# Micro Hydroelectric Power Facility

Marble Mountain, Newfoundland

**Streamline Engineering Consultants**
Memorial University of Newfoundland
S.J. Carew Building
EN 2050
St. John's, NL Canada
A1B 3X5
streamlineengconsultants@gmail.com

Streamline Engineering Consultants

**Streamline Engineering Consultants**
Memorial University of Newfoundland
S.J. Carew Building
EN 2050
St. John's, NL Canada
A1B 3X5
streamlineengconsultants@gmail.com

Monday February 4th, 2013

Mr. Robert Pike, Chair
Marble Mountain Development Corporation
P.O. Box 947
Corner Brook, NL Canada
A2H 6J2

Dear Mr. Pike,

Streamline Engineering Consultants is proud to be given the opportunity to investigate the development of a micro hydroelectric generation facility at Marble Mountain that can potentially provide a cost savings to the resort.

The enclosed project report contains our proposed two (2) phase development plan as well as detailed calculations and background information relevant to the project.

If you have any questions or concerns with our report, we would be happy to discuss them with you.

Sincerely,

Christopher Clark

Christopher Clark, Chief Project Manager and Communications Lead
Streamline Engineering Consultants

cc. Dr. Stephen Bruneau

## Table of Contents

## List of Figures

# 1. Project Team

Streamline Engineering Consultants are a group of passionate senior civil engineering students. The three (3) members of the project team have various responsibilities and diverse portfolios as outlined below.

### *Christopher Clark*

Chief Project Manager and Communication Lead

| Responsibilities | Previous Experience |
|---|---|
| • Project Managing<br>• Communications<br>• Schedules | • Department of Transportation and Works – Special Projects Division (Health Infrastructure)<br>• Department of Transportation and Works – Avalon Works<br>• Tiller Engineering/Rotary Club of Waterford Valley |

***Rob Ducey***
Technical Director of Engineering

| **Responsibilities** | **Previous Experience** |
|---|---|
| • Hydrology<br>• Mapping<br>• Drafting | • BAE-NewPlan Group Ltd./SNC Lavalin Inc.<br>• Stantec<br>• Department of Education |

***Alex Hawco***
Power Generation Specialist

| **Responsibilities** | **Previous Experience** |
|---|---|
| • Power Generation<br>• Technical Communications | • Newfoundland Power Inc.<br>• Department of Transportation and Works – Western Works/Avalon Works |

## 2. Introduction

Streamline Engineering Consultants have been given the opportunity, by the Marble Mountain Development Corporation, to complete a preliminary engineering study of the possibility of the implementation of a micro hydroelectric development at their site.

The idea of constructing a hydroelectric generating facility at Marble Mountain has been discussed for a number of years amongst various parties.

A hydroelectric development at Marble Mountain will utilize the river of Steady Brook, which is located just north of the skiable terrain of the resort (See figure 1).

**Figure 1 - Location of Steady Brook**

*Source: bing.com/maps*

There is a possibility purposed by the operations staff at Marble Mountain to also utilize the existing pipeline used for snowmaking, as a penstock for a future hydroelectric development.

Electrical usage at the resort represents a significant portion of their operating costs. The implementation of a micro hydroelectric facility could potential save the resort significant funds by offsetting the amount of power that would need to be purchased on an annual basis.

The following report will uncover the possible solutions that could be implemented at Marble Mountain to offset their large electrical power purchases.

## 3. Concept Generation

This project at Marble Mountain is very unique. As with any new hydroelectric development many possible solutions can be developed and implemented.

We have used a brainstorming technique to generate possible solutions through discussions within the design team and consultation with Marble Mountain, Memorial University of Newfoundland, and Newfoundland Power Inc. staff. Throughout this process we have generated the following concepts that may be acceptable for this project.

1. Original Pipeline
    a. Utilize the original pipeline as the penstock for a hydroelectric turbine that will be installed in the existing pump house structure.
2. Original Pipeline and Storage Tanks
    a. Utilize the original pipeline to generate power and pump water to a new storage tank near the summit of Marble Mountain during the rainy season and use this water for snowmaking via gravity feed in the winter months.
3. New Pipeline and Turbine Housing
    a. Install a new pipeline from the existing intake location and a new hydroelectric turbine near the base of Steady Brook Falls.
4. New Pipeline Past Chlorination Building and New Turbine Housing
    a. Install a new pipeline past the chlorination building and a new hydroelectric turbine near the base of Steady Brook Falls.
5. New Pipeline and Turbine Housing with Storage Dams
    a. The same as option three (3) but with upstream storage dams to regulate the flow in Steady Brook for year round generation of electricity.

# 4. Concept Selection

There are many methods to select a desired concept for a given project. The need for a concept selection analysis has stemmed from the existence of multiple viable options for this project. The various methods commonly used are as follows. (Bruneau)

1. External Decision
2. Product Champion
3. Intuition
4. Multi voting
5. Pros and Cons
6. Prototype and Testing
7. Decision Matrices

For this project we have chosen to use the decision matrices method to choose the dominant option.

The decision matrices method chosen consists of a two (2) step approach. These steps consist of a concept screening portion used to preliminary eliminate some of the options. Followed by a concept scoring exercise, which is a more detailed analysis of the remaining concepts to ultimately choose the dominant option. (Bruneau)

The first step in this process is to choose one (1) option to be the benchmark, which all other options will be compared against. For this project we have chosen the new pipeline with a new turbine housing as the benchmark option. This was chosen, as it appears to be in the middle of our options in terms of price and generation capabilities.

Factors to be analyzed for each option were chosen to be as follows.

1. Cost
2. Construction Labour
3. Aesthetic Appeal
4. Maintenance
5. Power Generated
6. Environmental Issues
7. Political Issues

A concept screening analysis can now be completed. The process is to place a (+) for better than the benchmark option or a (-) for worse than the benchmark option for each factor/option. With this information a net score can be developed for each option, a ranking of the options and choosing which options to go forward with into the next step of concept selection. The concept screening analysis for this project can be seen in Figure 2.

| | Original Pipeline | Original Pipeline and Storage Tanks | New Pipeline and Turbine Housing | New Pipeline Past Clorination Building and New Turbine | New Pipeline and Turbine Housing with Storage Dams |
|---|---|---|---|---|---|
| Cost | + | – | 0 | + | – |
| Construction Labour | + | 0 | 0 | 0 | – |
| Aesthetic Appeal | + | – | 0 | 0 | – |
| Maintenance | – | 0 | 0 | 0 | – |
| Power Generated | – | – | 0 | – | + |
| Environmental Issues | 0 | – | 0 | 0 | – |
| Political Issues | 0 | – | 0 | 0 | – |
| Sum of +'s | 3 | 0 | 0 | 1 | 1 |
| Sum of 0's | 2 | 2 | 7 | 5 | 0 |
| Sum of -'s | 2 | 5 | 0 | 1 | 6 |
| Net Score | 1 | -5 | 0 | 0 | -5 |
| Ranking | 1 | 4 | 2 | 2 | 5 |

**Figure 2 - Concept Screening Matrix**

Through this process it was chosen to keep the top three (3) concepts for further analysis. The top three (3) options are the original pipeline, new pipeline and turbine housing, and new pipeline past chlorination building and new turbine.

These three (3) options were further analyzed using a concept scoring analysis. In this analysis the same criteria as the concept screening matrix is used, but a weighted rank is placed on each criteria. The weights were derived from how much each criterion impacts the project.

A rank is given to each option with comparison to the reference option. The ranking system used is presented here.

1. Much worse than reference
2. Worse than reference
3. Same as reference
4. Better than reference
5. Much better than reference

These scores are multiplied by the weights of each criterion and summed to produce a total score. These option can now be ranked and a dominant option chosen. (Bruneau)

The concept scoring analysis for this project is presented in Figure 3.

| | | New Pipeline and Turbine Housing (Reference) | | Original Pipeline | | New Pipeline Past Clorination Building and New Turbine | |
|---|---|---|---|---|---|---|---|
| **Selection Criteria** | **Weight** | **Rating** | **Weighted Score** | **Rating** | **Weighted Score** | **Rating** | **Weighted Score** |
| **Cost** | **25%** | 3 | 0.75 | 5 | 1.25 | 4 | 1 |
| **Construction Labour** | **5%** | 3 | 0.15 | 4 | 0.2 | 4 | 0.2 |
| **Aesthetic Appeal** | **10%** | 3 | 0.3 | 5 | 0.5 | 3 | 0.3 |
| **Maintenance** | **5%** | 3 | 0.15 | 2 | 0.1 | 2 | 0.1 |
| **Power Generated** | **25%** | 3 | 0.75 | 1 | 0.25 | 1 | 0.25 |
| **Environmental Issues** | **15%** | 3 | 0.45 | 4 | 0.6 | 3 | 0.45 |
| **Political Issues** | **15%** | 3 | 0.45 | 4 | 0.6 | 3 | 0.45 |
| **Total Score** | | 3 | | 3.5 | | 2.75 | |
| **Rank** | | 2 | | 1 | | 3 | |
| **Continue** | | Yes | | Yes | | No | |

**Figure 3 - Concept Scoring Matrix**

As seen in the concept scoring matrix we have chosen two (2) options to go forward with for this project. We purpose that a two (2) phase implementation of the two (2) dominant options be implemented for this project.

The first phase of this project would be to utilize the original pipeline to generate electricity by installing a hydroelectric turbine at the end of the existing pipeline. Phase two (2) of this project would be implemented a few years down the road by installing a new penstock pipeline from the current intake location, constructing a new turbine building near the base of Steady Brook Falls and installing a hydroelectric turbine at this location.

The choice to implement a two (2) phase approach for this project will take advantage of the ease of implementation of phase one (1) and use this as a trail period for the system. Accompanied with the increased power generation capabilities of phase two (2), if the system is initially successful.

# 5. Phase One (1)

## 5.1. Introduction

Phase one (1) of the proposed project consists of utilizing the original pipeline used for snowmaking operations to generate electricity at the Marble Mountain site.

The original pipeline at Marble Mountain originates on steady brook, which is just north of the skiable terrain of the resort.

Water is extracted from Steady Brook at an elevation of approximately 197 m (646 ft.) above sea level. This water then travels along a 2,642 m (8,668 ft.) pipeline. The dimensions of the pipeline vary from 305 mm (12 in.) at the intake to 254 mm (10 in.) at the pump house.

In phase one (1) this pipeline will be utilized by connecting a hydroelectric turbine to the pipeline at the existing pump house location.

## 5.2. Analysis of Pipeline

Since there is no site-specific information on the flow characteristics of the original pipeline, a study of the pipeline was conducted using relevant calculations.

The pipeline was analyzed using the following flow principles.

1. Manning
2. Hazen Williams
3. Darcy Weisbach

These three (3) flow analysis methods are highly used in the determination of friction loss in a pipeline.

### 5.2.1. Manning Analysis

Manning's equation was experimentally developed for open channel flow using the slope of the channel and a friction factor (n) to calculate the friction loss in waterway. This method may not be perfect for pressurized pipe flow but is presented in this analysis for comparison against the other methods. The equation for friction head loss using Manning's equation is presented in equation (1). (Robert J. Houghtalen)

$$h_L = \frac{10.3 * n^2 * L}{D^{5.33} * Q^2} \qquad (1)$$

*Where,*
*n is the Manning's friction factor (0.009)*
*L is the length of the pipeline (m)*
*D is the pipeline diameter (m)*
*Q is the pipeline flow rate ($m^3/s$)*

This friction loss equation was then used to calculate the optimum flow rate that is possible in the original pipeline. This was done by calculating the friction loss in each section of the original pipeline and summing the losses together. This loss in head due to friction was subtracted from the total available head and the potential power generation capability was calculated using equation (2).

$$P = \frac{\gamma_{Water} * Q * H_{Net}}{1000} \qquad (2)$$

*Where,*
γ is the unit weight of water (9810 N/m³)
*Q is the pipeline flow rate (m³/s)*
*$H_{Net}$ is the total head minus $h_L$*

The Manning's equation analysis is summarized in the following tables (See Figures 4 and 5) and graph (See Figure 6) to show the theoretical available power.

| Inputs | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Friction Factor (n) | 0.009 | Section #1 | | Section #2 | | Section #3 | | Section #4 | |
| Unit Weight of Water (N/m³) | 9810 | Diameter (m) | 0.3 | Diameter (m) | 0.3 | Diameter (m) | 0.25 | Diameter (m) | 0.25 |
| Total Head (m) | 177 | Length (m) | 404 | Length (m) | 404 | Length (m) | 853 | Length (m) | 980 |

**Figure 4 - Manning's Equation Input Parameters**

| Results | | | | | | | |
|---|---|---|---|---|---|---|---|
| Flow Rate (m³/s) | Section #1 Friction Head Loss (m) | Section #2 Friction Head Loss (m) | Section #3 Friction Head Loss (m) | Section #4 Friction Head Loss (m) | Total Friction Loss (m) | Net Head (m) | Power (kW) |
| 0.01 | 0.02 | 0.02 | 0.12 | 0.13 | 0.29 | 176.71 | 17.34 |
| 0.03 | 0.19 | 0.19 | 1.04 | 1.19 | 2.60 | 174.40 | 51.33 |
| 0.05 | 0.52 | 0.52 | 2.88 | 3.31 | 7.22 | 169.78 | 83.28 |
| 0.07 | 1.01 | 1.01 | 5.64 | 6.48 | 14.15 | 162.85 | 111.83 |
| 0.09 | 1.67 | 1.67 | 9.33 | 10.72 | 23.39 | 153.61 | 135.62 |
| 0.11 | 2.50 | 2.50 | 13.93 | 16.01 | 34.94 | 142.06 | 153.30 |
| 0.13 | 3.49 | 3.49 | 19.46 | 22.36 | 48.80 | 128.20 | 163.50 |
| 0.15 | 4.65 | 4.65 | 25.91 | 29.77 | 64.97 | 112.03 | 164.86 |
| 0.17 | 5.97 | 5.97 | 33.28 | 38.23 | 83.44 | 93.56 | 156.02 |
| 0.19 | 7.46 | 7.46 | 41.56 | 47.76 | 104.23 | 72.77 | 135.63 |
| 0.21 | 9.11 | 9.11 | 50.78 | 58.34 | 127.33 | 49.67 | 102.32 |
| 0.23 | 10.93 | 10.93 | 60.91 | 69.98 | 152.74 | 24.26 | 54.73 |

**Figure 5 - Manning's Equation Power Results**

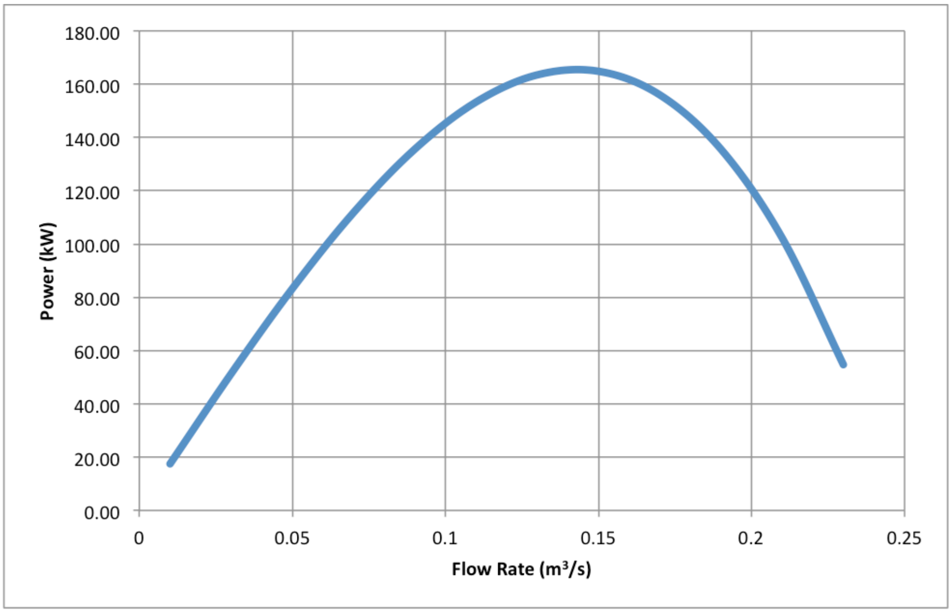



**Figure 6 - Manning's Equation Power Results Graph**

From the Manning's analysis, the potential power generation capabilities of the original pipeline are governed by a maximum flow rate of 0.15 $m^3/s$. This flow rate corresponds to the generation of 165 kW of power.

