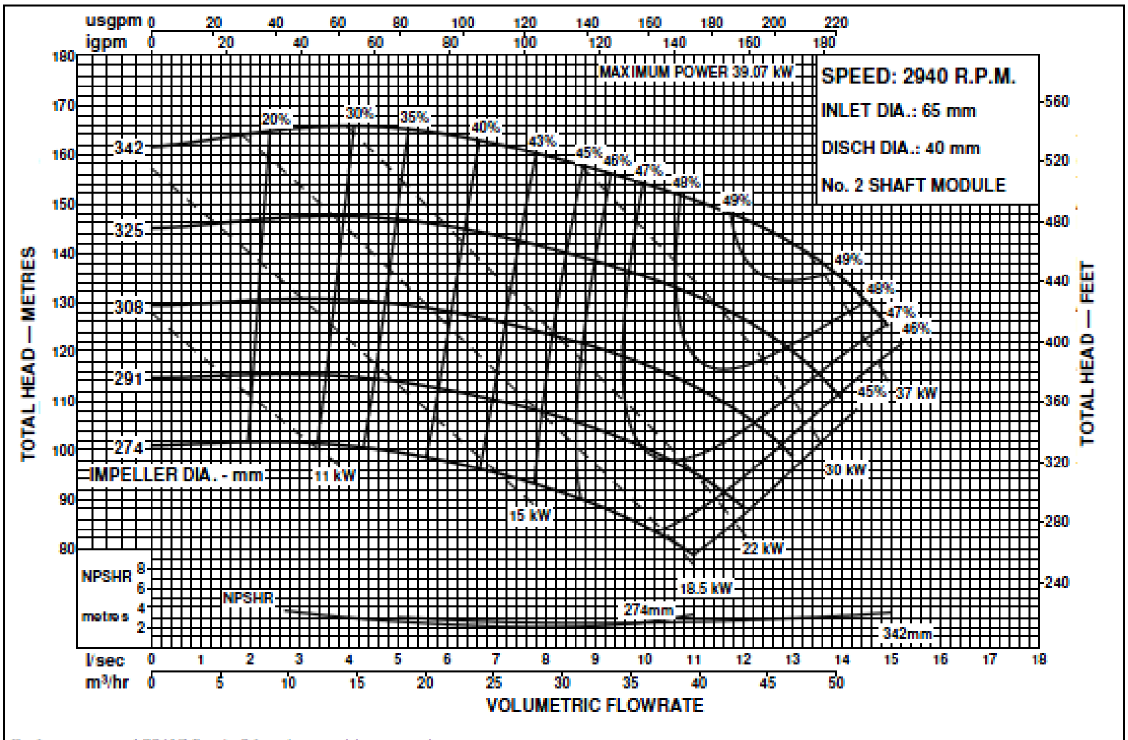
Southern Cross

CENTRIFUGAL PUMP PERFORMANCE DATA

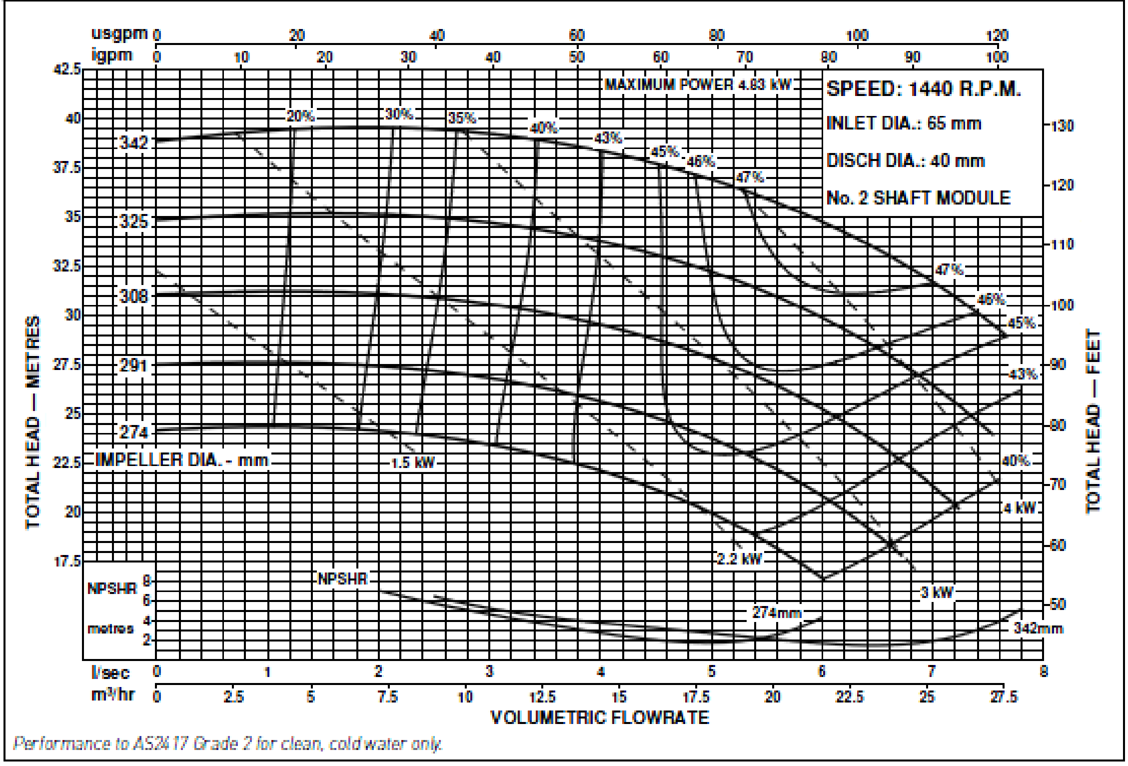
ISO2858

END SUCTION PUMPS
50Hz PERFORMANCE

MODEL
65x40-315



Performance to AS2417 Grade 2 for clean, cold water only.



Performance to AS2417 Grade 2 for clean, cold water only.

