# SMALL HYDRO IN MANITOBA

BY

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A Thesis
Submitted to the Faculty of Graduate Studies
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for the Degree of

MASTER OF SCIENCE

Department of Mechanical & Industrial Engineering
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THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES

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A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University of Manitoba in partial fulfillment of the requirement of the degree

Of

MASTER OF SCIENCE

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# ABSTRACT

This thesis examines the feasibility of implementing small hydro as an alternative energy source in Manitoba. An alternative resource is sought to serve consumers in an environmentally and economically acceptable manner. Small hydro uses run-of-the-river concepts with kinetic turbine technologies; it does not allow water retention exceeding twenty four hours. This thesis examines small hydro according to the subjects of turbine technologies, flow management, site selection and economic analysis. Current reaction turbines and new off-the-shelf kinetic turbine designs may be used in conjunction with methodologies for increasing flow rates to produce a reasonable amount of power in an environmentally acceptable manner. Undeveloped small hydro sites exist in northern Manitoba where communities are currently served by costly diesel generation, and in more southern locations with transmission and road access. An economic analysis of small hydro requires a community survey, a cost-benefit analysis, and comparisons with other technologies. Conclusions indicate that small hydro is potentially viable in Manitoba and warrants a more detailed feasibility study.

# ACKNOWLEDGEMENTS

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# 1. INTRODUCTION

## 1.1 Purpose

This thesis evaluates the feasibility of the implementation of small hydro in Manitoba. Table 1.1 indicates the classifications of hydro as referenced in this thesis.

Table 1.1: Hydro Definitions

| Classification | | Turbines Employed | Power Output | Storage Capacity |
|---|---|---|---|---|
| Large Hydro | Low Head | Reaction | ≥ 50 MW | Unlimited |
| | High Head | Impulse | ≥ 50 MW | Unlimited |
| Small Hydro | Conventional | Reaction | ≤ 10 MW | ≤ 24 hours |
| | Non-Conventional | Tidal | ≤ 5 MW | None |
| | | Kinetic | ≤ 1 MW | None |

As demonstrated in Table 1.1, small hydro, (defined by Manitoba Hydro as 1 to 50 MW), may be classified as a hydro project producing less than 50 MW; however, a more detailed distinction is warranted. Run-of-the river hydro projects store water for less than 24 hours creating a design that may be used for large or small hydro. The majority of small hydro facilities are run-of-the-river; however the application of non-conventional technologies, including tidal and kinetic turbines, produces power without the utilization of any water storage. The development of non-conventional turbines is on-going and therefore the 5 and 1 MW classifications are approximations.

The completed research considers small hydro due to its potential for providing generation capacity, offsetting diesel fuel costs by serving remote communities, as well as requiring minimal infrastructure, resulting in reduced environmental impacts and costs. Potential economic benefits such as independent power producers (IPP) may occur as an indirect result of small hydro. The proposed small hydro is examined in reference to turbine technologies, river infrastructure, site selection and economics.

## 1.2 Problem

Current turbine designs require head and concrete dams, which can be costly and cause unfavourable environmental effects. It is desired to implement technologies which use run-of-the river concepts, thereby reducing costs and environmental impacts. Furthermore, small hydro is examined as an alternative energy resource with the potential for increasing capacity and/or replacing more costly energy sources.

## 1.3 Scope

The Background of the thesis provides a brief history of hydropower and distinguishes between large hydro and small hydro technologies to be researched. The Problem and Criteria Definition section discusses the problems associated with large and small hydro, as well as the aspects of small hydro to be examined. The chapters entitled Turbine Technologies, Flow Management, Site Selection and Economic Analysis provide a detailed analysis of potential small hydro implementation in Manitoba, and lead to Conclusions and Recommendations.

Since non-conventional small hydro technologies are continually being developed, the Internet became an important source for current information, in addition to journal articles and papers. The research examines the feasibility of implementing a new small hydro facility and therefore the issues associated with refurbishment or uses of existing civil structures have not been discussed. The major goal of this project is to assess the feasibility of establishing a small hydro installation, and therefore issues associated with grid connection and transmission, and controls were considered outside the scope of the research.

# 2. BACKGROUND

In today's world, the production of electricity and its usage has become necessary for our everyday living and needs; power production is directly linked to our standard of living. It is necessary to produce electricity in the most economic and environmentally benign fashion. Manitoba currently uses conventional large hydro to produce electricity, thus depending on a renewable resource. However, it is desired to seek new and novel developments in this industry, thus improving Manitoba's energy supply. Table 2.1 summarizes the capacity and cost of electricity produced from a sample of renewable resources in Canada.

Table 2.1: Electricity from Renewable Sources, 2002
Adapted from [39]

| Technology | Installed Capacity in Canada (MW) | Capital Cost ($/kW) | Cost of Energy ($/kWh) |
|---|---|---|---|
| Large Hydro | 67 000 | 1 000 - 2 000 | 0.03 - 0.08 |
| Small Hydro | 1 500 | 1 500 - 5 000 | 0.04 - 0.10 |
| Tidal | 20 | High | 0.08 - 0.20 |
| Wind | 230 | 1 000 - 4 000 | 0.05 - 0.20 |
| Photovoltaic | 10 | 5 000 - 20 000 | 0.35 - 1.50 |

As demonstrated in Table 2.1, hydro provides a significant contribution to electricity produced from renewable sources, and is done so with the lowest cost as compared to tidal, wind and photovoltaic power.

Over the past century, the production of hydroelectricity has progressed through many developments leading to distinct classifications of hydro turbines and their applications. Large hydro is still present, but when civil structures are removed, (completely or partially), and the scale of production is reduced, the operation may be referred to as small hydro.

## 2.1 A Brief History of Hydropower

The production of hydropower begins with the simple concept of capturing energy resulting from water and gravity. Today there are two general classifications of conventional turbines: impulse and reaction. Impulse turbines operate on the principle of momentum where a jet of water strikes a series of blades. Reaction turbines use both pressure and velocity forces from water to produce torque, which is then used to produce electrical or mechanical energy.

The development of impulse turbines began with the Pelton turbine, which has a design based on the same basic principles as the waterwheel. Further developments lead to the Turgo turbine, and finally the cross-flow turbine. Dant Banki designed a specific cross-flow turbine in 1917.

Reaction turbines depend on pressure forces in addition to water momentum. Unlike the impulse turbine, the runner for a reaction turbine operates within a water-filled casing, and the water exits through a draft tube below the runner. The propeller turbine, which has a Kaplan variant, was being developed at approximately the same time as the Pelton turbine. Another common reaction turbine is the Francis turbine.

Today, there exist various other impulse and reaction turbine designs, all of which are variations of the basic designs discussed previously and may be applied for conventional hydro. In addition, new non-conventional turbine developments for wind, tidal and small hydro applications are progressing. Potentially successful technologies applicable to non-conventional small hydro include tidal and kinetic turbines.

## 2.2 Large Hydro

To distinguish between large hydro and small hydro technologies being researched, it is helpful to make comparisons between three separate aspects of the hydro plants. The components of a hydro-electric facility, which include civil structure requirements in addition to the turbine, vary. The output and applications of the hydro plant are also distinguishing features.

### 2.2.1 Components

To describe the components of a conventional hydro plant, one begins with the intake method used. A concrete dam or weir may be used to divert water in a desired manner. Water is collected in a tank known as the forebay, before being transferred to the turbine in a tube known as penstock. Such applications require a spillway to permit overflow of water, if required, and is independent of the draft tube. A shaft connects the turbine to the generator for the production of electricity. A typical hydro plant is pictured in Figure 2.1.

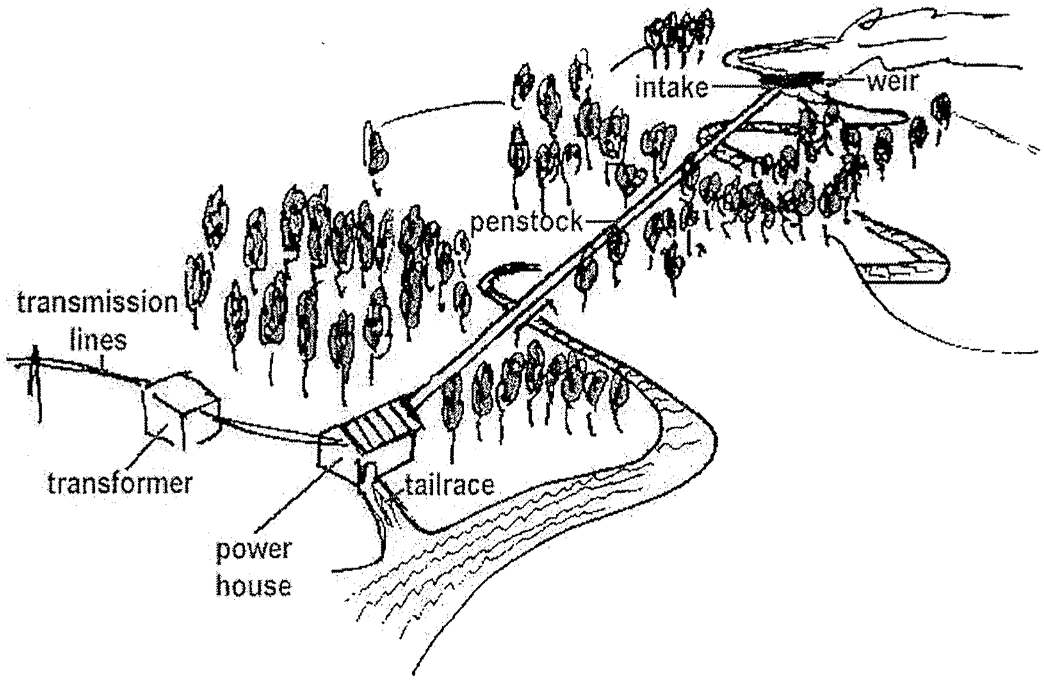


Figure 2.1: Typical Components of a Hydro Plant [26]

### 2.2.2 Output

The output of a large hydro plant is usually at least 50 MW. However, since the general accepted classification of small hydro is less than 10 MW, a hydro plant with a capacity of at least 25 MW may be considered large hydro.

### 2.2.3 Applications

The use of concrete dams and parent foundation material such as rock, to create an artificial lake, will create a reliable power supply as well as irrigation and flood control benefits. However, the construction of dams has the potential consequence of flooding land that was possibly fertile and displacing communities [6].

## 2.3 Small Hydro

### 2.3.1 Components

A small hydro plant utilizing run-of-the river concepts minimizes civil structures thereby having small or no dam or water storage. "The civil works purely serve the function of regulating the level of the water at the intake to the hydro-plant" [43]. A small hydro plant employing conventional turbine technologies may use some or all of the components of a large hydro plant. Non-conventional small hydro does not utilize water storage. A tidal or kinetic turbine does not require any structure other than that to mount the turbine.

### 2.3.2 Output

Many sources agree that an internationally accepted output range limit for small hydro does not exist. Sources indicate 25 MW as a maximum, as it is in China, or simply 10 MW [43]. The International Electrotechnical Commission Standard IEC 1116 recognizes small hydro "for installations with units having power outputs less that 5 MW and turbines with nominal runner diameters less than 3 m" [25]. Consistent reports indicate the term mini hydro applies to outputs in the 500 kW to 2 MW range, while micro refers to hydro with less than 500 kW output [43], [25]. A more general definition offers small hydro as "defined as unit sizes from 100 kW up to 5 000 kW for a range of net heads from 3 to 50 m (10 to 165 ft)" [50].

### 2.3.3 Applications

Small hydro provides an acceptable energy production solution for remote communities, developing countries and other situations where large hydro is already developed but small hydro sites may remain available, or where non-conventional small hydro is more environmentally and economically acceptable than conventional hydro.

# 3. PROBLEM AND CRITERIA DEFINITION

## 3.1 Problems with Large Hydro

Large hydro uses conventional turbine designs which require head and civil structures such as concrete dams. Construction of dams and the presence of head have the potential for high costs and environmental impacts. Environmental impacts may include the displacement of local communities and the vegetation and animal habitat changes caused by the flooding of large land areas. Fish survival and migration are also issues to be considered.

## 3.2 Problems with Small Hydro

Cost is an issue with small hydro. Table 2.1 indicates the capital and energy costs associated with conventional small hydro are both greater than that of large hydro. Current energy costs for tidal power are as high as $0.20 /kWh. Therefore, even if tidal turbines are successfully applied to small hydro they cannot compete with the upper range energy cost of $0.10 /kWh for conventional small hydro. Cost information for non-conventional small hydro technologies such as kinetic turbines, is not readily available.

Problems with small hydro are that many applicable technologies are still being developed. Technologies appropriate for small hydro implementation in Manitoba need to be identified. Non-conventional technologies are relatively new, with few case studies and completed projects available to demonstrate non-conventional small hydro's potential success and feasibility. A further disadvantage of small hydro is the river flow varies with seasons destabilizing the amount of firm energy that can be produced. Small hydro is a site-specific technology, thus creating difficulties for producing general conclusions without considering a particular site. The identification of these problems is important, however one must consider whether these problems are associated with the production of hydro electricity in general, or if they relate to both or either conventional or non-conventional small hydro specifically.

## 3.3 Evaluation Criteria

The following aspects of small hydro are examined to evaluate the feasibility of implementing small hydro in Manitoba.

### 3.3.1 Turbine Technologies

A review and evaluation of turbine technologies is required to identify those which are applicable to small hydro and are particularly suited for large flow and small head, which is characteristic of many rivers in Manitoba. Information regarding small hydro (1 to 50 MW) which captures energy from rivers using run-of-the river concepts is sought. Hydraulic equipment requires sufficient cross sectional area for low head with high flow applications. Many non-conventional turbine designs are intended for tidal flow, where the velocity rarely exceeds 1.5 m/s, (5 ft/s). Since flow in Manitoba's rivers can exceed this, and thereby produce more power, it is necessary to research turbine technologies which can tolerate such high flow velocities.

### 3.3.2 Flow Management

It is necessary to research and examine various methods to increase the flow rates of rivers. Since power is proportional to the velocity cubed, an increase in flow velocity will cause a significant increase in power density across the same flow cross section. Flows with significant velocities contain a large amount of energy without the requirement of substantial head. Kinetic versus potential energy are equivalent from an availability standpoint. Conventional methodologies that can increase the flow velocity, such as small structures, penstocks, enclosures and diversions (weirs) must be examined. Furthermore, the environmental impacts of these structures must be identified.

### 3.3.3 Site Selection

In order to implement small hydro in Manitoba, a potential hydro site must be identified. Rivers in southern Manitoba have flow rates, which could be applicable to small hydro. Northern Manitoba rivers have even more potential with their high flow rates, but their remoteness creates economic concerns. The nature of flow in the river, as well as participation of communities near the hydro site must also be considered for site selection.

### 3.3.4 Economic Analysis

Economic requirements for the successful implementation of small hydro must be examined. Construction, installation, and maintenance costs are affected by turbine and site selection. Costs to be considered as well as analysis techniques must be identified to begin analyzing the economics of small hydro.

# 4. TURBINE TECHNOLOGIES

## 4.1 Introduction

A hydraulic turbine produces energy, or power, which varies with the amount of water and head available. Head is defined as the difference in water elevations between the intake and discharge points of the power plant. The general action completed by a turbine is the flow of water over a runner, which is connected to a shaft to produce power. There are various types of turbines, and important factors such as available head should be taken into consideration when selecting the appropriate turbine. In addition, the turbine is usually attached to a generator and resulting revolutions per minute must also be considered. When characteristics such as discharge and head are known, the horsepower output capability of the turbine may be determined. Other important factors include turbine efficiency, water velocity, and structure requirements to permit the installation of the turbine.

As defined previously, (Table 1.1), turbine designs may be separated into conventional and non-conventional categories. There are two general types of conventional turbines – impulse and reaction. Within each category or type are specific turbines with various capabilities and requirements. Tidal and kinetic turbines are classified as non-conventional. A non-conventional turbine is considered kinetic if its power output depends only on the following equation:

$$\left.\begin{aligned} P &= \frac{1}{2}\dot{m}V^2 \\ P &= \frac{1}{2}(\rho V A)V^2 \\ P &= \frac{1}{2}\rho A V^3 \end{aligned}\right\} \qquad (4.1)$$

Where $P$ = power output

$\dot{m}$ = mass flow rate

$\rho$ = fluid density

$A$ = cross sectional area of turbine, and

$V$ = fluid stream velocity

The difference between an impulse or reaction turbine, and a kinetic turbine can be explained using the Bernoulli equation for the energy of steady, incompressible, frictionless fluid flow along a streamline, [18]:

$$z+\frac{p}{\rho}+\frac{V^2}{2g}=\text{constant} \qquad (4.2)$$

Where $z$ = fluid elevation, which can = 0 if $z$ = origin of coordinates

$\frac{V^2}{2g}=\frac{(flow\ velocity)^2}{2\bullet acceleration\ due\ to\ gravity}$ = kinetic energy

$\frac{p}{\rho}=\frac{pressure}{density}$ = energy caused by external pressure, (water head)

For an impulse or reaction turbine, head is high and the water head is the dominant term. However, for a kinetic turbine with ultra-low head or free fluid flows, kinetic energy becomes the dominant factor.

Initial conclusions may lead one to believe that only reaction or kinetic turbines should be considered for small hydro. The head for a small hydro plant would most likely be too small for an impulse turbine, and the flow of a river is faster than that of the ocean for which tidal turbines are designed. However, to consider all applications and possibilities of small hydro, it is necessary to identify all of the various turbines available and contrast their capabilities to determine which may be adapted for small hydro development in Manitoba. Therefore, all four turbine types (impulse, reaction, tidal, and kinetic) are researched. Two additional non-conventional turbine designs were identified and included under the category of new designs. For the purpose of selecting an "off-the-shelf" design, or perhaps for designing a new turbine, the important turbine characteristics are identified. Since the turbine is an important contributor to the power capacity of the hydro plant, comparisons to wind and solar power are presented in this chapter.

## 4.2 Turbine Characteristics

There are various characteristics used to identify the factors affecting the operation and output of the turbine. The following presents some basic fluid dynamics and theory of turbines.

### 4.2.1 Euler Turbine Equation

An important governing equation, the Euler turbine equation, considers the torque on a turbomachinery rotor and determines the specific energy transferred by the runner. To present this equation as outlined by R.I. Lewis [30], one must visualize meridional flow through a rotor and flow through a streamtube along the surface of revolution mapped out by the meridional streamline $\psi_o$, as pictured in Figures 4.1 (a) and (b), respectively.

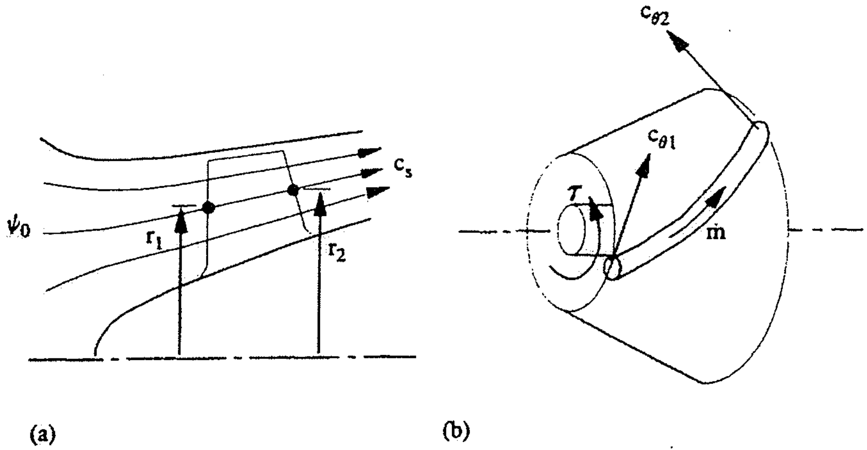


Figure 4.1 (a): Meridional Flow through a Turbomachine
(b): Flow along a Surface through a Streamtube [30]

The fact that the flow is meridional means that the flow is axisymmetric. The Euler turbine equation is:

$$E = h_{o1} - h_{o2} = U_1 c_{\theta 1} - U_2 c_{\theta 2} \quad \text{for compressible flow} \qquad (4.3a)$$

$$E = (p_{o1} - p_{o2})/\rho = U_1 c_{\theta 1} - U_2 c_{\theta 2} \quad \text{for incompressible flow} \qquad (4.3b)$$

Where subscripts 1 and 2 denote inlet and outlet, respectively

$E$ = specific energy $[m^2/s^2]$

$h_o$ = stagnation specific enthalpy $[m^2/s^2]$

$U = r\Omega$ = blade speed $[m/s]$, where $\Omega$ = rotor angular velocity $[s^{-1}]$

$c_\theta$ = tangential velocity $[m/s]$

$p_o$ = stagnation pressure $[N/m^2]$

$\rho$ = density $[kg/m^3]$

### 4.2.2 Reaction, $R$, for a Stage

A stage consists of a stationary blade row, usually referred to as the stator, and a moving blade row, the rotor. A turbine may consist of a single stage or multi-stages; however a single stage configuration is most common for hydro applications. The reaction, $R$, for an axial turbine may be defined as:

$$R = \frac{pressure\ drop\ across\ rotor}{pressure\ drop\ across\ stage} \tag{4.4}$$

For a Pelton turbine, (an impulse turbine), pressure drop occurs only across the stationary components and not the rotor, making its $R = 0$. For reaction turbines some pressure drop does occur across the rotor as well as the stator. Typical values include $R = 90\%$ for a Kaplan turbine, $R = 75\%$ for a Francis turbine, and $R = 50\%$ for a pump turbine [12].

### 4.2.3 Power

An important factor is the amount of power available which varies with water flow and head:

$$P = \rho g Q H \tag{4.5}$$

Where $P$ = power output measured in watts [W]

$\rho$ = density [kg/m$^3$]

$g$ = acceleration due to gravity [m/s$^2$]

$Q$ = volumetric flow rate [m$^3$/s]

$H$ = pressure head across turbine [m]

The above power represents the total power available and may be referred to as the gross power.

The net power considers losses by taking into account the turbine's efficiency:

$$P = \eta \rho g Q H \tag{4.6}$$

Where $\eta$ = turbine's hydraulic efficiency

### 4.2.4 Efficiency

Drtina and Sallaberger [12] define overall efficiency, $\eta_o$, as "the ratio of the power delivered to the shaft to that available in the water entering the turbine."

$$\eta_o = \frac{T\Omega}{\rho g Q H} \tag{4.7}$$

Where $\eta_o$ = overall efficiency [-] or [%]

$T$ = torque, [N-m]

Typical efficiency curves are recognized for various turbines and presented in Figure 4.2.

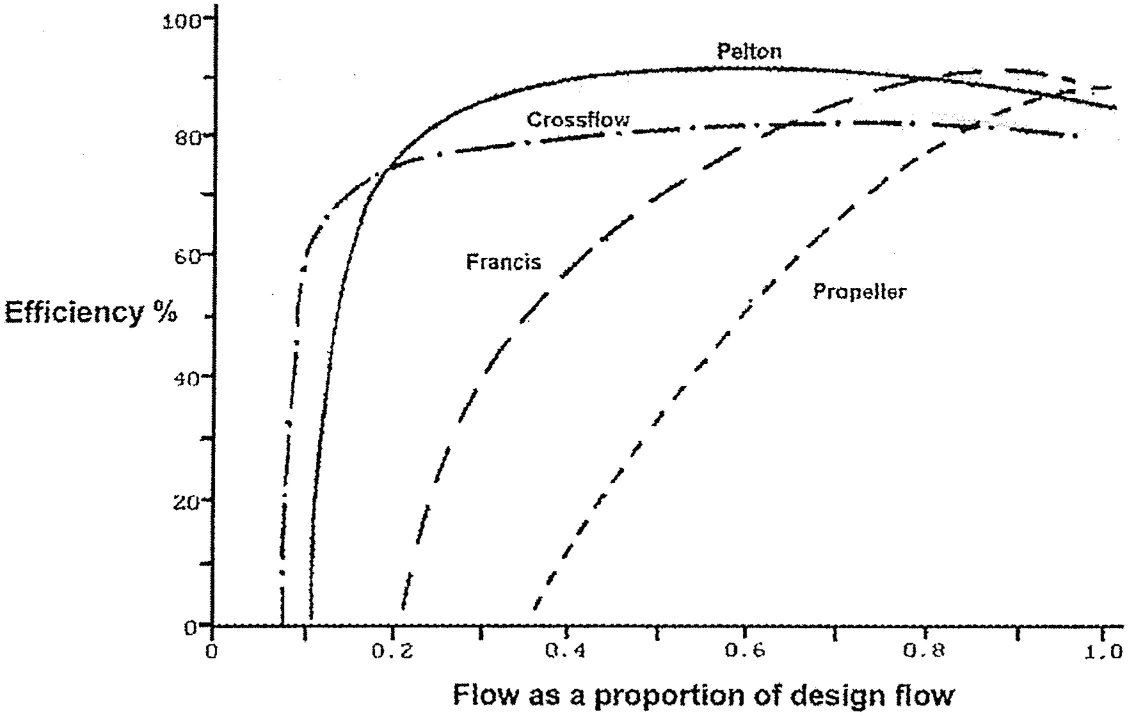


Figure 4.2: Part-Flow Efficiencies [43]

Some analyses may divide efficiency into three parts [13]:

$$\text{Volumetric efficiency} = \frac{\text{water acting on the turbine blades}}{\text{water entering turbine casing}} \quad (4.8)$$

$$\text{Hydraulic efficiency} = \frac{\text{power input to turbine shaft}}{\text{power input to turbine blades}} \quad (4.9)$$

$$\text{Mechanical efficiency} = \frac{\text{power transmitted through turbine shaft}}{\text{power transmitted through generator}} \quad (4.10)$$

### 4.2.5 Duty Coefficients

Two duty parameters result from dimensional analysis [30]. They are the flow coefficient, $\Phi$, and the head coefficient, $\Psi$. Alternative sources, [12], use a circumferential blade speed, $C$:

$$\Phi = \frac{4Q}{\pi C D^2} \tag{4.11}$$

$$\Psi = \frac{2gH}{C^2} \tag{4.12}$$

Where $D$ = characteristic length, maximum diameter

$C$ = circumferential blade speed

### 4.2.6 Specific Speed

The specific speed, $\nu_s$, is dimensionless and may be expressed in terms of the duty parameters.

$$\nu_s = \frac{\Omega}{\pi^{1/2}} = \frac{Q^{1/2}}{(2gH)^{3/4}} = \frac{\Phi^{1/2}}{\Psi^{3/4}} \tag{4.13}$$

Specific speed may be used to classify and select turbines.

### 4.2.7 Turbine Selection and Design Criteria

Various criteria, some referring to the above parameters, may be used in turbine design and are summarized in Table 4.1.

Table 4.1: Turbine Design Criteria, Adapted from [12]

| **Criteria** | **Options** |
|---|---|
| Shaft orientation | - Horizontal axis or vertical axis |
| Specific speed | - High, medium or low |
| Operating head | - High pressure 200 m < H < 2000 m<br>- Medium pressure 20 m < H < 200 m<br>- Low pressure H < 20 m |
| Type of regulation | - Single, variable stator vanes, e.g. Francis<br>- Double, variable runner and stator vanes, e.g. Kaplan or variable needle stroke and variable number of jets |
| Design concepts | - Single-stage or multistage<br>- Single-volute or double-volute<br>- Single-jet or multi-jet |

Each turbine has a range of volume flow rates and corresponding head values, which dictate its operating range. Figure 4.3 displays operating regimes for a given flow, Q, and head, H.

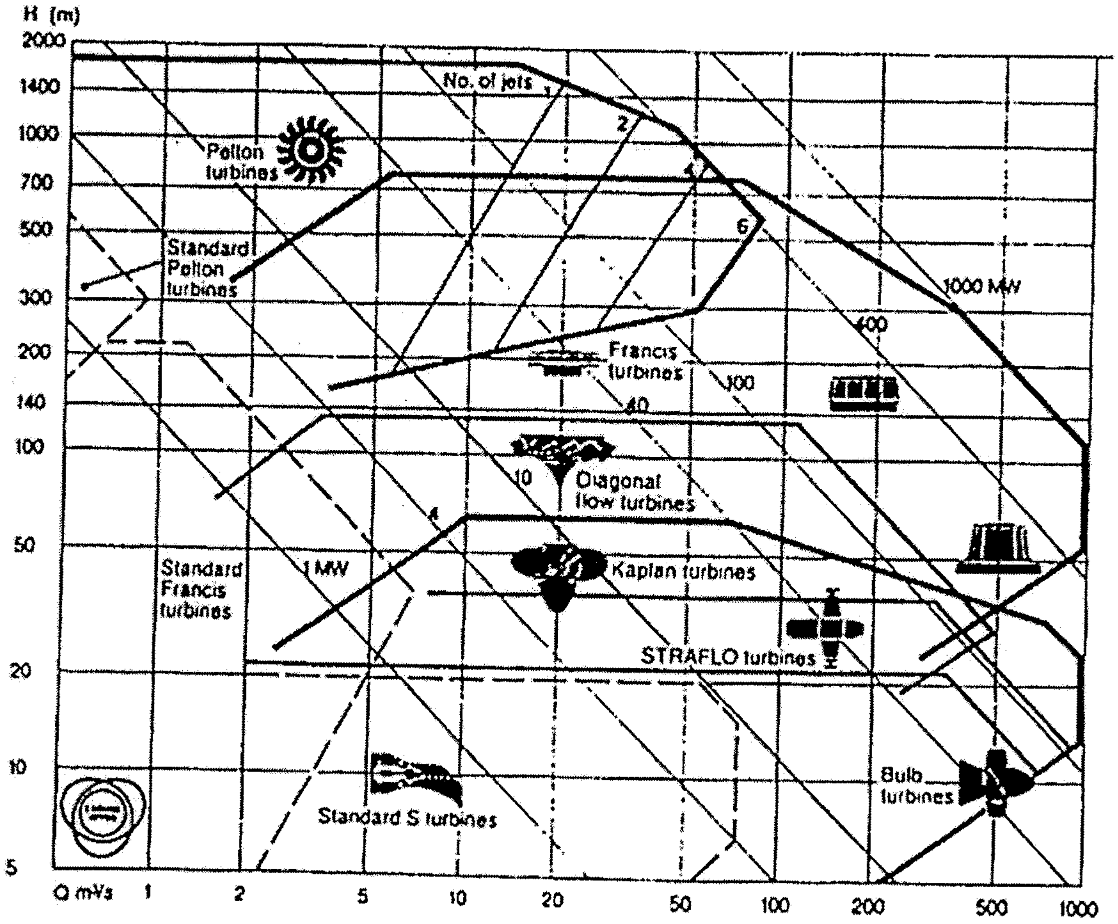


Figure 4.3: Turbine Runners and their Operating Regimes [12]

Figure 4.3 also displays the absolute power output for each turbine category. Alternatively, specific speed in variation with head may also be used for turbine selection as displayed in Figure 4.4.