### 5.2.2. Hazen Williams Analysis

Hazen Williams' equation was experimentally developed for pressurized pipe flow using the length of the pipeline and a friction factor ($C_{HW}$) to calculate friction loss in a pipeline. The equation for friction head loss using Hazen Williams' equation is presented in equation (3). (Robert J. Houghtalen)

$$h_L = \left(\frac{10.67}{C_{HW}{}^{1.85}}\right) * L * \left(\frac{Q^{1.85}}{D^{4.87}}\right) \qquad (3)$$

*Where,*
*$C_{HW}$ is the Hazen Williams friction factor (150)*
*L is the length of the pipeline (m)*
*Q is the pipeline flow rate ($m^3/s$)*
*D is the pipeline diameter (m)*

The Hazen Williams' equation analysis is summarized in the following tables (See figures 7 and 8) and graph (See Figure 9) to show the theoretical available power.

| Inputs | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Friction Factor ($C_{HW}$) | 150 | Section #1 | | Section #2 | | Section #3 | | Section #4 | |
| Unit Weight of Water ($N/m^3$) | 9810 | Diameter (m) | 0.3 | Diameter (m) | 0.3 | Diameter (m) | 0.25 | Diameter (m) | 0.25 |
| Total Head (m) | 177 | Length (m) | 404 | Length (m) | 404 | Length (m) | 853 | Length (m) | 980 |

**Figure 7 – Hazen Williams' Equation Input Parameters**

| Results | | | | | | | |
|---|---|---|---|---|---|---|---|
| Flow Rate ($m^3/s$) | Section #1 Friction Head Loss (m) | Section #2 Friction Head Loss (m) | Section #3 Friction Head Loss (m) | Section #4 Friction Head Loss (m) | Total Friction Loss (m) | Net Head (m) | Power (kW) |
| 0.01 | 0.03 | 0.03 | 0.15 | 0.15 | 0.35 | 176.65 | 17.33 |
| 0.03 | 0.22 | 0.22 | 1.12 | 1.12 | 2.67 | 174.33 | 51.31 |
| 0.05 | 0.56 | 0.56 | 2.87 | 2.87 | 6.87 | 170.13 | 83.45 |
| 0.07 | 1.04 | 1.04 | 5.36 | 5.36 | 12.80 | 164.20 | 112.76 |
| 0.09 | 1.66 | 1.66 | 8.53 | 8.53 | 20.38 | 156.62 | 138.28 |
| 0.11 | 2.41 | 2.41 | 12.36 | 12.36 | 29.54 | 147.46 | 159.13 |
| 0.13 | 3.28 | 3.28 | 16.83 | 16.83 | 40.23 | 136.77 | 174.42 |
| 0.15 | 4.28 | 4.28 | 21.93 | 21.93 | 52.43 | 124.57 | 183.31 |
| 0.17 | 5.39 | 5.39 | 27.65 | 27.65 | 66.08 | 110.92 | 184.97 |
| 0.19 | 6.63 | 6.63 | 33.97 | 33.97 | 81.18 | 95.82 | 178.59 |
| 0.21 | 7.97 | 7.97 | 40.87 | 40.87 | 97.70 | 79.30 | 163.37 |
| 0.23 | 9.44 | 9.44 | 48.37 | 48.37 | 115.60 | 61.40 | 138.53 |
| 0.25 | 11.01 | 11.01 | 56.43 | 56.43 | 134.88 | 42.12 | 103.29 |

**Figure 8 – Hazen Williams' Equation Power Results**

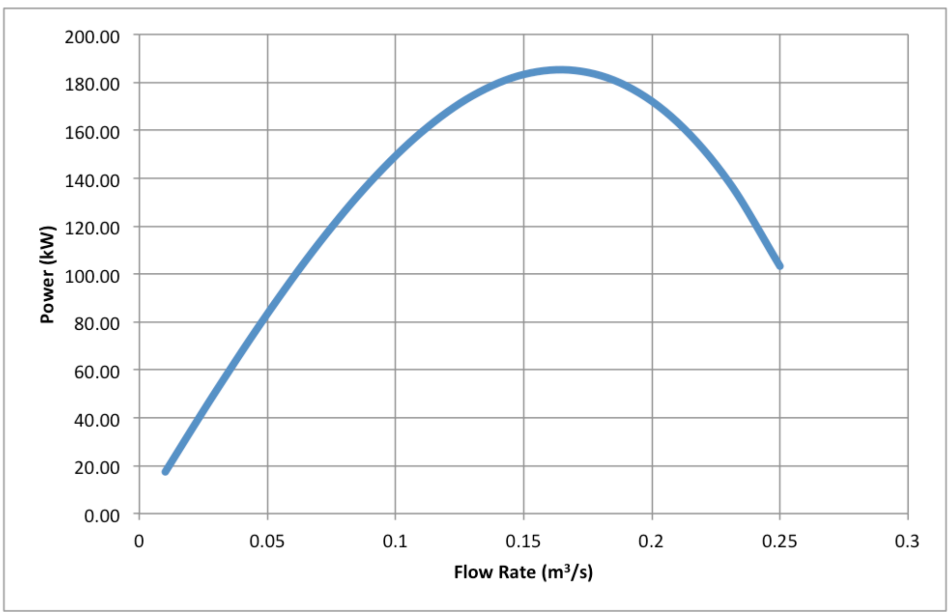



**Figure 9 – Hazen Williams' Equation Power Results Graph**

From the Hazen Williams' analysis, the potential power generation capabilities of the original pipeline are governed by a optimum flow rate of 0.17 $m^3/s$. This flow rate corresponds to the generation of 185 kW of power.

### 5.2.3. Darcy Weisbach Analysis

Darcy Weisbach's equation was experimentally developed for pressurized pipe flow using a roughness factor (€) to calculate the friction factor (f) of the pipeline (See equation (4)). This factor and the length of the pipeline are used to calculate the friction loss. The equation for friction head loss using Darcy Weisbach's equation is presented in equation (5). (Robert J. Houghtalen)

$$f = \left(-5637.2 * \left(\frac{D}{€}\right)^2\right) + \left(14.448 * \left(\frac{D}{€}\right)\right) + 0.0111 \qquad (4)$$

*Where,*
*D is the pipeline diameter (m)*
*€ is the pipeline roughness (0.0015)*

$$h_L = \frac{0.0826 * f * L}{D^5 * Q^2} \qquad (5)$$

*Where,*
*f is the friction factor*
*L is the length of the pipeline (m)*
*D is the pipeline diameter (m)*
*Q is the pipeline flow rate (m³/s)*

The Darcy Weisbach's equation analysis is summarized in the following tables (See figures 10 and 11) and graph (See Figure 12) to show the theoretical available power.

| Inputs | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Roughness Factor (€) | 0.0015 | Section #1 | | Section #2 | | Section #3 | | Section #4 | |
| Unit Weight of Water (N/m$^3$) | 9810 | Diameter (m) | 0.3 | Diameter (m) | 0.3 | Diameter (m) | 0.25 | Diameter (m) | 0.25 |
| Total Head (m) | 177 | Length (m) | 404.33 | Length (m) | 404.33 | Length (m) | 852.94 | Length (m) | 980 |
| | | D/€ | 0.000005 | D/€ | 0.000005 | D/€ | 0.000006 | D/€ | 0.000006 |
| | | Friction Factor (f) | 0.0112 | Friction Factor (f) | 0.0112 | Friction Factor (f) | 0.0112 | Friction Factor (f) | 0.0112 |

**Figure 10 – Darcy Weishach's Equation Input Parameters**

| Results | | | | | | | |
|---|---|---|---|---|---|---|---|
| Flow Rate (m$^3$/s) | Section #1 Friction Head Loss (m) | Section #2 Friction Head Loss (m) | Section #3 Friction Head Loss (m) | Section #4 Friction Head Loss (m) | Total Friction Loss (m) | Net Head (m) | Power (kW) |
| 0.01 | 0.02 | 0.02 | 0.08 | 0.09 | 0.20 | 176.80 | 17.34 |
| 0.03 | 0.14 | 0.14 | 0.73 | 0.83 | 1.84 | 175.16 | 51.55 |
| 0.05 | 0.38 | 0.38 | 2.02 | 2.32 | 5.10 | 171.90 | 84.32 |
| 0.07 | 0.75 | 0.75 | 3.95 | 4.54 | 10.00 | 167.00 | 114.68 |
| 0.09 | 1.24 | 1.24 | 6.54 | 7.51 | 16.54 | 160.46 | 141.67 |
| 0.11 | 1.86 | 1.86 | 9.77 | 11.22 | 24.70 | 152.30 | 164.35 |
| 0.13 | 2.59 | 2.59 | 13.64 | 15.67 | 34.50 | 142.50 | 181.73 |
| 0.15 | 3.45 | 3.45 | 18.16 | 20.86 | 45.93 | 131.07 | 192.87 |
| 0.17 | 4.44 | 4.44 | 23.32 | 26.80 | 59.00 | 118.00 | 196.80 |
| 0.19 | 5.54 | 5.54 | 29.13 | 33.47 | 73.69 | 103.31 | 192.55 |
| 0.21 | 6.77 | 6.77 | 35.59 | 40.89 | 90.03 | 86.97 | 179.18 |
| 0.23 | 8.12 | 8.12 | 42.69 | 49.05 | 107.99 | 69.01 | 155.71 |
| 0.25 | 9.60 | 9.60 | 50.44 | 57.95 | 127.59 | 49.41 | 121.19 |

**Figure 11 – Darcy Weisbach's Equation Power Results**

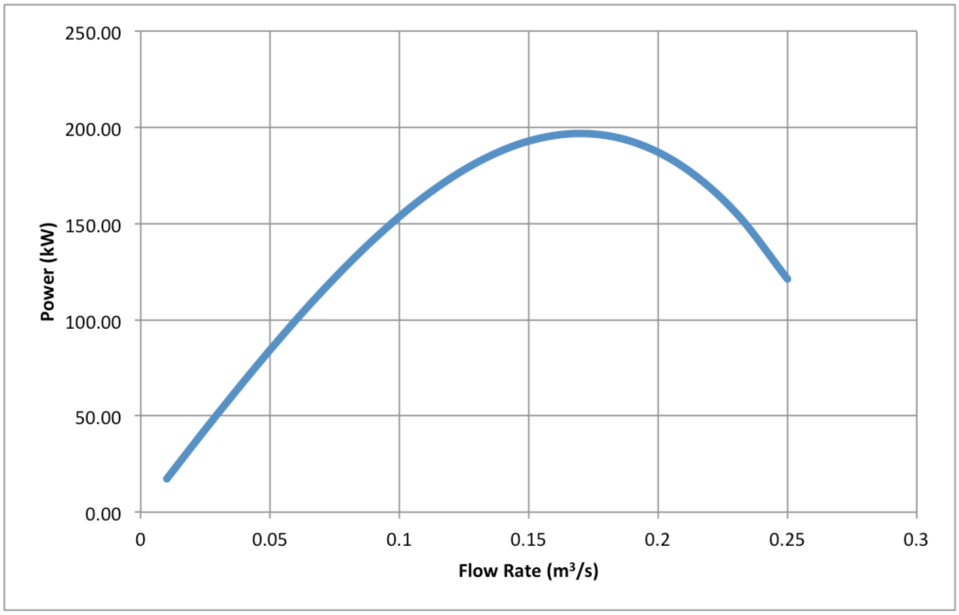



**Figure 12 – Darcy Weisbach's Equation Power Results Graph**

From the Darcy Weisbach's analysis, the potential power generation capabilities of the original pipeline are governed by a maximum flow rate of 0.17 $m^3/s$. This flow rate corresponds to the generation of 196 kW of power.

### 5.2.4. Pipeline Analysis Summary

After calculating the potential power generation capabilities using the three (3) methods listed above, the following table summarizes the results (See figure 13).

| Method | Maximum Flow Rate ($m^3/s$) | Potential Power (kW) |
|---|---|---|
| Manning | 0.15 | 165 |
| Hazen Williams | 0.17 | 185 |
| Darcy Weisbach | 0.17 | 196 |

**Figure 13 - Pipeline Analysis Summary**

After consultation with local experts in pipeline hydraulics, it was decided that the Hazen Williams' analysis was the most exact method studied above. For this reason the design flow rate for phase one (1) is 0.17 $m^3/s$.

## 5.3. Turbine Selection

There are many various types of turbines that can be used for a hydroelectric generation project and these are summarized in the table below (See figure 14). (Adam Harvey)

| Turbine Runner Type | Head Pressure | | |
|---|---|---|---|
| | High | Medium | Low |
| Impulse | Pelton<br>Turgo<br>Multi-Jet Pelton | Crossflow<br>Turgo<br>Multi-Jet Pelton | Crossflow |
| Reaction | | Francis<br>Pump-As-Turbine | Propeller<br>Kaplan |

**Figure 14 - Groups of Impulse and Reaction Turbines**

From table 14 we can see that the type of turbine is highly dependent on the hydraulic head present. For phase one (1) of this project the hydraulic head is approximately 147m based on a manufacturer turbine quote, which represents a high head pressure situation for the turbine. Therefore, the table indicates that a Pelton, Multi-Jet Pelton or a Turgo turbine would be most appropriate for the high level of head available.

A Pelton turbine is designed to convert the energy created by the shooting jet of water into mechanical energy. After the water has exited the jet it strikes the bucket to transfer its kinetic energy to the runner (See figure 15). After contact there should be little kinetic energy present and the water then falls away from the turbine under the force of gravity into the tailrace (See figure 16).

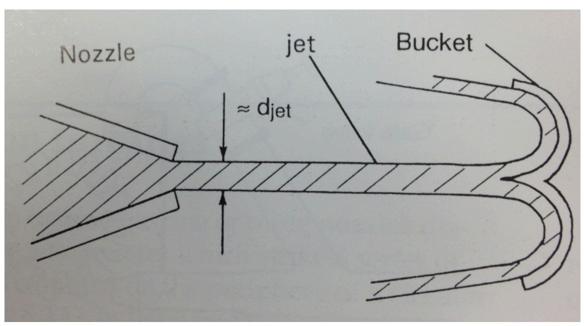



**Figure 15 - Pelton Turbine Details**

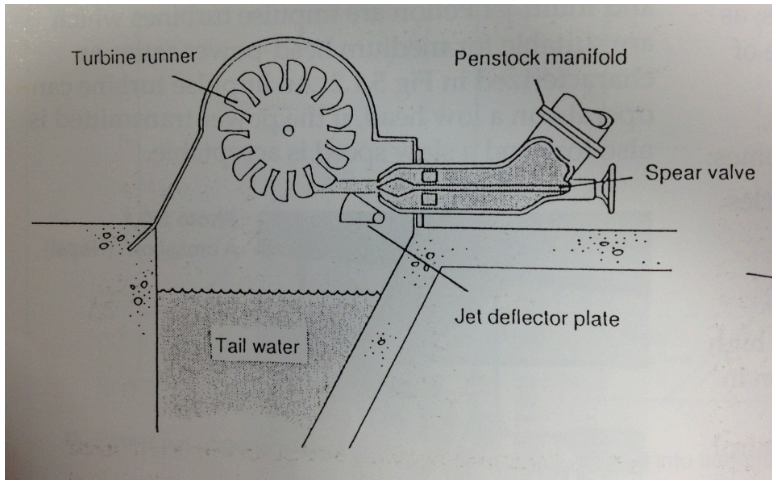



**Figure 16 - Pelton Turbine**

A multi-jet pelton is similar to the pelton turbine except there are multiple jets transferring their energy to the buckets, which results in an increased rotational speed. This higher mechanical rotation will allow for a smaller runner to be used. The number of jets that are used can be altered (ie. Shut off) to accommodate seasonal variations in flow to the turbine. Together all these advantageous qualities of the Multi-Jet Pelton turbine tend to produce a more competitive price and simpler design.