PENTAIR

Appendix C

Matlab Code for Simulations

Head Required for each Pump Model at BEP's

```
%Required Head for different pump models
clear
clc
%Turbine Speed
Nt=2300;
%For Model 50x32-200 Southern Cross Centrifugal
%Pump Speed at BEP

Np=2960;
nth=.73;
Hbep=57;
Ht=((Nt/Np)^2)*(Hbep/(nth^1.2));
ifHt< 40;
disp('Optimal Head (m)');
disp(Ht);
else
%Pump 65*40-342
Np=2940;
nth=.49;
Hbep=150;
Ht=((Nt/Np)^2)*(Hbep/(nth^1.2))
disp('65*40-342 Not within Head Limit');
end

%Pump 65x40-274
Np=2940;
nth=.46;
Hbep=90;
Ht=((Nt/Np)^2)*(Hbep/(nth^1.2))
ifHt< 40;
disp('65x40-274 within limit, Optimal Head (m).');
disp(Ht);
```

```
else
disp('65x40-274 Not within Head Limit');
end

%Pump 65x40-278
Np=2920;
nth=.56;
Hbep=100;
Ht=((Nt/Np)^2)*(Hbep/(nth^1.2))
ifHt< 40;
disp('65x40-278 within limit, Optimal Head (m).');
disp(Ht);
else
disp('65x40-278 Not within Head Limit');
end

%Pump 65x40-222
Np=2920;
nth=.55;
Hbep=62;
Ht=((Nt/Np)^2)*(Hbep/(nth^1.2))
ifHt< 40;
disp('65x40-222 within limit, Optimal Head (m).');
disp(Ht);
else
disp('65x40-222 Not within Head Limit');
end

%Pump 65x40-228
Np=2910;
nth=.66;
Hbep=70;
Ht=((Nt/Np)^2)*(Hbep/(nth^1.2))
```

```
ifHt< 40;
disp('65x40-228 within limit, Optimal Head (m).');
disp(Ht);
else
disp('65x40-228 Not within Head Limit');
end

%Pump 65x40-182
Np=2910;
nth=.64;
Hbep=42;
Ht=((Nt/Np)^2)*(Hbep/(nth^1.2))
ifHt< 40;
disp('65x40-182 within limit, Optimal Head (m).');
disp(Ht);
else
disp('65x40-182 Not within Head Limit');
end

%Pump 65x50-182
Np=2890;
nth=.71;
Hbep=39;
Ht=((Nt/Np)^2)*(Hbep/(nth^1.2))
ifHt< 40;
disp('65x50-182 within limit, Optimal Head (m).');
disp(Ht);
else
disp('65x50-182 Not within Head Limit');
end

%Pump 65x50-146
Np=2890;
```

```
nth=.67;
Hbep=26;
Ht=((Nt/Np)^2)*(Hbep/(nth^1.2))
ifHt< 40;
disp('65x50-146 within limit, Optimal Head (m).');
disp(Ht);
else
disp('65x50-146 Not within Head Limit');
end

%Pump 50x32-228
Np=2900;
nth=.55;
Hbep=65;
Ht=((Nt/Np)^2)*(Hbep/(nth^1.2))
ifHt< 40;
disp('50x32-228 within limit, Optimal Head (m).');
disp(Ht);
else
disp('50x32-228 Not within Head Limit');
end

%Pump 50x32-182
Np=2900;
nth=.54;
Hbep=42;
Ht=((Nt/Np)^2)*(Hbep/(nth^1.2))
ifHt< 40;
disp('50x32-182 within limit, Optimal Head (m).');
disp(Ht);
else
disp('50x32-182 Not within Head Limit');
end
```

```
%Pump 50x32-182.2
Np=2880;
nth=.625;
Hbep=40;
Ht=((Nt/Np)^2)*(Hbep/(nth^1.2))
ifHt< 40;
disp('50x32-182.2 within limit, Optimal Head (m).');
disp(Ht);
else
disp('50x32-182.2 Not within Head Limit');
end

%Pump 50*32-146
Np=2880;
nth=.6;
Hbep=25;
Ht=((Nt/Np)^2)*(Hbep/(nth^1.2))
ifHt< 40;
disp('50*32-146 within limit, Optimal Head (m).');
disp(Ht);
else
disp('50*32-146 Not within Head Limit');
end

%Pump 50*32-160
Np=2880;
nth=.62;
Hbep=31;
Ht=((Nt/Np)^2)*(Hbep/(nth^1.2))
ifHt< 40;
disp('50*32-160 Experimental Prototype within limit, Optimal Head (m).');
disp(Ht);
```

```
else
disp('50*32-160. Experimental Prototype Not within Head Limit');
end
```

Output into Command Window

```
Ht=  216.0812
65*40-342 Not within Head Limit

Ht=  139.8602
65x40-274 Not within Head Limit

Ht=  124.4126
65x40-278 Not within Head Limit

Ht =   78.8218
65x40-222 Not within Head Limit

Ht =   71.9971
65x40-228 Not within Head Limit

Ht =   44.8232
65x40-182 Not within Head Limit

Ht =   37.2576
65x50-182 within limit, Optimal Head (m).
   37.2576

Ht =   26.6283
65x50-146 within limit, Optimal Head (m).
   26.6283

Ht =   83.7795
50x32-228 Not within Head Limit
```

Ht = 55.3397

50x32-182 Not within Head Limit

Ht = 44.8409

50x32-182.2 Not within Head Limit

Ht = 29.4326

50*32-146 within limit, Optimal Head (m).

29.4326

Ht = 35.0883

50*32-160 Experimental Prototype within limit, Optimal Head (m).

35.0883

Flow Required at BEP's

```
%Turbine Speed
Nt=2300;
%For Models of Southern Cross Centrifugal pumps
%Pump Speed at BEP

disp('Operation Conditions as 2300 RPM');

%For model 50x32-146
Np=2880;
nth=.60;
%Flow rate at BEP (L/s)
Qbep=5;
%Qt=flow rate (L/s)
Qt=(Nt/Np)*(Qbep/(nth^0.8));
disp('Flow rate condition For model 50x32-146 (l/s)');
disp(Qt);

%For model 50x32-160
Np=2880;
nth=.62;
%Flow rate at BEP (L/s)
Qbep=5.5;
%Qt=flow rate (L/s)
Qt=(Nt/Np)*(Qbep/(nth^0.8));
disp('Flow rate condition For model 50x32-160 (l/s)');
disp(Qt);

%For model 65x50-146
Np=2890;
nth=.67;
%Flow rate at BEP (L/s)
Qbep=6.9;
```

```
%Qt=flow rate (L/s)
Qt=(Nt/Np)*(Qbep/(nth^0.8));
disp('Flow rate condition For model 65x50-146 (l/s)');
disp(Qt);

%For model 65x50-182
Np=2890;
nth=.71;
%Flow rate at BEP (L/s)
Qbep=10.4;
%Qt=flow rate (L/s)
Qt=(Nt/Np)*(Qbep/(nth^0.8));
disp('Flow rate condition For model 65x50-182 (l/s)');
disp(Qt);
```

Output into Command Window

```
Operation Conditions as 2300 RPM
Flow rate condition For model 50x32-146 (l/s)
    6.0088
Flow rate condition For model 50x32-160 (l/s)
    6.4385
Flow rate condition For model 65x50-146 (l/s)
    7.5652
Flow rate condition For model 65x50-182 (l/s)
   10.8857
```

Appendix D

Risk Assessment

University of Southern Queensland

Risk Management Plan

http://www.usq.edu.au/hr/healthsafe/safetyproc/whsmanual/whsmanr1.htm

Date: 03/06/2013	**Faculty/Dept:** FACULTY OF ENGINEERING AND SURVEYING	**Assessment completed by:** Nicholas Burton-Ree Les Bowtell Malcolm Gillies	**Contact No:** 0400861173
What is the task? Testing hydroelectric generator prototype		**Location where task is being conducted:** Hydraulic labs - Z block	
Why is the task being conducted? To gather data for the operation of the PAT system			
What are the nominal conditions? Controlled Environment with minimal Hazards			

Personnel	Equipment	Environment	Other
Nicholas Burton-Ree Les Bowetell Malcolm Gillies	Prototype, Taco Meter, Flow Meter, Barometer, Tool Set, Volt Meter, Amp Meter, Wind Resistor, First Aid Kit	Hydraulic labs - Z block (controlled)	

Briefly explain the procedure for this task (incl. Ref to other procedures)

PAT prototype is connected to the 15m head tank system

The system is opened up and testing begins

Data is recorded and then the test is disconnected then packed up.