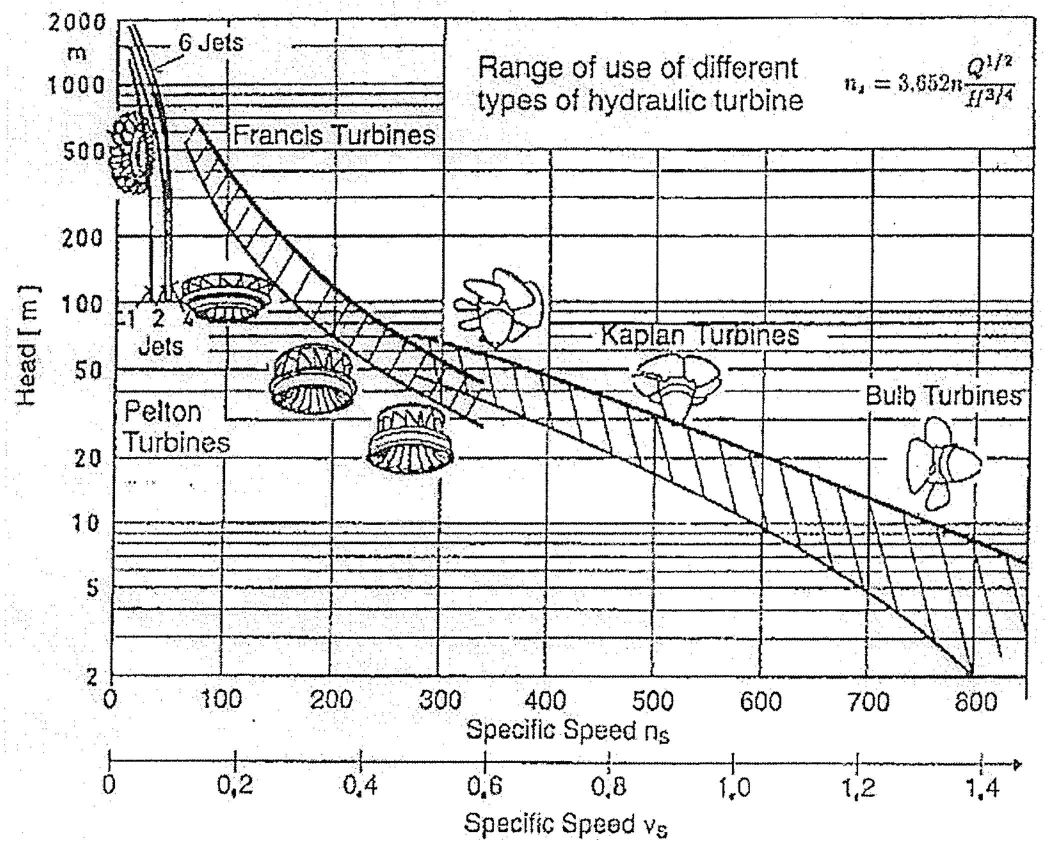


Figure 4.4: Turbine Selection Diagram, Specific Speed vs. Head [12]

Figure 4.4 displays the impeller forms for various turbines. Also referring to Figure 4.4, $n_s$ is the rotational speed, measured in revolutions per minute. “In general, the number of runner vanes or buckets decreases with increasing specific speed” [12].

## 4.3 Impulse Turbines

Impulse turbines operate with the water remaining exposed to air, and utilize jets of water to propel the turbine runner. Three common impulse turbines are the Pelton, the Turgo and the cross-flow.

### 4.3.1 Pelton Turbine

The Pelton turbine, also referred to as the Pelton wheel, was invented by Lester Pelton during the 1870's. The Pelton turbine operates using a wheel with buckets or spoon shaped blades. Water from a jet or nozzle hits the edge of one or more of the blades, causing the water to change its direction of motion by almost 180° and push the wheel around. Pelton turbines may be designed with various numbers of nozzles, however six is common, (Figure 4.5).

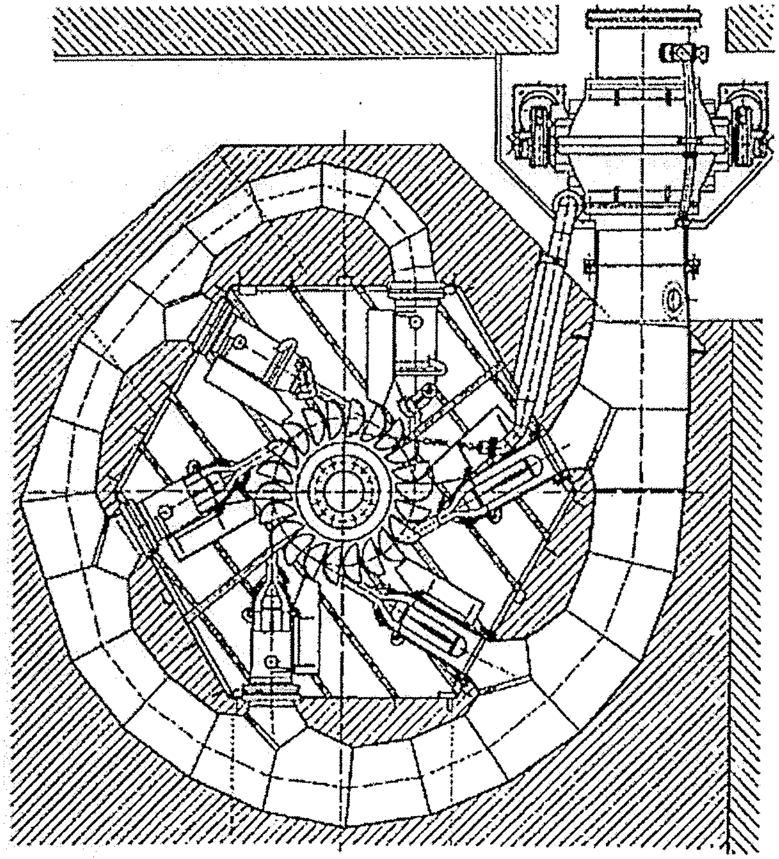


Figure 4.5: Pelton Turbine with Six Jets [12]

Power output increases linearly with increasing the number of nozzles. The operating speed for a Pelton turbine may have the range of 1000 to 3600 rpm [13]. The shaft for a Pelton turbine may be orientated either horizontally or vertically.

Some energy is lost due to friction, but the efficiency is high. With very high heads, greater than 50 m, and low flow rates, a Pelton turbine may have an efficiency of 80%.

### 4.3.2 Turgo Turbine

Similar to the Pelton turbine, the Turgo turbine operates by water jets striking a runner with efficiencies of 80% and operating speeds of 1000 to 3600 rpm [13]. However, in a Turgo turbine the jet is at an angle, (usually 20°), and water hits along a specific plane of the runner thereby only turning 145° as displayed in Figure 4.6.

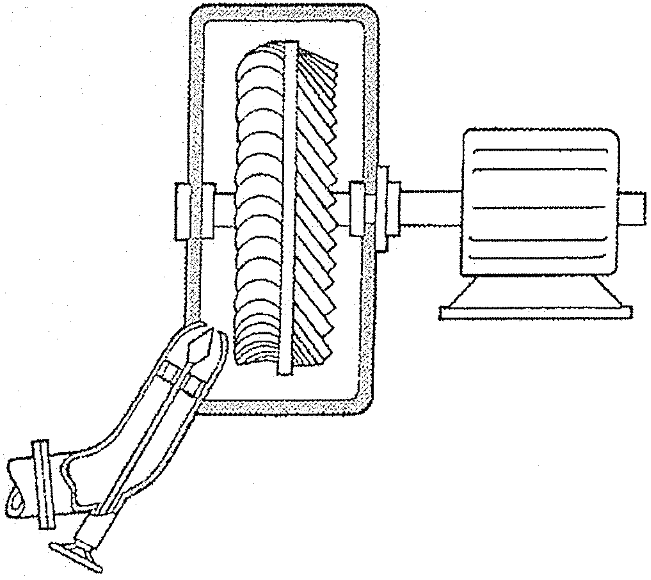


Figure 4.6: Turgo Turbine [43]

Water enters on one side of the runner and exits on the other thereby decreasing the limiting flow rate for a Turgo turbine, as compared to Pelton turbines. In turn, the runner for a Turgo turbine could be smaller than that of a Pelton turbine. More than one runner may be hit by the water by a single water stream. The Turgo turbine is appropriate for medium to high heads in the range of 30 to 300 m, and medium flow rates. The shaft for a Turgo turbine may be orientated either horizontally or vertically.

### 4.3.3 Cross-Flow Turbine

The cross-flow turbine has been developed by various contributors and early theories were published in the early 19th century. The first cross-flow turbine was a machine developed and patented by A.S. Michell in 1903. Further research was completed by D. Banki from 1912 to 1919, with a machine identified as the Michell-Banki turbine patented in 1917. Additional development introduced the Michell-Ossberger turbine which was patented in 1933. A cross-flow turbine, presented in Figure 4.7, consists of rectangular blades surrounding a runner.

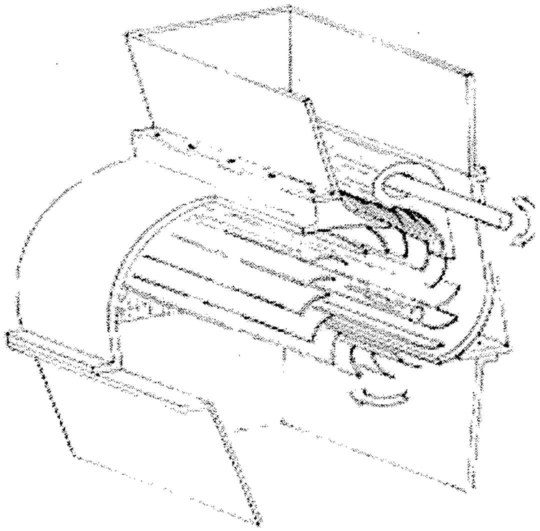


Figure 4.7: Cross-Flow Turbine [55]

Water strikes the rectangular blades, and then passes through the centre of the runner to strike a blade once again, as it exits. It is believed that the majority of energy produced is generated as the water enters the turbine. Cross-flow turbines are designed for flow rates similar to reaction turbines, and heads in the range of 1.5 to 80 m. The efficiency of a cross-flow turbine may reach 80%. The absence of high velocity water jets reduces the need for special manufacturing allowing the Banki turbine to be constructed “at home” with efficiencies as high as 60%. Due to the important role of hydro pressures in the operation of the turbine, the cross-flow turbine is an excellent transition to begin describing reaction turbines.

## 4.4 Reaction Turbines

Reaction turbines are well suited for high flow rates and low head situations. Unlike impulse turbines, reaction turbines are completely submersed in water. The pressure forces turning the runner and the kinetic energy created by the flowing water are important in the operation of a reaction turbine. The important operating principle of a reaction turbine is that hydrodynamic lift forces created by the water flow are used to propel the runner blades. A 'draft tube' exists below the runners for the purpose of water discharge in all reaction turbines.

### 4.4.1 Kaplan Turbine

A Kaplan turbine, pictured in Figure 4.8, is designed for axial flows with large flow rates. It is appropriate for low heads in the range of 15 to 50 meters.

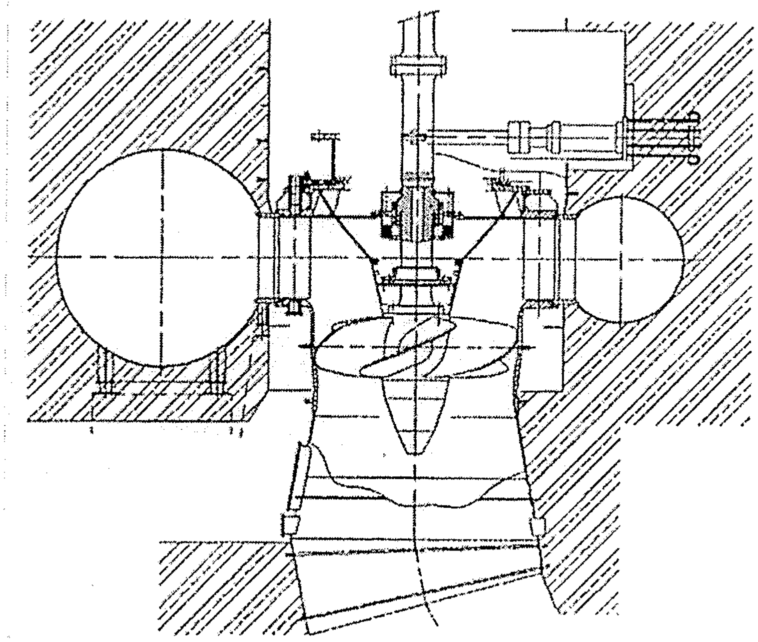


Figure 4.8: Kaplan Turbine [31]

The runner in a Kaplan turbine is surrounded by water within a chamber. Its guide vanes and runner blades are adjustable.

Manufacturers have created various types of Kaplan turbines with vertical and horizontal versions.

#### 4.4.1.1 Bulb Turbine

One variation of the Kaplan turbine is the bulb turbine. The Kaplan and bulb turbines have similar runners. A bulb turbine has its generator and blades located in a sealed "bulb" shaped unit which sits directly in the river, as illustrated in Figure 4.9.

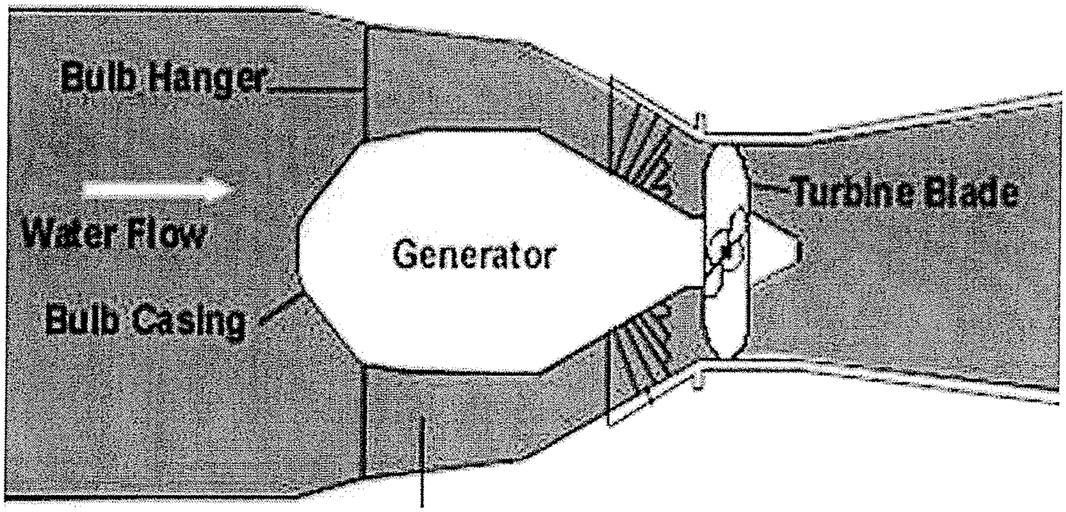


Figure 4.9: Bulb Turbine [42]

Bulb turbines are designed for low head and high flows. Hitachi Hydro Turbines, pictured in Figures 4.10 and 4.11, are intended for heads below 40 m and have an output range of 10 to 100 MW [22].

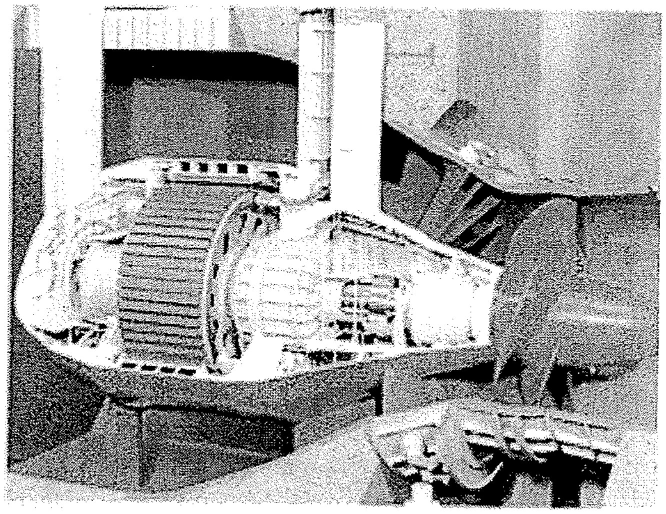


Figure 4.10: Hitachi Bulb Turbine Model [22]

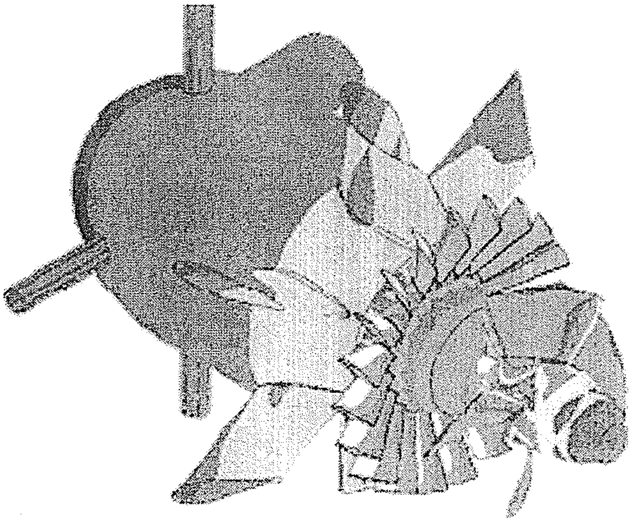


Figure 4.11: Hitachi Bulb Turbine [22]

The bulb turbine is appropriate for tidal applications, although one disadvantage of the bulb turbine is the difficulty to perform maintenance because water which surrounds the turbine must be stopped. As demonstrated in Figure 4.3, the bulb turbine is a low-head turbine, and may therefore be appropriate for small hydro.

#### 4.4.1.2 Straflo Turbine

Another variation is the Straflo turbine (Figure 4.12) where the generator is attached and surrounds the blades.

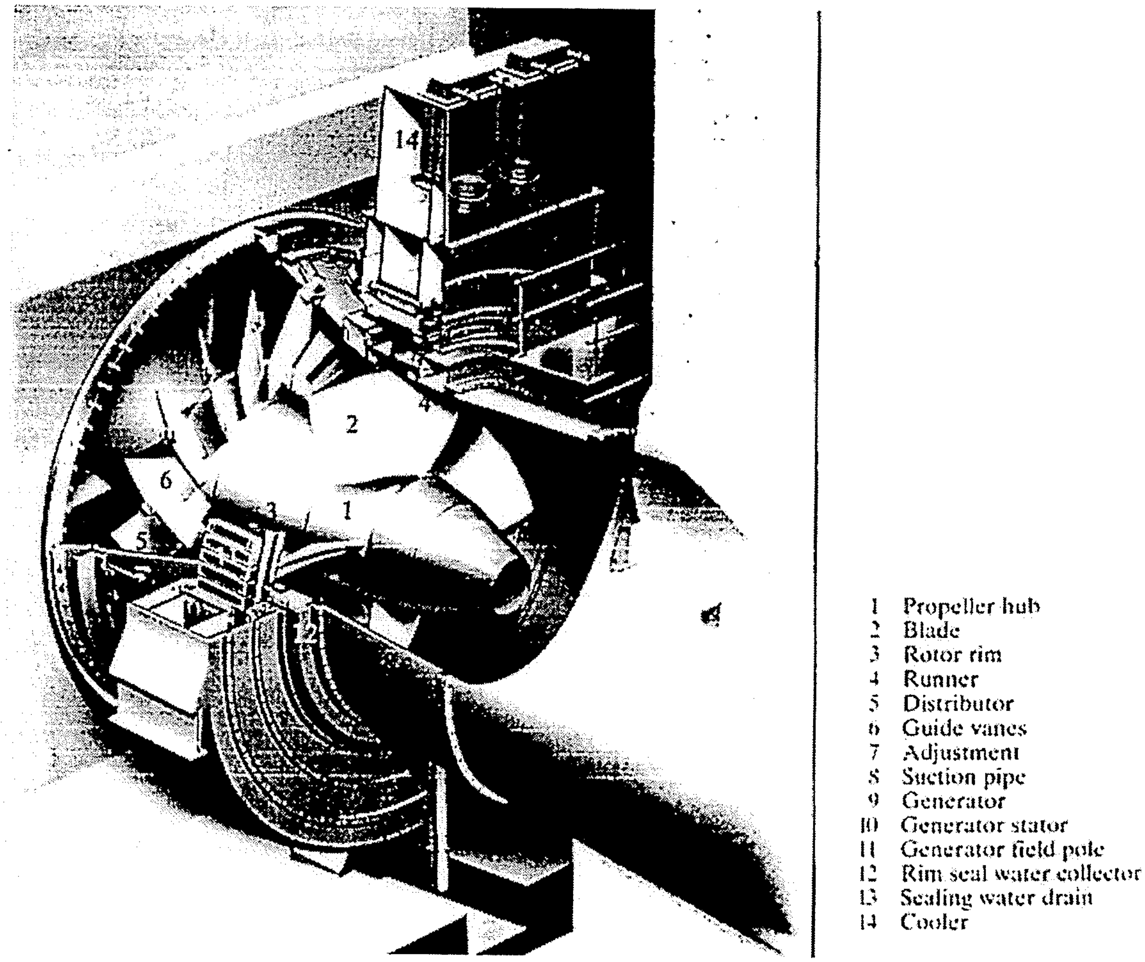


Figure 4.12: Straflo Turbine [46]

#### 4.4.1.3 Tube Turbine

Alternatively, the tube turbine (Figure 4.13) is designed such that the “penstock bends just before or after the blades, allowing a shaft connected to the blades to protrude outside the penstock and connect to the generator” [13].

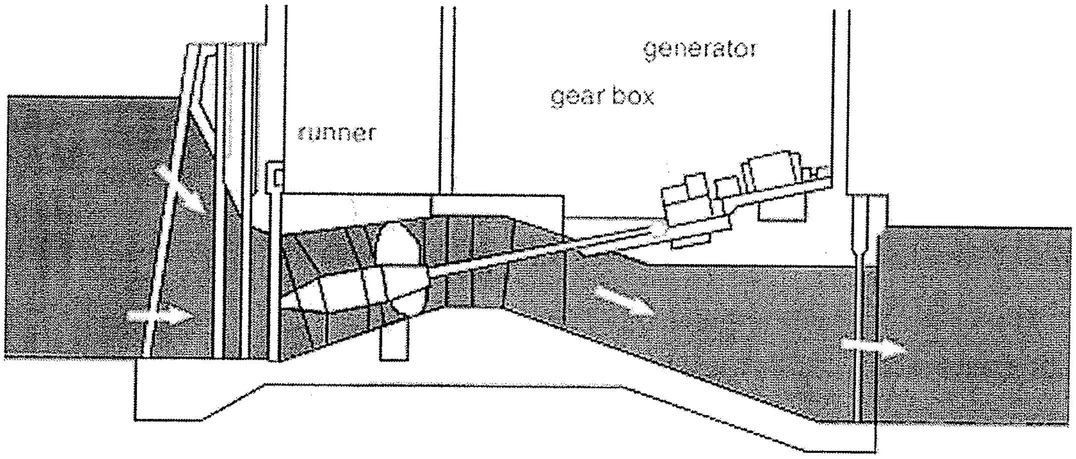


Figure 4.13: Tubular Turbine [42]

A new variation of this turbine has been developed the German company Ossberger-Turbinenfabrik and is called an 'S-type' turbine [2]. The S-type turbine, applicable for small hydro, is based on the Kaplan 'tubular turbine', but with the inlet redesigned to have a horizontal rather than vertical orientation.

### 4.4.2 Francis Turbine

A Francis turbine (Figure 4.14) utilizes large radial flow and medium flow rates, with a medium head range of 10 to 250 m.

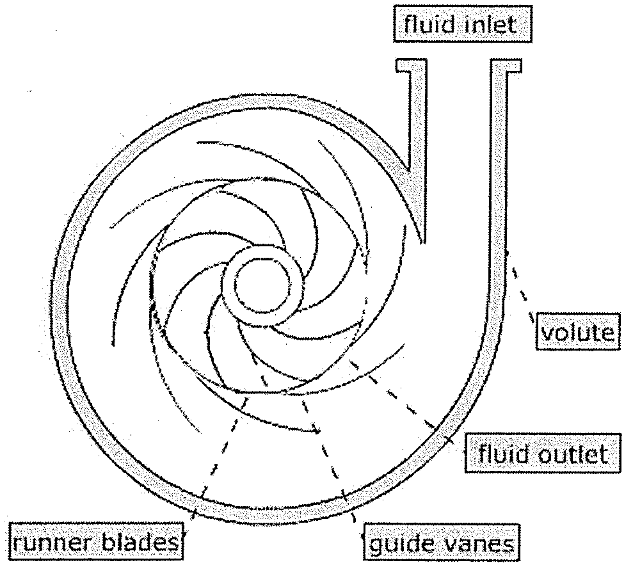


Figure 4.14: Francis Turbine [26]

The design of a Francis turbine includes guide vanes which surround the runner and control the water. A Francis turbine may exist in a horizontal or vertical design orientation. Power outputs of 5000 kW are appropriate for small hydro applications of the Francis turbine, although larger developments are possible. The complex vane arrangement makes for an efficient but costly turbine. When a comparison is made to Kaplan turbines, the peak efficiency for a low head Francis turbine is greater by 1 to 1.5 percent [50].

### 4.4.3 Fixed-Blade Propeller Turbine

The design of a propeller type turbine is basically the attachment of a propeller to penstock. The number of blades on the propeller may range from three to six. Unlike a Kaplan turbine, the pitch angle of the rotor blades cannot be altered, hence the name fixed-blade propeller. Swivel gates or static blades located upstream of the propeller are used to regulate water flow.

## 4.5 Tidal Power

Tidal power differs from conventional hydroelectricity in that water flows in both directions, adding a new design constraint. Many generating systems only generate power from the outgoing, (the ebb tide), or incoming tide, but two way generation systems are possible. An ebb generating system, as pictured in Figure 4.15, employs sluice gates to fill a tidal basin with the incoming tides and exit with the outgoing tide, after passing through the turbine.

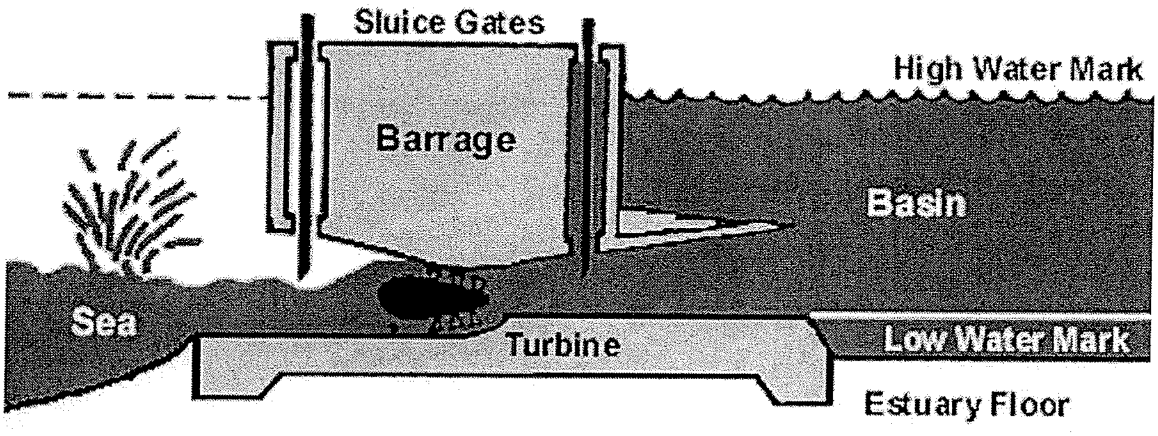


Figure 4.15: Ebb Generating System with a Bulb Turbine [42]

Figure 4.16 displays tidal fences, which “completely block a channel, forcing all of the water through them” [42].

[19].

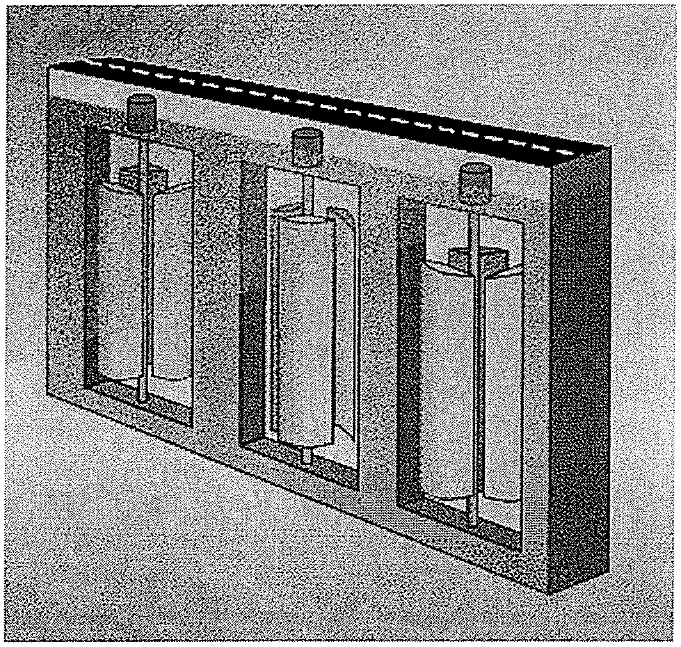


Figure 4.16: Tidal Fence [42]

Turbines used in tidal power stations have included the bulb turbine, the Straflo and the tubular turbine. However, new alternative designs, as presented in the following, are coming forth.