Finally a Turgo turbine is similar to a Pelton turbine in operation but it has two distinct characteristics, which distinguish its design. The first of these properties is the angle of the jet. A Turgo turbine ejects water into the runner at a specific angle, commonly 20° (See figure 17). This combined with the passage of water in one side of the turbine and out the other means that its incoming jets are not interrupted by outgoing flow. Therefore a Turgo turbine can have a smaller runner for the same output of power from a Pelton turbine. However, due to its complex design it cannot be manufactured locally which has an impact on its economic feasibility in some cases.

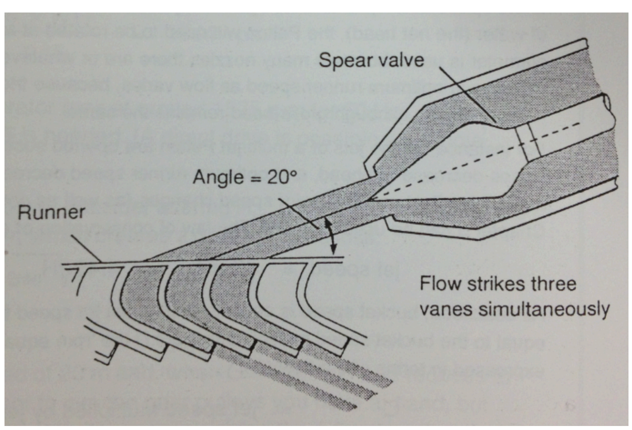



**Figure 17 - Turgo Turbine**

To further quantify the reasoning for choosing a specific turbine type the power output and specific speed need to be calculated using equations (6) and (7).

$$\text{Power Output} = e * 10 * Flow\ Rate * Net\ Head \qquad (6)$$

$$\text{Specific Speed} = \frac{1.2 * Altenator\ Speed * \sqrt{Power\ Output}}{Net\ Head^{1.25}} \qquad (7)$$

The inputs and results of this analysis are presented in figure 18.

| Inputs | |
|---|---|
| Net Head (m) | 147 |
| Flow Rate ($m^3/s$) | 0.12 |
| Effiency of Turbine (e) | 0.8 |
| Alternator Speed (rpm) | 1200 |

| Results | |
|---|---|
| Power Output (kW) | 141.1 |
| Specific Speed | 33.4 |

**Figure 18 – Phase One (1) Turbine Selection Analysis**

Using the power output and specific speed, figure 19 provides a method to choose a specific type of turbine. (Adam Harvey)

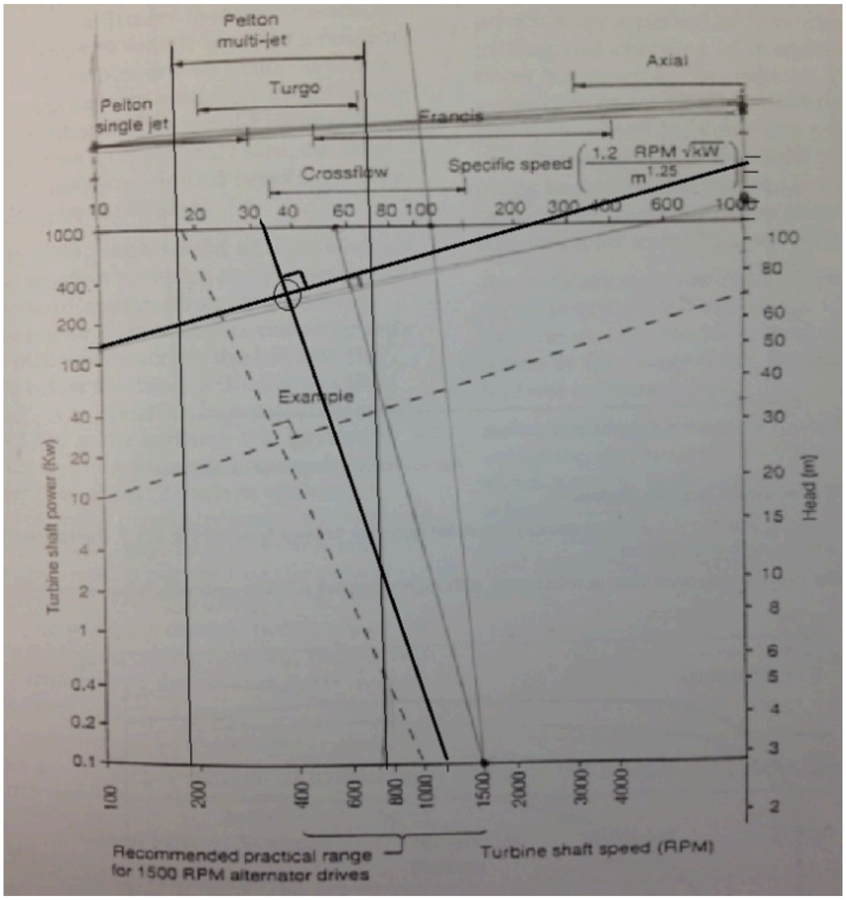



**Figure 19 – Phase Two (2) Turbine Selection**

This graphical solution gives us the option of choosing a Turgo turbine or a Multi-Jet Pelton turbine. A multi-jet turbine was ultimately chosen because it will be the most efficient at the rated power output of 142kW.

## 5.4. Tailrace Design

The designed flow rate of 0.17 $m^3/s$ must be discharged from the turbine. A HDPE pipe from the turbine location in the pump house to a discharge location in a nearby semi natural stream will be utilized to achieve this desired discharge.

The HDPE pipe was designed using open channel flow analysis. The design equation used for open channel flow is presented in equation (8). (Robert J. Houghtalen)

$$Q = \left(\frac{1}{FS}\right) * \left[\left(\frac{1}{n}\right) * A * R^{\frac{2}{3}} * S_0^{\frac{1}{2}}\right] \quad (8)$$

*Where,*
*FS is a factor of safety (3)*
*n is the Manning's friction factor (0.012)*
*A is the cross sectional area of the pipe*

*R is the hydraulic radius of the pipe*
*$S_0$ is the elevation change of the pipeline from intake to discharge location (0.5m)*

For safety considerations this pipeline was designed to never be more than half full. With this assumption and a factor of safety of 3, this pipeline should never contain pressurized flow and therefore never back the water up into the pump house.

Using a HDPE pipe for the tailrace design, this equation yields a pipe diameter of 300 mm (12 in.), to convey 0.175 $m^3/s$ of water away from the turbine. The inputs and results of this analysis are presented in figure 20.

| Inputs | |
|---|---|
| Pipe Type | HDPE |
| Diameter (m) | 0.3 |
| $Z_1$ (m) | 19 |
| $Z_2$ (m) | 18.5 |
| n | 0.012 |

| Results | |
|---|---|
| y (m) | 0.150 |
| Area ($m^2$) | 0.141 |
| R (m) | 0.075 |
| $S_0$ (m) | 0.500 |
| Q ($m^3/s$) | 0.175 |

**Figure 20 - Phase One (1) Tailrace Design**

## 5.5. Surge Analysis

A sudden change of flow rate in a large pipeline (caused by valve closure, pump shutoff, etc.) may affect a large mass of water moving inside the pipe. The force resulting from changing the speed of the water mass could cause a pressure rise in the pipe with a magnitude several times greater than the normal static pressure in the pipe. This phenomenon is commonly known as the *water hammer phenomenon*. The excessive pressure may fracture the pipe walls or cause other damage to the pipeline system. The possible occurrence of water hammer, its magnitude, and the propagation of the pressure wave must be carefully investigated in connection with the pipeline design. (Robert J. Houghtalen)

To calculate the increase in pressure due to a rapid valve closure in the original pipeline at Marble Mountain, we have used commonly accepted equations. The equation used to calculate the increase in pressure due to a rapid valve closure is show in equation (9). (Robert J. Houghtalen)

$$\Delta P = V_0 * \sqrt{(\rho * E_C)} \tag{9}$$

*Where,*
*$\Delta P$ is the increase in pressure ($N/m^2$)*
*$V_0$ is the initial velocity in the pipeline (m/s)*
*$\rho$ is density of water ($kg/m^3$)*
*$E_C$ is the is a composite modulus of elasticity ($N/m^2$)*

The composite modulus of elasticity is based on the modulus of elasticity of water and of the pipe and is calculated using equation (10). (Robert J. Houghtalen)

$$E_C = \frac{1}{\left\{\left(\frac{1}{E_b}\right) + \left[\frac{D * k}{E_p * e}\right]\right\}} \qquad (10)$$

*Where,*
*$E_C$ is the is a composite modulus of elasticity ($N/m^2$)*
*$E_b$ is the modulus of elasticity of water ($N/m^2$)*
*D is the inside diameter of the pipe (m)*
*k is ($1 - 0.25^2$)*
*$E_p$ is the modulus of elasticity of the pipeline ($N/m^2$)*
*e is the pip wall thickness (m)*

With the increase in pressure we then added this pressure to the static pressure in the pipe to calculate the total increase in pressure due to water hammer (See equation (11). (Robert J. Houghtalen)

$$P_{maximum} = \gamma H_0 + \Delta P \qquad (11)$$

*Where,*
*$P_{Maximum}$ is the maximum pressure in the pipeline ($N/m^2$)*
*$\gamma$ is the unit weight of water (9810 $N/m^3$)*
*$H_0$ is the static head (m)*
*$\Delta P$ is the pressure due to water hammer ($N/m^2$)*

The results of the water hammer analysis on the original pipeline based on the pipe type that has been indicated by the client as BlueBrute™ DR14 and DR18 HDPE pipe can be seen in figure 21.

| Inputs | |
|---|---|
| Q ($m^3/s$) = | 0.17 |
| A ($m^2$) = | 0.063793966 |
| $D_{Inside\ Diameter}$ (m) = | 0.285 |
| $e_{Wall\ Thickness}$ (m) = | 0.024 |
| $\rho_{Water}$ ($kg/m^3$) = | 1000 |
| $\gamma_{Water}$ ($N/m^3$) = | 9810 |
| $H_0$ (m) = | 177 |
| k = | 0.9375 |
| $E_b$ ($N/m^2$)= | 2200000000 |
| $E_p$ ($N/m^2$) = | 14000000000 |

| Results | |
|---|---|
| $V_0$ (m/s) = | 2.664828841 |
| $E_C$ ($N/m^2$) = | 800162370.6 |
| $\Delta P$ ($N/m^2$) = | 2383737 |
| $P_{maximum}$ (kPa) = | 4120 |

**Figure 21 - Water Hammer Analysis for Phase One (1)**

Based on the data provided by the manufacturer the maximum burst pressure that the DR18 pipe can withstand is 5206 kPa as seen in figure 22 (Eagle). This results in a factor of safety of 1.36 for the pressure surge in the pipeline. This number is a reasonably factor of safety for a small pipeline that is submerged in the ground. For this reason there is no need for additional water hammer protection on the system. (Robert J. Houghtalen)

| DR | PRESSURE CLASS (psi) | | MINIMUM BURST PRESSURE AT 73°F (psi) |
|---|---|---|---|
| | AWWA C900-97/FM 1612 | AWWA C900-07 | |
| 25 | 100 | 165 | 535 |
| 18 | 150 | 235 | 755 |
| 14 | 200 | 305 | 985 |

**Figure 22 - Minimum Burst Pressures**

***(Source: http://www.jmeagle.com/pdfs/2008%20Brochures/Blue%20Brute_web.pdf)***

### 5.6. Cost Analysis

Phase 1 has a capital cost of $215,770.69 which includes the quote for pricing for the turbine from Dependable Turbines Ltd (See Appendix A for quote) as well as all construction and implementation costs which is depicted in the table below. The costing for the materials comes from the RS Means software and expert advice given by engineers with experience in the costing of hydro projects.

| Material | Quantity | Unit | Cost per unit | Cost |
|---|---|---|---|---|
| Concrete incl. finishing | 6 | $m^3$ | $313.91 | $1,883.45 |
| Reinforcement for tailrace | 0.06 | tons | $2,420 | $145.20 |
| Concrete Formwork for tailrace | 50 | $ft^2$ | $14.00 | $700.00 |
| Concrete Formwork for slab | 35 | $ft^2$ | $20.00 | $700.00 |
| 12" HDPE Culvert | 100 | m | $114.80 | $11,480.00 |
| Excavator for 5 days | 5 | days | $1,200.00 | $6,000.00 |
| Class A Fill | 20 | $m^3$ | $60.17 | $1,203.31 |
| Compaction | 20 | $m^3$ | $3.40 | $68.01 |
| Labourer for compaction - @$20/hr | 24 | hr | $25.00 | $600.00 |
| Grading | | | | $1,400.00 |
| Common Fill | 40 | $m^3$ | $45.78 | $1,831.13 |
| Concrete demolition cut-out | 3.2 | $m^2$ | $150.69 | $482.22 |
| Concrete demolition equipment (saw and grinder) | | | | $1,000.00 |
| Labourer for hand removal - 3@$20/hr | 30 | hr | $20.00 | $600.00 |

| | | | | |
|---|---|---|---|---|
| Concrete demolition disposal | 1 | $m^3$ | $19.62 | $19.62 |
| Turbine | 1 | Unit | $98,000.00 | $98,000.00 |
| Forklift to lift turbine into place | | | | $5,000.00 |
| 2 Technicians to commission the Turbine - wages | 800 | hr | $50.00 | $40,000.00 |
| 2 Technicians to commission the Turbine - living expenses apartment | 5.00 | months | $1,000.00 | $5,000.00 |
| 2 Technicians to commission the Turbine - living expenses consumables | 5.00 | months | $500.00 | $2,500.00 |
| 2 Technicians to commission the Turbine - living expenses flights | 4 | flights | $1,000.00 | $4,000.00 |
| Labour to Install Turbine - 2 weeks wages for an Electrician | 80 | hr | $25.00 | $2,000.00 |
| Labour to Install Turbine - 2 weeks wages for a Pipe Fitter | 80 | hr | $20.00 | $1,600.00 |
| Labour to Install Turbine - 2 weeks wages for a Welder | 80 | hr | $25.00 | $2,000.00 |
| Piping 10" for turbine hookup | 10 | m | $55.77 | $557.74 |
| Miscellaneous Electrical | 1 | Unit | | $27,000.00 |
| | | | TOTAL | $215,770.69 |

**Figure 23 - Cost Analysis for Phase One (1)**

Based on this cost estimate along with a $36,000 training of Marble staff to properly operate and maintain the turbine a cost analysis was conducted. This analysis was conducted on a basis that Marble Mountain Resort would use 2515200 kWh/year without the use of power generation. With power generation by the use of the 142kW generator and the flow rates chosen in the design which account for present snowmaking operations, the generation would amount to 1146600kWh/yr. The following graph shows these usages.