Risk Register and Analysis

[ALARP = As Low As Reasonably Practicable]

Element or Sub Element/ Process Step	**The Risk:** **What can happen and what will be the result**	EXISTING CONTROLS	Risk **Rating** with existing controls? See next page			**Is it ALARP?** **Yes/No**	ADDITIONAL CONTROLS REQUIRED	**Risk Rating with additional controls?**			**Is it ALARP?** **Yes/No**	**Risk Decision:** **Accept** **Transfer** **Treat**
– List major steps or tasks in process	– Electric shock – Eye infection – Fire / explosion – Physical injury – Cut / graze – Chemical burn	List all current controls that are already in place or that will be used to undertake the task eg – List of Personal Protective Equipment (PPE) – Identify types facility, location – Existing safety measurers – Existing emergency procedures	**Consequences**	**Likelihood**	**Rating**		Additional controls may be required to reduce risk rating eg – Greater containment (PC2) – Additional PPE – gloves safety glasses – Specific induction / training	**Consequences**	**Likelihood**	**Rating**		
PAT prototype is connected to the 15m head tank system	Physical Injury Slip Hazard	Lifting Correctly Ensuring all water spills are cleaned up immediately PPE was worn	2	D	L	yes						

Element or Sub Element/ Process Step	**The Risk:** **What can happen and what will be the result**	EXISTING CONTROLS	Risk **Rating** with existing controls? See next page			**Is it ALARP?** **Yes/No**	ADDITIONAL CONTROLS REQUIRED	**Risk Rating with additional controls?**			**Is it ALARP?** **Yes/No**	**Risk Decision:** **Accept** **Transfer** **Treat**
The system is opened up and testing begins	Moving components could cause injury Slip Hazard	Guards built on the PAT Ensuring all water spills are cleaned up immediately PPE was worn	3	E	L	Yes						
Data is recorded and then the test is disconnected then packed up.	Physical Injury Slip Hazard	Lifting Correctly Ensuring all water spills are cleaned up immediately PPE was worn	2	D	L	yes						

Risk Treatment Schedule

Notes
The Testing was supervised by both Ma Les Bowetell and Malcolm Gillies
All conditions during testing were controlled to minimise Hazards
Personnel Protective Equipment was worn (PPE)

The task should not proceed if the risk rating after the controls are implemented is still either HIGH or EXTREME or if any risk is not As Low As Reasonably Practicable (ALARP).

<u>This Risk Assessment score of Low (L) is only on the condition that all existing and additional controls are in place at the time of the task being conducted.</u>

Assessment completed by:

Name: Nicholas Burton-Ree

Position: Student

Date: 03/06/2013

Supervisor or Designated Officer

Name: Les Bowtell

Position: Supervisor

Date:03/06/2013

Guidance Notes for review of Controls and Risk Management Plan.

When monitoring the effectiveness of **control measures**, it may be helpful to ask the following questions:

- **Have the chosen control measures been implemented as planned?**
    - Are the chosen control measures in place?
    - Are the measures being used?
    - Are the measures being used correctly?
- **Are the chosen control measures working?**
    - Have any the changes made to manage exposure to the assessed risks resulted in what was intended?
    - Has exposure to the assessed risks been eliminated or adequately reduced?
- **Are there any new problems?**
    - Have the implemented control measures introduced any new problems?
    - Have the implemented control measures resulted in the worsening of any existing problems?

To answer these questions:

- consult with workers, supervisors and health and safety representatives;
- measure people's exposure (e.g. taking noise measurements in the case of isolation of a noise source);
- consult and monitor incident reports; and
- review safety committee meeting minutes where possible.

Set a date for the review of the **risk management process**. When reviewing, check if:

- the process that is currently in place is still valid;
- things have changed that could make the operating processes or system outdated;
- technological or other changes have affected the current workplace; and
- a different system should be used altogether.

Note: In estimating the level of risk, initially estimate the risk with existing controls and then review risk controls if risk level arising from the risks is not minimal

Table 1 - Consequence

Level	Descriptor	Examples of Description
1	Insignificant	No injuries. Minor delays. Little financial loss. $0 - $4,999*
2	Minor	First aid required. Small spill/gas release easily contained within work area. Nil environmental impact. Financial loss $5,000 - $49,999*
3	Moderate	Medical treatment required. Large spill/gas release contained on campus with help of emergency services. Nil environmental impact. Financial loss $50,000 - $99,999*
4	Major	Extensive or multiple injuries. Hospitalisation required. Permanent severe health effects. Spill/gas release spreads outside campus area. Minimal environmental impact. Financial loss $100,000 - $250,000*
5	Catastrophic	Death of one or more people. Toxic substance or toxic gas release spreads outside campus area. Release of genetically modified organism (s) (GMO). Major environmental impact. Financial loss greater than $250,000*

* Financial loss includes direct costs eg workers compensation and property damage and indirect costs, eg impact of loss of research data and accident investigation time.

Table 2 - Probability

Level	Descriptor	Examples of Description
A	Almost certain	The event is expected to occur in most circumstances. Common or repetitive occurrence at USQ. Constant exposure to hazard. Very high probability of damage.
B	Likely	The event will probably occur in most circumstances. Known history of occurrence at USQ. Frequent exposure to hazard. High probability of damage.

C	Possible	The event could occur at some time. History of single occurrence at USQ. Regular or occasional exposure to hazard. Moderate probability of damage.
D	Unlikely	The event is not likely to occur. Known occurrence in industry. Infrequent exposure to hazard. Low probability of damage.
E	Rare	The event may occur only in exceptional circumstances. No reported occurrence globally. Rare exposure to hazard. Very low probability of damage. Requires multiple system failures.

Table 3 – Risk Rating

Probability	**Consequence**				
	Insignificant 1	**Minor** 2	**Moderate** 3	**Major** 4	**Catastrophic** 5
A (Almost certain)	**M**	**H**	**E**	**E**	**E**
B (Likely)	**M**	**H**	**H**	**E**	**E**
C (Possible)	**L**	**M**	**H**	**H**	**H**
D (Unlikely)	**L**	**L**	**M**	**M**	**M**
E (Rare)	**L**	**L**	**L**	**L**	**L**

Recommended Action Guide:

Abbrev	Action Level	Descriptor
E	Extreme	The proposed task or process activity MUST NOT proceed until the supervisor has reviewed the task or process design and risk controls. They must take steps to firstly eliminate the risk and if this is not possible to introduce measures to control the risk by reducing the level of risk to the lowest level achievable. In the case of an existing hazard that is identified, controls must be put in place immediately.
H	High	Urgent action is required to eliminate or reduce the foreseeable risk arising from the task or process. The supervisor must be made aware of the hazard. However, the supervisor may give special permission for staff to undertake some high risk activities provided that system of work is clearly documented, specific training has been given in the required procedure and an adequate review of the task and risk controls has been undertaken. This includes providing risk controls identified in Legislation, Australian Standards, Codes of Practice etc.* A detailed Standard Operating Procedure is required. * and monitoring of its implementation

		must occur to check the risk level
M	Moderate	Action to eliminate or reduce the risk is required within a specified period. The supervisor should approve all moderate risk task or process activities. A Standard Operating Procedure or Safe Work Method statement is required
L	Low	Manage by routine procedures.

*Note: These regulatory documents identify specific requirements/controls that must be implemented to reduce the risk of an individual undertaking the task to a level that the regulatory body identifies as being acceptable.