### 4.5.1 Davis Turbine

The Davis turbine, a reaction turbine, was designed by Barry Davis, using his previous engineering experience with the Avro Arrow supersonic jet developed by the Canadian government and the D'Havilland Bras D'Or 400 naval destroyer developed by the Canadian navy. In particular, the design is based on Georges Derrieus' undeveloped 1927 patent on a vertical axis windmill. The company Nova Energy Ltd. developed three prototypes before being renamed as Blue Energy Canada Inc. in 1997 [19].

The turbine consists of four fixed hydrofoil blades which use the principle of lift to move more quickly than the surrounding water. The blades are connected to a rotor which is in turn connected to a gear box and generator. All components are enclosed in a water tight casing for the unit to be anchored to the ocean floor. The Davis turbine is designed for slow ocean flows, but advancements are being attempted to make the technology appropriate for river applications. The Davis turbine creates a modular design, becoming the major component of the "Blue Energy Power System." The system claims it is applicable for 200 MW to 8000 MW sites in ocean applications and for 5 kW to 500 kW sites in rivers [8]. For the "Blue Energy System," Blue Energy claims a tidal fence can be created across a river where velocities are greater than 1.75 m/s (3.5 knots), to produce a peak power of 12 MW with the 10.5 meter diameter turbines. The "Mid-Range" 250 kW unit, Figure 4.17, may be applicable for the "Blue Energy Power System."

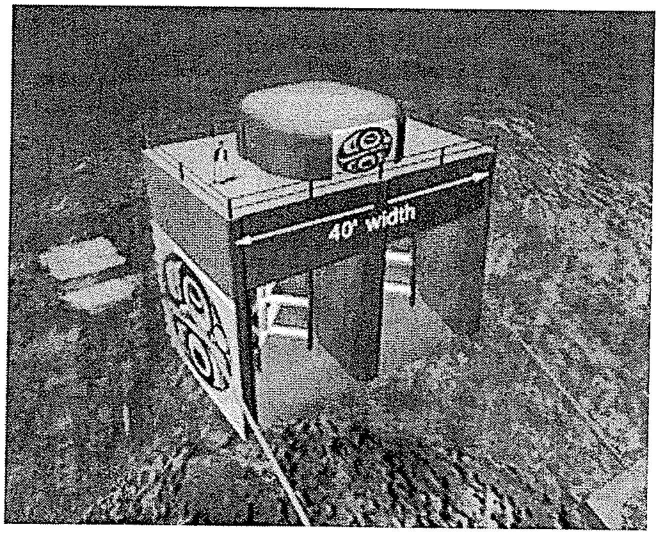


Figure 4.17: Computer Rendering of 250 kW Mid-Range Unit [8]

The "Mid-Range" unit requires a depth of at least 10 meters and can be used in tidal fences or individually where velocities exceed 1.75 m/s. The "Mid-Range" unit would not be appropriate for small hydro in Manitoba at this time. Initial information indicates this unit is actually a floating unit which could lead to problems with ice. Furthermore, the successful demonstration of a project where this design is applied for a river should be completed. Current projects include a four kilometre tidal fence for the Dalupiri Ocean Power Plant in the Philippines and a 500 kW demonstration project off the coast of British Columbia which employs two floating 250 kW units. The results of these projects are not currently available. It appears that current applications of this technology are leading towards the bridge or tidal fence concept which is not necessarily appropriate for Manitoba.

An independent assessment of the hydro turbine was completed by H.N. Halvorson Consultants for the British Columbia government in 1994, [19]. The report concluded that while the tidal application turbine was technologically sound and environmentally benign, more development was required to make the technology cost effective.

### 4.5.2 Marine Current Turbines

Marine Current Turbines, (MCT), introduced a new concept in tidal power originally developed by the technical consultancy company IT Power. MCT, based in the UK, is a "consortium of companies with a common interest in developing tidal stream technology, including IT Power

Seacore, Bendalls Engineering and Corus UK (formerly British Steel)" [16]. The design of a MCT, illustrated in Figure 4.18, is similar to that of a wind turbine.

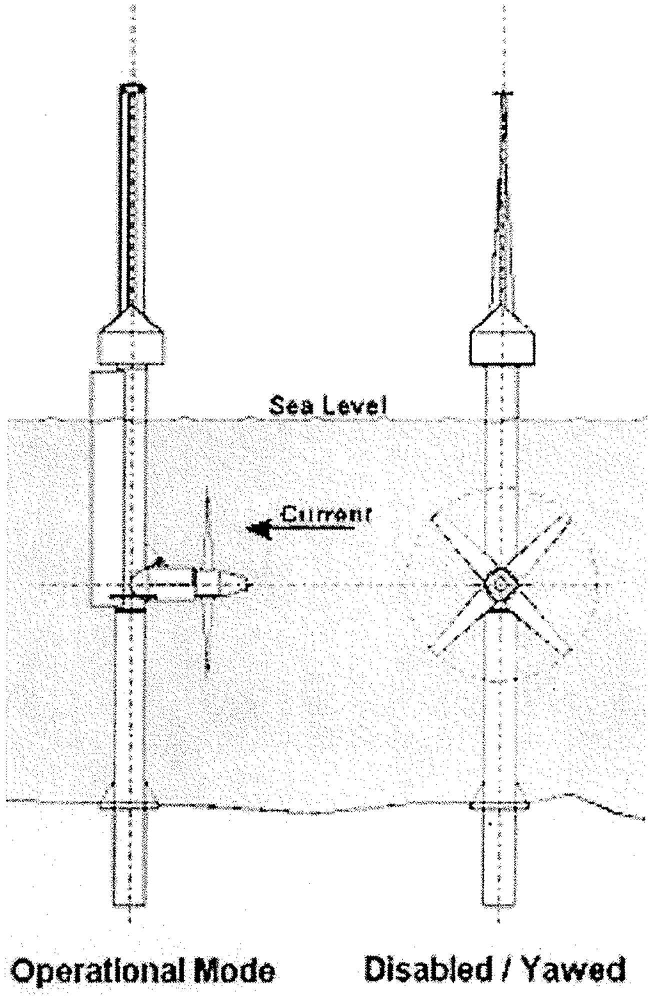


Figure 4.18: Marine Current Turbine [42]

Marine current turbines require tide velocities of the order of 2 to 2.5 m/s (4 to 5 knots) and water depths between 20 and 35 m [16]. Marine current turbines offer the advantages of a large renewable resource with minimal environmental impact. The power produced depends on the tide, and is therefore predictable. A tidal current turbine rated at 2 to 3 m/s in seawater can result in four times as much energy per year per meter squared of rotor swept area, as a similarly rated power wind turbine [7]. Although designed specifically for tidal applications, the tidal turbine can be classified as a kinetic turbine since its output power depends on Equation (4.1).

In the process of using rotational energy, transforming it into electrical power and transferring the power to land, all within a harsh marine environment, various issues arise and must be examined for the successful implementation of MCT. Structural problems such as a method for anchoring the turbine and overcoming strong thrust forces exist. Cavitation, which depends on velocity and pressure, is most likely to occur when pressure is low and blade speed is high. Research must be completed to ensure that cavitation does not occur or is minimized and does not affect the normal operation of the blade. When considering maintenance, safety and speed are important, and climate conditions play an important role. Divers or remotely operated vehicles are not an option due to the storm-like environmental conditions surrounding the turbines in a tidal setting. Maintenance must be considered during the design stages of the turbine. Good quality design and the ability to raise the turbine unit above the water can reduce maintenance frequency and improve accessibility.

The marine environment itself poses three issues to be addressed. Firstly, marine growth can occur on blades and hinder operations. However, this may not be a problem due to the high speed of the blades causing any seaweed or other plants to break free. Secondly, any debris can potentially cause damage, especially to blade tips. Thirdly, corrosion must be prevented by sealing and protecting, (paint or galvanize), or selecting corrosion resistant materials. Another solution is to manufacture steel parts thicker in anticipation of corrosion losses.

Project work completed to date for MCT has been either theoretical or for a small-scale application. Further projects are planned beginning with a 300 kW demonstrator unit, followed by a twin rotor prototype producing 700 to 800 kW, and finally a tidal farm producing 3 to 5 MW by means of four twin rotor turbines. It appears, that the tidal turbines may developed commercially around 2005-06 [16]. One further application of a MCT that could be considered in the future is the addition of a wind turbine (located above the water) to the MCT's structure. It should be noted that for MCT application in Manitoba, issues associated with ice should also be considered, especially since a portion of the turbine's structure remains exposed above the water.

### 4.5.3 Helical Turbine

The helical turbine, classified as a kinetic turbine, has a design based on the Darrieus reaction turbine, patented in 1931. The helical turbine, developed in 1994 - 1995, is designed for slow currents of 0.5 to

1 m/s (1 to 2 knots) in free flow with low head. Similar to the Darrieus turbine, there is a shaft perpendicular to fluid flow and curved blades complete the barrel shape. For a helical turbine, blades are in a helical arrangement. This eliminates the pulsation due to rotation, which causes blade failure in the Darrieus turbine. A double helix turbine is pictured in Figure 4.19.

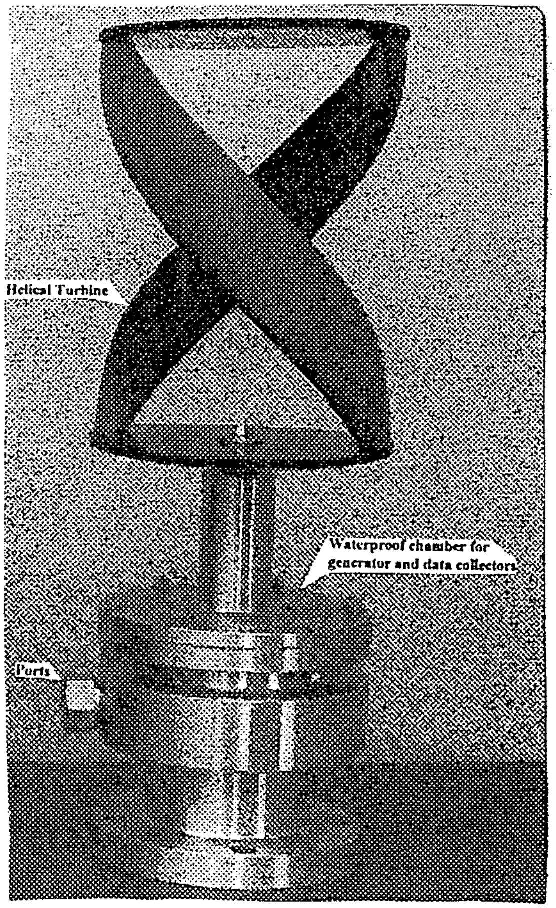


Figure 4.19: Double-Helix Turbine with Electric Generator [17]

Tests were successfully completed in 1996 on 15 cm (6 inch) turbines with 2 to 3 blades and 21 cm (8.5 inch) turbines with 3 to 6 blades, as well as 0.6 m (2 ft) diameter helical turbines, [18]. Testing the triple-helix turbine in 1997 demonstrated a stable efficiency of approximately 35% for various water velocities, ranging from 0.6 to 2.4 m/s (2 to 8 ft/s) [17]. Gorlov, [17], suggests the application of helical turbines as "the key power modules" for ocean stream power farms.

## 4.6 Kinetic Turbines

Kinetic turbines are unique from conventional turbines in their ability to capture the kinetic energy of water flow, thus making them applicable for ultra-low head applications, as an alternative to applying conventional turbines.

### 4.6.1 UEK Turbine

The US company UEK Corporation, in operation since 1981, produces hydro kinetic turbines for tidal, ocean and river applications. The Underwater Electric Kite, (UEK) turbines are free flow turbines, applied with site specific designs. Turbines are available in two configurations. The single unit configuration, designed for river and tidal applications, may have a 3, 10, or 22 foot diameter. The unit may be mounted at the bottom with a structure attached, stand alone or connect to the utility.

In conjunction with Ontario Power Generation, UEK is testing 'Twin turbines', (Figure 4.20).

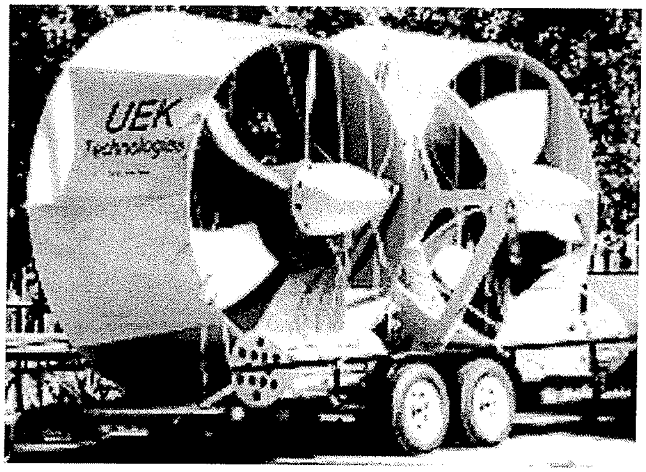


Figure 4.20: UEK 10 ft Twin Turbine [53]

“The small 3 ft. twin is designed for isolated posts such as communication power sources at fire towers, hunting ground shelters, mining exploration and military communication needs” [54]. “The 10 ft. is designed for rural electrification in river setting for small agglomerations where grid interconnection is prohibitive due to the economics of distance” [54]. The 10 ft. diameter twin does not require substantial civil work for installation. A 22 ft. diameter twin is being developed for ocean current setting. Figure 4.21 displays the power output for the twin unit for various velocities measured in knots.

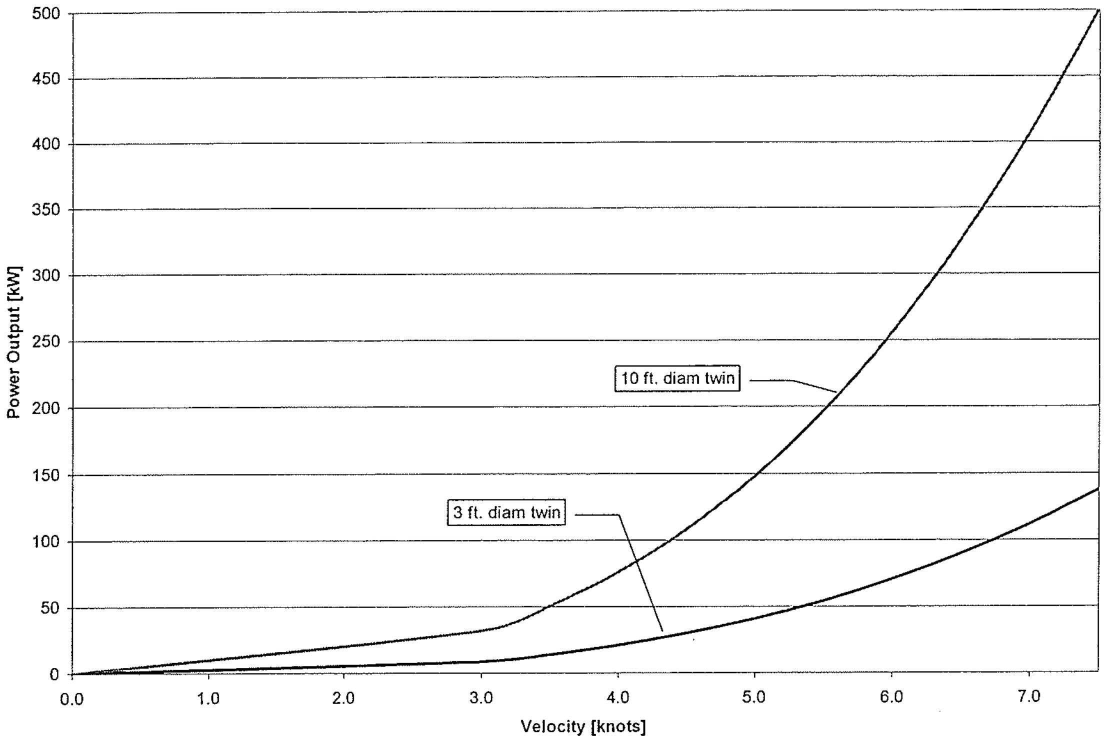


Figure 4.21: UEK Twin Configuration Turbine Power Output, Adapted from [54]

Referring to Figure 4.21, the power output for a single unit may be determined by dividing the above output by two. It should also be noted the power above is that at the point of generation; delivered power would be less due to transmission losses. President and CEO Philippe Vauthier indicates that to make an installation cost competitive with other conventional generating sources the best flow is 2.3 to 2.5 m/s (4.5 to 5 knots) [54].

The low impact UEK turbines are located beneath the water's surface and do not require civil structures such as dams. The runners move at a slow speed so as not to harm small marine life, while screens protect larger marine life. The turbines may be installed in the format of an underwater park, consisting of twelve or more units, thus creating power output in the range of hundreds of megawatts. Testing is still being completed for applications of the UEK turbine. The permit for the first application of the 10 ft. diameter twin unit was granted in January, 2003 for application on the Yukon River. Successful demonstration of project completion is required before further consideration regarding UEK turbine application in Manitoba. Then, issues with determining appropriate flow rates may also be addressed. The flow rate available in a Manitoba river must coincide with that required for optimum operation of the turbine.

## 4.7 New Designs

Two known companies are developing turbines with very new and innovative designs. It is expected that as the demand for new technologies with simple installation and acceptable impacts increases, more designs will become available. The following are two examples of turbines that are not currently well recognized, but may demonstrate potential applications upon further development.

### 4.7.1 Mini-Aqua by Alstom Power

Mini-Aqua, developed by Alstom Power Hydro in the 18 months prior to August 2001, is "an integrated package including a turbine, a generator and control system to be used on a turnkey basis" [5]. The application ranges for Mini-Aqua are as follows:

- Output: 300 kW to 15 MW

- Flow: 0.2 to 200 $m^3/s$
- Head: 2 to 1000 m
- Voltages: 3 to 15 kV

Specific turbine types are used for high, medium and low head applications:

- High head applications incorporate Pelton turbine
- Medium head applications incorporate Francis turbine
- Low head applications incorporate Kaplan turbine

Specific configurations, such as with vertical and horizontal shafts are available for each turbine and to coincide with appropriate civil structures.

The control system, the Aqua, and small standardized generators developed by the Alstom Power Generator Technology Centre in Birr, Switzerland complete the system.

As of 2001, "first customer reactions are positive, says Alstom, with recent orders for 15 machines in Brazil, including four units ordered by Brazil-based Guaranta for its 7500 kW Paso Do Meio plant, and two machines in Morocco" [5].

### 4.7.2 Hub-less Turbine by Ecopower

A new axial hydropower turbine is being developed by the Swiss-based company Ecopower, in conjunction with the Biel Engineering School. The turbine has a "new patented design where the hub has been removed" [3]. The turbine is designed for flow rates less than 0.2 $m^3/s$, heads less than 10 m, and has a power output of 10 kW. "The main innovations in the design include:

- Ability to work at variable speed.
- Fully axial in-line concept.
- Propeller without a central hub.
- Generator is placed around the runner" [3].

Inlet and outlet guide vanes account for variations in head and flow, thus ensuring the turbine rotates at a constant speed. The "absence of a hub results in less blockage by small or medium-sized debris" [3]. This allows for the turbine to be installed in waste water pipelines and water collections systems, in addition to small rivers.

### 4.8 Comparison to Wind and Solar Power in Manitoba

Wind is an attractive renewable resource gaining attention. However, further technological advancements are required to improve the economics associated with wind power. If efficiency is defined as the ratio of energy produced to output available, windmills have efficiencies which will not exceed 30 percent [13].

There are two common methods of producing solar power. Photovoltaics use light to produce electric currents in silicon wafer or discs. The power produced is usually in a direct current (DC) form and must be converted to an alternating current (AC) form to match the local grid system, resulting in energy losses. Solar power may also be produced thermally where liquids or solids are heated and circulated.

One feasibility study [40] completed at Race rocks, near Victoria, BC sought to examine the feasibility of implementing a “sustainable energy system” to replace diesel generation. Tidal, wind and solar power were compared as energy sources by calculating daily average energy fluxes measured in units of kilowatt-hours per day per square meter, (Figure 4.22).

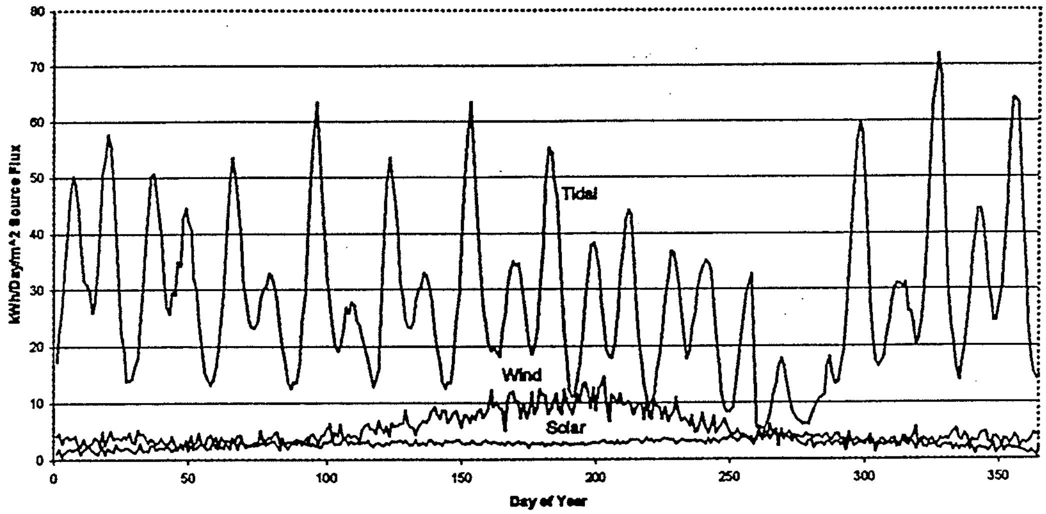


Figure 4.22: Daily Average Energy Fluxes at Race Rocks [40]

Referring to Figure 4.23, the following equation was used to convert wind and tidal data into an hourly energy flux, $\dot{E}$:

$$\dot{E} = \frac{1}{2}\rho V^3 \tag{4.13}$$

Where $\rho$ = fluid density

$V$ = flow velocity

Solar data was provided in the energy flux units, kilowatt-hours per day per square meter. Referring to Figure 4.22, the amount of energy available from tidal power varies due to tidal currents running every six hours, however, tidal power is considered reliable because tides are predictable. Wind and solar power may be considered less reliable than tidal power due to unpredictable climatic conditions making it possible for wind and solar energy to remain unavailable for days. As displayed in Figure 4.22, tidal power provides the most amount of available energy.

A similar analysis was performed to compare water, wind and solar power in Manitoba. Water flow rates were obtained from the Manitoba Conservation Water Branch for the Winnipeg River below Slave Falls [32]. A flow rate for each month from the median data for 1970 to 1999 was used in conjunction with Equation $(4.13)$ to obtain the power available in watts per meter squared. To transform the flow rates into velocities, the highest flow rate was assumed to coincide with a velocity of 10 m/s, and all other flow rates were proportioned to this ratio. Solar and wind data were obtained for the latitudinal and longitudinal position of 53 and 101, respectively, from the NASA Surface Meteorology and Solar Energy Data Set [48]. Insolation on a horizontal surface was provided in units of kilo-watt-hours per meter squared per day for monthly average values based on a 10 year average between July 1, 1983 and June 30, 1993. Wind power was calculated using Equation $(4.13)$, and wind speeds at a 50 m elevation for monthly values, based on a 10 year average, in units of meters per second. The resulting powers are compared in and Table 4.2. The difference in water power available is even greater for Manitoba than for Race Rocks, since river applications with flow rates greater than those for tidal applications are considered.

Table 4.2: Water, Solar, and Wind Power Values in Manitoba

| Month | Power<br>kW/m$^2$ | | |
|---|---|---|---|
| | Water | Solar | Wind |
| Jan | 482 | 0.04 | 0.07 |
| Feb | 448 | 0.08 | 0.06 |
| Mar | 463 | 0.15 | 0.05 |
| Apr | 458 | 0.19 | 0.05 |
| May | 316 | 0.23 | 0.04 |
| Jun | 390 | 0.22 | 0.03 |
| Jul | 278 | 0.20 | 0.02 |
| Aug | 153 | 0.17 | 0.03 |
| Sep | 138 | 0.13 | 0.03 |
| Oct | 209 | 0.08 | 0.05 |
| Nov | 358 | 0.05 | 0.07 |
| Dec | 466 | 0.03 | 0.08 |

As demonstrated in Table 4.2, water provides the greatest amount of power available. The power available in a Manitoba river is much greater than wind or solar power such that if plotted on a graph the solar and wind would appear to produce almost no power in comparison to the water power. Referring to Table 4.2, the units of kilo-watt-hours per square meter are required because this analysis determines the maximum amount of power available. If area were to be considered technological limitations of the extraction devices would also be involved in the analysis, and the power calculated would no longer be total available power.

Once the amount of available power is assessed, one must extract this power. Another analysis determines the power extracted from air by wind turbines by means of treating the general extraction device as an actuator disc [13]. The analysis is presented with specific reference to wind turbines, however the result applies to any fluid the turbine may operate on, such as water or air. Using conservation of mass and momentum theories results in a power coefficient, $C_p$:

$$C_p = \frac{Power}{\frac{1}{2}\rho U_\infty^3 A_d} \tag{4.15}$$

Where $Power$ = available power in air without actuator disc present

$U_\infty$ = flow velocity far upstream

$A_d$ = actuator disc area

The analysis continues to present the Betz limit:

$$C_{p_{\max}} = 0.593 \tag{4.16}$$

This is the maximum achievable power coefficient which no wind turbine is capable of exceeding. This analysis demonstrates that there is a limit to the amount of power that can be extracted. The maximum efficiency of a wind or propeller-type turbine is 59% regardless of the working fluid employed. A more extensive derivation of the actuator disk theory is presented in Appendix A.

## 4.9 Turbines Applicable to Small Hydro in Manitoba

### 4.9.1 Criteria

For a turbine to be considered for small hydro application in Manitoba, it must meet the following criteria:

- None or minimal civil structure requirements
- Minimal environmental impacts
- Turbine must be located below water surface (due to ice)
- Withstand velocities as high as 10 m/s
- Large flow, (more flow = more power)
- No head required

### 4.9.2 Options

Of the various turbines previously described, it is necessary to identify those which should be examined further, for the possible implementation of small hydro in Manitoba. Table 4.3 provides a summary of the characteristics of all turbines researched.

Table 4.3: Turbine Summary

| Turbine | | | Head | Flow Rate | Notes |
|---|---|---|---|---|---|
| Conventional | Impulse | Pelton | High, H > 50 m | low | high head, efficiency |
| | | Turgo | Medium/High, H > 10 m | low | appropriate for water supplies that fluctuate |
| | | Cross-Flow | Medium/Low, H < 50 m | low | simple to manufacture |
| | Reaction | Kaplan | Low, H < 10 m | high | various versions available |
| | | Bulb | Low, H < 40 m | high | submerged, potential maintenance problem |
| | | Straflo | Low | high | compact design |
| | | Tube | Low | high | appropriate for large hydro |
| | | Francis | Medium/Low, H < 50 m | high | good for continuous flows |
| | | Fixed-Blade Propeller | Low, H < 10 m | high | less adjustable than Kaplan |
| Non-Conventional | Tidal | Davis | none | 1.75 m/s | appropriate for tidal applications |
| | | Marine Current Turbine | none | 2.5 m/s | appropriate for tidal applications |
| | | Helical | none | 1 m/s | appropriate for tidal applications |
| | Kinetic | UEK | none | 2.5 m/s | being developed for river applications |

It is difficult to provide specific information such as power output and required flow rates for each turbine, because manufacturers claim such large ranges are possible for the turbines. When selecting a turbine, the characteristics of the site will greatly influence the turbine selection.

The impulse turbines are not appropriate for small hydro in Manitoba, because none of them are located below (submerged) the water's surface. Some reaction turbines such as the Kaplan and Francis turbines require a significant head.

Turbines, which should be further examined, are the bulb turbine, the Davis turbine and the UEK kinetic turbine. The bulb turbine has promising characteristics as it is located below the water's surface level; however some head is still required. The Davis turbine, also located below the water surface, is intended for tidal applications, thus it can not handle the high river velocities characteristic of Manitoba's rivers. If a Davis turbine were implemented, cavitation would result. Information regarding UEK's kinetic turbine is limited since the technology is still developing. However, it is known that the turbine is located below the water's surface, civil structure required is minimal, interference with marine life is minimal, and energy generation can be continuous. The UEK kinetic turbine can be compared to a propeller, except that it is located below the water's surface. Of the non-conventional turbines researched, the UEK and the marine current turbine have the highest velocity ratings, in the order of 2.5 m/s. Manitoba's rivers have velocities greater than 2.5 m/s leading to the suggestion of designing or developing a turbine for the specific application of high river flow with no head. River velocities in Manitoba are as high as 10 m/s. For optimum turbine performance and environmental considerations, the velocity employed in a small hydro application in Manitoba may be approximately 5 m/s, which remains greater than that for which current non-conventional turbine designs are intended.

# 5. FLOW MANAGEMENT

## 5.1 Introduction

As mentioned previously in Chapter 2, a conventional hydro plant consists of various components, many of which are civil structures. Civil structures provide flow management and are often are required for turbine installation. Chapter 5 examines the various civil structures of a hydro plant to determine which are appropriate for a small hydro plant.

A second important issue relating to flow management is the identification of methods for increasing flow rates of water entering the turbine. Recalling Equation (4.1) for a kinetic turbine, power is proportional to the fluid velocity cubed. Therefore, a moderate increase in flow velocity will provide a large increase in power output, making identifying and selecting flow rate increase methods a profitable endeavour.

Thirdly, environmental issues concerning hydro plants are influenced by how the plant's water flow is managed making environmental compatibility an appropriate issue to be discussed in conjunction with flow management.

## 5.2 Civil Structures

As pictured in Figure 2.1, there are various components in the form of civil structures that make up a hydro plant. Generally, a weir and intake upstream of the plant itself help regulate flow, before it moves through a settling basin and into a channel. The forebay holds water before it is transported to the turbine through a penstock. In the case of excess water, a spillway allows for overflow. Each civil structure plays an important role, representing possible energy increases or losses in the production of hydro power. To provide a complete understanding of civil structures utilized in hydro productions, information regarding all civil structures is presented.