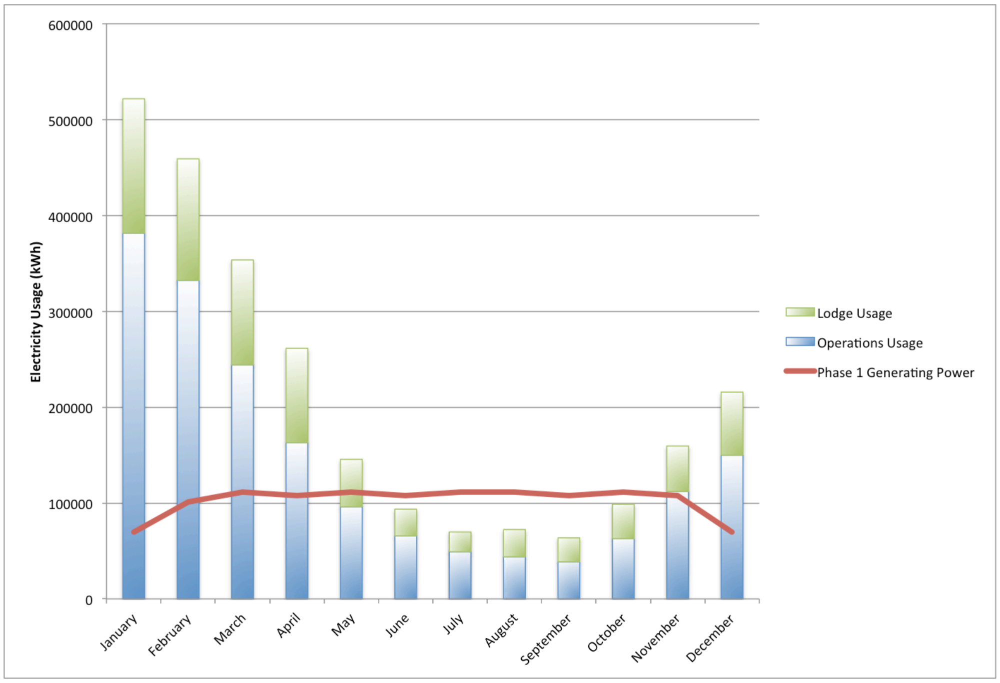



**Figure 24 - Power Generation for Phase (1)**

The cost analysis shown is also highly subjective to the assumptions that have been made. The following is a list of the assumptions made.

- Discount Rate/Nominal Interest Rate – 5.5%
  - 4% interest rate plus the inflation rate of 1.5% as markets suggest (Bruce)
- Inflation Rate – 1.5% based on (Historical Inflation Rates for Canada (2003 to 2013))
- Technician for training - $50/hr based on (Research)
- Labour hourly rate - $25
- Energy cost – based on (Hydro)
  - 9.05¢/kWh for first 100000kWh, 7.93¢/kWh after 100000kWh
- Selling rate of Electricity
  - 8¢/kWh based on advice from Brad Tucker from NL Power
- Training hours necessary
  - 8h per day for 5 days a week for 12 weeks = 480 hours
- O&M
  - 2% of capital costs on a yearly basis (Adam Harvey)
- Training
  - Training Technician = $50/hr x 480hrs
  - Employees to train = $25/hr x 480 hrs
  - Total = $36,000
- Power will be balanced throughout the day and night to ensure that the generated power is maximized for Marbles consumption.

Otherwise this excess power will be used by NL power for free unless it is negotiated by a net power agreement.

With the assumptions explained the following is a summary of the cost analysis of the turbine for a 20 year lifespan. See Appendix B for detailed cost analysis.

| Net Benefits (with PV) | Costs (with PV) | ROI (with PV) | Savings | Simple Payback (years) |
|---|---|---|---|---|
| $1,390,680.57 | -$325,598.63 | 427% | $1,716,279.20 | 1.88 |

**Figure 25 - Phase One (1) Cost Analysis Results**

The cost analysis terminology used warrants an explanation in order to ensure that the analysis is not misunderstood. The list of the terms is as follows:

- Savings
  - Net savings due to power generation
    - Difference between cost of powering Marble facilities on a yearly basis before power generation to the cost to power Marble facilities once power is generated by the turbine (if any)
- Present value
  - The cost in today's dollars
- ROI – Return on Investment
  - The percentage of return that will be achieved on the investment put into the project
  - Calculated as Total Net Benefits/ Total Net Costs
- Simple Payback
  - The amount in years for the project to pay back the capital invested in the project
- Savings
  - The cumulative benefits total at the end of the 15 year lifespan
- Technician

A competent engineer/or person of technical background to train employees in proper operation and maintenance of turbine

# 6. Phase Two (2)

## 6.1. Introduction

Phase two (2) of this project will utilize all available water from Steady Brook while keeping in mind that the river is used by multiple sources. This phase is studied for the maximum available power that could be generated from Steady Brook, to provide guidance on how much money can be made, and how this system is designed.

## 6.2. Site Hydrology

Since the goal of phase two (2) is to maximize the power generated at Marble Mountain a detailed analysis of the Steady Brook watershed must be completed. This is to understand the details of the amount of water that will be available for use to generate hydroelectric power.

### 6.2.1. Steady Brook Watershed

The Steady Brook watershed has been calculated using watershed delineation techniques. The watershed area was found to be 88 $km^2$ (55 $miles^2$) (See Figure 26).

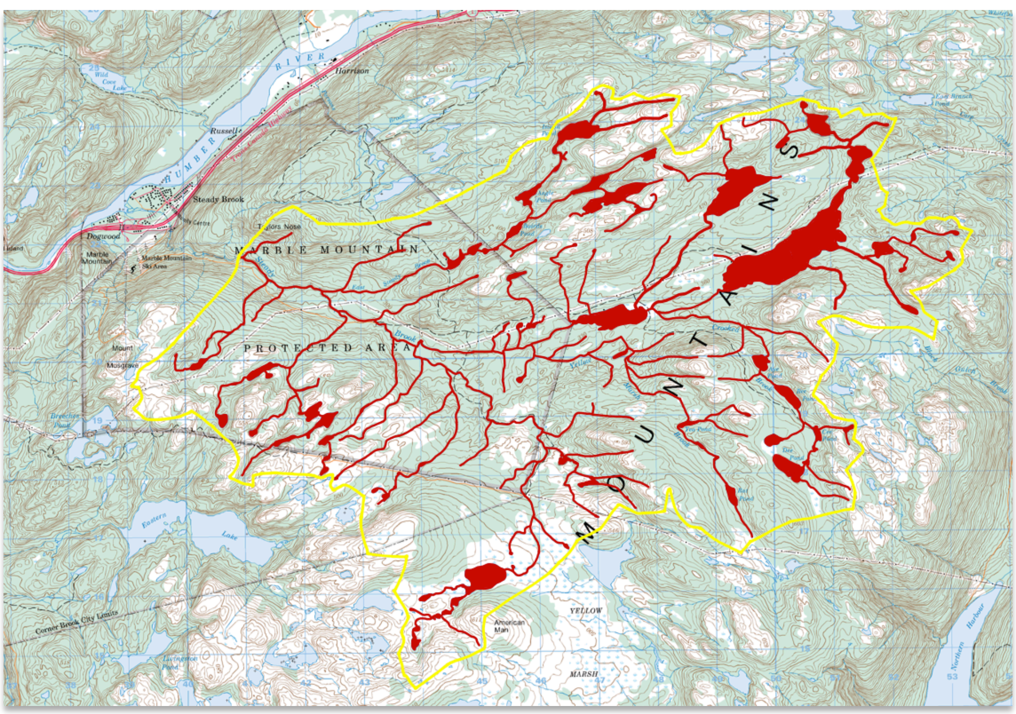



**Figure 26 - Steady Brook Watershed**

Since Steady Brook is not a gauged river, the flow rates generated by this watershed were interpolated using two (2) adjacent watersheds. The adjacent watersheds used were the South Brook watershed located in Pasadena and the

Corner Brook watershed located at the Watson's Brook powerhouse in the city of Corner Brook.

Flow duration curves have been developed using the data from these two (2) watersheds. The data available for the South Brook watershed ranges between the years of 1983 -2011. The average daily flow rates were used to develop the flow duration curve for the watershed (See Figure 27).

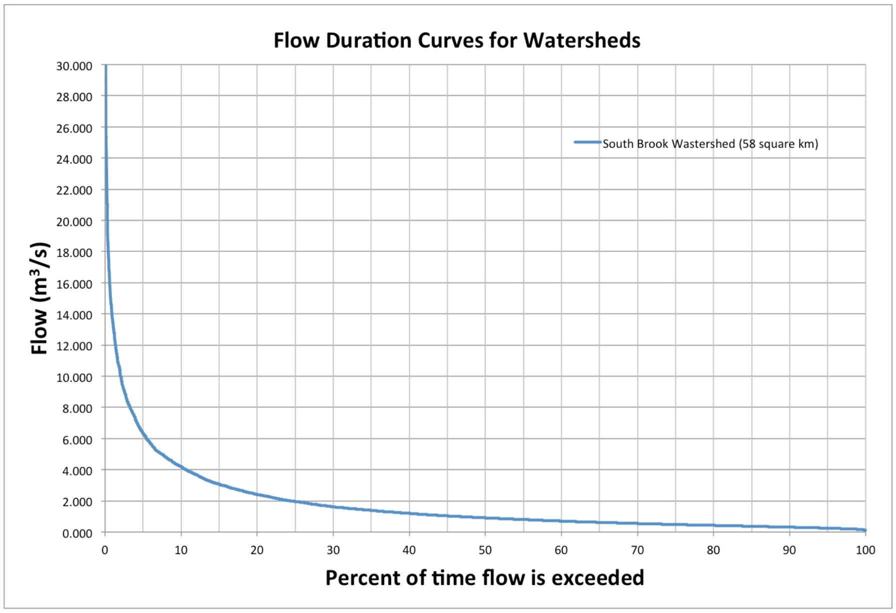



**Figure 27 - Flow Duration Curve for the South Brook Watershed**

The data available for the Corner Brook Stream watershed ranges from 1981 to 2010. The average daily flow rates were used to develop the flow duration curve for the watershed (See Figure 28).

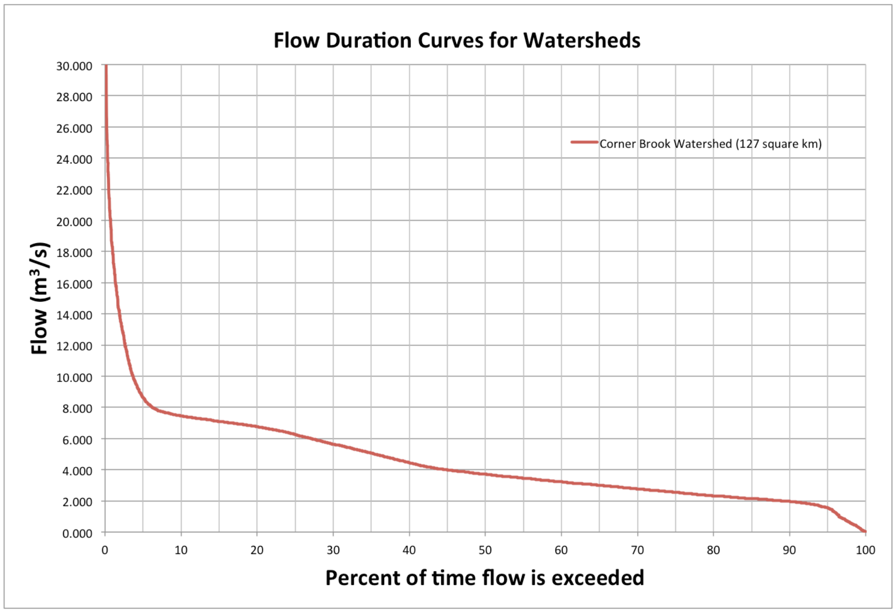



**Figure 28 - Flow Duration Curve for the Corner Brook Stream Watershed**

These two (2) watersheds were used to model the Steady Brook watershed. The watershed for this project was then scaled against each of the two (2) adjacent watersheds. The interpolation based on the South Brook watershed provided an increase in flow rate due to the Steady Brook watershed being slightly larger than the South Brook watershed. The results of this are presented in Figure 29.

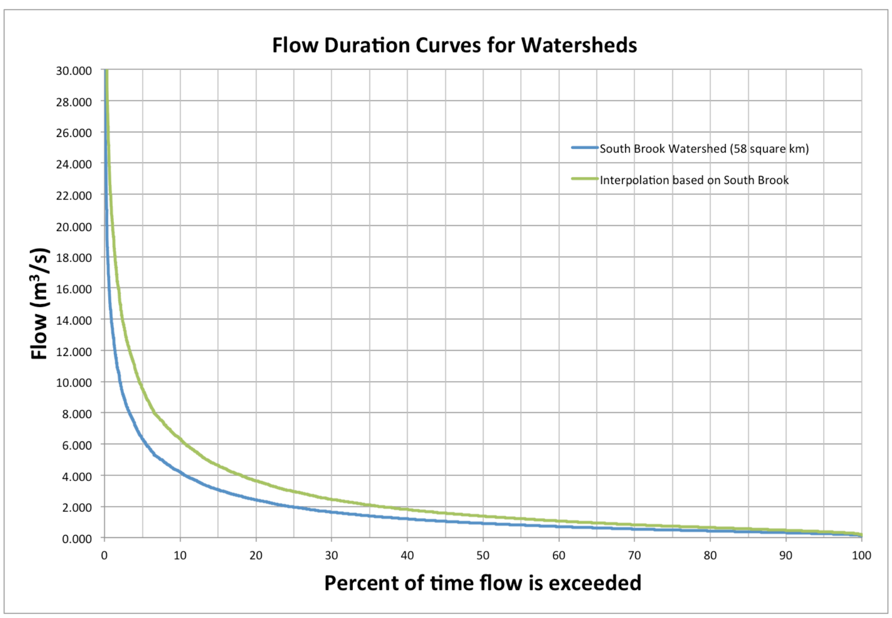



**Figure 29 - Interpolation of the South Brook Watershed**

The interpolation based on the Corner Brook watershed yielded lower flow rates than observed in that watershed. This is due to the Steady Brook watershed being only a portion of the size of the Corner Brook watershed. The results of this are presented in Figure 30.

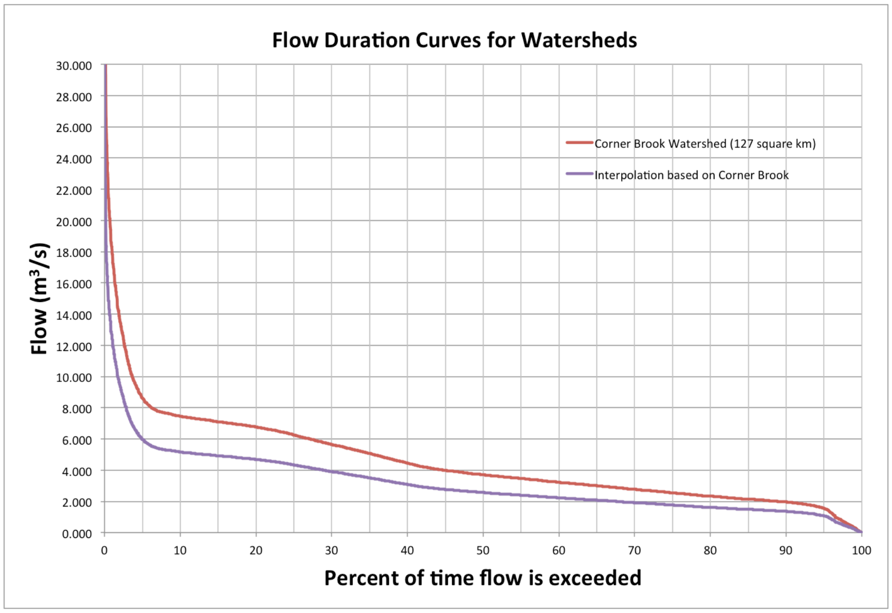



**Figure 30 - Interpolation of the Corner Brook Watershed**

These two (2) interpolations were then plotted along side each other and an average was chosen as the design flow for the development. The two (2) interpolations are presented side by side in figure 31.