Task Safety Analysis Form

Risk Assessment No: 1 Task No: 1

Task:	Maintenance on Prototype Pump	Work Area:	Hydraulic Labs, Z Block, USQ	Date:	02/06/13
Title of person/s who does job:	Mr Nicholas Burton-Ree	Supervisor	Malcolm Gillies, Les Bowtell		
Department:	Engineering	Faculty/Section:	Faculty of Health, Science and Engineering	Has Supervisor reviewed & approved?	**Y**
Assessed by:	Les Bowetell				
PPE Required:	Closed in shoes	Tools/Equipment required:	Spanner Set, Hammers, Drill		
	Long Sleeve Shirt		Rags		

Task Step:	Hazards:	Existing Provisions	Proposed Improvements
Isolate pump from electric motor	Electric motor could start	Motor unplugged	NA
Remove casing	Hit knuckles or drop casing on foot	Steel capped boots	NA
Clean Rubbish of impellor	Injure self with file Rubbish in eye	Wear Safety Glasses	NA
Change oil	Spill Oil and Slip	Ensure all oil can be caught and have a rag ready to clean up	NA
Put casing back onto pump	Drop on feet	Steel capped boots	NA

Appendix E

Tables

Table 15 Gantt Chart

Table 16 - Deadlines

Project 2013			
Tasks	Start	Days	End
Project Specification	4-Mar	23	27-Mar
Literature research	27-Mar	16	12-Apr
Dissertation	12-Apr	192	21-Oct
Literature research (PAT)	12-Apr	41	23-May
Chapter 1	19-Apr	27	16-May
Chapter 2	26-Apr	27	23-May
Presentation	16-May	7	23-May
Preliminary Report	12-May	17	29-May
Lab Testing	29-May	31	29-Jun
Theoretical Calculations	29-Jun	53	21-Aug
Chapter 3	10-Jun	28	8-Jul
Chapter 4	8-Jul	33	10-Aug
Chapter 5	10-Aug	41	20-Sep
Chapter 6	20-Sep	18	8-Oct
Second Presentation	20-Sep	14	4-Oct
Proof Reading	8-Oct	13	21-Oct

Power Required for AC appliances

Table 17 Average Ceiling fan consumption

Model	Carera 3 blade	Bayside 5 blade	Maribel 5 blade	Sonic 4 blade	Wengue 3 blade	Xavier 5 blade	Average Power consumption
Fan consumption (Kwhr . year)	876	403	876	569	350	569	607
Fan consumption (Watts)	100	46	100	65	40	65	69

Table 18 Average Refrigerator consumption

Model	Lemair 42L	Airflow 115L	Hair 55L	Fisher and Paykel 115L	Hair 75L	Smeg 135L	Average Power consumption
Fridge consumption (Kwhr . year)	220	262	146	279	183	245	223
Fridge consumption (Watts)	25	30	17	32	21	28	26

Table 19 Pump Model BEP's

Pump Model	**Head (m)**	**BEP %**	**RPM**
65x50-146	27	67	2890
50x32-146	30	59	2880
50x32-160 Prototype	35	62	2880
65x50-182	37	71	2890
50x32-182	45	63	2880
65x40-182	45	64	2910
50x32-182.2	55	54	2900
65x40-228	72	66	2910
65x40-222	79	55	2920
50x32-228	84	55	2900
65x40-278	124	56	2920
65x40-274	140	46	2940
65x40-342	216	49	2940

The Total Flow Rate through the system				**This number represents the head that is lost and not available to the turbine**		
10	**L/s**	0.01	m3/s	**Total Loss**	**9.18342179**	
0.003	mm	0.000003	m	Velocity	0.548201456	m/s
152.4	mm	0.1524	m	Reynolds	83545.90189	
100	m			f	0.018664609	bar equation quick rough estimate of more accurate colebrook white
0.5						
2				Friction loss	0.187592424	m
				Kinetic head	0.01531727	m
				Minor Loss	0.038293175	m
32	mm	0.032	m	Velocity	12.43397993	m/s
0.45				Kinetic head	7.879911156	m
				Minor loss in 6" - 32mm	3.54596002	m
0.003	mm	0.000003	m	Velocity	5.092958179	m/s
50	mm	0.05	m	Reynolds	254647.9089	
10	m			f	0.015466923	bar equation quick rough estimate of more accurate colebrook white
1						
0	no fittings in exit pipe			Friction loss	4.089546452	m
				Kinetic head	1.322029715	m
				Minor Loss	1.322029715	m

Appendix F

Stormwater Runoff

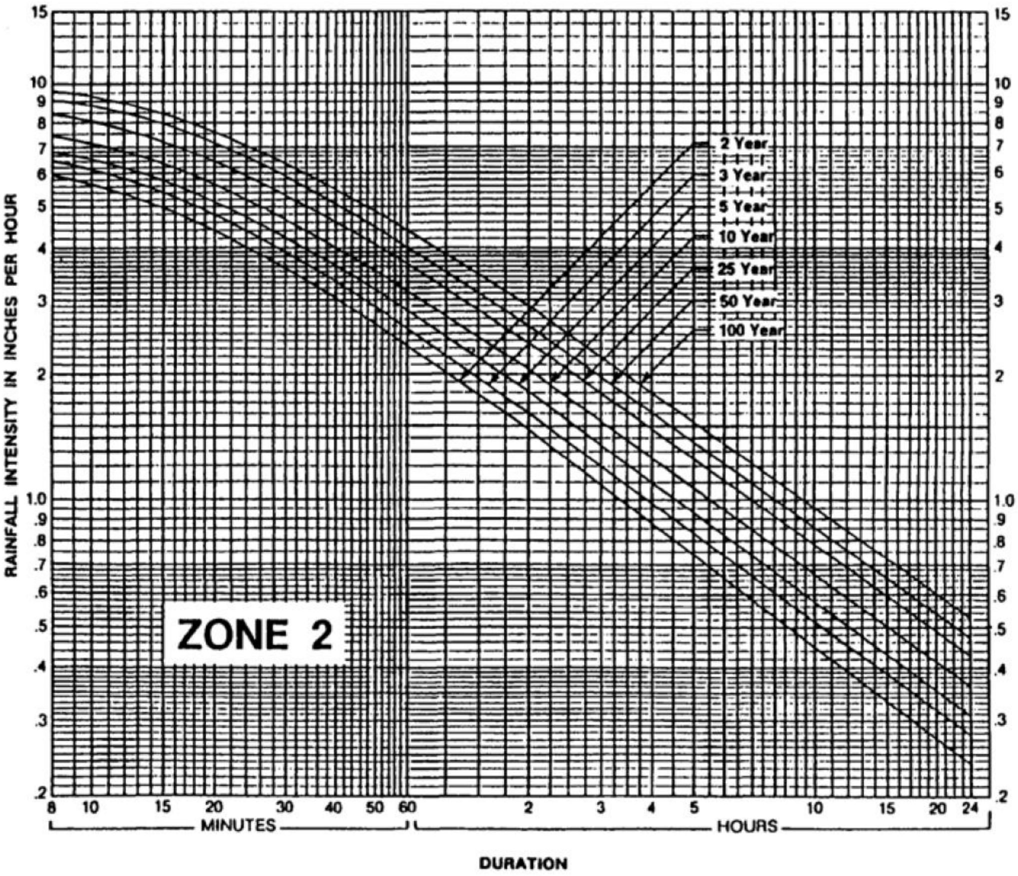
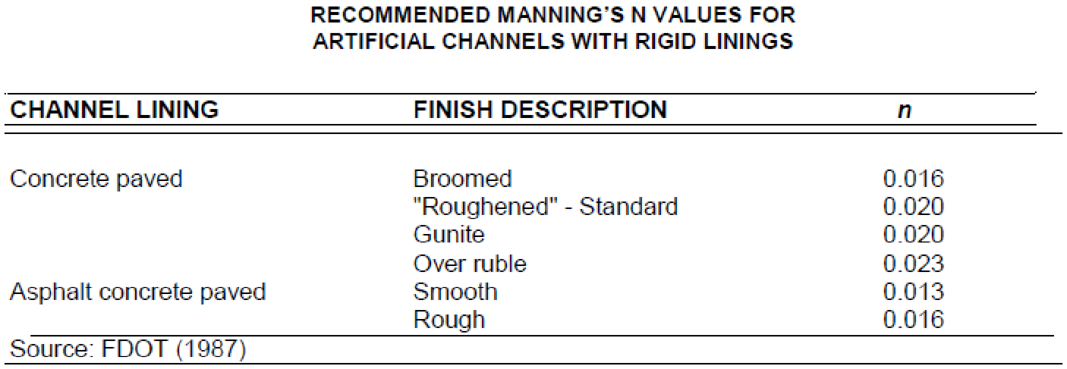