### 5.2.1 Weirs

Water flow varies with seasons and so it must be controlled to ensure steady operation of the hydro plant. In addition to measuring water flow, a common application for a weir is to raise water levels, thus ensuring a constant water supply for the intake. Two common weir types are the broad-crested weir and the sharp-crested weir. The streamlines above a broad-crested weir remain straight, but curve above a sharp-crested weir. A further distinction is whether or not the flow over the weir is submerged. Submerged flow occurs when the water level downstream is raised so much that it affects the upstream flow. The weir may have the full width of the channel or be contracted. Rectangular weirs are common, but triangular (vee) is also an option. Important calculations relating to weirs include determining the discharge or flow rate over the weir. Common known parameters include the weir height, upstream total head and a dimensionless discharge coefficient which accounts for any deviation from a hydrostatic pressure distribution over the crest. The downstream tailwater level must be known to determine if the flow is submerged. In addition to varying with weir type, various numerical formulas are used for the discharge coefficient. Therefore various sources cite different formulas for discharges, (sources such as [10], [11], and [28]). Brown, [4], suggests common errors made in designing weirs and intakes:

- Undercutting of concrete weirs due to inefficient sealing
- Leaks in weirs that could not easily be drained
- Scaling down designs from large schemes, for example, combining a weir and settling tank in a costly layout,
- Setting headrace pipes too high in the weir, causing air entrainment.

### 5.2.2 Intake

The purpose of an intake is to divert river flow into the hydro plant. The amount of flow diverted can range from a small portion to all of the total river flow. Three common small intakes applicable for small hydro are a side intake, with and without a weir, and a bottom intake. For a side intake with a weir, the weir may be completely or partially submerged. However, for a bottom intake, the weir will be completely submerged. Table 5.1 summarizes the advantages and disadvantages for each intake type.

Table 5.1: Intake Types Comparison, Adapted from [27]

| Intake Type | Advantages | Disadvantages |
|---|---|---|
| Side intake without weir | - relatively economical<br>- simple construction | - requires maintenance and/or repairs regularly<br>- not applicable for rivers with flow variations, because unable to divert flow for low flows |
| Side intake with weir | -controls water level<br>- can be designed for minimal maintenance | - requires modern materials such as concrete<br>- does not divert low flows properly |
| Bottom intake | - applicable for flow variations, no problems with low flows<br>- can be designed for no maintenance | - costly<br>- blockage by sediment may occur, unless have good design<br>- local materials may not be used |

### 5.2.3 Channel

A channel transports water from the intake to the forebay, possibly creating head. Channels may be excavated or constructed from large pipe or a conduit. Sealing the channel with cement, clay or polythene sheet may prevent leakages and minimize friction. Precautions to consider in the use of a concrete channel include [4]:

- Drainage, to prevent water build-up and possible collapse of channel
- Have channel set in ground to reduce stress on walls, and the amount of concrete material used

Components such as a settling basin, spillway and forebay tank may be incorporated into a channel.

### 5.2.4 Settling Basin

A settling basin may serve two purposes. First, since water in the river may contain sediment which can damage turbine runners, it is desired to remove this sediment. Secondly, a stilling basin allows for the safe dissipation of the flow's kinetic energy. In a stilling basin, water flow is slowed down, allowing particles to settle on the basin floor before being flushed away periodically. The slower the water is flowing, the fewer number of particles will be transported. One approach for slowing the water flow is to increase the channel cross sectional area.

### 5.2.5 Spillway

A spillway controls water flow, allowing the passage of excess flow. In conjunction with gates, a spillway can empty a channel if necessary. Flow must re-enter the river in a controlled fashion so as not to damage the channel.

### 5.2.6 Forebay

The tank connecting the channel and the penstock is known as the forebay. The forebay acts as a reservoir, storing water. Gates and a trashrack, which stop the passage of large objects, may be present at the entrance to the penstock. A small hydro plant in Manitoba would not store water, thereby eliminating the requirement for a forebay. Penstock, however, may be present for a small hydro plant.

### 5.2.7 Penstock

An important part of the hydro system, penstock transports water from the forebay to the turbine, while under pressure. It is important for the penstock to be designed optimally, minimizing cost and friction. An increase in pipe diameter reduces friction, but increases cost. Material is also an important decision for the penstock. Table 5.2 contrasts the various material options and deciding factors for penstock.

Table 5.2: Penstock Materials Comparison, Adapted from [27]

| | Factor<br>* = poor ***** = excellent | | | | | |
|---|---|---|---|---|---|---|
| Material | Friction | Weight | Corrosion | Cost | Jointing | Pressure |
| Ductile Iron | **** | * | **** | ** | **** | **** |
| Asbestos Cement | *** | **** | **** | *** | *** | * |
| Concrete | * | * | ***** | *** | *** | * |
| Wood Stave | *** | *** | **** | ** | **** | *** |
| GRP | ***** | ***** | *** | * | **** | ***** |
| uPVC | ***** | ***** | **** | **** | **** | ***** |
| Mild Steel | *** | *** | *** | **** | **** | ***** |
| HDPE | ***** | ***** | ***** | ** | ** | ***** |

A critical design concern regarding penstocks is vibration, [23], [47]. Unacknowledged, excessive vibration can lead to failure. Brown, [4], states that when designing penstocks the following tasks should be performed:

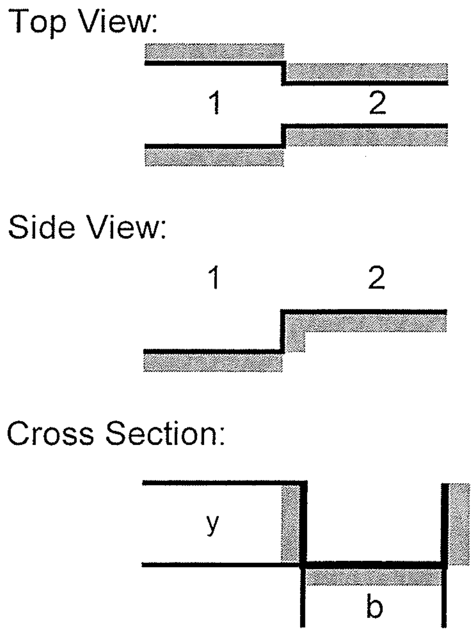
- Calculate forces on all bends
- Perform pressure tests
- Provide allowances for thermal expansion
- Flush out debris before connecting to the turbine

## 5.3 Flow Rate Increase Methods

The application of hydraulic engineering principles allows for the prediction of flow conditions under various constraints, and determines acceptable methods for increasing flow velocities. A most common method for increasing flow velocity is to restrict the area of which the flow is travelling. Secondly, the presence of head, allows for the addition of potential energy resulting from a change in elevation. The limitations of these flow methods must also be identified so as not to disturb the surrounding environment.

### 5.3.1 Maximum Width Constriction for a Given Channel

Constricting river flow may increase the flow velocity, but there exists a limit as to how much the river can be constricted before flow conditions upstream of the constriction are affected. It is desired to have the upstream conditions of the river remain uninfluenced. When selecting the appropriate velocity, one must also consider the increase in velocity causes an increase in sediment transport causing problems with river bed degradation and blade pitting from material transported into the turbine. Figure 5.1 displays the general geometry of the rectangular channel considered.



Top View:

Side View:

Cross Section:

Where 1 = section 1, (upstream)
2 = section 2, (downstream)
y = water depth
b = channel width

Figure 5.1: Rectangular Channel Sketch

Referring to Figure 5.1, all subscripts in the analysis refer to their respective sections. The following analysis involves continuity and energy equations.

Analysis inputs:

- Flow rate, $Q$
- Channel width of upstream section, $b_1$
- Water depth of upstream section, $y_1$
- Channel elevations of upstream and downstream sections, $z_1$ and $z_2$

Analysis Outputs:

- Minimum channel width required, $b_2$
- Accompanying water depth, $y_2$
- Associated flow velocities, $V_1$ and $V_2$

Analysis:

- Flow rate, $Q$, remains constant throughout the channel, (continuity).

$$Q = Vby \tag{5.1}$$

Equation $(5.1)$ allows for the determination of $V_1$.

- Specific discharge, $q$

$$q = Q/b \tag{5.2}$$

It is important to calculate $q_1$ immediately, as it will be required for future calculations.

- The specific energy of a section of channel with small slope and no losses is

$$E = y + \frac{V^2}{2g} = y + \frac{q^2}{2gy^2} = y + \frac{Q^2}{2b^2y^2} \tag{5.3}$$

Where $g$ = constant of acceleration due to gravity.

Equations $(5.1)$ and $(5.2)$ allow the specific energy to be expressed in various forms. For this analysis, Equation $(5.3)$ is applied at section 1 to determine the specific energy for the non-constricted section, $E_1$.

- Assuming no energy losses,

$$E_1 = E_2 + \Delta z \qquad (5.4)$$

Where $$\Delta z = z_2 - z_1 \qquad (5.5)$$

The value of $E_2$ may now be determined.

- For a given change in elevation and specific energy, $E_1$, the maximum amount of constriction possible will occur for critical flow, where specific energy is minimized, in the constricted section. For critical flow in a rectangular channel [37 p.30]:

  $$E_{\min} = \frac{3}{2} y_c \qquad (5.6)$$

  Where $y_c$ = critical water depth.

  For this analysis, $E_2 = E_{\min}$, and $y_c$, which is equivalent to $y_2$, may be determined using Equation $(5.6)$.

- An alternative expression involving the critical water depth for a rectangular channel is

  $$y_c = \sqrt[3]{\frac{q^2}{g}} \qquad (5.7)$$

  Rearranging $(5.7)$ allows for the determination of $q_2$.

- The channel width of the constricted section is calculated by expressing $(5.7)$ in an alternative form:

  $$b_2 = \sqrt{Q^2/(g y_c^3)} \qquad (5.8)$$

  This is the minimum channel width required for upstream flow to remain unaffected.

- Finally, the flow velocity for the constricted section, $V_2$, is calculated by rearranging $(5.1)$

Example:

A spreadsheet designed to compute the minimum width requirement calculation is located in Appendix B. For a channel flow rate of 900 cms (32 000 cfs), an elevation drop of 1.5 m (5 ft), and initial channel width of 300 m (1 000 ft) and water depth of 4.5 m (15 ft), the minimum channel width required in the constriction is approximately 35 m (115 ft) resulting in a water depth of 4 m (13.4 ft). The velocity will increase from 0.6 m/s (2 ft/s) in the non-constricted section to 6 m/s (20 ft/s) in the constricted section.

### 5.3.2 Velocity Resulting from Constricting Channel Width

Similar to the previously described analysis, if one assumes that the channel is constricted such that upstream flow remains uninfluenced, the velocity which results from creating a constriction in the river may be determined. Once again, Figure 5.1 represents the rectangular channel considered in this analysis.

Analysis inputs:

- Flow rate, $Q$
- Channel width of upstream and downstream sections, $b_1$ and $b_2$
- Water depth of upstream section, $y_1$
- Channel elevations of upstream and downstream sections, $z_1$ and $z_2$

Analysis Outputs:

- Water depth of downstream, constricted section, $y_2$
- Flow velocities, $V_1$ and $V_2$

Analysis:

- Initially, Equation $(5.2)$ may be used to calculate $q_1$ and $q_2$.
- Similarly, Equation $(5.1)$, may be used to calculate $V_1$. An alternative equation form uses the specific discharge:

$$V = q/y \tag{5.9}$$

- The specific energy for the non-constricted section, $E_1$, is determined using Equation $(5.3)$.
- Equations $(5.4)$ and $(5.5)$ calculate $E_2$.
- Applying Equation $(5.3)$ for $E_2$, where $E_2$ is known, creates an equation in terms of $y_2$:

$$y_2^3 - y_2^2 E_2 + q_2^2/(2g) = 0 \tag{5.10}$$

- The above cubic equation is solved for the new water depth, $y_2$, using a numerical method [44]. For a given cubic equation such as:

$$x^3 + a_1 x^2 + a_2 x + a_3 = 0 \tag{5.11}$$

Where $a_1$, $a_2$, and $a_3$ are real coefficients. The following three computing coefficients must first be calculated:

$$S = \frac{a_1^2 - 3a_2}{9} \tag{5.12}$$

$$R = \frac{2a_1^3 - 9a_1 a_2 + 27a_3}{54} \tag{5.13}$$

$$Y = \arccos\left(R/\sqrt{Q^3}\right) \tag{5.14}$$

Then, the three roots may be determined:

$$\left.\begin{aligned} x_1 &= -2\sqrt{Q}\cos\left(\frac{Y}{3}\right) - \frac{a_1}{3} \\ x_2 &= -2\sqrt{Q}\cos\left(\frac{Y+2\pi}{3}\right) - \frac{a_1}{3} \\ x_3 &= -2\sqrt{Q}\cos\left(\frac{Y+4\pi}{3}\right) - \frac{a_1}{3} \end{aligned}\right\} \tag{5.15}$$

Of the three water depths calculated, one is an unreal number, which may be discarded. The reaming two values are alternative depths of one another. One must select the water depth, $y_2$, which corresponds to the appropriate flow regime. This is usually the value of $y_2$ that is closet to $y_1$.

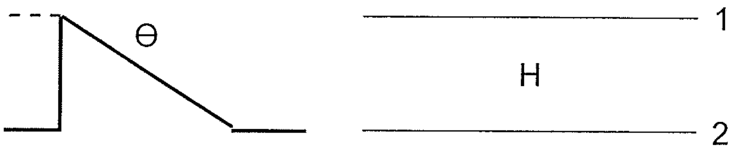
- Finally, Equation $(5.9)$ is used to determine the velocity of the constricted section, $V_2$.

Example:

Appendix C contains a spreadsheet summarizing the velocity calculations resulting from a constriction with specific numerical values. For a channel flow rate of 900 cms (32 000 cfs), an elevation drop of 1.5 m (5 ft), and initial channel width of 300 m (1 000 ft) and water depth of 4.5 m (15 ft), and a constricted channel width of 45 m (150 ft), the water depth in the constriction will be approximately 5.5 m (18 ft). The velocity increases from approximately 0.6 to 3.6 m/s (2 to 12 ft/s).

### 5.3.3 Velocity Resulting from a Given Head

Kinetic turbines are generally intended for power applications where head is not present. The objective of this research is to develop power with head minimized as much as possible, however one must acknowledge that the presence of head, even in a small amount is one method to increase the flow rate and consequently power output. Therefore, a simple analysis which determines the velocity resulting from a given head was performed. The described situation is presented in Figure 5.2, from a side viewpoint.



Where - - - - = initial water surface level

Θ = angle between water level and penstock to transport water

H = height difference

Figure 5.2: Head Drop Sketch

Analysis inputs:

- Pipe diameter, $D$
- Length of pipe, $L$, or parameters such as drop height, $H$, and angle between the pipe and the horizon, $\theta$, which will determine pipe length.

- Initial and final elevations, $z_1$ and $z_2$, where $H = z_1 - z_2$
- Pressure drop, $\Delta p$

Analysis Outputs:

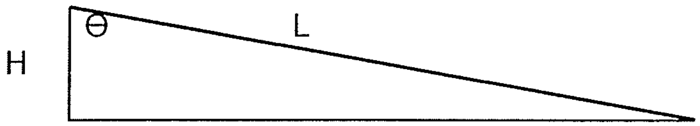
- Water flow rate, $Q$, or velocity, $V$.

Assumptions:

- Both ends of system are open to atmosphere. Therefore there is no change in pressure, $p_1 = p_2 = p_{atm}$ or $\Delta p = 0$.
- Initial average velocity, $\overline{V}_1' \cong 0$
- Kinetic energy coefficient for section 2, $\alpha_2 \cong 1.0$
- No minor losses, $h_{lm} = 0$
- Fully developed flow
- Area of pipe remains constant

Analysis:

- If necessary, determine pipe length, $L$, using trigonometric relations, Figure 5.3.



Where
H = drop height
Θ = drop angle
L = pipe length

Figure 5.3: Parameters for Determination of Pipe Length

$$L = H/\cos\theta \tag{5.11}$$

- The general computing equation required for this analysis may be derived using conservation of energy [15]:

$$\left(\frac{p_1}{\rho}+\alpha_1\frac{\overline{V}_1^2}{2}+gz_1\right)-\left(\frac{p_2}{\rho}+\alpha_2\frac{\overline{V}_2^2}{2}+gz_2\right)=h_{lT} \qquad (5.12)$$

Where $\rho$ = fluid density

$g$ = constant of acceleration due to gravity

The total energy losses per unit mass, often referred to as head loss, are represented by $h_{lT}$:

$$h_{lT}=h_l+h_{lm} \qquad (5.13)$$

Where $h_l$ are the major losses due to friction, and $h_{lm}$ are the minor losses caused by fittings, entrances, etc. Since there are no minor losses, $h_{lT}=h_l+0=h_l$.

- For turbulent flow, the losses are given by

$$h_l=f\frac{L}{D}\frac{\overline{V}^2}{2} \qquad (5.14)$$

Where $f$ = friction factor

$\overline{V}$ = average flow velocity

- By substituting Equation $(5.14)$ into Equation $(5.12)$, and considering the simplifying assumptions, Equation $(5.12)$ may be rewritten as

$$g(z_1-z_2)-\frac{\overline{V}_2^2}{2}=f\frac{L}{D}\frac{\overline{V}_2^2}{2} \qquad (5.15)$$

- The maximum flow velocity will occur if no friction is present, ($f$ = 0):

$$\overline{V}_2 = \sqrt{2g(z_1 - z_2)} \tag{5.16}$$

- The analysis with friction present requires further steps. If $H = z_1 - z_2$, Equation $(5.15)$ may be rewritten as

$$\overline{V}_2 = \left[\frac{2gH}{f(L/D)+1}\right]^{1/2} \tag{5.17}$$

- The friction factor, $f$ may be determined by referring to [15, Figure 8.13, p.360]. This chart shows $f$ as a function of the Reynolds number, $\mathrm{Re}$. The roughness, $e$, of the pipe material is also required. A number of $e$ values are provided in [15, Table 8.1, p.359].
- An initial guess for $f$ may be made by assuming a presence in the fully rough region of [15, Figure 8.13, p.360].
- The first approximation of $\overline{V}_2$ is calculated.
- For this value of $\overline{V}_2$, the value of $\mathrm{Re}$ is calculated.
- A new $f$ may now be determined.
- Finally a second approximation for $\overline{V}_2$ may be calculated.

Example:

For the case of a smooth plastic pipe with no friction, an angle of 60° with the horizon, and a height drop of 6 m (20 ft), a velocity of approximately 11 m/s (36 ft/s) will result.

## 5.4 Environmental Issues

Since hydro plants depend on a renewable resource, they may be considered an environmentally acceptable source of producing power. However, it is desired to ensure the plant is installed as harmoniously as possible with its surrounding environment. The marine life of the river, in particular the survival of fish is a very important issue. Another major environmental issue is pollution, which may occur from turbine operation. Noteworthy issues outside the scope of the research include the impacts of transmission line development as well as road access to turbines and transmission lines.

### 5.4.1 Fish Survivability

There are four general known causes of damage or mortality of fish passing through a turbine.

#### 5.4.1.1 Abrasion, Grinding and Strike

Problem:

Abrasion or grinding occurs when a fish rubs against turbine components or objects in the flow field, causing damage. Strike occurs when a fish is struck by a stationary or a mobile object such as a turbine blade, causing injury or death.

Influential factors:

- Fish size
- Turbine size
- Turbine speed
- Number of turbine blades, gates and stay vanes

- Clearance between blades and wicket gates
- Blade profile

Solutions, for a given fish size:

- Big turbine
- High specific speed
- Fewer number of blades
- More space between wicket gates and runner blades
- Blades with thick entrance edges can guide fish better

#### 5.4.1.2 Pressure Change

Problem:

Rapid pressure change damage a fish's buoyancy bladder [14]. It has been stated that "fish are more sensitive to pressure decreases than pressure increases, and that pressure-related mortality results from injury to the swim bladder from decompression" [6].

Influential factors:

- Fish type
- Plant head
- Turbine size
- Fish location in upper reservoir and turbine intake location
- Penstock length

Solutions:

- Diffusion into the blood is used by some fish, such as perch and bass, to adjust their body's gas content. This process may take hours, thereby allowing for damage. Other fish, such as salmon and trout, use a pneumatic duct connecting the swim bladder and the esophagus, in conjunction with the mouth, to output or input gas more quickly than diffusion.

- Pressure change is directly proportional to plant head.
- A small, high head turbine will result in a high pressure change rate. A big, low head turbine will result is a slow pressure change rate.
- More damage will occur for plant with lower rather than higher intake. This is because fish will experience a pressure rise as they move through the penstock before the rapid pressure decrease in the turbine. When fish enter an intake at the bottom of the plant they are already at a high pressure.
- As compared to a short penstock with the same conditions, a long penstock allows for pressure adaptation while approaching the turbine, making fish more susceptible to affects caused by rapid pressure decrease through the turbine.

It should be noted that this problem would most likely not occur with a kinetic turbine.

### 5.4.1.3 Cavitation

Problem:

Cavitation refers to the formation of bubbles due to pressure in liquid dropping to or below vapour pressure. As the bubbles move into regions of higher pressure, they collapse causing noise, vibrations, and pressure fluctuations thereby damaging solid surfaces as well as fish.

Influential factors:

- Turbine operation
- Runner geometry
- Submergence

Solutions:

- Operating a turbine over a restricted range minimizes cavitation [14]. "Operational cavitation constant must be such that cavitation does not start to be damaging to the turbine" [41].
- Design runner to minimize cavitation by considering high velocity/low pressure zones, surface irregularities, sudden flow direction changes, and location or submergence [40].
- Extra submergence provides "a margin of safety against cavitation" [36].

#### 5.4.1.4 Turbulence

Problem:

Rapid change in velocity leads to stress and turbulence, potentially damaging fish.

Influential factors:

- Efficiency
- Design criteria

Solutions:

- Fish are more likely to survive when turbine is operating at or near its best efficiency [36]. Too low or high a head or output causes turbulence, shear stress and cavitation.
- There exists ongoing research to define appropriate limits for stress, turbulence and pressure changes [41].

### 5.4.2 Pollution

The operation of the turbine itself may result in pollution. Oil and grease used for lubrication of various parts are normally sealed in a chamber to prevent contact with water. However, if a seal fails, oil or grease may pollute the water. Two design considerations can prevent this problem, [14]. Greaseless bushings in place of greased lubricated bushings or biodegradable and non toxic lubricants may be used.

# 6. SITE SELECTION

## 6.1 Introduction

The identification and selection of a potential small hydro site is an important part of assessing the feasibility of small hydro. The completion of site selection research consisted of two main steps. Firstly, the characteristics of a successful small hydro site as well as the appropriate factors for evaluating a small hydro site were identified. Secondly, the identification and evaluation of undeveloped conventional small hydro sites in Manitoba was conducted. Information is currently not available for small hydro sites with non-conventional applications; however, upon further research the identified conventional sites may be adaptable for non-conventional small hydro.

## 6.2 Site Characteristics

There are various characteristics which make a small hydro site suitable and therefore a successful endeavour. To select a small hydro site for either conventional or non-conventional applications, it is necessary to limit the characteristics to a smaller number of evaluation factors which may be used to identify the optimum site.

### 6.2.1 Characteristics

Consulting various information sources such as articles identifies a number of concerns for considering a specific location for small hydro. The two most important factors are head and flow because [23]:

$$\text{Power} = 8 \times \text{Head} \times \text{Design Flow} \quad (6.1)$$

While both of the above factors are important, the type of turbine employed will dictate which of the two factors will have greater influence. A conventional small hydro site considers head as well as flow. However, a non-conventional small hydro site, and recalling Equation (4.1) for a kinetic turbine, does not utilize any head thereby making flow the most important factor.

Various site characteristics can be grouped into common categories including naturally occurring characteristics, transmission, communities and environmental impacts.

- Existing channel characteristics
    - Head
    - Flow velocity
    - Seasonal flow patterns
    - Tailwater level
    - Natural water storage
- Transmission
    - Proximity to transmission lines
    - Grid connection
    - Upgrade charges to accommodate local electrical distribution network
- Community
    - Distance to populated area

    - Nearest community may provide or indicate:
        - Operating and maintenance personnel
        - Energy demand
        - Transmission
    - Effects on recreation or commercial activities
    - Conservation of area – possible historic value
    - Road access
    - Current power source
- Environmental Impacts
    - Screen cleaning requirements
    - Fishery board authorities
    - Marine and plant life

### 6.2.2 Evaluation Factors

A few site characteristics were deemed of critical importance and selected as factors to evaluate the identified small hydro sites in Manitoba. The evaluation factors are:

- Available flow
- Proximity to transmission lines
- Characteristics of load centre
    - Distance
    - Population
    - Current power source

It can be noted that by identifying the distance and population of the nearest community, considerations such as energy demand, staffing personnel availability and proximity to transmission lines are also taken into account. Furthermore, the recognition of a community's current source of power indicates potential energy cost savings through the implementation of a small hydro facility. The next step is to evaluate potential small hydro sites in Manitoba.

## 6.3 Potential Small Hydro Sites in Manitoba

There are a number of hydro sites in Manitoba which may be classified as small hydro and are currently undeveloped. The process of identifying sites and generating a list of selected sites consisted of a number of steps. Using a map identifying developed and undeveloped hydro in Manitoba, supplied by Manitoba Hydro [33], a complete list of undeveloped small hydro sites in Manitoba was prepared. Unfortunately this map was the only information source available and the font was rather illegible, consequently the resulting data may have errors. To further evaluate these sites, an attempt was made to identify the associated rivers. Once all sites were identified, it was necessary to select a limited number of sites for future consideration. Two important factors became evident to produce this site list. Firstly, if small hydro can be implemented to replace costly diesel generation, the site is appropriate for further consideration. Secondly, if transmission is not a concern for a site, the site is considered attractive. The following section presents results from these analyses.

### 6.3.1 Manitoba Small Hydro Sites

Small hydro sites are identified as those undeveloped hydro sites with a potential capacity of 50 MW or less. Manitoba has various rivers and locations with varying head applicable for small hydro, (Figure 6.1).

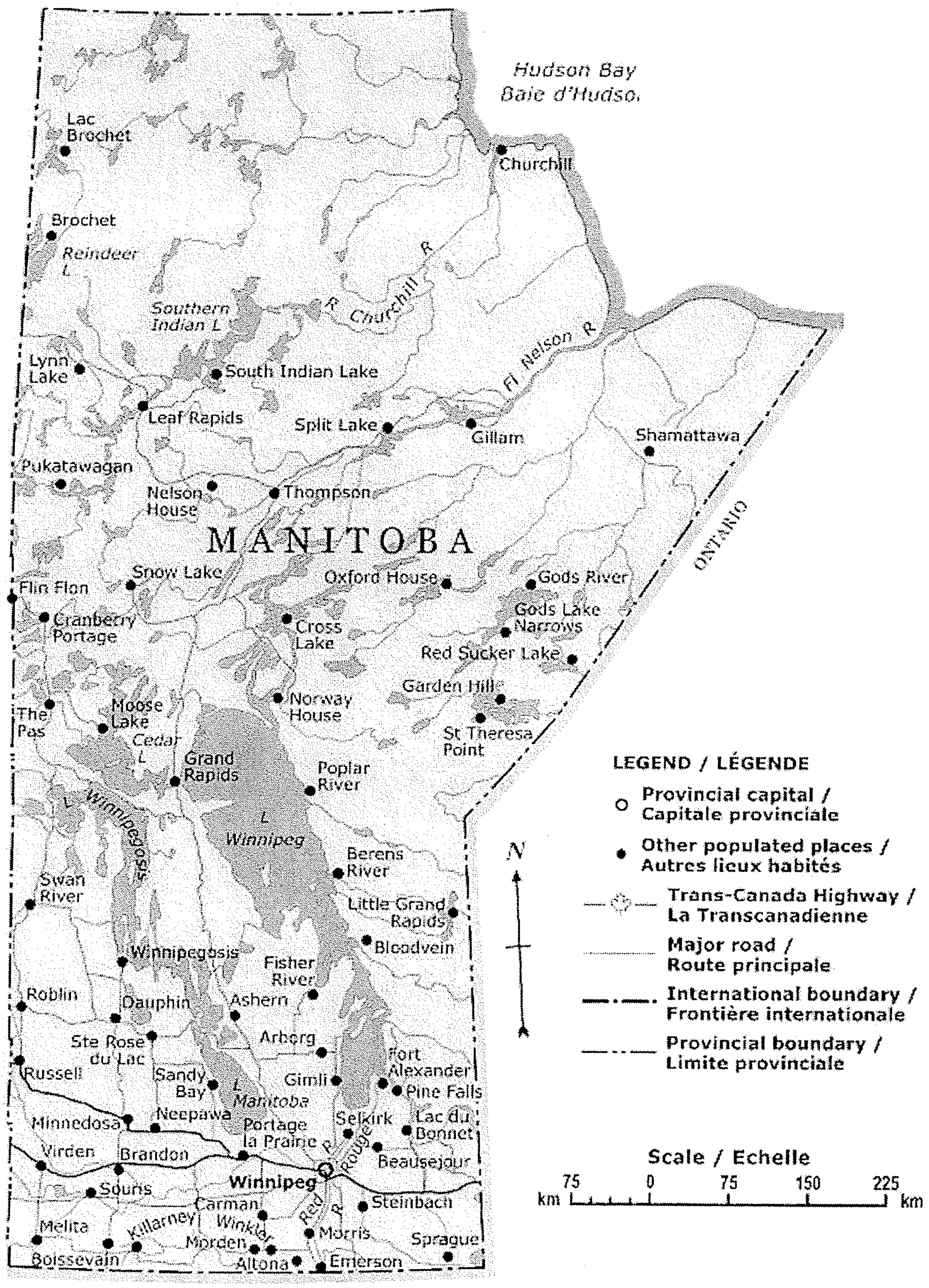


Figure 6.1: Map of Manitoba [38]

Referring to Figure 6.1, the rivers with a number of potential small hydro sites include the Seal River, (illegible on map), in the north, and the Hayes River northeast of Lake Winnipeg. The Poplar River, Berens River, and Bloodvein River, all east of Lake Winnipeg, also have potential for small hydro development. Not shown in Figure 6.1, but located directly south of the Bloodvein River, is the Manigotagon River which contains four undeveloped small hydro sites.

Table 6.1 presents a list of all undeveloped conventional small hydro sites in Manitoba. In addition to their geographical location, Manitoba's potential small hydro sites vary with available head and potential capacity. All site numbers were determined by Manitoba Hydro, [33] and capacities "reflect an approximate capacity factor of 0.65." All flow values have been extrapolated using Equation $(4.5)$, with a density of 1000 kg/m$^3$, the acceleration due to gravity of 9.81 m$^3$/s and a capacity factor of 0.65.