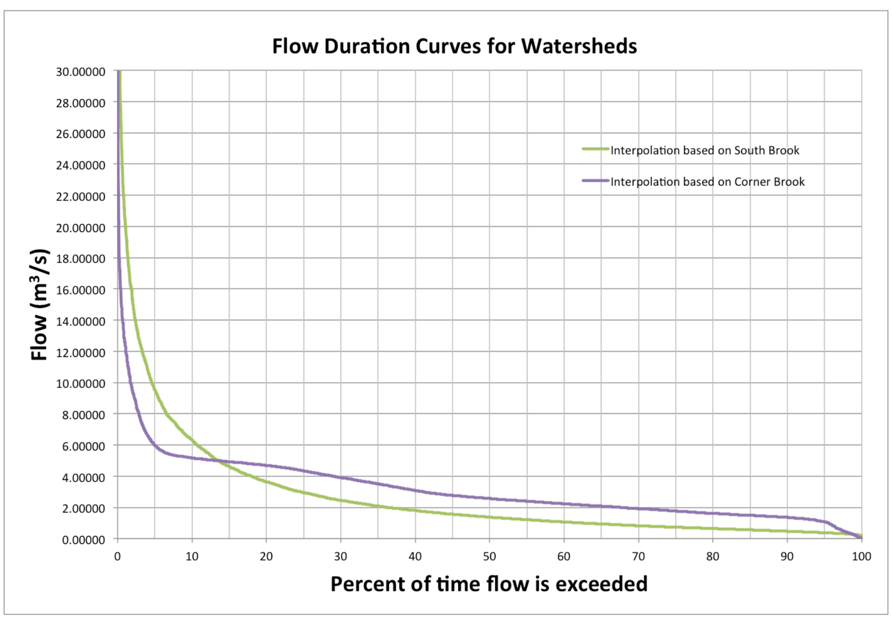



**Figure 31 - Interpolations of the Steady Brook Watershed**

### 6.2.2. Flow Rate Selection

In choosing the design flow rate for phase two (2) the following issues had to be considered.

1. The Town of Steady Brook uses Steady Brook for drinking water
2. Steady Brook Falls can not run dry for aesthetic purposes
3. The water is also used for snowmaking

It has been calculated that the average water usage in Newfoundland and Labrador per capita is 0.561 $m^3$/day (Klassen). The population of Steady Brook is around 300 people, and for this study we will not be planning for future growth of this community. The reason for omitting to account for an increase in population is the fact that the community of Steady Brook is currently exploring the possibility of utilizing a ground water source for their municipal water use. By using there current population the daily water usage is approximately 168 $m^3$/day.

Since water demand changes throughout the day we have varied the water usage across a 24-hour period and presented this usage in figure 32.

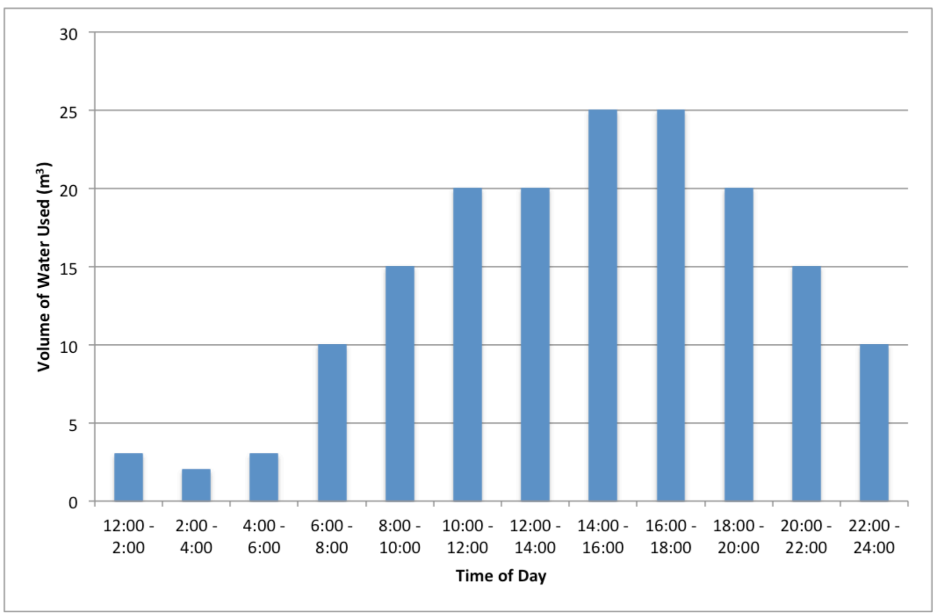



**Figure 32 - The Town of Steady Brook's Daily Water Consumption**

This shows that the peak water demand will occur around suppertime with a usage estimated at 25 $m^3$ in a two (2) hour span. This corresponds to a flow rate in Steady Brook of 0.0035 $m^3$/s.

To calculate the minimum flow rate that is required to flow over Steady Brook Falls, we have chosen to use half of the minimum flow rate in Steady Brook. The minimum flow was taken from and average of the $Q_{95}$ values of the two (2) interpolations of Steady Brook (See figure 28). The $Q_{95}$ for the Steady Brook interpolation based on the South Brook watershed is 0.39 $m^3/s$. The $Q_{95}$ for the Steady Brook interpolation based on the Corner Brook Stream Watershed is 1.15 $m^3/s$. The average of these values is 0.77 $m^3/s$, so our design minimum flow rate for the Steady Brook Falls will be half of this average at a value of 0.385 $m^3/s$.

This results in a required flow rate in Steady Brook in all months of the year where snowmaking is not in progress to be 0.389 $m^3/s$.

The snowmaking facilities at Marble Mountain utilize a maximum flow rate of 0.32 $m^3/s$ while the system is running at full capacity. For this reason we will be subtracting a flow rate of 0.32 $m^3/s$ for half of the days in the months of December and January.

A graph of the water consumption for drinking water for the town of Steady Brook, Steady Brook falls, and snowmaking requirements are shown in figure 33.

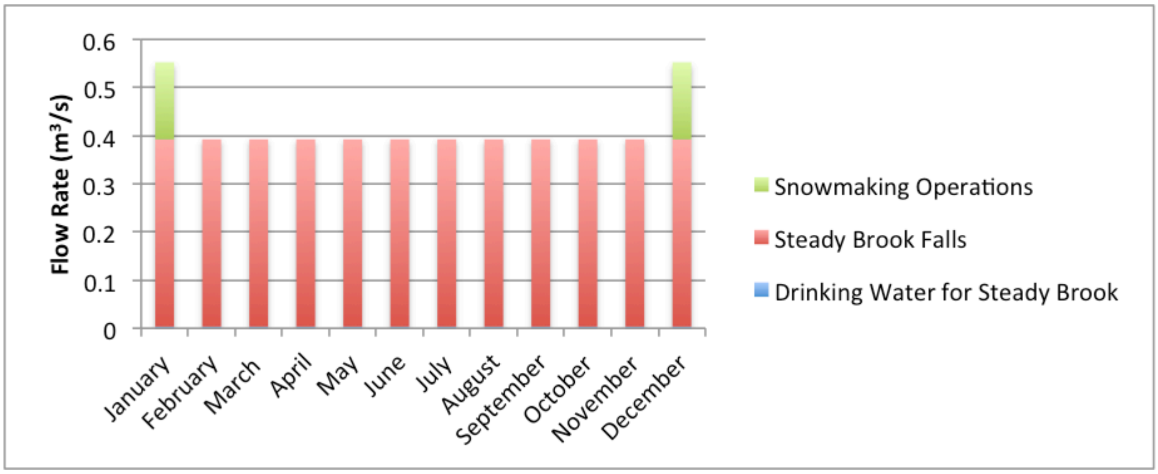



**Figure 33 - Water Consumption for Steady Brook**

As seen in this figure, drinking water is negligible to the process of generating hydroelectric power from Steady Brook. The availability of water though is highly dependent on the amount of water that is required to flow over Steady Brook falls.

For this project we will base our generation capabilities on the assumptions made above, but a reduction in the available water for Steady Brook falls in the future will result in increased power generation.

Due to the choice of running a low flow rate for a longer period of the year or a high flow rate for a reduced period, an analysis of the power generation capabilities had to be completed. The following table presents the given flow rates of Steady Brook along with the reduced flow rates due to the loss of water as described above (See figure 34).

| % of Time Flow Exceeded | Steady Brook Flow Rate ($m^3/s$) | Reduced Flow Rates ($m^3/s$) | |
|---|---|---|---|
| | | Drinking Water + Steady Brook Falls | Drinking Water +Steady Brook Falls + Snowmaking Operations |
| $Q_{80}$ | 1.1307 | 0.7417 | 0.5817 |
| $Q_{75}$ | 1.248 | 0.859 | 0.699 |
| $Q_{70}$ | 1.3734 | 0.9844 | 0.8244 |
| $Q_{65}$ | 1.5001 | 1.1111 | 0.9511 |
| $Q_{60}$ | 1.6493 | 1.2603 | 1.1003 |
| $Q_{55}$ | 1.805 | 1.416 | 1.256 |
| $Q_{50}$ | 1.9713 | 1.5823 | 1.4223 |
| $Q_{45}$ | 2.1507 | 1.7617 | 1.6017 |

**Figure 34 - Flow Rates in Steady Brook**

As it is seen in the table above there are higher flow rates corresponding with lower percentages of time exceedance, which means less run time per year. Therefor there is an optimum flow rate to be chosen based on the percent of time exceedance and the amount of power that can be generated. By using a higher flow rate, more kW can be produced but the turbine can only be run for a limited time. By using a lower flow rate, less kW can be generated but the turbine can be run for a longer time. The following graph shows where the optimum percent of time exceedance based on the amount of power generated at each interval (See figure 35).

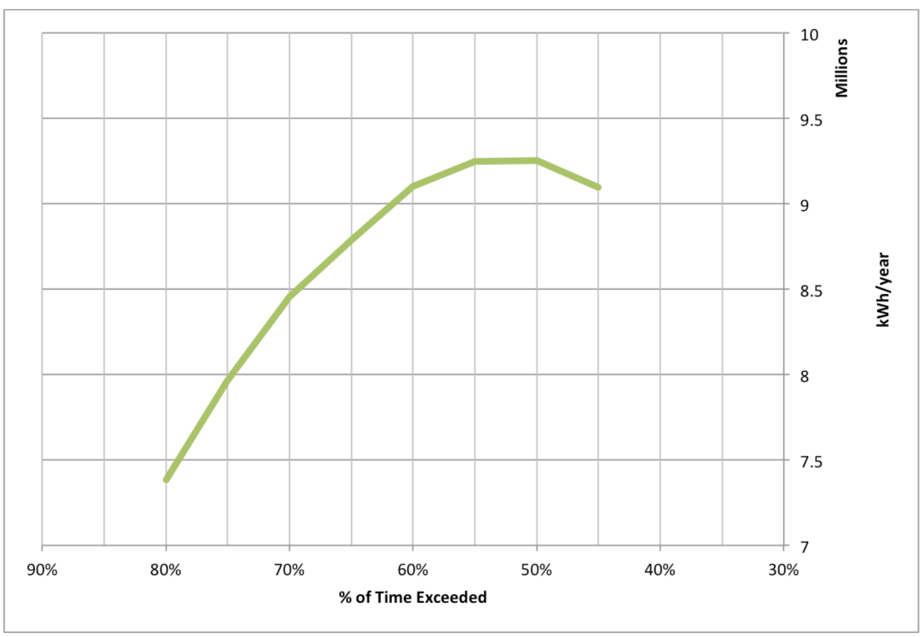



**Figure 35 - Optimum Percent of Time Exceedance**

This graph clarifies that the optimum percent of time exceeded is 55%. From figure 31, the flow rates that correspond to 55% time exceedance are 1.416 $m^3/s$ for the months of the year when snowmaking is not in progress and 1.256 $m^3/s$ for the two (2) months of the year when snowmaking is ongoing.

Therefore the design flow rate going forward for phase two (2) is 1.4 $m^3/s$. and the system will run at a flow rate of 1.2 $m^3/s$ for the months of December and January.

### 6.3. Pipeline Selection

Once a design flow rate of 1.4 $m^3/s$ was chosen the next problem is what size of pipeline will be used to deliver this flow rate to the turbine. As in phase one (1) the pipeline will be analyzed using the Hazen-Williams method. This method and equations are described extensively in section 5.2.2.

By specifying a flow rate the Hazen Williams equation can be manipulated to produce the minimum pipe size that will effectively transfer the design flow rate in the pipeline.

The following spreadsheet shows the inputs for this analysis (See figure 36).

| Inputs | |
|---|---|
| Flow Rate ($m^3/s$) | 1.4 |
| Length (m) | 1450.4 |
| Friction Factor | 150 |
| Total Head (m) | 177 |
| Unit Weight of Water ($N/m^3$) | 9810 |

**Figure 36 - Pipe Size Selection Inputs**

Equation (3) was again utilized to calculate the friction head loss in the new pipeline. For this analysis we know that the flow rate is 1.4 $m^3/s$ and therefor we can vary the diameter of the pipeline to choose an optimum pipe diameter.

There is a certain diameter of the pipeline, when by increasing the size of the pipeline will only marginally improve the head loss due to friction. Since cost of large pipelines escalates exponentially, the point when any further increase in pipe diameter will only result in minor benefits of decreased friction, this pipe diameter will be chosen.

As seen in Figure 37, the friction loss curve flattens out around a diameter of 0.75 m. For this reason the chosen pipeline for phase two (2) will be 0.75 m (30 in.) in diameter.

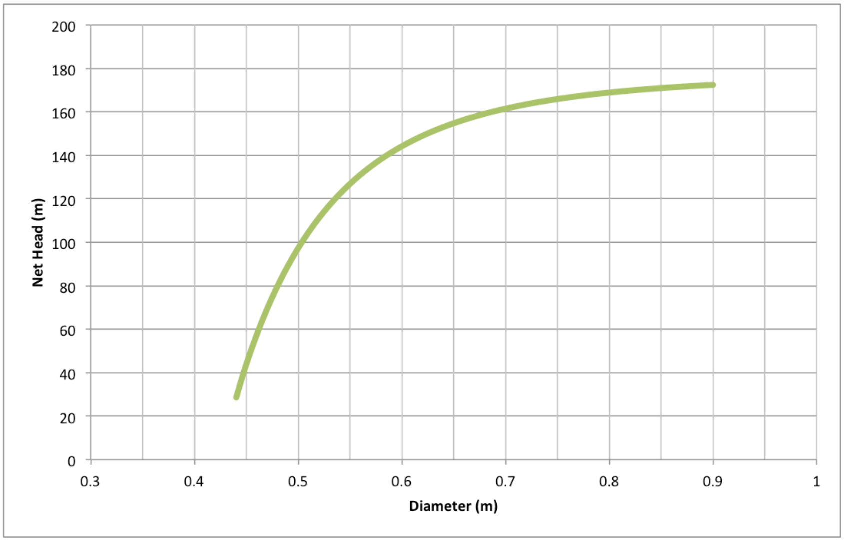



**Figure 37 - Pipe Diameter Selection**

## 6.4. Turbine Selection

The turbine selection process for phase two (2) will follow the same procedure as outline in section 5.3 of phase one (1).