Figure 37 Rain Intensity Duration

Table 20 Recommended Manning's Value



RECOMMENDED MANNING'S N VALUES FOR ARTIFICIAL CHANNELS WITH RIGID LININGS

CHANNEL LINING	FINISH DESCRIPTION	*n*
Concrete paved	Broomed	0.016
	"Roughened" - Standard	0.020
	Gunite	0.020
	Over ruble	0.023
Asphalt concrete paved	Smooth	0.013
	Rough	0.016

Source: FDOT (1987)

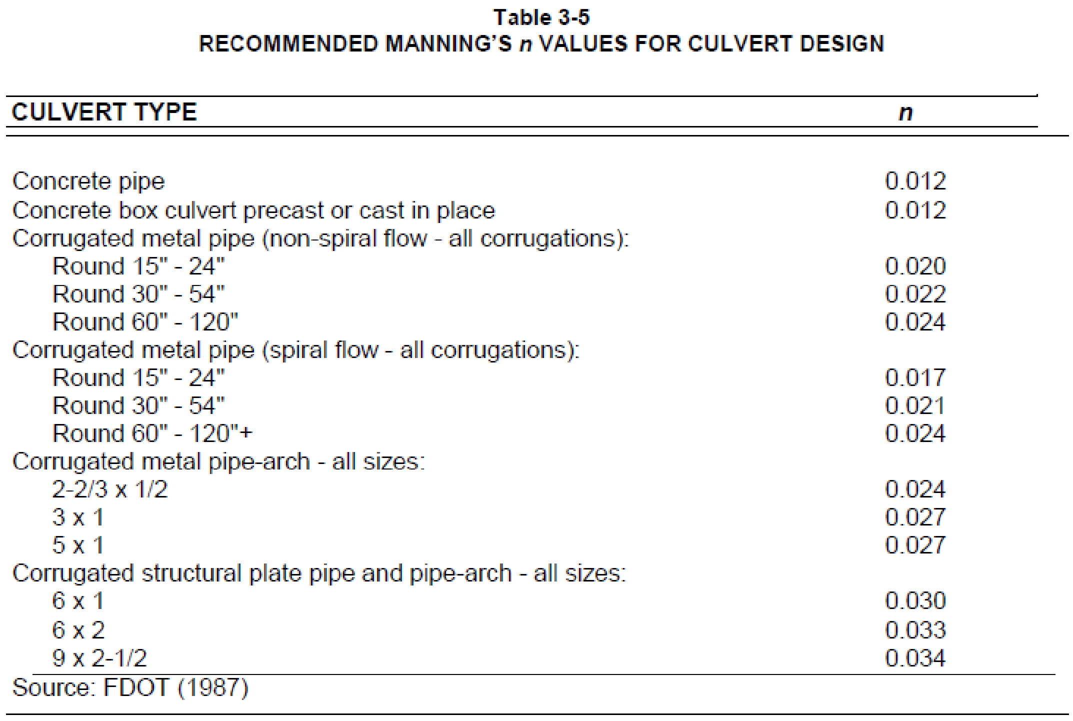


Table 3-5
RECOMMENDED MANNING'S *n* VALUES FOR CULVERT DESIGN

CULVERT TYPE	*n*
Concrete pipe	0.012
Concrete box culvert precast or cast in place	0.012
Corrugated metal pipe (non-spiral flow - all corrugations):	
Round 15" - 24"	0.020
Round 30" - 54"	0.022
Round 60" - 120"	0.024
Corrugated metal pipe (spiral flow - all corrugations):	
Round 15" - 24"	0.017
Round 30" - 54"	0.021
Round 60" - 120"+	0.024
Corrugated metal pipe-arch - all sizes:	
2-2/3 x 1/2	0.024
3 x 1	0.027
5 x 1	0.027
Corrugated structural plate pipe and pipe-arch - all sizes:	
6 x 1	0.030
6 x 2	0.033
9 x 2-1/2	0.034

Source: FDOT (1987)