Table 6.1: Undeveloped Small Hydro Sites in Manitoba, Adapted from [33]

| All Small Hydro Sites | | | | | |
|---|---|---|---|---|---|
| **Site Number** | **Name** | **Head [m]** | **Flow [$m^3/s$]** | **Potential Capacity [MW]** | **River / Lake** |
| 2 | Pine Falls Extension | 11 | 64 | 45 | Winnipeg River |
| 3 | Muskrat | 26 | 2 | 3 | Manigotagon River |
| 4 | Pillow Falls | 24 | 2 | 3 | Manigotagon River |
| 5 | Cascade Portage | 15 | 2 | 2 | Manigotagon River |
| 6 | Wood Falls | 17 | 2 | 2 | Manigotagon River |
| 7 | Bushy Lake | 17 | 10 | 11 | Bloodvein River |
| 8 | Stonehouse Lake | 17 | 10 | 11 | Bloodvein River |
| 9 | Kautunigan Lake | 17 | 10 | 11 | Bloodvein River |
| 10 | Sasaginnigak River | 17 | 10 | 11 | Bloodvein River |
| 11 | Minago Creek | 17 | 10 | 11 | Bloodvein River |
| 12 | Leyond River | 17 | 10 | 11 | Bloodvein River |
| 13 | Night Owl | 19 | 27 | 33 | Berens River |
| 14 | Paint Moose | 12 | 27 | 21 | Berens River |
| 15 | Smoothrock | 18 | 29 | 33 | Berens River |
| 16 | Old House | 19 | 28 | 34 | Berens River |
| 17 | Round Tent | 17 | 29 | 31 | Berens River |
| 18 | Lewis Lake | 23 | 3 | 5 | Poplar River |
| 19 | Harrop Lake | 21 | 4 | 5 | Poplar River |
| 20 | Wrong Lake | 16 | 6 | 6 | Poplar River |
| 21 | Weaver Lake | 13 | 8 | 7 | Poplar River |
| 22 | Whitemud Rapids | 5 | 13 | 4 | Poplar River |
| 23 | Robinson Falls | 20 | 5 | 6 | Hayes River |
| 24 | Wipanipanis Falls | 10 | 7 | 4.5 | Hayes River |
| 25 | Knife Rapids | 10 | 12 | 7.5 | Gods Lake |
| 26 | Apakisthemosi Rapids | 10 | 13 | 8.5 | Hayes River |
| 27A | Pakisikan Rapids | 20 | 15 | 19 | Hayes River |
| 28 | Hayes River | 32 | 17 | 35 | Hayes River |
| 31 | Mostone No.1 | 11 | 6 | 4 | Fox River |
| 31A | Mostone No.2 | 12 | 6 | 4.5 | Fox River |
| 31B | Mostone No.3 | 15 | 6 | 5.5 | Fox River |
| 32 | Camp Rapids | 17 | 12 | 13 | Fox River |
| 33 | Gowan Rapids | 35 | 13 | 28 | Fox River |
| 34 | Fox River | 32 | 14 | 29 | Fox River |
| 35 | Kanuchuanus Rapids | 15 | 16 | 15 | Red Sucker Lake |
| 35A | Bad Rapids | 10 | 19 | 12 | Red Sucker Lake |
| 36 | Kanuchuan Rapids | 21 | 25 | 33 | Bloodvein Lake |
| 37 | Allen Island | 13 | 35 | 29 | Gods River |
| 37A | Twenty Islands | 9 | 35 | 20 | Gods River |
| 38A | Sturgeon Falls | 10 | 37 | 23.5 | Gods River |
| 39A | Red Sucker River | 15 | 5 | 5 | Gods River |
| 41 | Waterhen River | 5 | 9 | 3 | Waterhen Lake |
| 43 | Clay Falls | 14 | 8 | 7 | Burntwood River |
| 44 | Gate Falls | 11 | 7 | 5 | Burntwood River |
| 45 | Reed Lake | 15 | 1 | 1 | Reed Lake |
| 46 | Wekusko Falls | 22 | 3 | 4 | Wekusko Lake |
| 47 | Whitewood Falls | 31 | 5 | 10 | Setting Lake |
| 48 | Lynx Falls | 37 | 11 | 25 | Paint Lake |
| 49 | Witchai Lake | 18 | 17 | 19 | Burntwood River |
| 50 | Laurie River No.3 | 14 | 6 | 5 | Lauire River |
| 51 | Chipewyan | 5 | 60 | 19 | Chipewyan Falls |
| 52 | Brochet | 17 | 39 | 42 | Reindeer Lake |
| 53 | Porcupine | 30 | 24 | 45 | Seal River |
| 54 | Bain Lake | 15 | 30 | 29 | Seal River |
| 55 | Macleod Lake | 24 | 8 | 12 | Seal River |
| 56 | Wolverine | 15 | 14 | 13 | Seal River |
| 80 | God's Rapids | 12 | 25 | 19 | Southern Indian Lake |

As documented there are a large number of undeveloped conventional small hydro sites in Manitoba. The total potential capacity, determined by summing all potential capacities from Table 6.1, for undeveloped small hydro in Manitoba is 888 MW.

### 6.3.2 Small Hydro and First Nation Communities

There are four communities, Brochet, Lac Brochet, Tadoule Lake and Shamattawa, currently served by diesel generation by Manitoba Hydro, (Figure 6.2).

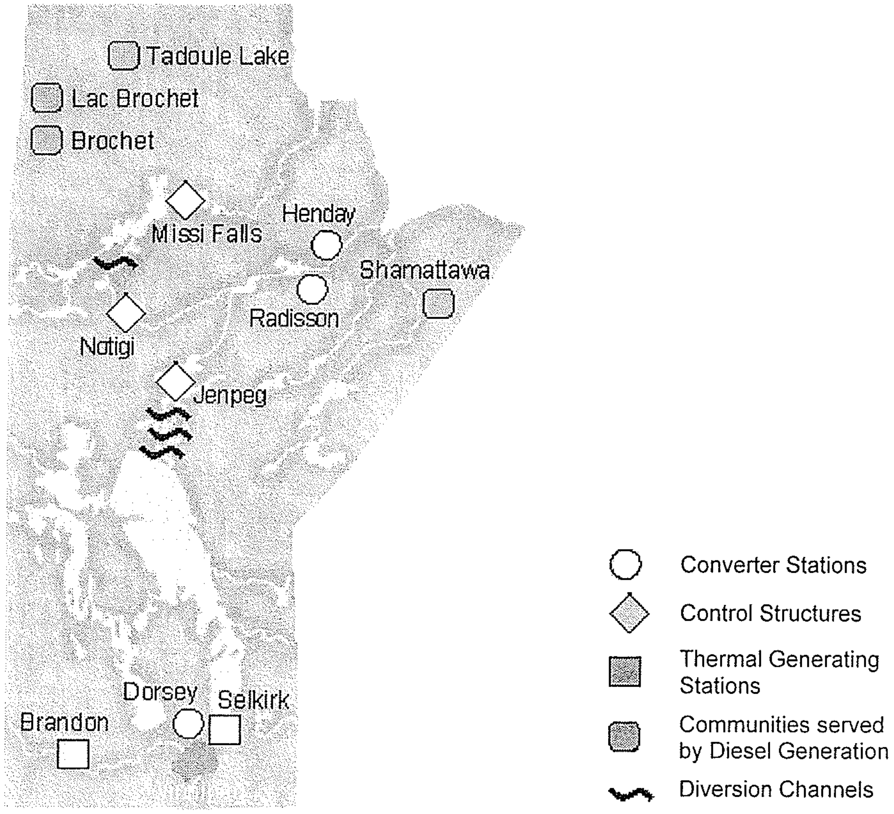


Figure 6.2: Manitoba Hydro System Components Other Than Hydraulic Generating Stations [35]

In North America, an independent power producer (IPP) may receive \$0.0584/kWh for electricity sold to a central grid. However, for the case of an isolated diesel grid, the IPP may receive more than \$0.20/kWh [45]. Therefore, if a small hydro facility serves a community currently using diesel generation, its potential for economic feasibility greatly improves. Brochet, Lac Brochet, Tadoule Lake and Shamattawa are all First Nation communities located in remote areas of Manitoba. Table 6.2 summarises various characteristics of these communities including population and road access.

Table 6.2: Profiles of Communities Served by Diesel Generation
Adapted from [1]

| | Community Served by Diesel Generation, (as labeled on Figure 6.2) | | | |
|---|---|---|---|---|
| | Brochet | Lac Brochet | Tadoule Lake | Shamattawa |
| First Nation Detail | | | | |
| Official Name | Barren Lands | Northlands | Sayisi Dene First Nation | Shamattawa First Nation |
| Number | 308 | 317 | 303 | 307 |
| Address | Brochet | Lac Brochet | Tadoule Lake | Shamattawa |
| Reserve | | | | |
| No. | 6458 | 6468 | 6464 | 6460 |
| Name | Brochet No. 197 | Lac Brochet No. 197A | Churchill Indian Reserve No. 1 | Shamattawa No. 1 |
| Location | 256 Km NW of Thompson | 240 Km NW of Thompson | 320 Km N of Thompson | 320 Km W of Thompson |
| Hectares | 4339.4 | 464.3 | 212.1 | 2316.9 |
| Geography | | | | |
| Geographic Zone | First Nation has no year-round road access to a service centre and, as a result, experiences a higher cost of transportation | First Nation has no year-round road access to a service centre and, as a result, experiences a higher cost of transportation | First Nation has no year-round road access to a service centre and, as a result, experiences a higher cost of transportation | First Nation has no year-round road access to a service centre and, as a result, experiences a higher cost of transportation |
| Subzone | Distance, measured directly, to the nearest service centre is between 320 and 400 Km | Distance, measured directly, to the nearest service centre is between 320 and 400 Km | Distance, measured directly, to the nearest service centre is between 320 and 400 Km | Distance, measured directly, to the nearest service centre is between 320 and 400 Km |
| Environmental Index | Geographic location between 55 and 60 degrees latitude | Geographic location between 55 and 60 degrees latitude | Geographic location between 55 and 60 degrees latitude | Geographic location between 55 and 60 degrees latitude |
| Population | | | | |
| Total Registered Population | 873 | 891 | 665 | 1160 |

Table 6.3 presents the potential small hydro sites which could provide electricity for these remote communities.

Table 6.3: Small Hydro Sites to Potentially Replace Diesel Generation Adapted from [33]

**Small Hydro Sites to Replace Diesel Generation**

| Site Number | Name | Head [m] | Flow [$m^3/s$] | Potential Capacity [MW] | River / Lake |
|---|---|---|---|---|---|
| 23 | Robinson Falls | 20 | 5 | 6 | Hayes River |
| 24 | Wipanipanis Falls | 10 | 7 | 4.5 | Hayes River |
| 25 | Knife Rapids | 10 | 12 | 7.5 | Gods Lake |
| 26 | Apakisthemosi Rapids | 10 | 13 | 8.5 | Hayes River |
| 27A | Pakisikan Rapids | 20 | 15 | 19 | Hayes River |
| 28 | Hayes River | 32 | 17 | 35 | Hayes River |
| 37 | Allen Island | 13 | 35 | 29 | Gods River |
| 37A | Twenty Islands | 9 | 35 | 20 | Gods River |
| 38A | Sturgeon Falls | 10 | 37 | 23.5 | Gods River |
| 39A | Red Sucker River | 15 | 5 | 5 | Gods River |
| 51 | Chipewyan | 5 | 60 | 19 | Chipewyan Falls |
| 52 | Brochet | 17 | 39 | 42 | Reindeer Lake |
| 53 | Porcupine | 30 | 24 | 45 | Seal River |
| 54 | Bain Lake | 15 | 30 | 29 | Seal River |
| 55 | Macleod Lake | 24 | 8 | 12 | Seal River |
| 56 | Wolverine | 15 | 14 | 13 | Seal River |

The small hydro sites numbered 52, 51, and 54 could serve Brochet, Lac Brochet and Tadoule Lake, respectively. Sites 53, 55 and 56 are located closest to Tadoule Lake, but at a greater distance than site 54. The remaining sites are all in the vicinity of Shamattawa. With regards to Shamattawa, in the north east corner of the province, (south of Hudson Bay), the Hayes River and Gods River are of particular interest.

Shamattawa is the most southerly located community considered. Therefore, it would probably be most straightforward for transmission connection and road access, as compared to the more northerly situated communities. In addition, Shamattawa has the largest population and a greater number of potential small hydro sites located nearby, creating a greater possibility of feasibility. Therefore, Shamattawa is recommended to be the first area to study the feasibility of small hydro to replace diesel generation.

However, the transmission system in northern Manitoba is not as well developed as compared to the south. Therefore, it is necessary to identify small hydro sites located in non-remote areas of Manitoba where transmission would not be a limitation for small hydro implementation.

### 6.3.3 Small Hydro with Minimal Transmission Requirements

There are two interesting general locations of undeveloped small hydro in the southern half of Manitoba. One group is located just north of Lake Winnipeg, and listed in Table 6.4, and the other east of Lake Winnipeg, and presented in Table 6.5.

Table 6.4: Small Hydro Sites North of Lake Winnipeg, Adapted from [33]

**Small Hydro Sites North of Lake Winnipeg**

| Site Number | Name | Head [m] | Flow [$m^3/s$] | Potential Capacity [MW] | River / Lake |
|---|---|---|---|---|---|
| 45 | Reed Lake | 15 | 1 | 1 | Reed Lake |
| 46 | Wekusko Falls | 22 | 3 | 4 | Wekusko Lake |
| 47 | Whitewood Falls | 31 | 5 | 10 | Setting Lake |

Sites 45, 46, and 47 were selected for their relatively southern location despite being north of Lake Winnipeg. Site 47, Whitewood Falls, is recommended to be considered for further research because its potential capacity is relatively high, 10 MW. Further south in the province, the Berens River has high potential capacities, (Table 6.5).

Table 6.5: Small Hydro Sites East of Lake Winnipeg, Adapted form [33]

| Small Hydro Sites East of Lake Winnipeg | | | | | |
|---|---|---|---|---|---|
| **Site Number** | **Name** | **Head [m]** | **Flow [m$^3$/s]** | **Potential Capacity [MW]** | **River / Lake** |
| 13 | Night Owl | 19 | 27 | 33 | Berens River |
| 14 | Paint Moose | 12 | 27 | 21 | Berens River |
| 15 | Smoothrock | 18 | 29 | 33 | Berens River |
| 16 | Old House | 19 | 28 | 34 | Berens River |
| 17 | Round Tent | 17 | 29 | 31 | Berens River |

The sites on the Berens River are recommended for further assessment because there is more total capacity on the Berens River, 152 MW, as compared to the Poplar, Bloodvein and Manigotagon Rivers, which have total potential capacities of 11, 66, and 10 MW, respectively. Even though it has already been demonstrated that further research is required for site selection, one may devise important conclusions and recommendations at this time. However, the site's characteristics greatly influence the economic feasibility of small hydro, leading the importance of completing an economic analysis for small hydro.

# 7. ECONOMIC ANALYSIS

## 7.1 Introduction

To assess the economic success of a small hydro project in Manitoba, various steps were required. Firstly, it was necessary to identify the factors which influence the cost of a small hydro site. Secondly, it was necessary to identify the economic parameters which dictate the criteria to determine if a small hydro site may be considered economically feasible. There exist various methodologies which may be used to extract a variety of information relating to the economics of a small hydro project. Thirdly, identifying and understanding tools, such as computer programs, aids in the economic analysis of a small hydro site.

## 7.2 Cost Influencing Factors

First, it must be stated that the analysis of a small hydro sites is very site specific. Location and site conditions determine 75% of the development cost while manufacturing the electromechanical equipment contributes the smaller portion of normally fixed cost, 25%, [45]. Generally, however, high head is less costly than low head, [25], [43]. This statement is with respect to small hydro and is illustrated in Figure 7.1

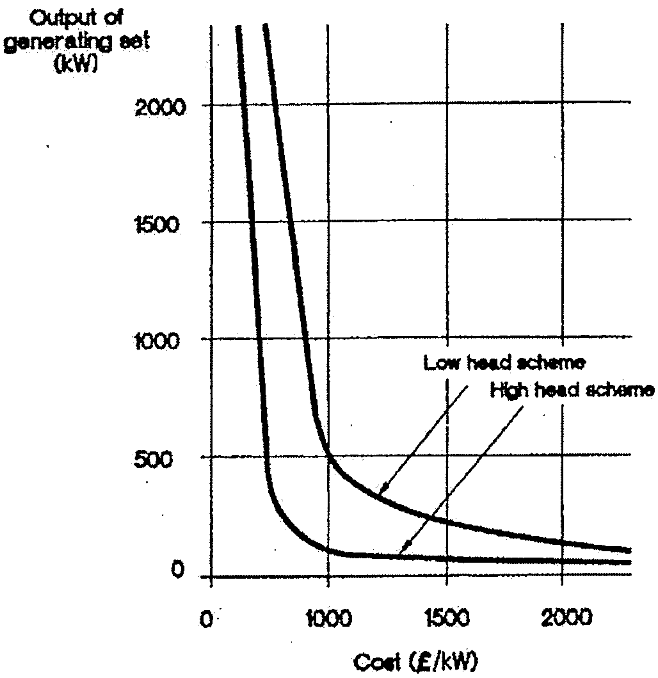


Figure 7.1: Costs [25]

This is because high head requires less water for a given power output and therefore requires small, less costly mechanical equipment. Other influential factors are:

- Load centre characteristics
  - Electricity demand
  - Transmission distance
- Capital costs
  - Costs required to complete project
- Operation and maintenance costs
  - Most small hydro plants can not support a full time operator. Therefore, it is appropriate to automate much of the operation, including screen-cleaning systems.

- Payback period
    - Life span of project – A small hydro development from conception to final commissioning will usually take 2 to 5 years. The useful life of a hydro plant may be much greater than 50 years [45].
- Planning
    - Engineering
    - Transport
    - Tools
- Civil engineering costs
    - Creating pondage
    - Conveying water (pipeline)
    - Powerhouse building

Civil engineering costs may vary greatly as demonstrated in Table 7.1.

Table 7.1: Cost Contributions with Varying Civil Features Costs
Adapted form [23]

| Cost Component | Contribution for Minimal Civil Features | Contribution for Maximum Civil Features |
|---|---|---|
| Civil Feature | 15% | 45% |
| Turbine & Generator | 39% | 18% |
| Accessory Electrical Equipment | 11% | 4% |
| Misc. Power Plant Equipment | 5% | 3% |
| Engineering & Legal | 20% | 20% |
| Interest during Construction | 10% | 10% |

As confirmed, civil engineering cost may vary greatly and is an influential component of small hydro costs. Now that the cost components of a small hydro project are known one must identify methodologies for extracting and processing information.

## 7.3 Economic Analysis

To complete the economic analysis of a small hydro project, one must determine an appropriate technique, and select parameters and requirements to indicate the feasibility of a project.

### 7.3.1 Analysis Techniques

A variety of information may be collected to examine small hydro feasibility. In collecting information, one must determine the detail of information desired. For example, present day costs should be considered, but a more comprehensive analysis would consider future costs such as fuel costs, and energy demands, [49]. Determining the value of energy involves assumptions and calculations, and results in value comparisons, (Section 7.3.2). This leads to selecting acceptable costs and their amounts to determine feasibility.

A case study entitled "Appraising renewable energy developments in remote communities: the case of the North Assynt Estate, Scotland," [20], suggests consulting visitors and community residents to analyze their support of proposed renewable energy projects. Two appraisal techniques, a local economic impact study and a contingent valuation study were used to evaluate three renewable energy options including a three-turbine wind farm, a small-scale hydro scheme and biomass development for the remote community located in North West Scotland.

The local economic impact study consisted of a questionnaire aimed at the area's visitors to asses their perception of benefits, costs and effects resulting from the implementation of the renewable energy projects. Tourism was considered an important part of the local economy with the potential for growth. It was deemed important to consider tourists' reactions to the projects because renewable energy projects such as hydro and wind may change the landscape of an area and thereby affect tourism.

The contingent valuation questioned local residents to assess their willingness to pay for environmental improvement, or willingness to accept compensation, [20], for "a deterioration in environmental provision, or to forgo an improvement in environmental quality." In particular, if a resident was supportive of a technology, they were asked if they would contribute funds towards the project, and if so how much. If a resident was un-supportive of a technology option, they were asked if compensation in the form of reducing electricity bills or creating local employment would improve their opinion of the option, and if so, the amount of compensation required.

The case study's results demonstrated the public's familiarity with the technology options, important considerations, such as precise project location, and the advantages and disadvantage of such evaluation techniques in particular reference to their application for remote communities. A survey provides an appropriate alternative to public meetings; however, survey respondents must receive sufficient information to complete the survey. Both residents and visitors indicated that the most acceptable renewable energy option for the North Assynt Estate, Scotland, is small-hydro.

Other analysis techniques include a comparison study; perhaps compare small hydro, with diesel and utility energy costs, [49]. Comparisons should be made using annual rather than capital costs, [29 p.61]. In addition to considering costs, benefits and risks may also be compared.

Computer programs, either commercial or government may be available to assist in the analysis. For example, the micro-computer program "SHYDRO", described at the conference "Water Power '91: A New View of Hydro Resources," [52], was prepared for the government of Canada and available in the public domain. Currently, one may access analysis software from the RETScreen International Renewable Energy Decision Support Centre, (Section 7.4). The centre's contributors include the Canadian government as well as international partners.

### 7.3.2 Decision Indicators

The following lists possible parameters used to asses the economic feasibility of a small hydro project and provide a comparison between potential projects whether they are small hydro or employ other energy sources.

- Installed cost

  Installed cost may be presented in terms of dollars per kilowatt-hour. Table 7.2 presents examples of installed costs.

Table 7.2: Installed Costs, Adapted from [43]

| kW Installed | Installed Cost $US/kW |
|---|---|
| kW installed > 500 kW (500 – 2000 kW) | $2500 - $3000/kW |
| kW installed < 500 kW | $1000 - $10 000/kW |

As demonstrated in Table 7.2, installed costs vary greatly with the quantity of power installed. For small hydro projects, the installation cost may become very expensive, but may be reduced by using local technology and skill.

- Annual Cost

  The annual cost of a project considers interest, depreciation, operation and maintenance, taxes and insurance, and water rights. The interest rate varies with the economy and its method for determination depends on the borrower as well as the project's depreciation. Depreciation must be distinguished from amortisation. Depreciation represents the decrease in a project's value. These annual allowances may be used to replace the existing project with a new project. Annual payments for amortisation represent the reduction of debt required to finance the project. However, for a water resources project, either amortisation or depreciation, but not both should be considered [29 p.64]. The solution is to employ depreciation payments which consider the useful life of a project, usually 50 years. Annual costs and annual benefits may be constant for each year of the project, or vary throughout the project's life.

- Benefits

Terms used to describe the benefits of a project include a benefit-cost ratio, net benefits, and a rate of return. A benefit-cost ratio of less than 1.0 indicates the project would be unjustifiable for implementation. Net benefits are calculated by summing all benefits and subtracting all costs. The rate of return is defined as the interest rate required for all costs to equal all benefits.

Various classifications may used to measure benefits. Benefits may be identified as either direct or indirect benefits. Direct benefits occur as a direct result of the project, while indirect benefits occur subsequently. Examples of direct benefits include electricity production and flood control. Benefits occurring from those able to purchase products because they received direct benefits are considered indirect benefits. Benefits that may be measured in dollars are considered tangible. Intangible benefits, such as environmental quality improvement, cannot be measured in a monetary value easily.

## 7.4 Economic Analysis Tools – RETScreen International

The RETScreen International Renewable Energy Decision Support Centre provides tools for the technical and financial analysis of renewable energy systems. The RETScreen International Renewable Energy Project Analysis Software is used by a large number of people worldwide with varying backgrounds. The software is provided free-of-charge via the internet with an online user manual as well as product, cost, and weather databases. Eight project models are currently available, including:

- Wind Energy
- Small Hydro
- Photovoltaics
- Solar Air Heating
- Biomass Heating
- Solar Water Heating
- Passive Solar Heating
- Ground-Source Heat Pumps

"The RETScreen International Small Hydro Project Model can be used worldwide to easily evaluate the energy production, life-cycle costs and green house gas emission reduction for central-grid and isolated-grid connected small hydro projects, ranging in size from multi-turbine small and mini hydro installations to single-turbine micro hydro systems [45]." The model works well for evaluating run-of-the-river projects, however, hydro projects with storage can be analysed as well provided various assumptions, (requires average value for gross head, but head does vary with reservoir levels), are made. One other important assumption is no variation in energy demand for isolated-grid applications in isolated areas. However, one can make adjustments to account for variations in the amount of delivered renewable energy.

The RETScreen Small Hydro Project Mode operates from a Microsoft Excel workbook file, consisting of six worksheets. There are four main worksheets and two sub-worksheets:

- Energy Model
    - Hydrology and Load
    - Equipment Data
- Cost Analysis
- Greenhouse Gas Analysis
- Financial Summary

The worksheets are intended to be completed in the above stated order. A complete list of all required inputs is located in Appendix D. Appendix E contains a complete description of the program.

A RETScreen analysis was completed for the small hydro site Robinson Lake located on the upper Hayes River in Manitoba. This site was selected because a study completed by consulting engineers KGS Group [24] provided particulars regarding the site and plant layout, as well as a comparison for the

RETScreen analysis. The values determined by KGS and RETScreen cannot be compared to those of Table 6.1. Table 6.1 displays values which dictate the available energy for a site, not parameters which apply for extracting the energy in the most suitable manner. The KGS study did not include transmission costs, and so the RETScreen analysis was completed in a likewise manner.

Information obtained from the KGS study included:

- Gross head = 20.0 m
- Design flow = 24 $m^3/s$
- Small reservoir available, therefore assumed no tailwater effect
- Flow duration curve
- One double regulated Kaplan S turbine
- One 5 km access road
- 200 m canal
- 180 m penstock
- 20% contingency for cost estimates

The RETScreen Energy Model determined the plant had firm capacity and annual energy production values of 3.997 MW and 22 800 MWh, respectively, which is consistent with the KGS values of 4 MW and 22 800 MWh. The flow duration curve used in the RETScreen analysis was derived using a weighted average of the summer and winter flow duration curves for the proposed site, as presented in the KGS study. The weighting coefficients were determined based on an annual energy production of 22 800 MWh with winter and summer energy productions of 9 110 MWh and 13 670 MWh, respectively. As transmission costs were not considered in the analysis, the grid type was selected as a central grid. Furthermore, the adjustment factors for transmission costs were set to zero. However, the transmission line length was included for informational purposes, estimated using a Manitoba Hydro map, [34]. The KGS study excluded costs for interest during construction, however an interest rate of 6% was considered for the RETScreen analysis. The project cost determined by the KGS study was $16 490 000 in 1993 dollars. RETScreen estimated initial costs as $18 778 860 in 2000 dollars.

RETScreen's financial analysis extended farther than the KGS study to include annual costs thereby determining the year-to-positive cash flow and a net present value. All financial parameters were determined based on RETScreen's suggested ranges. A very influential factor affecting a project's economic success is the parameter RETScreen refers to as "avoided cost of energy," which is entered as a $/kWh value. "This value typically represents either the "average" or the "marginal" unit cost of energy for the base case electricity system and is directly related to the cost of fuel for the base case electricity system" [45]. As mentioned in Chapter 6, an IPP may receive $0.0584/kWh for electricity sold to the central grid or as much as $0.20/kWh for an isolated diesel grid [45]. As identified in Table 6.3, Robinson Falls could potentially replace diesel generation. Robinson Lake may not be the most appropriate site to replace diesel generation, however, since diesel generation does exist in Manitoba, two RETScreen analyzes with differing avoided cost of energies were completed for demonstration purposes. Appendix F contains the complete

RETScreen Analysis for Robinson Lake with a value of $0.10/kWh for cost of avoided energy. A net present value and year-to-positive cash flow of $11 994 827 and 10.3 year, respectively were determined. However, since one could potentially receive $0.20/kWh when replacing diesel generation, a second financial summary was completed with a cost of avoided energy of $0.20/kWh, producing a net present value and year-to-positive cash flow of $45 739 219 and 2.2 year, respectively. The second financial summary is presented in Appendix G, and demonstrates that depending on the price received for the energy produced by a small hydro plant, the project can be considered extremely feasible in an economic sense. With respect to the communities of Brochet, Lac Brochet and Tadoule Lake, upon further research it may be demonstrated that the price received for energy provided to communities served by diesel generation will compensate for extra transmission and road access costs.

The RETScreen program requires many inputs thereby demonstrating to the user items necessary to consider for a renewable energy project. With straightforward program access and a user-friendly interface, the RETScreen Small Hydro analysis software can provide a useful and educational tool for an informed user and decision maker.

# 8. CONCLUSIONS

Although further research is required, small hydro does have the potential to be feasible in Manitoba. Preliminary conclusions regarding turbine technologies, flow management, site selection and economics are presented at this time.

An important identifying component of small hydro is the turbine to be utilized. Conventional technologies can be applied for small hydro. A reaction turbine would be more applicable than an impulse turbine because reaction turbines depend more on kinetic energy and less on potential energy than impulse turbines. Small hydro is based on harnessing the kinetic energy of a river and therefore, a Kaplan or Bulb turbine could be adapted. Non-conventional kinetic turbines are most suitable; however these technologies are still developing. Current tidal turbine designs are not appropriate for high flow rivers. The UEK turbines have the most potential to be appropriate, however, further testing and development is required. The UEK design is not yet applicable for river flow greater than 3 m/s. The best application for small hydro in Manitoba is a scenario with no head and high velocity. Unfortunately, a turbine which meets this criterion is not available at this time.

The second identifying feature of small hydro is its structures and flow management practices. Of the civil structures discussed, several are appropriate or required for the installation of a small hydro plant in Manitoba. Weirs and intakes have great potential for flow management and measurement, and may or may not be required. A channel and penstock will be required for a small hydro plant; however, a stilling basin, spillway and forebay are not necessary. Two methods for increasing the river flow velocity for the purpose of increasing power output are to constrict the flow area or to create head. For the case of constricting the flow area, caution must be observed so as not to influence the flow upstream of the hydro plant. Further cautionary steps can be completed at the design stage for the implementation of a small hydro plant in Manitoba to ensure complete environmental compatibility, relating in particular to fish survival and pollution control.