The inputs and results of equations (6) and (7) and are presented in figure 38.

| Inputs | |
|---|---|
| Net Head (m) | 160.5 |
| Flow Rate ($m^3/s$) | 1.4 |
| Effiency of Turbine (e) | 0.8 |
| Alternator Speed (rpm) | 1200 |

| Results | |
|---|---|
| Power Output (kW) | 1797.6 |
| Specific Speed | 106.9 |

**Figure 38 - Phase Two (2) Turbine Selection Analysis**

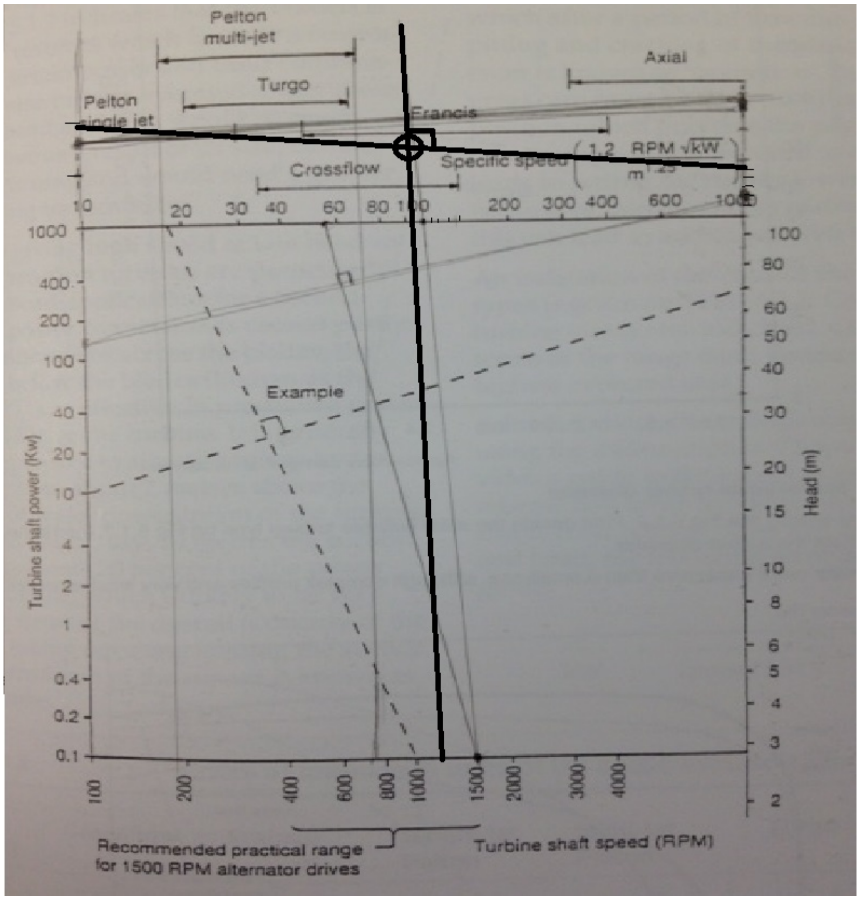



**Figure 39 - Phase Two (2) Turbine Selection**

The graphical solution presented in figure 39 indicates that a Francis turbine would be appropriate however, Francis turbines are not efficient at this high heads and thus the Turgo turbine will be chosen.

## 6.5. Tailrace Design

The tailrace for phase two (2) will follow the same open channel flow design as the tailrace for phase one (1) by using equation (8). The tailrace for phase two (2) will be designed for 1.4 $m^3/s$ but will still consist of a HDPE culvert pipeline.

Using equation (8) with a factor of safety of 3, the culvert diameter calculated is 0.66 m (26 in.). The inputs and results of this analysis are presented in figure 40.

| Inputs | |
|---|---|
| Pipe Type | HDPE |
| Diameter (m) | 0.66 |
| $Z_1$ (m) | 19 |
| $Z_2$ (m) | 18.5 |
| n | 0.012 |

| Results | |
|---|---|
| y (m) | 0.330 |
| Area ($m^2$) | 0.684 |
| R (m) | 0.165 |
| $S_0$ (m) | 0.500 |
| Q ($m^3/s$) | 1.429 |

**Figure 40 - Phase Two (2) Tailrace Design**

## 6.6. Surge Analysis

The water hammer phenomenon was presented in section 5.5 of phase one (1). The same analysis must be completed for this phase to protect the system from increased pressure. This phase will utilize a steel penstock.

First the maximum pressure must be calculated. This will be completed in the exact same manner as section 5.5 utilizing equations (9), (10), and (11). The inputs and results of this analysis are displayed in figure 41.

| Inputs | |
|---|---|
| $Q\ (m^3/s) =$ | 1.4 |
| $A\ (m^2) =$ | 0.430665425 |
| $D_{Inside\ Diameter}$ (m) = | 0.7405 |
| $e_{Wall\ Thickness}$ (m) = | 0.0095 |
| $\rho_{Water}\ (kg/m^3) =$ | 1000 |
| $\gamma_{Water}\ (N/m^3) =$ | 9810 |
| $H_0$ (m) = | 177 |
| k = | 0.9375 |
| $E_b\ (N/m^2)=$ | 2200000000 |
| $E_p\ (N/m^2) =$ | 1.9E+11 |

| Results | |
|---|---|
| $V_0$ (m/s) = | 3.250783364 |
| $E_C\ (N/m^2) =$ | 1191676123 |
| $\Delta P\ (N/m^2) =$ | 3548683 |
| $P_{maximum}$ (kPa) = | 5285 |

**Figure 41 - Water Hammer Analysis for Phase Two (2)**

Since the pressure in this pipeline due to water hammer peaks at 5285 kPa, surge mitigation techniques must be implemented.

To mitigate the increased pressure in this pipeline due to water hammer we have chosen to calculate the required thickness of a steel penstock that is needed to resist the increased pressure. The equation used to calculate the pressure resistance of steel pipeline is presented in equation (12).

$$P_{maximum} = \frac{2 * S_{yield} * t}{D - 2 * t} \quad (12)$$

*Where,*
*$P_{Maximum}$ is the maximum pressure the pipeline can resist ($N/m^2$)*
*$S_{yield}$ is the yield strength of the steel ($N/m^2$)*
*t is the pipeline thickness (m)*
*D is the outside diameter of the pipeline (m)*

The inputs and results to this analysis are presented in figure 42.

| Inputs | |
|---|---|
| Pipe Wall Thickness (mm) | 5.58 |
| Pipe Outside Diameter (m) | 0.75 |
| Yield Strength of Steel ($N/m^2$) | 350000000 |

| Results | |
|---|---|
| Surge Pressure (kPa) | 5285 |
| Calculated Pressure (kPa) | 5287 |

**Figure 42 - Pipeline Thickness Calculation**

As seen above the required thickness of a steel penstock is 5.6 mm. Due to common types of penstocks manufactured we have chose to select the standard thickness of a 0.75 m (30 in.) steel pipe which is 9.5 mm (0.375 in.). This provides us with a factor of safety against surge of 1.7.

### 6.7. Cost Analysis

Phase 2 has a capital cost of $5,315,149.82 which includes the quote for pricing for the turbine from Dependable Turbines Ltd as well as all construction and implementation costs which is depicted in the table below. The costing for the materials comes from the RS Means software and expert advice given by engineers with experience in the costing of hydro projects.

| | | | | |
|---|---|---|---|---|
| Building (16x16m) | 1 | Unit | | $390,000.00 |
| Turbine | 1 | Unit | $1,000,000.00 | $1,000,000.00 |
| 2 Technicians to commission the Turbine - wages | 800 | hr | $50.00 | $40,000.00 |
| 2 Technicians to commission the Turbine - living expenses appartment | 5.00 | months | $1,000.00 | $5,000.00 |
| 2 Technicians to commission the Turbine - living expenses consumables | 5.00 | months | $500.00 | $2,500.00 |
| 2 Technicians to commission the Turbine - living expenses flights | 4 | flights | $1,000.00 | $4,000.00 |
| Labour to Install Turbine - 1 weeks wages for an Electrician | 40 | hr | $25.00 | $1,000.00 |
| Labour to Install Turbine - 1 weeks wages for a Pipe Fitter | 40 | hr | $20.00 | $800.00 |
| Labour to Install Turbine - 1 weeks wages for a Welder | 40 | hr | $25.00 | $1,000.00 |
| Concrete inc finishing | 21 | $m^3$ | $313.91 | $6,592.07 |
| Reinforcement for tailrace | 0.3 | tons | $2,400.00 | $720.00 |
| Concrete Formwork for tailrace | 395 | $ft^2$ | $14.00 | $5,530.00 |
| Concrete Formwork for slab | 55 | $ft^2$ | $20.00 | $1,100.00 |
| 26" HDPE Culvert | 50 | m | $278.80 | $13,940.00 |
| Excavator for 5 days | 5 | days | $1,200.00 | $6,000.00 |
| Class A Fill | 40 | m3 | $60.17 | $2,406.63 |
| Grading | | | | $1,400.00 |
| Compaction | 40 | m3 | $4.78 | $191.36 |
| Labourer for compaction - @$20/hr | 24 | hr | $25.00 | $600.00 |
| Common Fill | 45 | m3 | $45.78 | $2,060.02 |

| | | | | |
|---|---|---|---|---|
| 30" Steel Penstock, 3/8" thick | 1450.4 | m | $1,640.00 | $2,378,656.00 |
| Concrete, Formwork and Reinforcement, Saddles (1m$^3$/Saddle) | 290.08 | m$^3$ | $1,200.00 | $348,096.00 |
| Concrete, Formwork and Reinforcement, for Thrust Blocks (11m$^3$/Block) | 88 | m$^3$ | $1,000.00 | $88,000.00 |
| Distribution Study by NL Power | | | | $15,000.00 |
| Piping 12" for turbine hookup | 10 | m | $55.77 | $557.74 |
| Miscellaneous Mechanical | 1 | Unit | | $500,000.00 |
| Miscellaneous Electrical | 1 | Unit | | $500,000.00 |
| | | | TOTAL | $5,315,149.82 |

**Figure 43 – Cost Analysis for Phase Two (2)**

Based on this cost estimate along with a $36,000 training of Marble staff to properly operate and maintain the turbine a cost analysis was conducted. This analysis was conducted on a basis that Marble Mountain Resort would use 2515200 kWh/year without the use of power generation. With power generation by the 1766 kW generator of phase two and the flow rates chosen in the design accounting for the Steady Brook falls and present snowmaking operations, the generation would amount to 9250000kWh/yr. The following graph shows these usages.

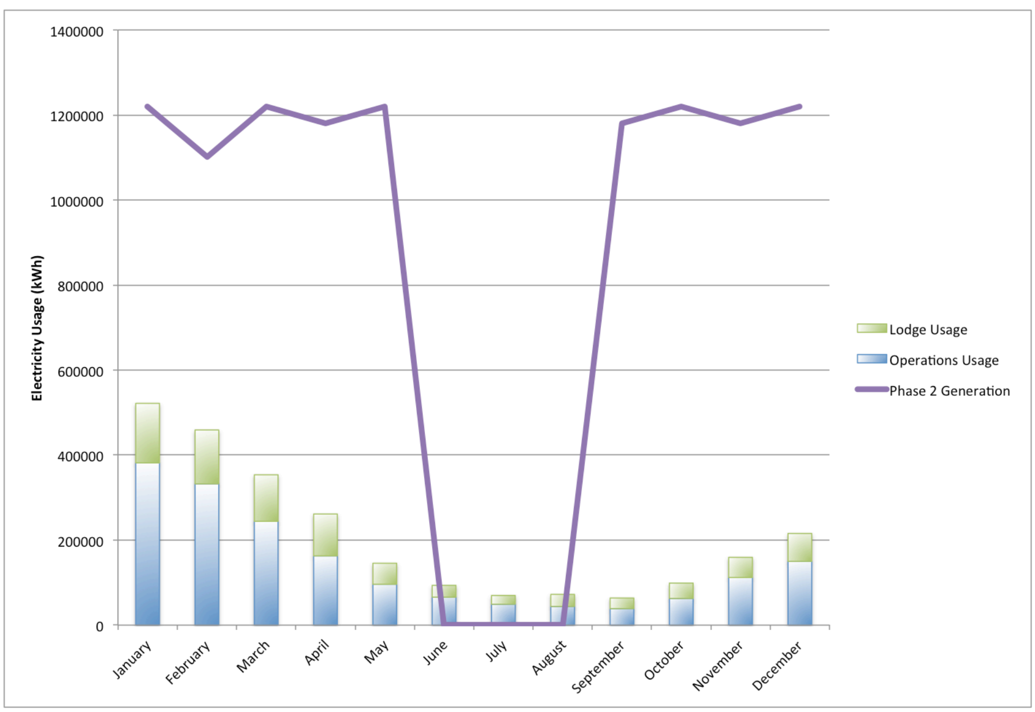



**Figure 44 - Power Generation for Phase Two (2)**

The cost analysis is also highly subjective to the assumptions that have been made. The following is a list of the assumptions made.

- Discount Rate/Nominal Interest Rate – 5.5%
    - 4% interest rate plus the inflation rate of 1.5% as markets suggest (Bruce)
- Inflation Rate – 1.5% based on (Historical Inflation Rates for Canada (2003 to 2013))
- Technician for training - $50/hr based on (Research)
- Labour hourly rate - $25
- Energy cost – based on (Hydro)
    - 9.05¢/kWh for first 100000kWh, 7.93¢/kWh after 100000kWh
- Selling rate of Electricity
    - 8¢/kWh based on advice from Brad Tucker from NL Power
    - Assumes a net power agreement can be negotiated with NL Hydro for this price
- Training hours necessary
    - 8h per day for 5 days a week for 12 weeks = 480 hours
- O&M
    - 2% of capital costs on a yearly basis (Adam Harvey)
- Training
    - Training Technician = $50/hr x 480hrs
    - Employees to train = $25/hr x 480 hrs
    - Total = $36,000

With the assumptions explained the following is a summary of the cost analysis of the turbine for a 20 year lifespan. See Appendix B for detailed cost analysis.

| Net Benefits (with PV) | Costs (with PV) | ROI (with PV) | Savings | Simple Payback (years) |
|---|---|---|---|---|
| $4,303,872.29 | -$6,920,293.40 | 62% | $11,224,165.69 | 7.91 |

**Figure 45 - Phase Two (2) Cost Analysis Results**

The cost analysis terminology used warrants an explanation in order to ensure that the analysis is not misunderstood. The list of the terms is as follows:

- Savings
    - Net savings due to power generation
        - Difference between cost of powering Marble facilities on a yearly basis before power generation to the cost to power Marble facilities once power is generated by the turbine (if any)
- Present value

  - The cost in today's dollars
- ROI – Return on Investment
  - The percentage of return that will be achieved on the investment put into the project
  - Calculated as Total Net Benefits/ Total Net Costs
- Simple Payback
  - The amount in years for the project to pay back the capital invested in the project
- Savings
  - The cumulative benefits total at the end of the 15 year lifespan
- Technician
  - A competent engineer/or person of technical background to train employees in proper operation and maintenance of turbine.

# 7. Future Considerations

## 7.1. Dam Structures for Phase Two (2)

To further regulate the amount of time that phase two (2) can generate electricity, dam structures may be placed in the Steady Brook watershed. The creation of manmade reservoirs will regulate the water flow in Steady Brook so that in seasons of ample rainfall water can be stored for use in times of little rainfall. This will increase the number of operating days in a year that the facility can generate electricity.

This was not considered in the current report as it was deemed to be too costly and would inhibit the politics of the project from moving forward at this time. It will be easier to convince the interested parties to install a run of the river hydroelectric plant without disrupting the local watershed, than to convince them to dam off sections of it.

## 7.2. Utilizing the Phase One (1) Turbine in Phase Two (2)

Although not designed in this report it would be beneficial to install the Pelton turbine that was selected for phase (1) of this report into the new phase two (2) turbine building. This turbine could then be utilized to generate power when there is a low flow rate of water in Steady Brook and also when the Turgo turbine is down for maintenance.

This would increase the annual generating capacity of phase two (2) while utilizing existing equipment already purchased for phase one (1).

# 8. Results

Phase One (1) of this project is very simple to install by utilizing current facilities at Marble Mountain.

There is ample volume of water to run this phase of the project all year long with interruptions only when the pipeline is used for snowmaking operations.

The potential savings over a 20 year life span of this project are around 1.7 million dollars.

Phase Two (2) requires much more capital investment to install but also seems very profitable, over a 20 year lifespan the potential savings are approximately 11.2 million dollars.

Drawings for this project are located in Appendix C of this report.

# 9. Conclusion

After completing the engineering and cost analysis for this project Streamline Engineering Consultants believe that the installation of a two (2) phase hydroelectric facility at Marble Mountain can significantly offset the current cost of electricity.

Depending on the political aspects, there is also a possibility of creating revenue from generated power with phase two (2) of the proposed project.

If both of these phases were installed there is the potential for Marble Mountain to become must more self sufficient for their power needs and provide an opportunity to create revenue.

## 10. Acknowledgements

Streamline Engineering Consultants would like to express a sincere thank you to the following individuals who have provided excessive guidance in the creation of this report.