Table 21 Surface Description

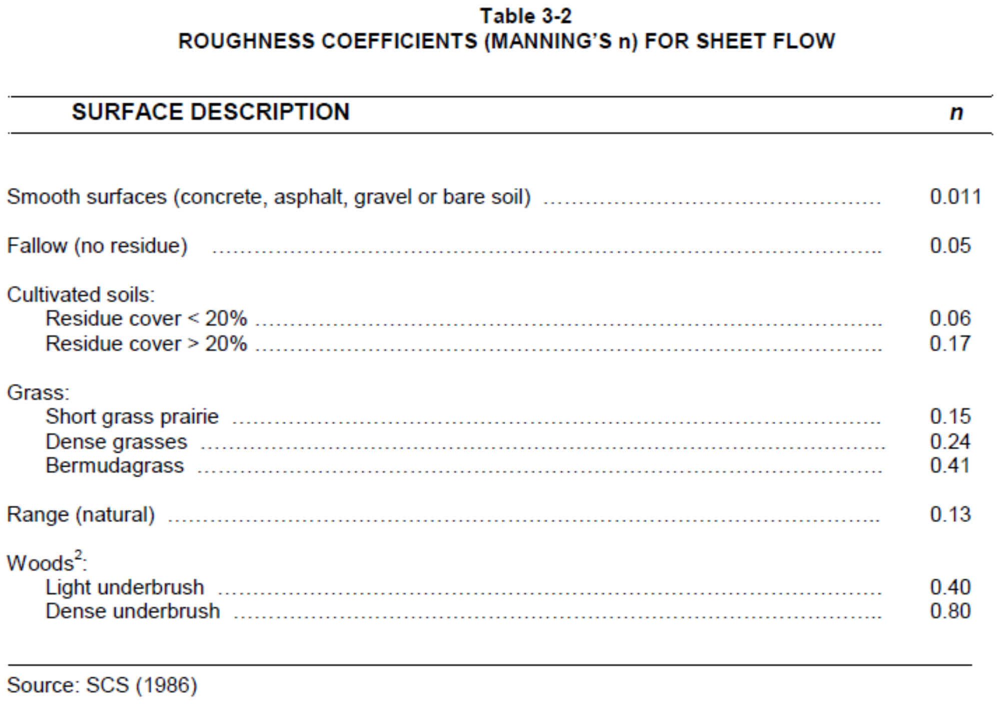
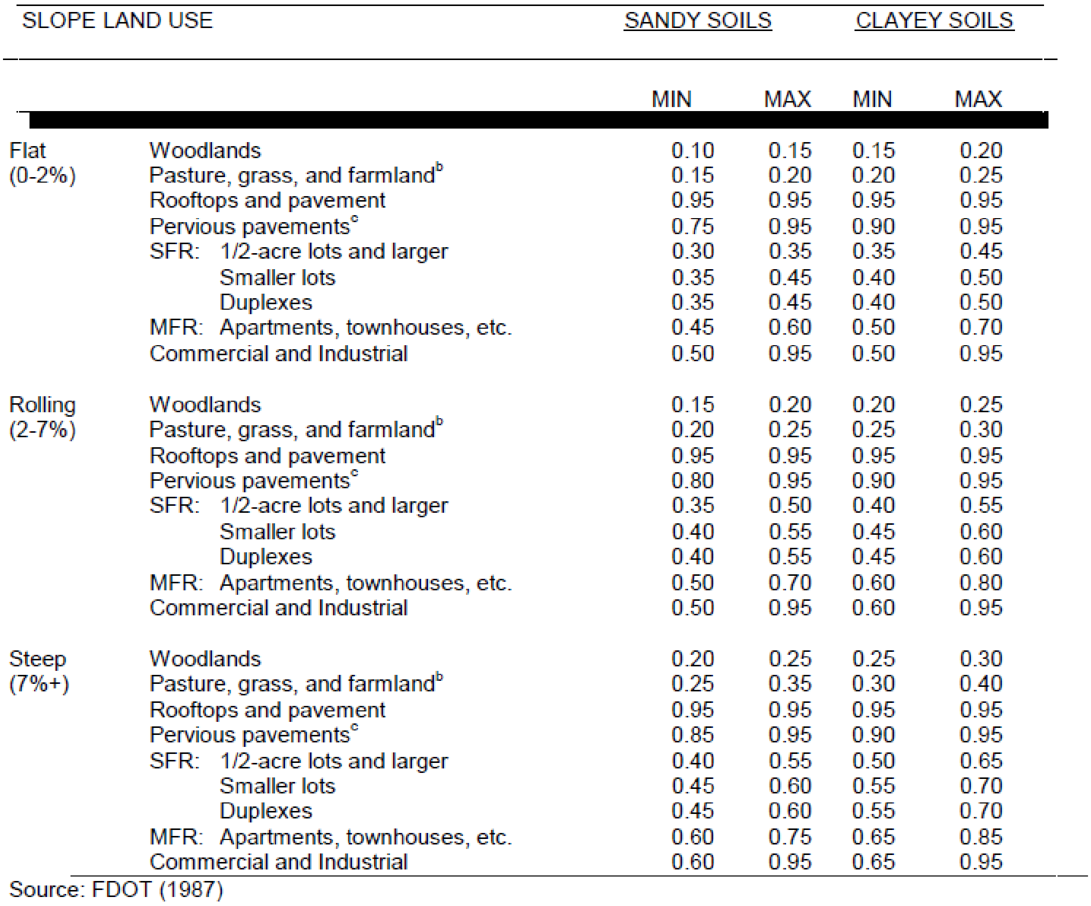


Table 3-2
ROUGHNESS COEFFICIENTS (MANNING'S n) FOR SHEET FLOW

SURFACE DESCRIPTION	*n*
Smooth surfaces (concrete, asphalt, gravel or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated soils:	
Residue cover < 20%	0.06
Residue cover > 20%	0.17
Grass:	
Short grass prairie	0.15
Dense grasses	0.24
Bermudagrass	0.41
Range (natural)	0.13
Woods[2]:	
Light underbrush	0.40
Dense underbrush	0.80

Source: SCS (1986)

Table 22 Channel Flow Pattern



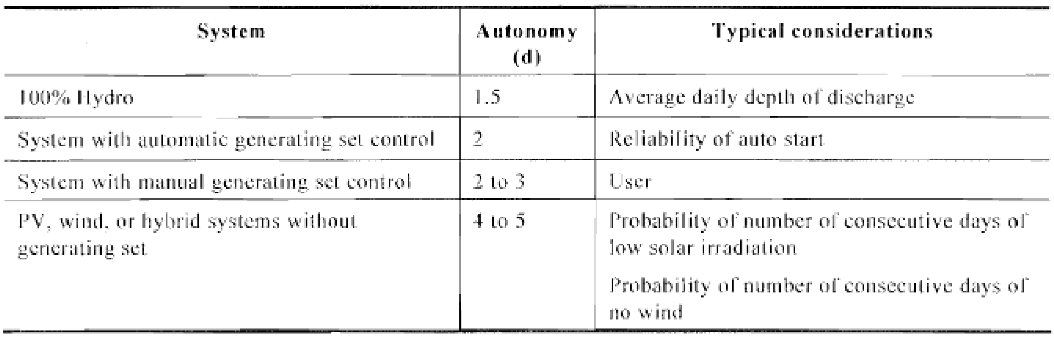
SLOPE	LAND USE	SANDY SOILS		CLAYEY SOILS	
		MIN	MAX	MIN	MAX
Flat (0-2%)	Woodlands	0.10	0.15	0.15	0.20
	Pasture, grass, and farmland[b]	0.15	0.20	0.20	0.25
	Rooftops and pavement	0.95	0.95	0.95	0.95
	Pervious pavements[c]	0.75	0.95	0.90	0.95
	SFR: 1/2-acre lots and larger	0.30	0.35	0.35	0.45
	Smaller lots	0.35	0.45	0.40	0.50
	Duplexes	0.35	0.45	0.40	0.50
	MFR: Apartments, townhouses, etc.	0.45	0.60	0.50	0.70
	Commercial and Industrial	0.50	0.95	0.50	0.95
Rolling (2-7%)	Woodlands	0.15	0.20	0.20	0.25
	Pasture, grass, and farmland[b]	0.20	0.25	0.25	0.30
	Rooftops and pavement	0.95	0.95	0.95	0.95
	Pervious pavements[c]	0.80	0.95	0.90	0.95
	SFR: 1/2-acre lots and larger	0.35	0.50	0.40	0.55
	Smaller lots	0.40	0.55	0.45	0.60
	Duplexes	0.40	0.55	0.45	0.60
	MFR: Apartments, townhouses, etc.	0.50	0.70	0.60	0.80
	Commercial and Industrial	0.50	0.95	0.60	0.95
Steep (7%+)	Woodlands	0.20	0.25	0.25	0.30
	Pasture, grass, and farmland[b]	0.25	0.35	0.30	0.40
	Rooftops and pavement	0.95	0.95	0.95	0.95
	Pervious pavements[c]	0.85	0.95	0.90	0.95
	SFR: 1/2-acre lots and larger	0.40	0.55	0.50	0.65
	Smaller lots	0.45	0.60	0.55	0.70
	Duplexes	0.45	0.60	0.55	0.70
	MFR: Apartments, townhouses, etc.	0.60	0.75	0.65	0.85
	Commercial and Industrial	0.60	0.95	0.65	0.95