To consider implementing a technology one must identify its location. This is very true for small hydro because any plant layout is very site specific. There are various characteristics which make a small hydro site appropriate for further development. The most important factors are the site's potential output, transmission, and the load centre. For small hydro the site's output would most likely be dictated by the river's flow rate, because flow determines kinetic energy, which, is the major contributor to power output for small hydro. Transmission and the load centre will greatly affect costs and benefits, and the value of energy, especially if the load centre is currently served by a more costly energy source.

A listing of undeveloped conventional small hydro sites in Manitoba was compiled, which determined two categories of potential small hydro sites, which should be considered separately. Firstly, there exist undeveloped small hydro sites in northern Manitoba which could provide energy for remote communities currently served by costly diesel generation. However, the access in terms of transmission and road access are difficult for these sites. Therefore, a second category of sites to consider are located in more southerly Manitoba locations with improved access. Specific sites of interest include three sites or groups of sites:

- Hayes or Gods Rivers
    - Serve Shamattawa community
    - Replace costly diesel generation
- Berens River
    - Five sites east of Lake Winnipeg with 152 MW potential capacity
- Whitewood Falls
    - Site located northeast of Lake Winnipeg with relatively high potential output of 10 MW

Further decisions and information are required for one specific small hydro site to be selected for serious consideration. More information is required to assess which of the identified conventional small hydro sites may be adapted for non-conventional small hydro. Further research may also indicate additional small hydro sites unsuitable for conventional hydro, but appropriate for non-conventional small hydro.

The final feasibility indicator for implementing small hydro is the economics involved. A specific site must be selected, and its annual and installed costs must be determined. Economic analysis techniques appropriate for small hydro include:

- Obtaining input from the community affected

- Determining and comparing costs and benefits
- Use of annual costs to compare with other potential renewable technologies
- Compare with current technology in use, especially for communities served by diesel generation
- Learn and employ software to assist in analysis
    - RETScreen International's Small Hydro Project Model is valuable

Once a site is selected further analysis may be commenced.

For a comprehensive economic analysis of a small hydro project, various analyses should be employed to asses community support, costs, benefits, and perform appropriate comparisons between other energy technologies. For the case of replacing high cost diesel generation, the project will most likely be considered an economically successful endeavour. Much of the information required is very site specific. A program, such as RETScreen International's Small Hydro Model, can be useful, but still requires research and information regarding the project. The user of such a program must be well-informed regarding the program's limitations and calculation abilities, to use the program and make informed decisions.

While the information acquired regarding small hydro as it applies to Manitoba is very preliminary, it does demonstrate the potential feasibility of introducing small hydro to Manitoba.

# 9. RECOMMENDATIONS

Further research is required to continue assessing the feasibility of small hydro in Manitoba. It is recommended to select one undeveloped small hydro site in Manitoba and then perform a more site-specific feasibility analysis.

It is recommended the analysis for site selection be performed with current and accurate resources to confirm the existence of all undeveloped conventional and non-conventional small hydro locations in Manitoba. In addition any identified small hydro sites will most likely be in a remote location, and therefore transmission will be an important consideration to fully asses the feasibility of the site. It is recommended to conduct research regarding the transmission aspects of implementing a small hydro site, which includes the identification of existing and future transmission lines in Manitoba. The purpose of a small hydro site which replaces diesel generation, differs from that in a less remote location. Therefore, it is unreasonable to compare sites with differing purposes, and it is suggested the feasibility of each site be determined based on its own merits as well as established criteria.

Once a site is selected, it may then be decided if a conventional turbine is applicable, or if a non-conventional turbine must be developed for the site. In the case of a no-head, high flow application, further turbine design, development or adaptation is required. It is recommended to maintain information regarding non-conventional small hydro as current as possible, as development with kinetic turbines, especially UEK and MCT, continues. Furthermore, environmental considerations and acceptable flow management practices should be considered during the design phase.

Since the purpose of introducing a new renewable energy technology is to provide consumers or a load centre with energy, it is recommended that once a site is selected, the affected community should be contacted. The community may be inclined to make a valuable contribution to the project. Determining more details relating to specific costs will also aid in the completion of a detailed feasibility study. A program such as RETScreen will be a valuable tool for completing a detailed economic analysis.

The completion of a site-specific detailed small hydro feasibility study will be an important asset in foreseeing the future of Manitoba's energy sources.

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Anon. "Inside out turbine." International Water Power & Dam Construction, v 49, n 9, September 1997, p 36.

"A Swiss power engineering firm has developed a new hub-less turbine which could have far-reaching benefits for small hydro generators."

Anon. "Micro hydro: current practice and future development." International Water Power & Dam Construction, v 42, n 6, June 1990, p 45 - 47.

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Chanson, Hubert. "The Hydraulics of Open Channel Flow: An Introduction." Arnold. London, 1999.

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Daugherty, Robert L.; Franzini, Joseph, B. "Fluid Mechanics with Engineering Applications." 6th Edition. McGraw-Hill Book Company, New York, 1965.

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Fisher, Richard K.; Roth, Alan D. "Design Considerations for Enhancing Environmental Compatibility of Hydraulic Turbines." Proceedings of the International Conference on Hydropower – Water Power, v 2, 1995, p 1406 – 1415.

This paper discusses further improvements to the already environmentally acceptable hydraulic turbines as a means for generating power. Topics addressed include fish survival, turbine design features, and the impacts of variable speed generators.

Fox, Robert W.; McDonald, T. "Introduction to Fluid Mechanics." 5th Edition. John Wiley & Sons, Inc. New York, 1999.

Textbook intended for introductory course in fluid mechanics. Subjects covered include fundamental concepts, fluid statics, integral form equations, differential analysis, incompressible inviscid flow, dimensional analysis, internal incompressible viscous flow, external incompressible viscous flow, fluid machinery, and an introduction to compressible flow.

Fraenkel, Peter. "The tide turns for marine current turbines." International Water Power & Dam Construction, v 53, n 12, December 2001, p 18 - 21.

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"This paper describes a turbine that is usually known as Banki's turbine. A comparison was made between two specialized types of this turbine: Ossberger's and Cink's turbines. Besides the theoretical basis, which is the same for the two types of turbine, the principal differences are specified. At the end of the paper a conclusion is drawn about the basic control properties and efficiency of both turbines."

Gorlov, Alexander M. "Helical Turbines for the Gulf Stream: Conceptual Approach to Design of a Large-Scale Floating Power Farm." Marine Technology, v 35, n 3, July 1998, p 175 - 182.

"The paper describes the helical turbine as an efficient new instrument for converting the kinetic energy of hydro streams into electric or other mechanical energy. A multi-megawatt project is proposed, conceived as an ocean power farm equipped with a number of helical turbines, along with a floating factory for in situ production of hydrogen fuel by means of electrolyzing ocean waters. Besides mega hydro-power farms, mini-power stations with helical turbines of a few kilowatts each are also proposed as possibilities for small communities or even individual households located near tidal shorelines or river banks with strong water currents. No construction of hydro dams is necessary for such applications."

Gorlov, Alexander M.; Rogers, Kenneth. "Helical Turbine as Undersea Power Source." Sea Technology, December 1997, p 39 – 43.

"Results of first stage experiment involve harnessing energy from slow undersea current for marine application."

H.N. Halvorson Consultants Ltd. "Evaluation of Nova Energy Ltd's Hydro Turbine for Ministry of Employment and Investment, Government of British Columbia." Victoria, British Columbia, December 9, 1994.

Uses interviews as well as reports from Nova Energy, National Research Council (NRC), and B.C. Hydro to provide the following conclusions regarding the Davis turbine: "a) the technology is basically sound although further work is needed to determine its financial viability; b) the Davis turbine is believed to be environmentally benign; and c) the intellectual property of the current designs appears to belong to Nova Energy Ltd." Nova Energy Ltd., was renamed as Blue Energy Canada Inc. in 1997.

Hamm, Hans W. "Low Cost Development of Water Power Sites." VITA, (Volunteers in Technical Assistance), 1600 Wilson Boulevard, Suite 710, Arlington, Virginia 22209 USA.

This technical paper provides basic guidelines for implementing a small hydro plant. Topics discussed include head and flow measurement, power computations, small dam construction, turbines and water wheels and site selection.

Hanley, Nick; Nevin, Ceara. "Appraising renewable energy developments in remote communities: the case of the North Assynt Estate, Scotland." Energy Policy, v 27, n 9, September 1999, p 527 – 547.

"In this paper two economic appraisal techniques are applied with the aim of evaluating three renewable energy options: a three-turbine wind farm, a small-scale hydro scheme and biomass development – for a remote community in North West Scotland." The advantages and limitations of applying these techniques in other remote areas are also discussed.

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HITACHI Hydro-turbine. "Bulb Turbine." Accessed January 6, 2003. <http://www.hitachi.co.jp/Div/hitachi/hydraulic-turbine/BULB.htm>

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Irish Energy Centre. "Small Scale Hydropower." Renewable Energy Information Office. Shinagh House, Bandon, Ireland.

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Topics discussed include identification of relevant components that influence the overall project economics, component benefits, component costs, evaluation of the risks associated with benefits and costs, the step-by-step principle, structure, calculations and an example with uses monte carlo simulation.

Jenssen, Lars; Gjermundsen, Tor. "Financing of Small-Scale Hydropower Projects." The International Energy Agency – Implementing Agreement for Hydropower Technologies and Programmes. March 2000.

Five main topics discussed to present methods for financing small-scale hydropower projects. Topics include general aspects of small hydropower financing, financing strategies for small hydropower projects, financing conditions, key points in successful financing, and possible improvements to the financing situation.

Karelin, V. Ya, Denisov, A.I. "Some problems of the calculation of hydraulic turbines." Hydrotechnical construction, v 24, n 9, March 1991, p 609 - 613.

Presents calculation methods for mixed-flow and adjustable-blade turbines.

KGS Group. "Small Hydro Assessment." October, 1993.

Report presenting results from study assessing small hydro sites in Northern Manitoba. The study examined sites with less than 10 MW capacity, producing conceptual layout and plans as well as cost estimates for two sites in Manitoba. One site is located on the upper Hayes River, and the other in the watershed east of Lake Winnipeg. The study was completed for Manitoba Hydro by the consulting engineers and project Managers, Kontzamanis-Graumann-Smith-Macmillan Inc. known as KGS Group.

Khennas, Smail; Doig, Alison. "Sustainability or profitability?" International Water Power & Dam Construction, v 50, n 10, October 1998, p 18 – 19.

Article suggesting that factors other than profit and loss should be considered when analyzing the economics of small hydro. Specific references are made to examples in Nepal and Sri Lanka.

Kirk, T. "Small-Scale Hydro-Power in the UK." Journal of the Chartered Institution of Water and Environment Management, v 13, n 3, June 1999, p 207 – 212.

"Small hydro-power technology is well established in the UK. A relatively recent renewal of interest in the development of mini hydro-electric projects may be attributed in part to the privatization of the electricity supply industry, various changes in legislation, and the provision of Government grant funding. With particular reference to potential applications in the water-

supply industry, this paper describes (a) considerations dictating site identification, (b) the establishment of potential power and energy outputs, (c) the selection and arrangement of plant, and (d) the connection of the generating sets to the electrical system. Typical plant and project costs, together with aspects of economic viability, are outlined."

Klunne, Wim. "Micro hydropower basics: Turbines." Micro hydropower basics: introduction website. Last modified December 24, 2000. Accessed January 14, 2003. <http://www.microhydropower.net/turbines.html>

Provides overview and illustrations of various impulse and reaction turbines.

Klunne, Wim. "Micro hydropower basics: Civil Work Components." Micro hydropower basics: civil work components. Last modified April 28, 2002. Accessed January 14, 2003. <http://www.microhydropower.net/components.html>

Web sites provides general discussion of civil components of hydropower station such as weir and intake, channels, settling basin, spillways, forebay tank, and penstock.

Kuiper, Edward. "Water Resources Development: Planning, Engineering and Economics." Butterworths. London, 1965.

Textbook addressing topics associated with river development.

Kuiper, Edward. "Water Resources Project Economics." Butterworths. London, 1971.

"This book deals with water resources planning in general and with water resources project economics in particular."

Leyland, B. "Variable speed bulb turbines with compact generators." International Journal on Hydropower and Dams, v 7, n 2, 2000, p 56 - 58.

"This paper discusses conventional bulb turbines, the latest advances in variable speed marine propulsion units and the advantages of bulb turbines with variable speed compact generators."

Li, Sc. "Giving the lowdown on small hydro." International Water Power & Dam Construction, v 52, n 11, November 2000, p 32 - 33.

Article presents description and design strategy for L-1 turbine design for low head, low cost and low maintenance for application at the Las Juntas hydro power station in Peru.

Lewis, R.I. "Turbomachinery Performance Analysis." Arnold. London, 1996.

Turbomachinery textbook with chapters including: basic equations and dimensional analysis, two-dimensional cascades, principles of performance analysis for axial turbines, performance analysis for axial compressors and fans, simplified meridional flow analysis for axial turbomachines, vorticity production in turbomachines and its influence upon meridional flows, mixed-flow and radial turbomachines, ducted propellers and fans, and selected supporting fluid dynamic analysis.

Lucas, Simon; Burton, John. "Jet propelled developments." International Water Power & Dam Construction, v 53, n 12, December 2001, p.24 - 26.

"Increasing the specific speed of impulse turbines without losing their inherent advantages of simplicity, efficiency and tolerance is commercially attractive in the modern hydro power world. The full admission axial impulse turbine demonstrates such characteristics and, on the basis of current research, may become a useful alternative to traditional turbine designs for small scale sites."

Magauer, Peter F.; Wolfartsberger, Kurt. "Design Concepts for Vertical Kaplan Turbines." Waterpower '91: A New View of Hydro Resources, 1991, p 2109 - 2118.

The paper presents general concepts, significant characteristics and specific design details of vertical Kaplan turbines. The Monroe Street project is referred to as an example of medium sized Kaplan turbine. A "simplified design concept for small sizes" is also described.

Manitoba Conservation – Water Branch. "Provisional Weekly River Flow Report." Accessed October 30, 2003. <http://www.gov.mb.ca/conservation/watres/river_report.html>

Website provides hydrologic data for various Manitoba stations.

Manitoba Hydro. "Location Plan of Hydro-Power Resources." Power Supply, Power Planning and Operations, Civil Engineering Department. March 27, 1997.

Map supplied by Manitoba Hydro indicating developed and undeveloped hydro power sites in Manitoba. Legend numerically identifies each site and indicates site head and potential capacity.

Manitoba Hydro. "Manitoba Hydro System." Surveys and Mapping Branch, Winnipeg, Canada. March, 2000.

Map supplied by Manitoba Hydro displaying existing and future transmission and sub transmission lines, as well as generation and converter stations. Displays from southern Manitoba to approximately 6 km north of Lake Winnipeg.

Manitoba Hydro. "System Maps – Other Facilities." Accessed November 24, 2003. <http://www.hydro.mb.ca./about_us/other_facilities.shtml>

Company web page with links leading to information regarding Manitoba Hydro and its operations. This particular map shows components of Manitoba Hydro's system other than hydraulic generating stations.

March, Patrick; Jones, Keith. "Laboratory and Field Experience with Cavitation Monitoring of Hydroturbines." Waterpower '91: A New View of Hydro Resources, 1991, p 2000 – 2010.

"When control of cavitation erosion can be accomplished by changes in operating conditions, real-time monitoring of cavitation level is a valuable tool. Three types of cavitation monitors were selected for laboratory development and field evaluations on Francis and Kaplan-type hydroturbines. The selected techniques include: an acoustic emission method which utilizes a high frequency accelerometer and a RMS-to-DC converter chip; a pressure-based method which calculates a dynamic cavitation index from the draft tube pressure and the measured flow rate; and an acoustic emissions method which computes spectral characteristics of the draft tube wall. The paper includes descriptions of laboratory facilities; outlines test equipment, methods, and procedures; and presents results from laboratory and field tests."

Maurer, E.A. "Semi-Kaplan turbines for economic low head power generation." International Journal on Hydropower & Dams, v 3, n 6, 1996, p 40 - 41.

"The El Hoyo hydroelectric plant, owned by Sociedad de Fomento Energetico in Spain, is an example of an ultra low head refurbishment scheme where an efficient and economic solution was found to be the installation of two Semi-Kaplan units."

Mikhailov, L., Fieldman, B., Linjuchev, V. "Small and micro hydro in the USSR." International Water Power & Dam Construction, v 42, n 10, October 1990, p 21 - 24.

Article discusses previous small hydro development and strategies for future development in the USSR.

Mockmore, C.A.; Mayfield, Fred. "The Banki Water Turbine." Bulletin Series No. 25. February 1949. Engineering Experimental Station, Oregon State System of Higher Education, Oregon State College, Corvallas.

"The object of the Bulletin is to present a free translation of Donat Banki's paper 'Neue Wasserturbine,' and to show the results of a series of tests on a laboratory turbine built according to the specifications of Banki."

Moore, E.T. "Avoiding Vibration in Penstocks." Waterpower '91: A New View of Hydro Resources, 1991, p 1585 – 1594.

"One objective of this paper is to indicate the potential sources of pressure pulsations within a hydraulic conduit system and the range of forcing frequencies associated with these sources. A second objective is to indicate what options are available to correct a severe, unacceptable penstock vibration which has developed due to resonance between the forcing frequentcy of a pressure pulsation and one of the natural vibrating frequencies of a reach of the penstock. In addition, the designer should gain an insight and understanding of how the overall hydraulic conduit system and, in particular, the exposed penstock might be configured and dimensioned during design to avoid possible resonance with calculated forcing frequencies. The designer will know the project's turbine operating characteristics and have the opportunity to make some modifications to the water conduit dimensions."

Moritz, E. "The low-head multi-jet Pelton turbine for Amsteg." International Journal on Hydropower & Dams, v 3, n 1, 1996, p 19 - 21.

"Trains climbing up towards the Gotthard alpine tunnel will be supplied with 16 2/3 Hz current from hydroelectric units driven by six-jet vertical-axis Pelton turbines. This paper describes the technical characteristics of the Pelton units and their particular advantages for this project, despite the relatively low head of 277 m."

Mosonyi, E. "Planning low head hydro plants." International Journal on Hydropower and Dams, v 8, n 2, 2001, p 85 - 86.

Summary of lecture delivered by Professor Emil Mosonyi during a colloquium held at the University of Karlsruhe, Germany, commemorating his 90th birthday and honouring is 66-year career as a researcher, teacher and practising engineer. Lecture highlights important aspects of initial steps for planning low head hydro plants.

Moxon, Suzanne. "A big burden for small shoulders." International Water Power & Dam Construction, v 52, n 6, June 2000, p 23.

Reports on excellent prospects for small hydro development in the US. However, various regulatory bodies are often making the development difficult.

Moxon, Suzanne. "Fish race 2000." International Water Power & Dam Construction, v 49, n 9, September 1997, p 38.

Article describes large fish ladder installed at Iffezheim power plant in the River Rhine in Europe. A 1.2 MW bulb turbine was also installed to "attract fish up the ladder and increase output."

Murillo, Rafael. "23.374 Hydraulics: Lecture Notes." University of Manitoba, December 2002.

Lecture notes compiled for the course 23.374 Hydraulics taught at the University of Manitoba in term 2 of the 2002/03 regular session. Topics covered include introductory concepts, uniform flow, gradually varied flow, the hydraulic jump, hydraulic structures, rapid transition and hydraulic models.

Natural Resource Canada. “The Atlas of Canada.” Reference Maps. Accessed November 26, 2003. <http://www.atlas.gc.ca/site/english/maps/reference/outlineprov_terr/man_outline>

2001 Natural Resources Canada map of Manitoba.

Natural Resource Canada. “Electricity from Renewable Sources, 2002.” Canada.

Table summarizing installed capacity, additional potential, capital cost, cost of energy, and investors for large hydro, small hydro, wind, photovoltaic, forest biomass, electricity from waster, landfill gas and tidal power in Canada in 2002.

Newman, Gemma. “Energy for the future.” International Water Power & Dam Construction, v 51, n 11, November 1998, p 21 - 22.

Reports issues including building new plants, as opposed to using existing structures, improving environmental friendliness and economics discussed at Hidroenergia 1999.

Newman, Gemma. “Report on Small Hydro 2000 Conference (Lisbon).” International Water Power & Dam Construction, v 52, n 6, June 2000, p 16 - 17.

Summary of issues such as grid connections, tariffs, financing, software, public opinions, and multi-purpose projects discussed at the Small Hydro 2000 Conference.

Newmills Hydro. “Hydroelectricity Waterpower Turbine Manufacturers.” Accessed October 10, 2003. <http://www.newmillshydro.freeserve.co.uk>

Company web pages with information regarding their Kaplan, Axial Flow, Pelton, Francis and propeller type turbines, as well and control gears and ancillaries.

Niet, T.; McLean, G. "Race Rocks Sustainable Energy System Development." Institute for Integrated Energy Systems, University of Victoria. 11th Canadian Hydrogen Conference. June 17 – 21, 2001, Victoria, BC.

Paper describes feasibility study comparing wind, solar and tidal power as renewable energy sources to replace diesel generating system at Race Rocks near Victoria, BC.

Odeh, M.; Sommers, G. "New design concepts for fish friendly turbines." International Journal on Hydropower and Dams, v 7, n 3, 2000, p 64 – 70.

This article presents "a summary of injury mechanisms affecting fish and new environmentally friendly hydro turbine design concepts."

O'Mara, Katrina; Rayner, Mark; Jennings, Philip. "Tidal Power." Australian Renewable Energy Website, June 1999. Accessed January 7, 2003. <http://www.acre.murdoch.edu.au/ago/ocean/tidal.html>

Presents general information regarding tidal power ranging from the physics of tidal power, turbines used in tidal power stations, and implementation techniques and issues. This information was prepared for the Australian Greenhouse Office by ACRE, (Australian Cooperative Research Centre for Renewable Energy).

O'Mara, Katrina; Rayner, Mark; Todd, John; Fletcher, Serena; Jennings, Philip. "Hydro-electric Power." Australian Renewable Energy Website, June 1999. Accessed January 7, 2003. <http://www.acre.murdoch.edu.au/ago/hydro/hydro.html>

Presents general information regarding hydro power covering the topics of history and development, operation of hydro-electric power stations, water turbine types, large scale hydro, pumped storage hydro-electric schemes, worldwide status of hydro power, constraints to large-scale hydro power use, small scale hydro power, micro-hydro power in Australia, micro-hydro power in Asia, the future for micro-hydro power, and hydraulic rams/pumps. This information was prepared for the Australian Greenhouse Office by ACRE, and is based on materials prepared for the Alternative Energy Development Board of Western Australia.

Paish, Oliver. “Small hydro power: technology and current status.” Renewable and Sustainable Energy Reviews, v 6, n 6, December 2002, p 537 - 556.

Paper summarises various small hydro technologies, industry innovations and problems.

Press, W.H.; Flannery, B.P.; Teukolsky, S.A.; Vetterling, W.T. “Numerical Recipes. (Fortran Version). The Art of Scientific Computing.” Cambridge University Press, p 146.

Numerical method for determining roots of cubic equation.

Pritchard, Suzanne. “Small steps to keep ... maintenance in mind.” International Water Power & Dam Construction, v 53, n 8, August 2001, p 26 - 27.

Discusses importance of various study details in design stage of small hydro, including maintenance.

Raschl, M. “Large bulb turbines installed at Wang Fu Zhou, China.” International Journal on Hydro Power and Dams, v 8, n 1, 2001, p 31 - 33.

“The last two Kaplan bulb units were recently commissioned at the Wang Fug Zhou powerplant in China. These turbines, manufactured by Andritz AG of Austria, are among the largest of their type in China, and also in the world.”

RETScreen International. “Case Study: Small Hydro Project.” Renewable Energy Decision Support Centre, Natural Resources Canada, 2001. Accessed October 22, 2003. <http://www.retscreen.net>

Website allows access to renewable energy analysis software as well as on-line manual, e-textbook, databases, and case studies. One case study analyses a small hydro plant in northern British Columbia where the RETScreen software is used for the feasibility study.

Ruoss, R.; Gyenge, J.; Fischer, F. “Upgrading of the Laufenburg Hydro Power Station (River Rhine) Using Straflo Turbines.” Sulzer Hydro, Sulzer-Escher Wyss Ltd, Zurich, Switzerland. November, 1994.

Describes refurbishment of power station where Francis turbines were replaced with Straflo turbines.

Ruud, Frederick O. "Vibration of Penstocks in Hydroelectric Installations." Waterpower '91: A New View of Hydro Resources, 1991, p 2214 - 2223.

"In many penstocks and pump discharge lines of turbines and pumps, pipe vibrations have been observed. Many of these installations have blade and vane arrangements other than the classic case presented by J.P. Den Hartog, where the number of blades and number of vanes differ by one. Curves are presented to show the envelope of lowest natural frequencies of pipeline vibration for various diameter, thickness, and stress level ratios. A large centrifugal pump is discussed, with seven impeller blades and thirteen guide vanes, rotating at 514 rpm, where a serous problem arises with 120 Hz pulsations."

Sahai, I. M. "Learning from India's experiences." International Water Power & Dam Construction, v 52, n 6, June, 2000, p 18 – 21.

"Various financial and political obstacles have been hindering the development of small hydro in India. I M Sahai explains how the situation is being improved."

Stackhouse, Paul W. Jr.; Whitlock, Charles H.; Barkstrom, Bruce R. "Surface Meteorology and Solar Energy." NASA's Earth Science Enterprise Program. August 19, 2003. Accessed October 31, 2003. <http://eosweb.larc.nasa.gov/sse>

Renewable energy resource web site sponsored by NASA's Earth Science Enterprise Program and providing solar and meteorology data including wind and temperature.

Stern, David P. "Planetary Swing-by and the Pelton Turbine." October 10, 2002. Accessed January 14, 2003 <http://www.istp.gsfc.nasa.gov/stargaze/spelton.htm>

Web page provides history and operational description of pelton turbine.

Stilwell, R. S. "Economics of Small Hydro." Canadian Water Resources Journal, v 6, n 3, 1981, p 84 – 99.

"Present day generating costs are illustrated by comparing small hydro energy costs with diesel and utility energy costs. Economic evaluation procedures for small hydro under current economic conditions are described. The effect of Federal Government incentives on the development of small hydro resources is commented upon together with a discussion of the availability and applicability of techniques for rapid economic assessment of sites."

Thicke, R.H., Casselman, C. "Innovative Designs of Units in Small Hydro Development". Presented to Hydraulic Power Section, Canadian Electrical Association. Toronto, Ontario. May 1991.

Paper presents various turbine designs including axial flow Kaplan, mixed flow Francis, and Bulb.

Tobias, Lang. "Relationships between Intake Geometry and Turbine Efficiency, Experimental Studies at Tubular-S-Turbine and Cross-Flow Turbine." Lehrstuhl und Versuchasanstalt fur Wasserbau and Wasserwirtschaft Technische Universitat Munchen, Germany. Accessed January 15, 2003. <http://www.wb.bv.tum.deldeutsch/forschung/lang/lang_geomkrit_e.pdf>

The research project "turbine inflow" examines intakes for run-of-power plants, providing experimental results.

Tondi, Gianluca; Chiaramonti, David. "Small hydro in Europe helps meet CO2 targets." International Water Power & Dam Construction, v 51, n 7, July 1999, p 36 – 40.

"A recent study has identified unexploited small hydro power potential in Italy and Portugal." Both refurbishment and new construction are important.

Tung, T. P.; Brown, D.H.; Keats, H.J. "Small Hydro Site Ranking, Cost Methodology and Program." Water Power '91: A New View of Hydro Resources, 1991, p 709 – 718.

"The user-friendly micro-computer program SHYDRO for costing small hydro has been prepared for the government of Canada and is available in the public domain." "This paper outlines simple methodologies which can be used to identify, cost and rank sites. It also outlines SHYDRO program functions and procedures."

UEK Corporation. "Underwater Electric Kite." Accessed January 24, 2003. <http://uekus.com>

Company web site with general information regarding company's hydrokinetic turbines.

VA Tech Hydro. "Bulb Turbines." Accessed September 7, 2001. <http://www.voesthydro.com/html/supplies_services/water_to_wire/hydro_tur.../bulb.htm>

Company web site with technical data for bulb turbines installed at specific sites.

VA Tech Hydro. "Compact Turbines." Accessed September 7, 2001. <http://www.voesthydro.com/html/supplies_services/water_to_wire/hydro_tur.../standard.htm>

Company web page with chart information regarding their modular designs for axial, Francis and Pelton small hydro turbines.

Vauthier, Philippe. UEK Corporation. Personnel correspondence. November 4, 2003. uekus@juno.com

Personnel correspondence through email with President & CEO regarding system configurations and power output.

WaterWheel Factory. "The Cross Flow Turbine." Accessed January 15, 2003. <http://www.waterwheelfactory.com/ossberg.htm>

Web page provides brief description and illustration of cross flow turbine.

WaterWheel Factory. "The Kaplan Turbine." Accessed October 29, 2003. <http://www.waterwheelfactory.com/kaplan.htm>

Web page provides brief description and illustration of Kaplan turbine.

WaterWheel Factory. "The Pelton Turbine." Accessed January 14, 2003. <http://www.waterwheelfactory.com/pelton.htm>

Web page provides brief description and illustration of Pelton turbine.

WaterWheel Factory. "The Turgo Turbine." Accessed January 14, 2003. <http://www.waterwheelfactory.com/turgo.htm>

Web page provides brief description of Turgo turbine

West, Harvey. "A question of mindset?" International Water Power & Dam Construction, v 50, n 4, April 1998, p 24 – 25.

Article discusses why small hydro may experience difficulty in implementation and development despite growing support for renewable energy resources.

Windstream Power Microhydro Information. "Microhydro Water Power Systems." Windstream Power System, Incorporated. Burlington, VT. Accessed October 3, 2002. <http://www.windstreamower.com/microhydro/hydroinfo.html>

Web page describes actions of Pelton turbine and appropriate generator equipment.

WKV. "WKV Products and Services." Accessed September 15, 2001. http://www.wkv-ag.com/englisch/produkte/produkte_e.htm

Company web page with chart depicting application ranges for various turbines as a function of discharge and net head.