***Robert Pike***
Chair of the Marble Mountain Board of Directors
Marble Mountain Development Corporation

***Chris Beckett***
General Manager
Marble Mountain Resort

***Tony Abbott***
Outside Operations Manager
Marble Mountain Resort

***Brad Tucker***
Electrical Engineer
Newfoundland Power Inc.

***Dr. Ken Snelgrove***
Faculty of Engineering and Applied Science
Memorial University of Newfoundland

***Dr. Steve Bruneau***
Faculty of Engineering and Applied Science
Memorial University of Newfoundland

Sincerely,

Christopher Clark

Christopher Clark, Chief Project Manager and Communications Lead

Rob Ducey

Rob Ducey, Director of Technical Engineering

Alex Hawco

Alex Hawco, Power Generation Specialist

## Works Cited

Adam Harvey, Andy Brown, Priyantha Hettiarachi, Allen Inversin. Micro-Hydro Design Manual - A Guide to Small-Scale Water Power Schemes. ITDG Publishing, 2002.

Bruce, Christopher. Selecting the Discount Rate. 1 March 2013 <http://www.economica.ca/ew01_3p3.htm>.

Bruneau, Dr. Steve. "Civil Engineering Term 8 Design Project." 2011. 1 March 2013 <http://www.engr.mun.ca/~sbruneau/teaching/8700project/archive/classof2011/8700%20lecture%204.pdf>.

Eagle, JM. "Blue Brute." JM Eagle. 1 March 2013 <http://www.jmeagle.com/pdfs/2008%20Brochures/Blue%20Brute_web.pdf>.

"Historical Inflation Rates for Canada (2003 to 2013)." Rate Inflation. 22 Mar 2013 <http://www.rateinflation.com/inflation-rate/canada-historical-inflation-rate>.

Hydro, NL. "Complete Schedule of Rates, Rules and Regulations – January 1, 2013." Newfoundland and Labrador Hydro. 20 Mar 2013 <http://www.nlh.nl.ca/hydroweb/nlhydroweb.nsf/SubContent/22DB93D546D178A4A32575BE004D9031/$File/CompleteSet_Jan1_2013.pdf>.

Klassen, Neal. "Why Newfoundlanders are the Highest Water Users in Canada." 2011. Water Bucket. 15 March 2013 <http://www.waterbucket.ca/wuc/sites/wbcwuc/documents/media/24.pdf>.

Research, MQO. "Member Salary Survey." PEGNL. 21 March 2013 <http://www.pegnl.ca/documents/Engineers%20Salary%20Survey%20-%20June%202012%20-%20Final%20Report.pdf>.

Robert J. Houghtalen, A. Osman Akan, Ned H.C. Hwang. Fundamentals of Hydraulic Engineering Systems. 4th Edition. Prentice Hall, 2010.

Schedule of Wage Rates: Newfoundland and Labrador - Central, West and Labrador Zone. 18 March 2013 <http://www.hrsdc.gc.ca/eng/labour/employment_standards/contracts/schedule/Newfoundland_and_Labrador/labrador_zone/schedule.shtml>.

# Appendix A

**DEPENDABLE TURBINES Ltd.**

17930 Roan Place Surrey, BC Canada V3S 5K1
Phone: 604-576-3175 Fax: 604-576-3183
Website: www.dtlhydro.com
E-mail: sales@dtlhydro.com

**BUDGET PROPOSAL** Date: March 19, 2013

*TO: Streamline Engineering Consultants*

*FROM: Robert Prior*

*REF: your request – Marble Mtn. Ski Resort Hydro Project Phase I*

Thank you, Mr. Clark for this opportunity.
DTL is pleased to submit the following quote for your consideration.

| ITEM | DESCRIPTION | UNIT | QTY |
|---|---|---|---|
| INLET VALVE | 8 inch Butterfly Valve, 52 Bar, Manual Operator, Dismantling Joint | each | one |
| HYDRO TURBINE | Horizontal Two Nozzle Pelton<br>Rated output 150 Kw at 1200 RPM.<br>Rated Head- 147 m, Flow – 120 l/s<br>Bronze Runner, Manual Spear Operators.<br>Weigh Lever deflector | each | one |
| GENERATOR | 142 kW Horizontal Induction<br>Three Phase, 1200 RPM, 480 Volt | each | one |
| TURBINE CONTROLLER | PLC Electronic Governor | each | lot |
| ELECTRICAL PACKAGE | Indoor 400 amp Switchgear<br>Turbine/Generator Protection and Control | each | lot |
| INSTALLATION SUPERVISION AND COMMISSIONING | 0 days on site | | |
| SHIPPING | Newfoundland site | | |

Payment Terms: Collectable on milestones

**BUDGET PRICE: $ 98,000**

Prices in Can. Dollars
Excluding Taxes.

Delivery: 5-6 months, ex works

**Project Data:**
Gross head – 177 meters
Penstock length – 2642 meters
Penstock diameter – 12 inch(808 m), 10 inches (1832m)
Design flow – 120 l/s
Expected net head – 147 meters

Adder for automatic operation including head probe, hydraulic spear and deflector operation and hydraulic pumping unit. - $ 12,000

**Proposal validity:** 60 days from this quotation date.
**Taxes:** Price(s) specified herein do not include any taxes.

**DEPENDABLE TURBINES Ltd.**

17930 Roan Place Surrey, BC Canada
V3S 5K1
Phone: 604-576-3175 Fax: 604-576-3183
Website: www.dtlhydro.com
E-mail: sales@dtlhydro.com

**Conditions:** Subject to Dependable Turbines Ltd. Terms & Conditions.

Trusting the above quote and attached documents are to your entire satisfaction. If you require any additional information or clarification, please do not hesitate to contact us. We look forward to discussing this opportunity further with you at your earliest convenience.

**DEPENDABLE TURBINES Ltd.**

17930 Roan Place Surrey, BC Canada
V3S 5K1
Phone: 604-576-3175 Fax:
604-576-3183
Website: www.dtlhydro.com
E-mail: sales@dtlhydro.com

**BUDGET PROPOSAL** **Date: March 19, 2013**

*TO: Streamline Engineering Consultants*

*FROM: Robert Prior*

*REF: your request – Marble Mtn. Ski Resort Hydro Project Phase II*

Thank you, Mr. Clark for this opportunity.
DTL is pleased to submit the following quote for your consideration.

| ITEM | DESCRIPTION | UNIT | QTY |
|---|---|---|---|
| INLET VALVE | 30 inch Butterfly Valve, 20 Bar, Manual Gear Operator, Dismantling Joint | each | one |
| HYDRO TURBINE | Horizontal Two Nozzle Turgo<br>Rated output 1840 Kw at 900 RPM.<br>Rated Head- 160.5 m, Flow – 1400 l/s<br>S/S Runner, Hydraulic Spear Operators.<br>Fail-Safe Deflector | each | one |
| GENERATOR | 1766 kW Horizontal Synchronous<br>Three Phase, 1200 RPM, 4160 Volt | each | one |
| TURBINE CONTROLLER | PLC Electronic Governor<br>Hydraulic Pumping Unit | each | lot |
| ELECTRICAL PACKAGE | Indoor 5 Kv Switchgear<br>Turbine/Generator Protection and Control | each | lot |
| INSTALLATION SUPERVISION AND COMMISSIONING | 0 days on site | | |
| SHIPPING | Newfoundland site | | |

Payment Terms: Collectable on milestones

**BUDGET PRICE: $ 1,000,000**

Prices in Can. Dollars
Excluding Taxes.
Delivery: 11 to 13 months, ex works

**Project Data:**
Gross head – 177 meters
Penstock length – 1450 meters
Penstock diameter – 30 inch
Design flow – 1400 l/s
Expected net head – 160.5 meters

**Proposal validity:** 60 days from this quotation date.
**Taxes:** Price(s) specified herein do not include any taxes.
**Conditions:** Subject to Dependable Turbines Ltd. Terms & Conditions.

**DEPENDABLE TURBINES Ltd.**

17930 Roan Place Surrey, BC Canada
V3S 5K1
Phone: 604-576-3175 Fax: 604-576-3183
Website: www.dtlhydro.com
E-mail: sales@dtlhydro.com

Trusting the above quote and attached documents are to your entire satisfaction. If you require any additional information or clarification, please do not hesitate to contact us. We look forward to discussing this opportunity further with you at your earliest convenience.

# Appendix B

| | | | |
|---|---|---|---|
| Discount Rate | 5.5% | | |
| Inflation Rate | 1.5% | | |
| Technician to conduct Training (Engineer Wages) - per hr | $50.00 | | |
| Labour Hourly Rate | $25.00 | | |
| Cost of O&M as a percentage of the capital cost annually | 2% | | |
| Energy Cost (per kWh) for first 100000 kWh | $0.0905 | $0.0793 | Energy Cost (per kWh) over 100000 kWh Usage |
| Selling Electricity Rate (per kWh) | $0.08 | | |
| Hours of Training | 480.00 | 8h per day for 5 days a week for 12 weeks | |
| Capital Cost for Phase | $215,770.69 | <<<Doesn't include training costs (which is a capital cost!) | |

| | | |
|---|---|---|
| Marble Power usage kWh/year | 2515200 | |
| Phase 1 Generated Power kWh/year | 1146600 | 130.890411 kWh per h |
| Marble Operations kWh/year | 1740000 | |
| Marble Lodge kWh/year | 775200 | |

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** | **2021** | **2022** | **2023** | **2024** |
| Capital Cost of Phase | -$215,770.69 | | | | | | | | | | |
| Electricity Cost at Marble without generation | -$226,757.06 | -$230,158.42 | -$233,610.80 | -$237,114.96 | -$240,671.68 | -$244,281.76 | -$247,945.98 | -$251,665.17 | -$255,440.15 | -$259,271.75 | -$263,160.83 |
| Electricity Cost at Marble with generation | -$109,698.72 | -$111,344.20 | -$113,014.37 | -$114,709.58 | -$116,430.23 | -$118,176.68 | -$119,949.33 | -$121,748.57 | -$123,574.80 | -$125,428.42 | -$127,309.85 |
| Operations and Maintenance Cost | -$5,035.41 | -$5,110.95 | -$5,187.61 | -$5,265.42 | -$5,344.40 | -$5,424.57 | -$5,505.94 | -$5,588.53 | -$5,672.36 | -$5,757.44 | -$5,843.80 |
| Training Cost | -$36,000.00 | | | | | | | | | | |
| Net Savings due to power generation | $117,058.34 | $118,814.21 | $120,596.43 | $122,405.37 | $124,241.46 | $126,105.08 | $127,996.65 | $129,916.60 | $131,865.35 | $133,843.33 | $135,850.98 |
| Benefits (in PV) | 117,058.34 | 112,620.11 | 108,350.15 | 104,242.09 | 100,289.78 | 96,487.33 | 92,829.04 | 89,309.45 | 85,923.31 | 82,665.56 | 79,531.32 |
| Benefits Cumulative Total | 117,058.34 | 229,678.45 | 338,028.60 | 442,270.69 | 542,560.47 | 639,047.80 | 731,876.84 | 821,186.29 | 907,109.61 | 989,775.17 | 1,069,306.49 |
| Costs | -256,806.10 | -5,110.95 | -5,187.61 | -5,265.42 | -5,344.40 | -5,424.57 | -5,505.94 | -5,588.53 | -5,672.36 | -5,757.44 | -5,843.80 |
| Costs (in PV) | -256,806.10 | -4,844.50 | -4,660.82 | -4,484.11 | -4,314.09 | -4,150.53 | -3,993.16 | -3,841.76 | -3,696.10 | -3,555.96 | -3,421.14 |
| Sum | -139,747.76 | 113,703.27 | 115,408.82 | 117,139.95 | 118,897.05 | 120,680.51 | 122,490.71 | 124,328.07 | 126,193.00 | 128,085.89 | 130,007.18 |
| Present Value | -139,747.76 | 107,775.61 | 103,689.33 | 99,757.98 | 95,975.69 | 92,336.80 | 88,835.88 | 85,467.69 | 82,227.21 | 79,109.59 | 76,110.18 |
| Net Present Value | 1,390,680.57 | | | | | | | | | | |

| | Capital Cost | Net Benefits (with PV) | Net Benefits (without PV) | Costs (with PV) | Costs (without PV) | ROI (with PV) | ROI (without PV) | Savings | Simple Payback |
|---|---|---|---|---|---|---|---|---|---|
| TOTAL | -$215,770.69 | $1,390,680.57 | $2,489,488.80 | -$325,598.63 | -$374,989.89 | 427.11% | 663.88% | $1,716,279.20 | 1.88 |
| | | | | | | | | | 1.00 |

| | | | |
|---|---|---|---|
| **Discount Rate** | **5.5%** | | |
| **Inflation Rate** | **1.5%** | | |
| **Technician to conduct Training (Engineer Wages) - per hr** | **$50.00** | | |
| **Labour Hourly Rate** | **$25.00** | | |
| **Cost of O&M as a percentage of the capital cost annually** | **2%** | | |
| **Energy Cost (per kWh) for first 100000 kWh** | **$0.0905** | **$0.0793** | **Energy Cost (per kWh) over 100000 kWh Usage** |
| **Selling Electricity Rate (per kWh)** | **$0.08** | | |
| **Hours of Training** | **480.00** | 8h per day for 5 days a week for 12 weeks | |
| **Capital Cost for Phase** | **$215,770.69** | <<<Doesn't include training costs (which is a capital cost!) | |

| | | |
|---|---|---|
| Marble Power usage kWh/year | 2515200 | |
| Phase 1 Generated Power kWh/year | 1146600 | 130.890411 kWh per h |
| Marble Operations kWh/year | 1740000 | |
| Marble Lodge kWh/year | 775200 | |

| | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | **2025** | **2026** | **2027** | **2028** | **2029** | **2030** | **2031** | **2032** | **2033** | **2034** |
| Capital Cost of Phase | | | | | | | | | | |
| Electricity Cost at Marble without generation | -$267,108.24 | -$271,114.87 | -$275,181.59 | -$279,309.31 | -$283,498.95 | -$287,751.44 | -$292,067.71 | -$296,448.72 | -$300,895.45 | -$305,408.89 |
| Electricity Cost at Marble with generation | -$129,219.50 | -$131,157.79 | -$133,125.15 | -$135,122.03 | -$137,148.86 | -$139,206.10 | -$141,294.19 | -$143,413.60 | -$145,564.80 | -$147,748.28 |
| Operations and Maintenance Cost | -$5,931.46 | -$6,020.43 | -$6,110.74 | -$6,202.40 | -$6,295.44 | -$6,389.87 | -$6,485.72 | -$6,583.00 | -$6,681.75 | -$6,781.97 |
| Training Cost | | | | | | | | | | |
| Net Savings due to power generation | $137,888.75 | $139,957.08 | $142,056.43 | $144,187.28 | $146,350.09 | $148,545.34 | $150,773.52 | $153,035.12 | $155,330.65 | $157,660.61 |
| Benefits (in PV) | 76,515.91 | 73,614.84 | 70,823.75 | 68,138.49 | 65,555.04 | 63,069.54 | 60,678.28 | 58,377.68 | 56,164.31 | 54,034.86 |
| Benefits Cumulative Total | 1,145,822.40 | 1,219,437.24 | 1,290,260.99 | 1,358,399.48 | 1,423,954.52 | 1,487,024.07 | 1,547,702.35 | 1,606,080.03 | 1,662,244.34 | 1,716,279.20 |
| Costs | -5,931.46 | -6,020.43 | -6,110.74 | -6,202.40 | -6,295.44 | -6,389.87 | -6,485.72 | -6,583.00 | -6,681.75 | -6,781.97 |
| Costs (in PV) | -3,291.43 | -3,166.64 | -3,046.57 | -2,931.06 | -2,819.93 | -2,713.02 | -2,610.15 | -2,511.19 | -2,415.98 | -2,324.38 |
| Sum | 131,957.29 | 133,936.65 | 135,945.70 | 137,984.88 | 140,054.65 | 142,155.47 | 144,287.81 | 146,452.12 | 148,648.91 | 150,878.64 |
| Present Value | 73,224.48 | 70,448.20 | 67,777.18 | 65,207.43 | 62,735.11 | 60,356.53 | 58,068.13 | 55,866.49 | 53,748.33 | 51,710.48 |
| Net Present Value | 619,142.35 | | | | | | | | | |

| TOTAL | Capital Cost | Net Benefits (with PV) | Net Benefits (without PV) | Costs (with PV) | Costs (without PV) | ROI (with PV) | ROI (without PV) | Savings | Simple Payback |
|---|---|---|---|---|---|---|---|---|---|
| | -$215,770.69 | $1,390,680.57 | $2,489,488.80 | -$325,598.63 | -$374,989.89 | 427.11% | 663.88% | $1,716,279.20 | 1.88 |
| | | | | | | | | | 1.00 |

| | | | |
|---|---|---|---|
| Discount rate | 5.5% | | |
| Inflation Rate | 1.5% | | |
| Technician to conduct Training (Engineer Wages) - per hr | $50.00 | | |
| Labour Hourly Rate | $25.00 | | |
| Cost of O&M as a percentage of the capital cost annually | 2% | | |
| Energy Cost (per kWh) for first 100000 kWh >>> | $0.0905 | $0.0793 | <<< Energy Cost (per kWh) over 100000 kWh Usage |
| Selling Electricity Rate (per kWh) | $0.08 | | |
| Hours of Training | 480.00 | 8h per day for 5 days a week for 12 weeks | |
| Capital Cost for Phase | $5,315,149.82 | <<<Doesn't include training costs (which is a capital cost!) | |

| | | |
|---|---|---|
| Marble Power usage kWh/year | 2515200 | |
| Phase 2 Generated Power kWh/year | 9250000 | 1055.936073 kWh per h |
| Marble Operations kWh/year | 1740000 | |
| Marble Lodge kWh/year | 775200 | |