Source: FDOT (1987)

Appendix G

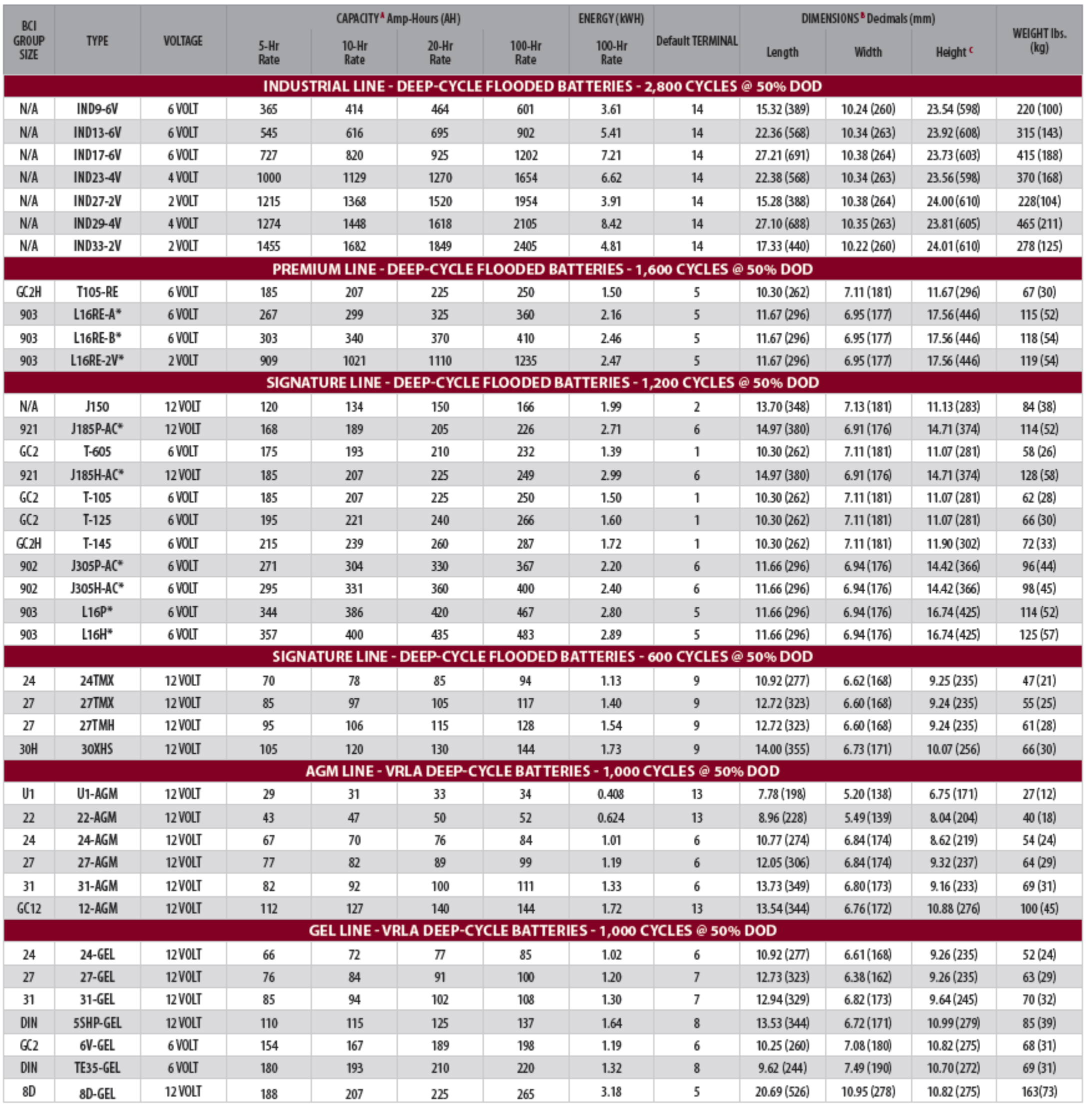
Battery Requirements

Table 23 Australian Standards - Autonomy



System	Autonomy (d)	Typical considerations
100% Hydro	1.5	Average daily depth of discharge
System with automatic generating set control	2	Reliability of auto start
System with manual generating set control	2 to 3	User
PV, wind, or hybrid systems without generating set	4 to 5	Probability of number of consecutive days of low solar irradiation Probability of number of consecutive days of no wind