WKV. "The WKV Crossflow Turbine." Accessed September 15, 2001. <http://www.wkv-ag.com/englisch/produkte/durch/durch01_e.htm>

Company web page explains features of crossflow turbine.

WKV. "The WKV Francis Turbine." Accessed January 16, 2003. <http://www.wkv-ag.com/englisch/produkte/francis/francis01_e.htm>

Company web page explains features of Francis turbine.

WKV. "The WKV Pelton Turbine." Accessed September 15, 2001. <http://www.wkv-ag.com/englisch/produkte/pelton/pelton01_e.htm>

Company web page explains features of Pelton turbine.

WKV. "The WKV Turgo Turbine." Accessed January 14, 2003. <http://www.wkv_ag.com/english/produkte/turgo/turgo01_e.htm>

Company web page explains features of the Turgo turbine.

Wood, Janet. "Action Plan." International Water Power & Dam Construction, v 50, n 4, April, 1998, p 26 – 27.

"World Bank representative met renewable energy providers recently, to discuss the role of rural energy in the Bank's poverty-alleviation and environmental programmes. Janet Wood finds a place for mini and micro hydro in the programme."

Wood, Janet. "Is there anyone there?" International Water Power & Dam Construction, v 50, n 8, August 1998, p 32.

Article discusses the remote operation small hydro plants and the economics of automation.

# APPENDIX A

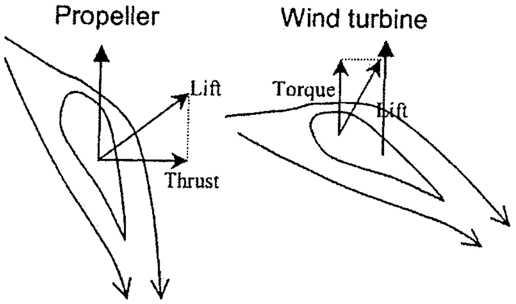
## Propellers and Wind Turbines: Actuator Disk Theory

All material is reproduced from [21].

# Propellers and Wind turbines: Actuator Disk Theory

## *Propellers and Wind turbines:*

- Propellers generate thrust by accelerating the fluid through the rotor.
- Wind (and tidal stream) turbines generate power by converting kinetic energy of the fluid flow into rotation of the rotor.
- They have no casing to guide the fluid through the machine
- They cannot maintain a pressure drop between upstream and downstream of the machine.
- Simple wind mill designs may have flat rotor blades which act like deflector plates. The torque on the rotor is given by how much the air stream is deflected by the blades. The real efficiency is much reduced because one cannot have ideal flow conditions across a moving deflector blades if it is to do work (use the velocity triangles: because the entry angle and the exit angle of the blade are the same, we cannot do the work gradually along the blade.
- Rotor blades are generally shaped like areofoils – they generate a lift force perpendicular to the fluid flow along the blade (remember that the blade is moving at the same time). Propellers want to generate forward thrust while wind turbines want to generate torque.

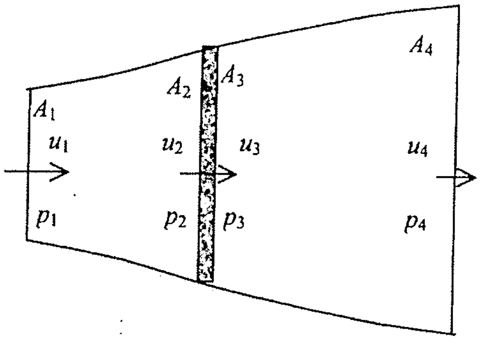


## *Actuator disk theory: Principle*

To get a good idea what one might get out at best, one can simplify the problem greatly. Instead of looking at the detailed flow through the turbine, we can treat the turbine itself as a black box and only look at its effect on the nearby fluid stream. One simplification is to regard the black box as a very thin disk just enclosing the rotor, the **actuator disk**. We can then define a control volume which encloses some fluid upstream of the rotor, the actuator disk, and some downstream fluid. Because the only object within that control volume is the actuator disk, we can use Bernoulli's equation everywhere, **except** across the disk. But the disk is the only thing which can affect the flow, so it is the only thing where a force can be exerted.

## *Actuator disk Control Volume*

The control volume wants to enclose the actuator disk completely but not look at the fluid flowing past it. We also want to use streamlines as the side boundaries so that we know that there is no fluid leaving the control volume through sides and that we can use Bernoulli's equation along the side. The streamline which just touches the edge of the disk is called the *slipstream*. Also, we need to extend the control volume to far enough away from the disk so that we look at simple, unperturbed flow:



## *Equations*

Pressure far upstream and downstream is unaffected: $p_4 = p_1 \quad = 0$

Mass flow through control volume: $\dot{m} = \rho A_1 u_1 = \rho A_2 u_2 = \rho A_3 u_3 = \rho A_4 u_4$

The disk is very thin: $A_3 = A_2 \quad = A$, where *A* is the swept area of the rotor.

By continuity, $Au_2 = Au_3$: $u_2 = u_3$

The force on the disk by the flow is the pressure difference across the disk: $F = (p_2 - p_3)A$

Bernoulli before disk: $p_2 = \frac{1}{2}\rho\left(u_1^2 - u_2^2\right)$

Bernoulli after disk: $p_3 = \frac{1}{2}\rho\left(u_4^2 - u_2^2\right)$

Inserting pressures gives force: $F = \frac{1}{2}\rho A\left(u_1^2 - u_4^2\right)$

Force on disk is also the net change in the momentum flow rate: $F = \dot{m}(u_1 - u_4)$

with Momentum flow rate into C.V.: $J_{in} = \dot{m}u_1$

Momentum flow rate out of C.V.: $J_{out} = \dot{m}u_4$

Equating both forces, using $\left(u_1^2 - u_4^2\right) = (u_1 - u_4)(u_1 + u_4)$, and re-arranging gives $u_2 = \frac{1}{2}(u_1 + u_4)$

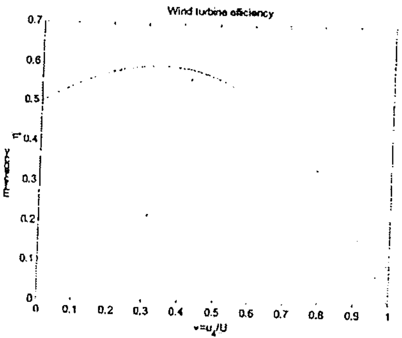
Power transmitted by disk: $P = Fu_2 = \frac{1}{4}\rho A\left(u_1^2 - u_4^2\right)(u_1 + u_4)$

Using $U = u_1$ and $\chi = \frac{u_4}{u_1}$: $P = Fu_2 = \frac{1}{4}\rho AU^3\left(1 - \chi^2\right)(1 + \chi) = \frac{1}{4}\rho AU^3\left(1 + \chi - \chi^2 - \chi^3\right)$

## *Wind turbine*

The flow of kinetic energy by the wind through an area *A* is $P_{air} = \frac{1}{2}\rho AU^3$

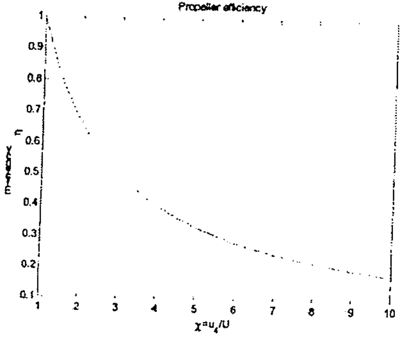
The efficiency of a stationary actuator disk is therefore: $\eta = \frac{P}{P_{air}} = \frac{1}{2}\left(1 + \chi - \chi^2 - \chi^3\right)$



## *Propeller*

If we consider a propeller, the power conversion between actuator disk and fluid is given by the force and the fluid velocity through the disk, $u_2$, but the **useful** power is that which is related to the actual speed of the aircraft, which is *U*, but the force is obviously still the same. So the useful output is $P_{out} = FU = \frac{1}{2}\rho AU^3\left(1 - \chi^2\right)$.

The efficiency is $\eta = \frac{P_{out}}{P_{turbine}} = \frac{2}{1 + \chi}$.

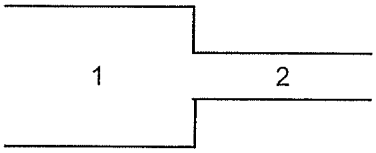


# APPENDIX B

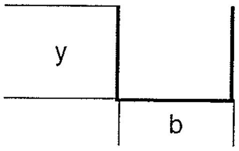
## Minimum Channel Width Requirement Calculation

## Calculation of Maximum Width Constriction, and Associated Velocity
(ie abrupt change in channel width)
**(Minimum Width Required for Upstream Flow to Remain Unaffected)**

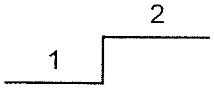
Top View:



Cross Section:



Side View:



| | | | | | | |
|---|---|---|---|---|---|---|
| Inputs: | $Q =$ | 32000 | cfs | $Q =$ | 900 | cms |
| | $b_1 =$ | 1000 | ft | $b_1 =$ | 300 | m |
| | $y_1 =$ | 15 | ft | $y_1 =$ | 4.57 | m |
| | $z_1 =$ | 0.00 | ft | $z_1 =$ | 0.00 | m |
| | $z_2 =$ | -5.00 | ft | $z_2 =$ | -1.52 | m |
| Outputs: | $y_2 =$ | 13.38 | ft | $y_2 =$ | 4.08 | m |
| | $b_2 =$ | 115.22 | ft | $b_2 =$ | 35.12 | m |
| | $V_1 =$ | 2.13 | ft/s | $V_1 =$ | 0.65 | m/s |
| | $V_2 =$ | 20.76 | ft/s | $V_2 =$ | 6.33 | m/s |
| Constant: | $g =$ | 32.2 | $ft/s^2$ | | | |

Assumptions: 1. Rectangular channel 2. $E_1 = E_2 + (z_2 - z_1)$

Calculations:

$q_1 =$ 32.00 $ft^2/s$

$V_1 =$ 2.13 ft/s

$E_1 =$ 15.07 ft

$E_2 = E_{min} =$ 20.07 ft

$y_2 = y_c = (2/3)E_{min} =$ 13.38 ft

$q_2 = (g*y_c^3)^{1/2} =$ 277.74 $ft^2/s$

$b_2 =$ 115.22 ft

$V_2 =$ 20.76 ft/s

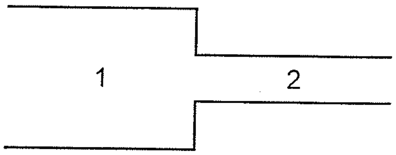
# APPENDIX C

## Velocity Resulting from Constricting Channel Calculation

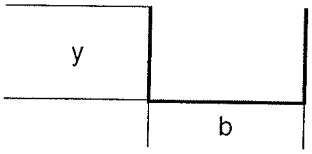
### Calculation of Flow Velocity Following Constriction

(abrupt change in channel width, $b_2$ > $b_2$ calculated in Appendix B)

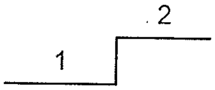
Top View:



Cross Section:



Side View:



| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Inputs: | $Q$ = | 32000 | cfs = | 900 | cms | Outputs: | $V_1$ = 2.13 | ft/s | = | 0.65 | m/s |
| | $b_1$ = | 1000 | ft = | 300 | m | | $V_2$ = 11.95 | ft/s | = | 3.64 | m/s |
| | $b_2$ = | 150 | ft = | 45 | m | | $y_2$ = 17.85 | ft | = | 5.44 | m |
| | $y_1$ = | 15 | ft = | 4.5 | m | | | | | | |
| | $z_1$ = | 0.00 | ft = | 0.00 | m | Constant: | $g$ = | 32.2 | $ft/s^2$ | | |
| | $z_2$ = | -5.00 | ft = | -1.52 | m | | | | | | |

Assumptions: 1. Rectangular channel 2. $E_1 = E_2 + (z_2 - z_1)$

Calculations:

| | | | | | |
|---|---|---|---|---|---|
| $q_1$ = | 32.00 | $ft^2/s$ | $q_2$ = | 213.33 | $ft^2/s$ |
| $V_1$ = | 2.13 | ft/s | | | |
| $E_1$ = | 15.07 | ft | $E_2$ = | 20.07 | ft |

$$y_2^3 - E_2 y_2^2 + q_2^2/2g = 0$$

$$y_2^3 \quad - 20.07 \quad {}^*y_2^2 \ + \quad 706.69 \quad = \quad 0.00$$

| | | | |
|---|---|---|---|
| $S$ = | 44.76 | $S^{1/2}$ = | 6.69 |
| $R$ = | 53.90 | $Y$ = | 1.39 |
| $y_2'$ = | -5.28 | $\lvert y_1 - y_2' \rvert$ = | 20.28 |
| $y_2''$ = | 17.85 | $\lvert y_1 - y_2'' \rvert$ = | 2.85 |
| $y_2'''$ = | 7.50 | $\lvert y_1 - y_2''' \rvert$ = | 7.50 |
| $y_2$ = | 17.85 ft | $V_2$ = | 11.95 ft/s |

# APPENDIX D

## RETScreen Small Hydro: Program Inputs

# RETScreen Analysis Inputs

## Summary:

There are 4 main worksheets:

- Energy Model
- Cost Analysis
- Greenhouse Gas Analysis
- Financial Summary

The Energy Model worksheet requires 2 sub-worksheets:

- Hydrology & Load
- Equipment Data

## Worksheet 1: Energy Model

Site Characteristics:

- Gross head [m]
- Maximum tailwater effect [m]
- Complete Hydrology & Load Sheet

System Characteristics:

- Design flow [$m^3/s$]
- Maximum hydraulic losses [%]
- Generator efficiency [%]
- Transfer losses [%]
- Parasitic electricity losses [%]
- Annual downtime losses [%]
- Complete Equipment Data Sheet

Annual Energy Production:

- Available flow adjustment factor [-]

## Worksheet 1a: Hydrology & Load

Hydrology Analysis:

- Project type --> run-of-river or reservoir
- Hydrology method --> specific run-off or user-defined
  - For user-defined:
    - Residual flow [$m^3/s$]
    - Percent time firm flow available
    - Flow duration curve
  - For specific run-off:
    - Drainage area above site [$km^2$]
    - Specific run-off [$m^3/s/km^2$], (from map)
    - Residual flow [$m^3/s$]
    - FDC type/proxy gauge # [-], (from weather data base)
    - Percent time firm flow available

Load Characteristics:

- Grid type --> central-grid or isolated grid
  - For isolated-grid:
    - Load duration curve --> typical or user-defined
      - For typical:
        - Grid peak load [kW]
      - For user-defined:
        - Load duration curve data, (kW vs %)

**Worksheet 1b: Equipment Data**

Small Hydro Turbine Characteristics:
- Turbine type --> Kaplan, Francis, Propeller, Pelton, Turgo, Cross-flow or Other
  - For Other:
    - Turbine efficiency curve
- Turbine efficiency curve data source --> standard or user-defined
  - For user-defined:
    - Turbine efficiency curve
- Number of turbines [turbine]
- Turbine manufacture/design coefficient [-]
- Efficiency adjustment [%]

**Worksheet 2: Cost Analysis**

Costing Method --> Formula or Detailed

Formula Costing Method:
- Input Parameters:
  - Project country --> Canada or Enter Name
    - For Enter Name:
      - Local vs. Canadian equipment costs ratio [-]
      - Local vs. Canadian fuel costs ratio [-]
      - Local vs. Canadian labour costs ratio [-]
      - Equipment manufacture cost coefficient [-]
      - Exchange rate [$/CAD]
  - Cold climate? --> yes or no
    - For Yes:
      - Frost days at site [-], (see map/visit NASA satellite data)
  - Project classification: Selected Classification --> micro, mini, or small
  - Existing dam? --> yes or no
    - For No:
      - New dam crest length [m]
  - Rock at dam site? --> yes or no
  - Intake and miscellaneous losses [%]
  - Access road required? --> yes or no
    - For Yes:
      - Length [km]
      - Tote road only? --> yes or no
      - Difficulty of terrain [-]
  - Tunnel required? --> yes or no
    - For Yes:
      - Length [m]
      - Allowable tunnel headloss factor [%]
      - Percent length of tunnel that is lined [%]
      - Tunnel excavation method [-] --> Hand-built or Mechanized
  - Canal required? --> yes or no
    - For Yes:
      - Length in rock [m]
      - Terrain side slope in rock (average) [degrees]
      - Length in impervious soil [m]
      - Terrain side slope in soil (average) [degress]
  - Penstock required? --> yes or no
    - For Yes:
      - Length [m]
      - Number of identical penstocks [penstock]
      - Allowable penstock headloss factor
  - Distance to borrow pits [km]
  - Transmission line
    - Length [km]
    - Difficulty of terrain [-]
    - Voltage [kV]
  - Interest rate [%]

- Initial Costs (Formula Method):
  - Enter Adjustment Factors for:
    - Feasibility Study
    - Development
    - Engineering
    - Renewable Energy (RE) Equipment
    - Balance of Plant:
      - Access road
      - Transmission line
      - Substation and trasformer
      - Penstock
      - Canal
      - Tunnel
      - Civil works (other)
      - Miscellaneous
  - Enter Amount [$] for:
    - Development:
      - Land rights
  - Enter Cost --> cost or credit, and cost (local currency) [$] for Miscellaneous:
    - Other
    - Credit

- Initial Costs (Credits) <-- Detailed Costing Method:
  - Feasibility Study:
    - Enter Quantity and Unit Cost for:
      - Site Investigation
      - Hydrologic assessment
      - Environmental assessment
      - Preliminary design
      - Detailed cost estimate
      - Report preparation
      - Project management
      - Travel and accomodation
  - Development:
    - Enter Quantity and Unit Cost for:
      - PPA negotiation
      - Permits and approvals
      - Land right
      - Land survey
      - Project financing
      - Legal and accounting
      - Project managemtn
      - Travel and accomodation
  - Engineering:
    - Enter Quantity and Unit Cost for:
      - Design and tender documents
      - Contracting
      - Construction supervision
  - Renewable Energy (RE) Equipment:
    - Enter Quantity for:
      - Equipment installation [%]
      - Transportation [%]
    - Enter Unit Cost for:
      - Trubine/generators, controls [$]

- Balance of Plant:
  - Enter Quantity and Unit Cost for:
    - Access road
    - Clearing
    - Earth excavsation
    - Rock excavation
    - Concrete dam
    - Timber crib dam
    - Earthfill dam
    - Spillway
    - Canal
    - Intake
    - Tunnel
    - Pipeline/penstock
    - Powerhouse civil
    - Fishway
    - Transmission line and substation
  - Enter Quantity [%] for:
    - Dewatering
    - Transportation
- Miscellaneous:
  - Enter Quantity and Unit Cost for:
    - Special equipment
    - Training
  - Enter Quantity [%] for:
    - Contractor's overhead
    - Interest during construction
    - Contingencies

Annual Costs (Credits):
- O & M:
  - Enter Quantity for:
    - Property taxes [%]
    - Insurance premiums [%]
    - Transmission line maintenance [%]
    - Spare parts [%]
    - O & M labour [p-yr]
    - Travel and accommodation [p-trip]
    - General and administrative [%]
    - Contingencies [%]
  - Enter Unit Cost [$] for:
    - Land lease
    - Water rental
    - O & M labour
    - Travel and accommodation

Periodic Costs (Credits):
- Turbine overhaul:
  - cost or credit
  - period [yr]
  - unit cost [$]
- End of project life:
  - cost or credit
  - unit cost [$]

**Worksheet 3: Greenhouse Gas (GHG) Emission Reduction Analysis**

Use GHG Analysis Sheet? --> yes or no

Type of Analysis? --> standard or custom

Standard Analysis:
- Basecase Electricity System (Reference):
  - Fuel type --> coal, natural gas, nuclear, large hydro, #6 oil, diesel (#2 oil), geothermal, biomass, small hydro, wind, solar, or propane
  - Fuel mix [%]
  - T & D losses [%]
- Proposed Case Electricity System (Mitigation):
  - Small hydro:
    - T & D losses [%]

Custom Analysis:
- Basecase Electricity System (Reference):
  - For each fuel type, (select from standard choices), enter:
    - Fuel mix [%]
    - $CO_2$ emission factor [kg/GJ]
    - $CH_4$ emission factor [kg/GJ]
    - $N_2O$ emission factor [kg/GJ]
    - Fuel conversion efficiency [%]
    - T & D losses [%]
- Proposed Case Electricity System (Mitigation):
  - Small hydro:
    - $CO_2$ emission factor [kg/GJ]
    - $CH_4$ emission factor [kg/GJ]
    - $N_2O$ emission factor [kg/GJ]
    - Fuel conversion efficiency [%]
    - T & D losses [%]

**Worksheet 4: Financial Summary**

Financial Parameters:
- Avoided cost of energy [$/kWh]
- RE production credit [$/kWh]
- GHG emission reduction credit [$/$t_{CO2}$]
- Avoided cost of excess energy [$/kWh]
- Avoided cost of capacity [$/kW-yr]
- Energy cost escalation rate [%]
- Inflation [%]
- Discount rate [%]
- Project life [yr]
- Debt ratio [%]
- Debt interest rate [%]
- Debt term [yr]
- Income tax analysis? --> yes or no
  - For Yes:
    - Effective income tax rate [%]
    - Loss carryforward? --> yes or no
    - Depreciation method --> None, Declining balance or Straight-line
      - For Declining balance or Straight-line:
        - Depreciation tax basis [%]
      - For Declining balance;
        - Depreciation rate [%]
      - For Straight-line:
        - Depreciation period [yr]
    - Tax holiday available? --> yes or no
      - For Yes:
        - Tax holiday duration [yr]

Project Costs and Savings:
- Incentives/Grants [$]

# APPENDIX E

## RETScreen Small Hydro: Program Description

The RETScreen Small Hydro Project Mode operates from a Microsoft Excel workbook file, consisting of six worksheets. There are four main worksheets and two sub-worksheets:

- Energy Model
    - Hydrology and Load
    - Equipment Data
- Cost Analysis
- Greenhouse Gas Analysis
- Financial Summary

The worksheets are intended to be completed in the above stated order. A complete list of all required inputs is located in Appendix D. The Model uses a colour coding system for its cells:

- White indicates output calculated by the model.
- Yellow indicates user input required to run the model.
- Blue indicates user input required to run the model, but the input may be selected from an online database.
- Grey indicates user input for reference purposes only, not required to run the model.

Each worksheet consists of various sections requiring input and decisions for approach methodology.

The Energy Model worksheet consists of three sections:

- Site Conditions
    - Requires the completion of the Hydrology and Load worksheet:

        - Hydrology Analysis
            - Select either run-of-the-river or storage project
            - Select hydrology method
                - Flow duration-curve, (flow measured in $m^3$/sec versus percent time flow equalled or exceeded, %)
        - Load Characteristics
            - Central or isolated grid
            - Enter load-duration curve for isolated grid type
- System Characteristics
    - Requires the completion of the Equipment Data worksheet
        - Small Hydro Turbine Characteristics
- Annual Energy Production
    - Final result: annual energy production in terms of mega-watt-hours

To complete the cost analysis, the user must choose between the "Formula" and the "Detailed" costing methods. The "Formula" costing method uses empirical data to provide a project cost estimate. The user must input quantities and unit costs to use the "Detailed" costing method. When using the "Detailed" costing method, one should compare its results to that of the "Formula" costing method. Both methods consider initial, annual, and periodic costs.

The Greenhouse Gas Analysis worksheet is optional, as it is not required to provide a complete analysis. If completed, the worksheet determines reductions in greenhouse gases through mitigation. The worksheet consists of the following four sections:

- Background Information
- Base Case System (Reference)
    - The spreadsheet is setup to select from twelve fuel types: coal, natural gas, nuclear, large hydro, #6 oil, diesel (#2 oil), geothermal, biomass (wood), small hydro, wind, solar, propane.
- Proposed Case System (Mitigation)
- GHG Emission Reduction Summary

The Financial Summary is the final worksheet to be completed and contains five sections:

- Annual Energy Balance
    - Summarises information from the Energy Model, Cost Analysis, and GHG Analysis worksheets
- Financial Parameters
    - Inputs required to complete worksheet's calculations
- Project Costs and Savings
    - Transfers important information from the Cost Analysis worksheet
- Financial Feasibility
    - Presents results from calculations
    - Results may be considered as financial indicators of project
- Yearly Cash Flows

    - Presents pre-tax, after-tax, and cumulative cash flows for the duration of the project life

In addition, the Financial Summary worksheet produces a cumulative cash flows graph.

# APPENDIX F

## RETScreen Small Hydro Analysis:

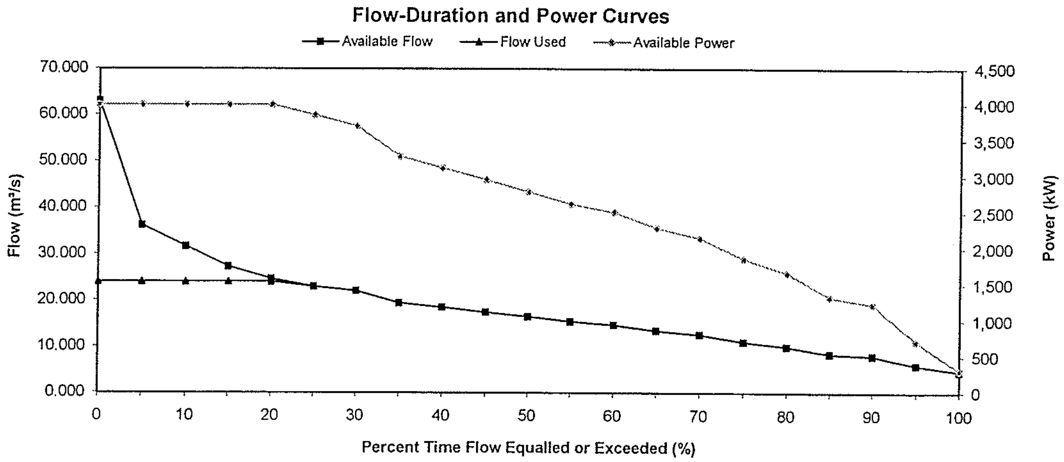
## Robinson Lake with $ 0.10/kWh for Avoided Cost of Energy

## RETScreen® Energy Model - Small Hydro Project

| Site Conditions | | Estimate | Notes/Range |
|---|---|---|---|
| Project name | | Robinson Lake | |
| Project location | | upper Hayes River | |
| Gross head | m | 20.0 | |
| Maximum tailwater effect | m | 0.00 | |
| Residual flow | m³/s | 0.00 | *Complete Hydrology & Load sheet* |
| Firm flow | m³/s | 4.60 | |

| System Characteristics | | Estimate | Notes/Range |
|---|---|---|---|
| Grid type | - | Central-grid | |
| Design flow | m³/s | 24.000 | |
| Turbine type | - | Kaplan | *Complete Equipment Data sheet* |
| Number of turbines | turbine | 1 | |
| Turbine peak efficiency | % | 92.5% | |
| Turbine efficiency at design flow | % | 92.1% | |
| Maximum hydraulic losses | % | 3% | 2% to 7% |
| Generator efficiency | % | 95% | 93% to 97% |
| Transformer losses | % | 0% | 1% to 2% |
| Parasitic electricity losses | % | 0% | 1% to 3% |
| Annual downtime losses | % | 4% | 2% to 7% |

| Annual Energy Production | | Estimate | Notes/Range |
|---|---|---|---|
| Small hydro plant capacity | kW | 3,997 | |
| | MW | 3.997 | |
| Small hydro plant firm capacity | kW | **312** | |
| Available flow adjustment factor | - | 1.00 | |
| Small hydro plant capacity factor | % | 65% | 40% to 95% |
| Renewable energy delivered | MWh | **22,800** | |
| | GJ | 82079 | |



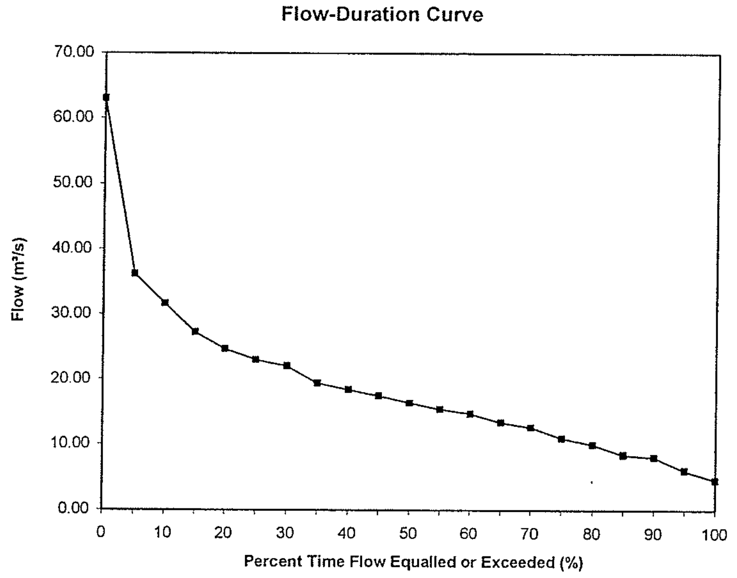
*Complete Cost Analysis sheet*

## RETScreen® Hydrology Analysis and Load Calculation - Small Hydro Project

| **Hydrology Analysis** |  | **Estimate** | **Notes/Range** |
|---|---|---|---|
| Project type |  | Reservoir |  |
| **Hydrology Parameters** |  |  |  |
| Residual flow | m³/s | 0 |  |
| Percent time firm flow available | % | 100% | 90% to 100% |
| Firm flow | m³/s | 4.60 |  |

**Flow-Duration Curve Data**

| Time (%) | Flow (m³/s) |
|---|---|
| 0% | 63.00 |
| 5% | 36.20 |
| 10% | 31.60 |
| 15% | 27.20 |
| 20% | 24.60 |
| 25% | 23.00 |
| 30% | 22.00 |
| 35% | 19.40 |
| 40% | 18.40 |
| 45% | 17.40 |
| 50% | 16.40 |
| 55% | 15.40 |
| 60% | 14.70 |
| 65% | 13.40 |
| 70% | 12.60 |
| 75% | 11.00 |
| 80% | 10.00 |
| 85% | 8.40 |
| 90% | 8.00 |
| 95% | 6.00 |
| 100% | 4.60 |



| **Load Characteristics** | **Estimate** | **Notes/Range** |
|---|---|---|
| Grid type | Central-grid |  |