Table 24 Battery Specification Guide



BCI GROUP SIZE	TYPE	VOLTAGE	CAPACITY ^{A} Amp-Hours (AH)				ENERGY (kWH)	Default TERMINAL	DIMENSIONS ^{B} Decimals (mm)			WEIGHT lbs. (kg)
			5-Hr Rate	10-Hr Rate	20-Hr Rate	100-Hr Rate	100-Hr Rate		Length	Width	Height ^{C}	
INDUSTRIAL LINE - DEEP-CYCLE FLOODED BATTERIES - 2,800 CYCLES @ 50% DOD												
N/A	IND9-6V	6 VOLT	365	414	464	601	3.61	14	15.32 (389)	10.24 (260)	23.54 (598)	220 (100)
N/A	IND13-6V	6 VOLT	545	616	695	902	5.41	14	22.36 (568)	10.34 (263)	23.92 (608)	315 (143)
N/A	IND17-6V	6 VOLT	727	820	925	1202	7.21	14	27.21 (691)	10.38 (264)	23.73 (603)	415 (188)
N/A	IND23-4V	4 VOLT	1000	1129	1270	1654	6.62	14	22.38 (568)	10.34 (263)	23.56 (598)	370 (168)
N/A	IND27-2V	2 VOLT	1215	1368	1520	1954	3.91	14	15.28 (388)	10.38 (264)	24.00 (610)	228(104)
N/A	IND29-4V	4 VOLT	1274	1448	1618	2105	8.42	14	27.10 (688)	10.35 (263)	23.81 (605)	465 (211)
N/A	IND33-2V	2 VOLT	1455	1682	1849	2405	4.81	14	17.33 (440)	10.22 (260)	24.01 (610)	278 (125)
PREMIUM LINE - DEEP-CYCLE FLOODED BATTERIES - 1,600 CYCLES @ 50% DOD												
GC2H	T105-RE	6 VOLT	185	207	225	250	1.50	5	10.30 (262)	7.11 (181)	11.67 (296)	67 (30)
903	L16RE-A*	6 VOLT	267	299	325	360	2.16	5	11.67 (296)	6.95 (177)	17.56 (446)	115 (52)
903	L16RE-B*	6 VOLT	303	340	370	410	2.46	5	11.67 (296)	6.95 (177)	17.56 (446)	118 (54)
903	L16RE-2V*	2 VOLT	909	1021	1110	1235	2.47	5	11.67 (296)	6.95 (177)	17.56 (446)	119 (54)
SIGNATURE LINE - DEEP-CYCLE FLOODED BATTERIES - 1,200 CYCLES @ 50% DOD												
N/A	J150	12 VOLT	120	134	150	166	1.99	2	13.70 (348)	7.13 (181)	11.13 (283)	84 (38)
921	J185P-AC*	12 VOLT	168	189	205	226	2.71	6	14.97 (380)	6.91 (176)	14.71 (374)	114 (52)
GC2	T-605	6 VOLT	175	193	210	232	1.39	1	10.30 (262)	7.11 (181)	11.07 (281)	58 (26)
921	J185H-AC*	12 VOLT	185	207	225	249	2.99	6	14.97 (380)	6.91 (176)	14.71 (374)	128 (58)
GC2	T-105	6 VOLT	185	207	225	250	1.50	1	10.30 (262)	7.11 (181)	11.07 (281)	62 (28)
GC2	T-125	6 VOLT	195	221	240	266	1.60	1	10.30 (262)	7.11 (181)	11.07 (281)	66 (30)
GC2H	T-145	6 VOLT	215	239	260	287	1.72	1	10.30 (262)	7.11 (181)	11.90 (302)	72 (33)
902	J305P-AC*	6 VOLT	271	304	330	367	2.20	6	11.66 (296)	6.94 (176)	14.42 (366)	96 (44)
902	J305H-AC*	6 VOLT	295	331	360	400	2.40	6	11.66 (296)	6.94 (176)	14.42 (366)	98 (45)
903	L16P*	6 VOLT	344	386	420	467	2.80	5	11.66 (296)	6.94 (176)	16.74 (425)	114 (52)
903	L16H*	6 VOLT	357	400	435	483	2.89	5	11.66 (296)	6.94 (176)	16.74 (425)	125 (57)
SIGNATURE LINE - DEEP-CYCLE FLOODED BATTERIES - 600 CYCLES @ 50% DOD												
24	24TMX	12 VOLT	70	78	85	94	1.13	9	10.92 (277)	6.62 (168)	9.25 (235)	47 (21)
27	27TMX	12 VOLT	85	97	105	117	1.40	9	12.72 (323)	6.60 (168)	9.24 (235)	55 (25)
27	27TMH	12 VOLT	95	106	115	128	1.54	9	12.72 (323)	6.60 (168)	9.24 (235)	61 (28)
30H	30XHS	12 VOLT	105	120	130	144	1.73	9	14.00 (355)	6.73 (171)	10.07 (256)	66 (30)
AGM LINE - VRLA DEEP-CYCLE BATTERIES - 1,000 CYCLES @ 50% DOD												
U1	U1-AGM	12 VOLT	29	31	33	34	0.408	13	7.78 (198)	5.20 (138)	6.75 (171)	27 (12)
22	22-AGM	12 VOLT	43	47	50	52	0.624	13	8.96 (228)	5.49 (139)	8.04 (204)	40 (18)
24	24-AGM	12 VOLT	67	70	76	84	1.01	6	10.77 (274)	6.84 (174)	8.62 (219)	54 (24)
27	27-AGM	12 VOLT	77	82	89	99	1.19	6	12.05 (306)	6.84 (174)	9.32 (237)	64 (29)
31	31-AGM	12 VOLT	82	92	100	111	1.33	6	13.73 (349)	6.80 (173)	9.16 (233)	69 (31)
GC12	12-AGM	12 VOLT	112	127	140	144	1.72	13	13.54 (344)	6.76 (172)	10.88 (276)	100 (45)
GEL LINE - VRLA DEEP-CYCLE BATTERIES - 1,000 CYCLES @ 50% DOD												
24	24-GEL	12 VOLT	66	72	77	85	1.02	6	10.92 (277)	6.61 (168)	9.26 (235)	52 (24)
27	27-GEL	12 VOLT	76	84	91	100	1.20	7	12.73 (323)	6.38 (162)	9.26 (235)	63 (29)
31	31-GEL	12 VOLT	85	94	102	108	1.30	7	12.94 (329)	6.82 (173)	9.64 (245)	70 (32)
DIN	5SHP-GEL	12 VOLT	110	115	125	137	1.64	8	13.53 (344)	6.72 (171)	10.99 (279)	85 (39)
GC2	6V-GEL	6 VOLT	154	167	189	198	1.19	6	10.25 (260)	7.08 (180)	10.82 (275)	68 (31)
DIN	TE35-GEL	6 VOLT	180	193	210	220	1.32	8	9.62 (244)	7.49 (190)	10.70 (272)	69 (31)
8D	8D-GEL	12 VOLT	188	207	225	265	3.18	5	20.69 (526)	10.95 (278)	10.82 (275)	163(73)

References

Alexandratos, N. (2005), *Countries with Rapid Population Growth and Resource Constraints: Issues of Food, Agriculture, and Development,* Population and Development Review**,** Volume 31, Issue 2: 237-258.

Bradshaw, Michael. (2013), Global Energy Dilemmas, Policy Press UK

Fischer, G. and Schrattenholzer, L., (2001), *Global bioenergy potentials through 2050*, in *Biomass and Bioenergy 20, p151-159,* Elsevier publishing.

Gaddis, John Lewis. *The United States and the End of the Cold War:Reconsiderations, Implications, Provocations*. New York: OxfordUniversity Press, 1992.

Haass, Richard. *The Reluctant Sheriff: The United States After theCold War*. New York: Council of Foreign Relations Press, 1997.

Rogner, Hans-Holger and Anca Popescu: Chapter1, World Energy Assessment, pp. 31-37, UNDP, 2000

Derakhshan, S. Nourbakhsh,(2007) A, *Experimental Study of Charecteristic curves of centrifugal pumps working as turbines in specific speeds,* Experimental Thermal and Fluid Sciencee, University Of Tehram, Iran

Rawel, S. Hshirsager.J.T, (2007), *Numerical Simulation on a Pump Operating in a Turbine Mode,* Cummins Research and Technology, Head, Coporate Research and Engineering Division, Pune, India.

G and M Poly Irrigation,(2012), *G and M Poly Irrigation 2012 Pricelist,* Murray Valley Highway, Cohuna

Australian/New Zealand Standar, (2010), *Stand Alone Power Systems. Part 2: System design,* Council of Standards Australia (22nd October 2010)

Hydroelectricity Fact Sheet,(2012)'An Overview of Hydroelectricity in Australia. p1-3, viewed 15 July 2013

Patent-based Technology Analysis Report, (2012)' Alternative Energy', World Intellectual property Organization, viewed 25 June 2013

Poullain. J. (2012), *Estimating Storm Water Runoff*. p 10-21, 5275 Meadow Estates Drive Fairfax, VA

Vinidex, System & Solutions,(2010), *PE Pipe Systems selection manual*, Irrigation Warehouse Group Pty Ltd <www.polypipe.com.au>

Williams,A. (1995), *Pumps As Turbines. A user's Guide*, Intermediate Technology Development Group, Intermediate Technology Publications

Moaveni, S. (2011), *Engineering Fundamentals : An Introduction to Engineering*, 4th edn, Institute of Technology, Kanpur

James,G.(2007), *Modern Engineering Mathematics*, 4th edn, Pearson, Edinburgh Gate, England.

Hamil, L.(2011), *Understanding Hydraulics*, 3rd edn, Palgrave Macmillan, p.337-471, Hampshire, England

William, J.P, (2011), *Introduction to Matlab for engineers*, 3rd edn, McGraw Hill, New York, USA

ELE1801 *N/A Electrical Technology : Study Book*, University Of Southern Queensland, Toowoomba