*Return to*
*Energy Model sheet*

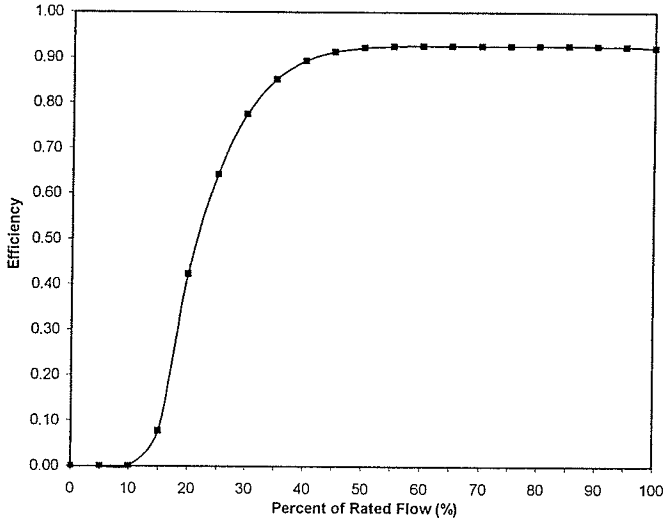
## RETScreen® Equipment Data - Small Hydro Project

| Small Hydro Turbine Characteristics | | Estimate | Notes/Range |
|---|---|---|---|
| Gross head | m | 20.0 | |
| Design flow | m³/s | 24.00 | |
| Turbine type | - | Kaplan | *See Product Database* |
| Turbine efficiency curve data source | - | Standard | |
| Number of turbines | turbine | 1 | |
| Small hydro turbine manufacturer | | | |
| Small hydro turbine model | | Double Regulated S Type | |
| Turbine manufacture/design coefficient | - | 4.5 | 2.8 to 6.1; Default = 4.5 |
| Efficiency adjustment | % | 0% | |
| Turbine peak efficiency | % | 92.5% | |
| Flow at peak efficiency | m³/s | 18.0 | |
| Turbine efficiency at design flow | % | 92.1% | |

**Turbine Efficiency Curve Data**

| Flow<br>(%) | Turbine efficiency | Turbines running<br># | Combined turbine efficiency |
|---|---|---|---|
| 0% | 0.00 | 0 | 0.00 |
| 5% | 0.00 | 1 | 0.00 |
| 10% | 0.00 | 1 | 0.00 |
| 15% | 0.08 | 1 | 0.08 |
| 20% | 0.42 | 1 | 0.42 |
| 25% | 0.64 | 1 | 0.64 |
| 30% | 0.77 | 1 | 0.77 |
| 35% | 0.85 | 1 | 0.85 |
| 40% | 0.89 | 1 | 0.89 |
| 45% | 0.91 | 1 | 0.91 |
| 50% | 0.92 | 1 | 0.92 |
| 55% | 0.92 | 1 | 0.92 |
| 60% | 0.93 | 1 | 0.93 |
| 65% | 0.93 | 1 | 0.93 |
| 70% | 0.93 | 1 | 0.93 |
| 75% | 0.93 | 1 | 0.93 |
| 80% | 0.93 | 1 | 0.93 |
| 85% | 0.93 | 1 | 0.93 |
| 90% | 0.93 | 1 | 0.93 |
| 95% | 0.92 | 1 | 0.92 |
| 100% | 0.92 | 1 | 0.92 |

Efficiency Curve - 1 Turbine(s)



*Return to*
*Energy Model sheet*

## RETScreen® Cost Analysis - Small Hydro Project

Costing method: Formula Currency: $ Cost references: Canada - 2000

| Formula Costing Method | | | | Notes/Range |
|---|---|---|---|---|
| **Input Parameters** | | | | |
| Project country | | Canada | | |
| Cold climate? | yes/no | Yes | | |
| Frost days at site | day | 219 | See Map | Visit NASA satellite data site |
| Number of turbines | turbine | 1.0 | | |
| Flow per turbine | $m^3/s$ | 24.0 | | |
| Approx. turbine runner diameter (per unit) | m | 2.0 | | |
| Project classification: | | | | |
| Suggested classification | - | Small | | |
| Selected classification | - | Small | | |
| Existing dam? | yes/no | No | | |
| New dam crest length | m | 50.0 | | |
| Rock at dam site? | yes/no | Yes | | |
| Maximum hydraulic losses | % | 3% | | |
| Intake and miscellaneous losses | % | 1% | | 1% to 5% |
| Access road required? | yes/no | Yes | | |
| Length | km | 5.0 | | |
| Tote road only? | yes/no | No | | |
| Difficulty of terrain | - | 3.0 | | 1.0 to 6.0 |
| Tunnel required? | yes/no | No | | |
| Canal required? | yes/no | Yes | | |
| Length in rock | m | 50 | | |
| Terrain side slope in rock (average) | ° | 0 | | Max. 45° |
| Length in impervious soil | m | 150 | | |
| Terrain side slope in soil (average) | ° | 5 | | Max. 15° |
| Total canal headloss | m | 0.20 | | |
| Penstock required? | yes/no | Yes | | |
| Length | m | 180.0 | | |
| Number of identical penstocks | penstock | 1 | | |
| Allowable penstock headloss factor | % | 1% | | 1% to 4% |
| Pipe diameter | m | 3.47 | | |
| Average pipe wall thickness | mm | 11.0 | | |
| Distance to borrow pits | km | 8.0 | | |
| Transmission line | | | | |
| Length | km | 70.0 | | |
| Difficulty of terrain | - | 1.0 | | 1 to 2 |
| Voltage | kV | 66.0 | | |
| Interest rate | % | 6.0% | | |

| Initial Costs (Formula Method) | | Cost (local currency) | Adjustment Factor | Amount (local currency) | Relative Costs |
|---|---|---|---|---|---|
| Feasibility Study | | $ 748,000 | 0.75 | **$ 561,000** | 3.0% |
| Development | | $ 782,000 | 1.00 | $ 782,000 | 4.2% |
| Land rights | | | | $ - | 0.0% |
| Subtotal: | | | | **$ 782,000** | 4.2% |
| Engineering | | $ 611,000 | 0.75 | **$ 458,250** | 2.4% |
| Renewable Energy (RE) Equipment | | $ 3,886,000 | 1.00 | **$ 3,886,000** | 20.7% |
| Balance of Plant | | | | | |
| Access road | | $ 1,224,000 | 1.00 | $ 1,224,000 | 6.5% |
| Transmission line | | $ 4,462,000 | 0.00 | $ - | 0.0% |
| Substation and transformer | | $ 84,000 | 0.00 | $ - | 0.0% |
| Penstock | | $ 827,000 | 0.43 | $ 355,610 | 1.9% |
| Canal | | $ 171,000 | 1.00 | $ 171,000 | 0.9% |
| Tunnel | | $ - | 1.00 | $ - | 0.0% |
| Civil works (other) | | $ 8,287,000 | 1.00 | $ 8,287,000 | 44.1% |
| Subtotal: | | $ 15,055,000 | | **$ 10,037,610** | 53.5% |
| Miscellaneous | | $ 3,054,000 | 1.00 | $ 3,054,000 | 16.3% |
| Other | Cost | $ - | | $ - | 0.0% |
| Credit | Credit | $ - | | $ - | 0.0% |
| Subtotal: | | | | **$ 3,054,000** | 16.3% |
| **Initial Costs - Total (Formula Method)** | | $ 24,136,000 | | **$ 18,778,860** | 100.0% |

| Annual Costs (Credits) | Unit | Quantity | Unit Cost | Amount | Relative Costs | Quantity Range | Unit Cost Range |
|---|---|---|---|---|---|---|---|
| O&M | | | | | | | |
| Land lease | project | 1 | $ - | $ - | 0.0% | | $0 - $2,000 |
| Property taxes | % | 0.2% | $ 18,778,860 | $ 37,558 | 12.4% | 0.0% - 0.6% | |
| Water rental | kW | 3,997 | $ 10 | $ 39,965 | 13.2% | | $0 - $20 |
| Insurance premiums | % | 0.25% | $ 18,778,860 | $ 46,947 | 15.5% | 0.25% - 1.00% | |

## RETScreen® Greenhouse Gas (GHG) Emission Reduction Analysis - Small Hydro Project

Use GHG analysis sheet? Yes

Type of analysis Standard

### Background Information

**Project Information**

| | |
|---|---|
| Project name | Robinson Lake |
| Project location | upper Hayes River |

**Global Warming Potential of GHG**

1 ton $CH_4$ = 21 tons $CO_2$ (IPCC 1996)

1 ton $N_2O$ = 310 tons $CO_2$ (IPCC 1996)

### Base Case Electricity System (Reference)

| Fuel type | Fuel mix (%) | $CO_2$ emission factor (kg/GJ) | $CH_4$ emission factor (kg/GJ) | $N_2O$ emission factor (kg/GJ) | Fuel conversion efficiency (%) | T & D losses (%) | GHG emission factor ($t_{CO2}$/MWh) |
|---|---|---|---|---|---|---|---|
| Diesel (#2 oil) | 100.0% | 74.1 | 0.0020 | 0.0020 | 30.0% | 8.0% | 0.975 |
| Electricity mix | 100% | 268.5 | 0.0072 | 0.0072 | | 8.0% | 0.975 |

### Proposed Case Electricity System (Mitigation)

| Fuel type | Fuel mix (%) | $CO_2$ emission factor (kg/GJ) | $CH_4$ emission factor (kg/GJ) | $N_2O$ emission factor (kg/GJ) | Fuel conversion efficiency (%) | T & D losses (%) | GHG emission factor ($t_{CO2}$/MWh) |
|---|---|---|---|---|---|---|---|
| Electricity system | | | | | | | |
| Small hydro | 100.0% | 0.0 | 0.0000 | 0.0000 | 100.0% | 8.0% | 0.000 |

### GHG Emission Reduction Summary

| | Base case GHG emission factor ($t_{CO2}$/MWh) | Proposed case GHG emission factor ($t_{CO2}$/MWh) | End-use annual energy delivered (MWh) | Annual GHG emission reduction ($t_{CO2}$) |
|---|---|---|---|---|
| Electricity system | 0.975 | 0.000 | 20,976 | 20,455 |
| | | | Net GHG emission reduction $t_{CO2}$/yr | 20,455 |

*Complete Financial Summary sheet*

## RETScreen® Financial Summary - Small Hydro Project

### Annual Energy Balance

| | | | | | |
|---|---|---|---|---|---|
| Project name | | Robinson Lake | | | |
| Project location | | upper Hayes River | | | |
| Renewable energy delivered | MWh | 22,800 | GHG analysis sheet used? | yes/no | Yes |
| Excess RE available | MWh | - | Net GHG emission reduction | $t_{CO2}$/yr | 20,455 |
| Firm RE capacity | kW | 312 | Net GHG emission reduction - 35 yrs | $t_{CO2}$ | 715,909 |
| Grid type | | Central-grid | | | |

### Financial Parameters

| | | | | | |
|---|---|---|---|---|---|
| Avoided cost of energy | $/kWh | 0.1000 | Debt ratio | % | 70.0% |
| RE production credit | $/kWh | - | Debt interest rate | % | 7.0% |
| | | | Debt term | yr | 10 |
| GHG emission reduction credit | $/$t_{CO2}$ | - | Income tax analysis? | yes/no | No |
| Avoided cost of capacity | $/kW-yr | - | | | |
| Energy cost escalation rate | % | 3.0% | | | |
| Inflation | % | 2.5% | | | |
| Discount rate | % | 9.0% | | | |
| Project life | yr | 35 | | | |

### Project Costs and Savings

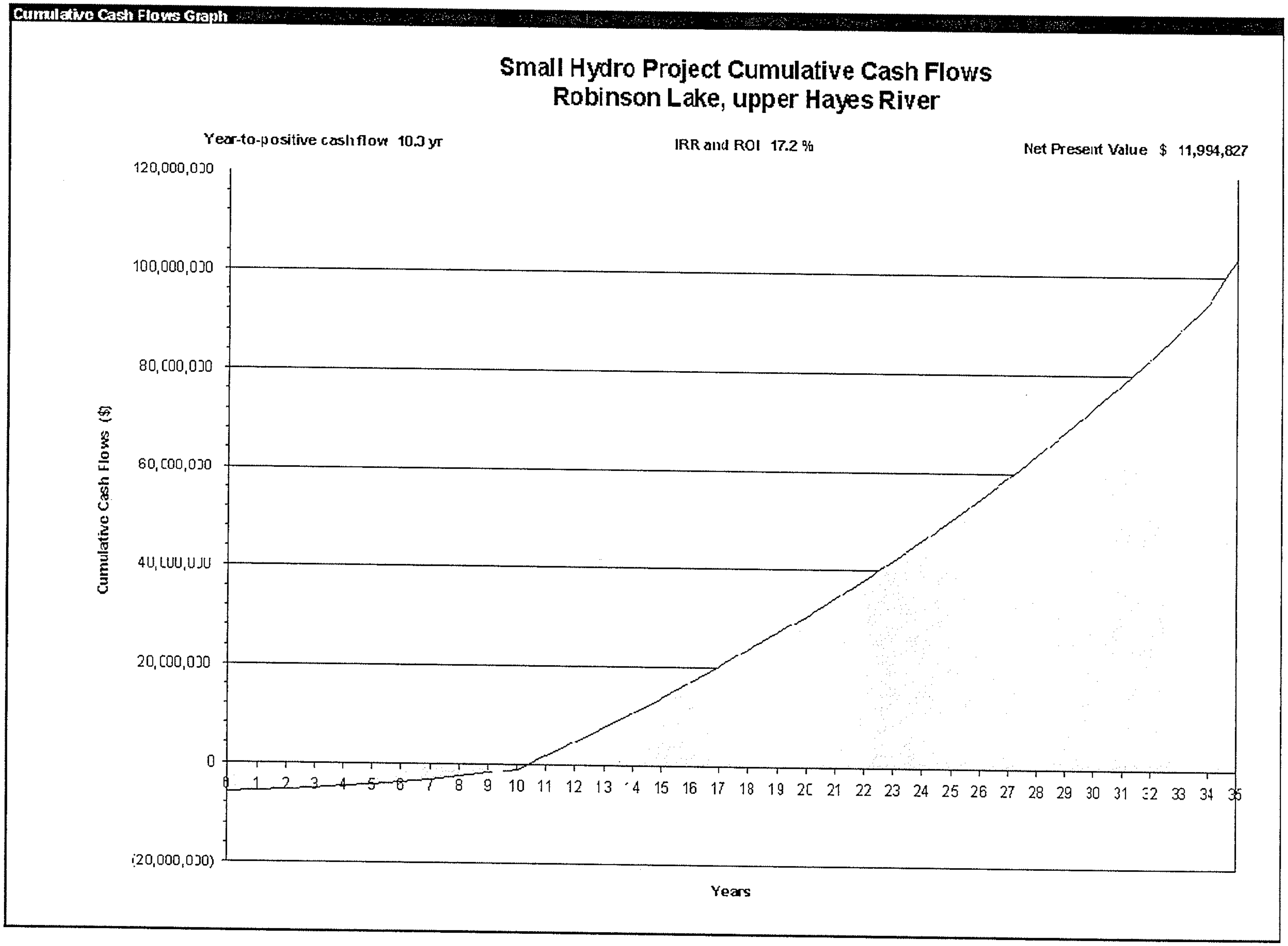
| | | | | | | |
|---|---|---|---|---|---|---|
| **Initial Costs** | | | | **Annual Costs and Debt** | | |
| Feasibility study | 3.0% | $ | 561,000 | O&M | $ | 302,859 |
| Development | 4.2% | $ | 782,000 | | | |
| Engineering | 2.4% | $ | 458,250 | Debt payments - 10 yrs | $ | 1,871,581 |
| RE equipment | 20.7% | $ | 3,886,000 | **Annual Costs - Total** | $ | **2,174,440** |
| Balance of plant | 53.5% | $ | 10,037,610 | | | |
| Miscellaneous | 16.3% | $ | 3,054,000 | **Annual Savings or Income** | | |
| **Initial Costs - Total** | 100.0% | $ | **18,778,860** | Energy savings/income | $ | 2,279,963 |
| | | | | Capacity savings/income | $ | - |
| Incentives/Grants | | $ | - | | | |
| | | | | **Annual Savings - Total** | $ | **2,279,963** |
| **Periodic Costs (Credits)** | | | | | | |
| Turbine overhaul | | $ | 200,000 | Schedule yr # 20 | | |
| | | $ | - | | | |
| | | $ | - | | | |
| End of project life - Credit | | $ | (1,500,000) | Schedule yr # 35 | | |

### Financial Feasibility

| | | | | | |
|---|---|---|---|---|---|
| | | | Calculate RE production cost? | yes/no | No |
| Pre-tax IRR and ROI | % | 17.2% | Calculate GHG reduction cost? | yes/no | No |
| After-tax IRR and ROI | % | 17.2% | | | |
| Simple Payback | yr | 9.5 | Project equity | $ | 5,633,658 |
| Year-to-positive cash flow | yr | 10.3 | Project debt | $ | 13,145,202 |
| Net Present Value - NPV | $ | 11,994,827 | Debt payments | $/yr | 1,871,581 |
| Annual Life Cycle Savings | $ | 1,135,141 | Debt service coverage | - | 1.09 |
| Profitability Index - PI | - | 2.13 | | | |

### Yearly Cash Flows

| Year<br>#  | Pre-tax<br>$ | After-tax<br>$ | Cumulative<br>$ |
|---|---|---|---|
| 0 | (5,633,658) | (5,633,658) | (5,633,658) |
| 1 | 166,350 | 166,350 | (5,467,308) |
| 2 | 229,040 | 229,040 | (5,238,268) |
| 3 | 293,650 | 293,650 | (4,944,618) |
| 4 | 360,237 | 360,237 | (4,584,381) |
| 5 | 428,863 | 428,863 | (4,155,517) |
| 6 | 499,590 | 499,590 | (3,655,927) |
| 7 | 572,481 | 572,481 | (3,083,446) |
| 8 | 647,603 | 647,603 | (2,435,843) |
| 9 | 725,024 | 725,024 | (1,710,819) |
| 10 | 804,813 | 804,813 | (906,006) |
| 11 | 2,758,624 | 2,758,624 | 1,852,618 |
| 12 | 2,843,370 | 2,843,370 | 4,695,988 |
| 13 | 2,930,708 | 2,930,708 | 7,626,696 |
| 14 | 3,020,716 | 3,020,716 | 10,647,412 |
| 15 | 3,113,477 | 3,113,477 | 13,760,890 |
| 16 | 3,209,075 | 3,209,075 | 16,969,965 |
| 17 | 3,307,595 | 3,307,595 | 20,277,560 |
| 18 | 3,409,127 | 3,409,127 | 23,686,687 |
| 19 | 3,513,763 | 3,513,763 | 27,200,450 |
| 20 | 3,293,873 | 3,293,873 | 30,494,323 |
| 21 | 3,732,726 | 3,732,726 | 34,227,049 |
| 22 | 3,847,251 | 3,847,251 | 38,074,300 |
| 23 | 3,965,275 | 3,965,275 | 42,039,575 |
| 24 | 4,086,906 | 4,086,906 | 46,126,481 |
| 25 | 4,212,252 | 4,212,252 | 50,338,733 |
| 26 | 4,341,427 | 4,341,427 | 54,680,160 |
| 27 | 4,474,547 | 4,474,547 | 59,154,707 |
| 28 | 4,611,733 | 4,611,733 | 63,766,440 |
| 29 | 4,753,109 | 4,753,109 | 68,519,549 |
| 30 | 4,898,801 | 4,898,801 | 73,418,350 |
| 31 | 5,048,941 | 5,048,941 | 78,467,291 |
| 32 | 5,203,665 | 5,203,665 | 83,670,956 |
| 33 | 5,363,112 | 5,363,112 | 89,034,068 |
| 34 | 5,527,426 | 5,527,426 | 94,561,494 |
| 35 | 9,256,563 | 9,256,563 | 103,818,057 |



Small Hydro Project Cumulative Cash Flows
Robinson Lake, upper Hayes River

Year-to-positive cash flow 10.3 yr

IRR and ROI 17.2 %

Net Present Value $ 11,994,827

# APPENDIX G

## RETScreen Small Hydro Analysis:

## Robinson Lake with $ 0.20/kWh for Avoided Cost of Energy

## RETScreen® Financial Summary - Small Hydro Project

### Annual Energy Balance

| | | | | | |
|---|---|---|---|---|---|
| Project name | | Robinson Lake | | | |
| Project location | | upper Hayes River | | | |
| Renewable energy delivered | MWh | 22,800 | GHG analysis sheet used? | yes/no | Yes |
| Excess RE available | MWh | - | Net GHG emission reduction | $t_{CO2}$/yr | 20,455 |
| Firm RE capacity | kW | 312 | Net GHG emission reduction - 35 yrs | $t_{CO2}$ | 715,909 |
| Grid type | | Central-grid | | | |

### Financial Parameters

| | | | | | |
|---|---|---|---|---|---|
| Avoided cost of energy | $/kWh | 0.2000 | Debt ratio | % | 70.0% |
| RE production credit | $/kWh | - | Debt interest rate | % | 7.0% |
| | | | Debt term | yr | 10 |
| GHG emission reduction credit | $/$t_{CO2}$ | - | Income tax analysis? | yes/no | No |
| Avoided cost of capacity | $/kW-yr | - | | | |
| Energy cost escalation rate | % | 3.0% | | | |
| Inflation | % | 2.5% | | | |
| Discount rate | % | 9.0% | | | |
| Project life | yr | 35 | | | |

### Project Costs and Savings

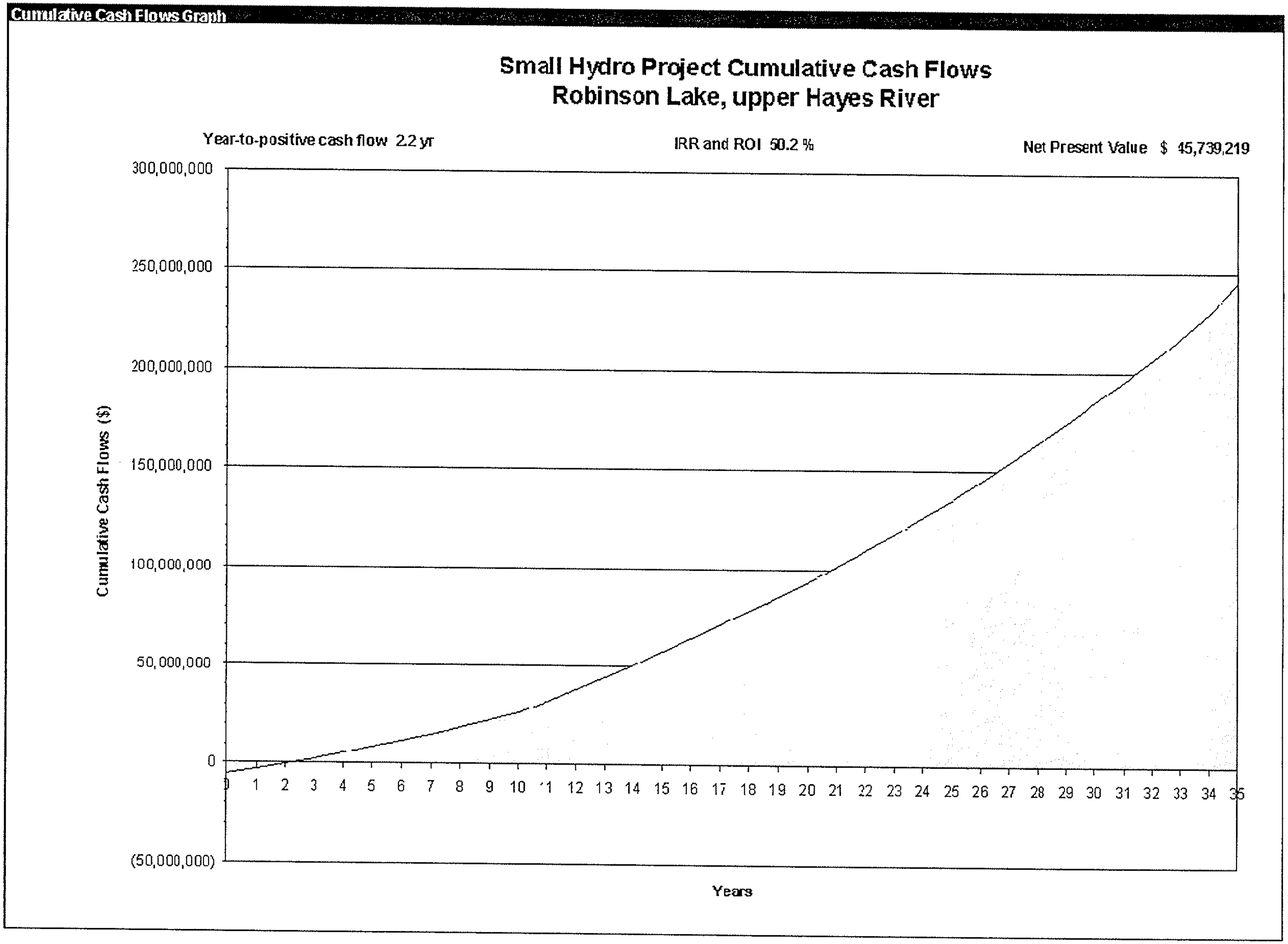
| | | | | | | |
|---|---|---|---|---|---|---|
| **Initial Costs** | | | | **Annual Costs and Debt** | | |
| Feasibility study | 3.0% | $ | 561,000 | O&M | $ | 302,859 |
| Development | 4.2% | $ | 782,000 | | | |
| Engineering | 2.4% | $ | 458,250 | Debt payments - 10 yrs | $ | 1,871,581 |
| RE equipment | 20.7% | $ | 3,886,000 | **Annual Costs - Total** | **$** | **2,174,440** |
| Balance of plant | 53.5% | $ | 10,037,610 | | | |
| Miscellaneous | 16.3% | $ | 3,054,000 | **Annual Savings or Income** | | |
| **Initial Costs - Total** | **100.0%** | **$** | **18,778,860** | Energy savings/income | $ | 4,559,926 |
| | | | | Capacity savings/income | $ | - |
| Incentives/Grants | | $ | - | | | |
| | | | | **Annual Savings - Total** | **$** | **4,559,926** |
| **Periodic Costs (Credits)** | | | | | | |
| Turbine overhaul | | $ | 200,000 | Schedule yr # 20 | | |
| | | $ | - | | | |
| | | $ | - | | | |
| End of project life - Credit | | $ | (1,500,000) | Schedule yr # 35 | | |

### Financial Feasibility

| | | | | | |
|---|---|---|---|---|---|
| | | | Calculate RE production cost? | yes/no | No |
| Pre-tax IRR and ROI | % | 50.2% | Calculate GHG reduction cost? | yes/no | No |
| After-tax IRR and ROI | % | 50.2% | | | |
| Simple Payback | yr | 4.4 | Project equity | $ | 5,633,658 |
| Year-to-positive cash flow | yr | 2.2 | Project debt | $ | 13,145,202 |
| Net Present Value - NPV | $ | 45,739,219 | Debt payments | $/yr | 1,871,581 |
| Annual Life Cycle Savings | $ | 4,328,569 | Debt service coverage | - | 2.34 |
| Profitability Index - PI | - | 8.12 | | | |

### Yearly Cash Flows

| Year #| Pre-tax $ | After-tax $ | Cumulative $ |
|---|---|---|---|
| 0 | (5,633,658) | (5,633,658) | (5,633,658) |
| 1 | 2,514,712 | 2,514,712 | (3,118,946) |
| 2 | 2,647,853 | 2,647,853 | (471,093) |
| 3 | 2,785,027 | 2,785,027 | 2,313,934 |
| 4 | 2,926,356 | 2,926,356 | 5,240,289 |
| 5 | 3,071,965 | 3,071,965 | 8,312,255 |
| 6 | 3,221,985 | 3,221,985 | 11,534,240 |
| 7 | 3,376,548 | 3,376,548 | 14,910,788 |
| 8 | 3,535,792 | 3,535,792 | 18,446,580 |
| 9 | 3,699,858 | 3,699,858 | 22,146,438 |
| 10 | 3,868,893 | 3,868,893 | 26,015,331 |
| 11 | 5,914,626 | 5,914,626 | 31,929,957 |
| 12 | 6,094,052 | 6,094,052 | 38,024,009 |
| 13 | 6,278,910 | 6,278,910 | 44,302,919 |
| 14 | 6,469,365 | 6,469,365 | 50,772,284 |
| 15 | 6,665,585 | 6,665,585 | 57,437,870 |
| 16 | 6,867,746 | 6,867,746 | 64,305,616 |
| 17 | 7,076,027 | 7,076,027 | 71,381,642 |
| 18 | 7,290,612 | 7,290,612 | 78,672,254 |
| 19 | 7,511,692 | 7,511,692 | 86,183,946 |
| 20 | 7,411,740 | 7,411,740 | 93,595,686 |
| 21 | 7,974,129 | 7,974,129 | 101,569,814 |
| 22 | 8,215,896 | 8,215,896 | 109,785,710 |
| 23 | 8,464,980 | 8,464,980 | 118,250,689 |
| 24 | 8,721,601 | 8,721,601 | 126,972,291 |
| 25 | 8,985,988 | 8,985,988 | 135,958,279 |
| 26 | 9,258,375 | 9,258,375 | 145,216,654 |
| 27 | 9,539,004 | 9,539,004 | 154,755,658 |
| 28 | 9,828,124 | 9,828,124 | 164,583,782 |
| 29 | 10,125,991 | 10,125,991 | 174,709,772 |
| 30 | 10,432,869 | 10,432,869 | 185,142,642 |
| 31 | 10,749,032 | 10,749,032 | 195,891,673 |
| 32 | 11,074,758 | 11,074,758 | 206,966,432 |
| 33 | 11,410,338 | 11,410,338 | 218,376,770 |
| 34 | 11,756,069 | 11,756,069 | 230,132,839 |
| 35 | 15,672,065 | 15,672,065 | 245,804,904 |



Cumulative Cash Flows Graph

Small Hydro Project Cumulative Cash Flows
Robinson Lake, upper Hayes River

Year-to-positive cash flow 2.2 yr

IRR and ROI 50.2 %

Net Present Value $ 45,739,219