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** | **2021** | **2022** | **2023** | **2024** |
| Capital Cost of Phase | -$5,315,149.82 | | | | | | | | | | |
| Electricity Cost at Marble without generation | -$226,757.06 | -$230,158.42 | -$233,610.80 | -$237,114.96 | -$240,671.68 | -$244,281.76 | -$247,945.98 | -$251,665.17 | -$255,440.15 | -$259,271.75 | -$263,160.83 |
| Electricity Surplus at Marble with generation | $538,784.00 | $546,865.76 | $555,068.75 | $563,394.78 | $571,845.70 | $580,423.38 | $589,129.74 | $597,966.68 | $606,936.18 | $616,040.22 | $625,280.83 |
| Operations and Maintenance Cost | -$107,023.00 | -$108,628.34 | -$110,257.77 | -$111,911.63 | -$113,590.31 | -$115,294.16 | -$117,023.57 | -$118,778.93 | -$120,560.61 | -$122,369.02 | -$124,204.56 |
| Training Cost | -$36,000.00 | | | | | | | | | | |
| Net Savings due to power generation | $765,541.06 | $777,024.18 | $788,679.54 | $800,509.74 | $812,517.38 | $824,705.14 | $837,075.72 | $849,631.86 | $862,376.33 | $875,311.98 | $888,441.66 |
| Benefits (in PV) | $765,541.06 | $736,515.81 | $708,591.04 | $681,725.03 | $655,877.63 | $631,010.24 | $607,085.68 | $584,068.21 | $561,923.44 | $540,618.29 | $520,120.91 |
| Benefits Cumulative Total | $765,541.06 | $1,502,056.87 | $2,210,647.91 | $2,892,372.94 | $3,548,250.58 | $4,179,260.81 | $4,786,346.49 | $5,370,414.70 | $5,932,338.15 | $6,472,956.44 | $6,993,077.35 |
| Costs | -$5,458,172.82 | -$108,628.34 | -$110,257.77 | -$111,911.63 | -$113,590.31 | -$115,294.16 | -$117,023.57 | -$118,778.93 | -$120,560.61 | -$122,369.02 | -$124,204.56 |
| Costs (in PV) | -$5,458,172.82 | -$102,965.25 | -$99,061.36 | -$95,305.48 | -$91,692.00 | -$88,215.52 | -$84,870.86 | -$81,653.01 | -$78,557.16 | -$75,578.69 | -$72,713.15 |
| Sum | -$4,692,631.75 | $668,395.84 | $678,421.78 | $688,598.10 | $698,927.07 | $709,410.98 | $720,052.15 | $730,852.93 | $741,815.72 | $752,942.96 | $764,237.10 |
| Present Value | -$4,692,631.75 | $633,550.56 | $609,529.68 | $586,419.55 | $564,185.64 | $542,794.71 | $522,214.82 | $502,415.20 | $483,366.29 | $465,039.60 | $447,407.77 |
| Net Present Value | $4,303,872.29 | | | | | | | | | | |

| | Capital Cost | Net Benefits (with PV) | Net Benefits (without PV) | Costs (with PV) | Costs (without PV) | ROI (with PV) | ROI (without PV) | Savings | Simple Payback |
|---|---|---|---|---|---|---|---|---|---|
| TOTAL | -$5,315,149.82 | $4,303,872.29 | $10,763,131.11 | -$6,920,293.40 | -$7,970,058.42 | 62% | 135% | $11,224,165.69 | 7.91 |
| | | | | | | | | | 7.00 |

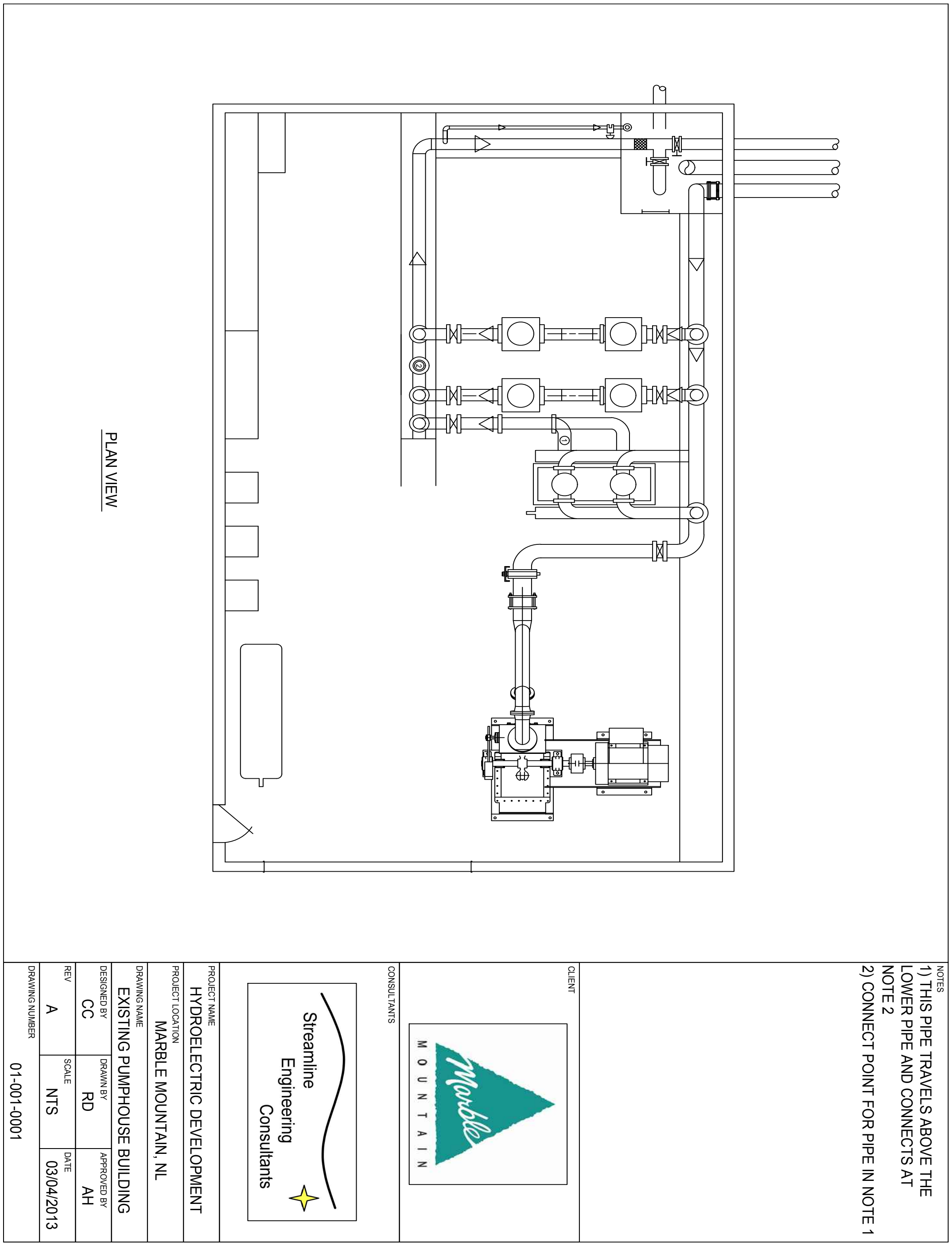
| | | | |
|---|---|---|---|
| Discount rate | 5.5% | | |
| Inflation Rate | 1.5% | | |
| Technician to conduct Training (Engineer Wages) - per hr | $50.00 | | |
| Labour Hourly Rate | $25.00 | | |
| Cost of O&M as a percentage of the capital cost annually | 2% | | |
| Energy Cost (per kWh) for first 100000 kWh >>> | $0.0905 | $0.0793 | <<< Energy Cost (per kWh) over 100000 kWh Usage |
| Selling Electricity Rate (per kWh) | $0.08 | | |
| Hours of Training | 480.00 | 8h per day for 5 days a week for 12 weeks | |
| Capital Cost for Phase | $5,315,149.82 | <<<Doesn't include training costs (which is a capital cost!) | |

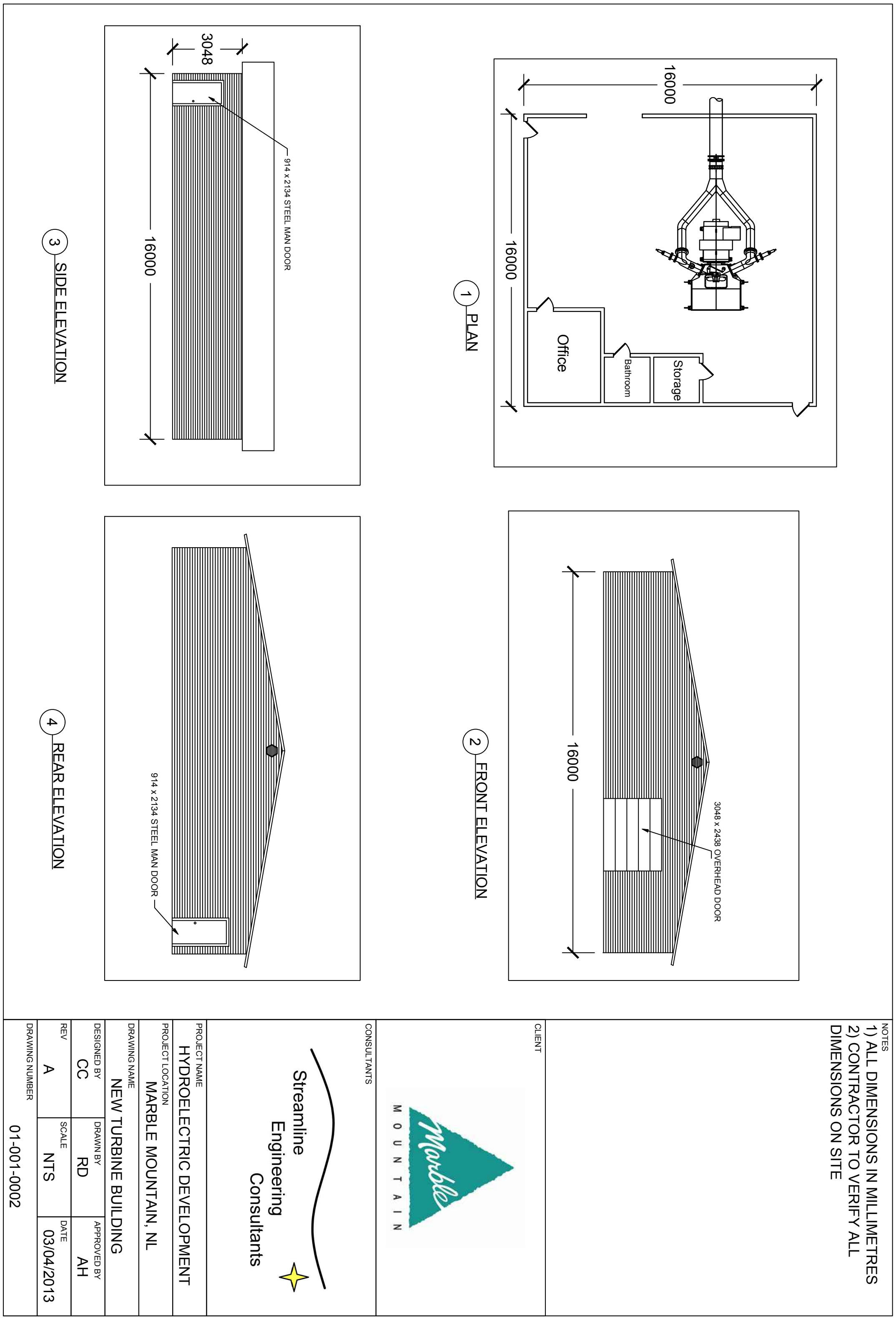
| | | |
|---|---|---|
| Marble Power usage kWh/year | 2515200 | |
| Phase 2 Generated Power kWh/year | 9250000 | 1055.936073 kWh per h |
| Marble Operations kWh/year | 1740000 | |
| Marble Lodge kWh/year | 775200 | |

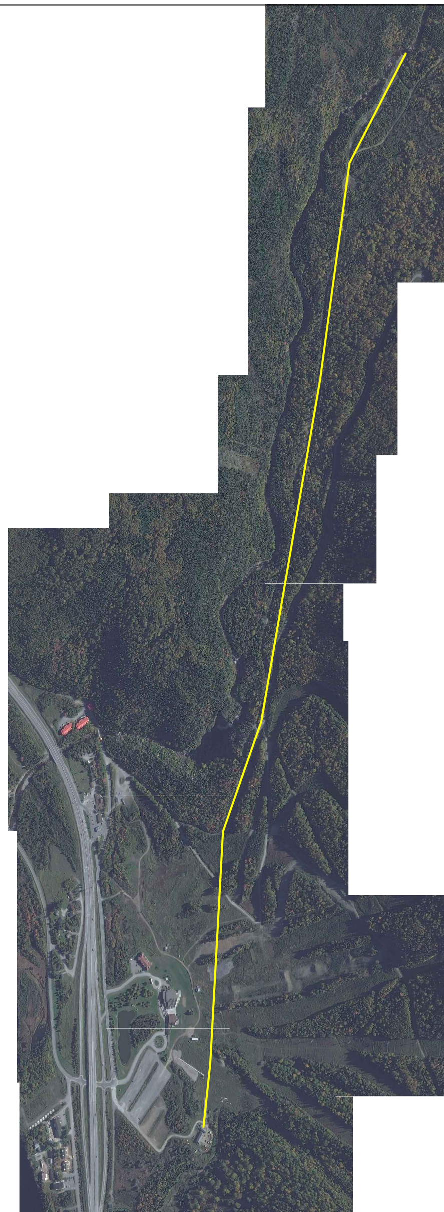
| | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | **2025** | **2026** | **2027** | **2028** | **2029** | **2030** | **2031** | **2032** | **2033** | **2034** |
| Capital Cost of Phase | | | | | | | | | | |
| Electricity Cost at Marble without generation | -$267,108.24 | -$271,114.87 | -$275,181.59 | -$279,309.31 | -$283,498.95 | -$287,751.44 | -$292,067.71 | -$296,448.72 | -$300,895.45 | -$305,408.89 |
| Electricity Surplus at Marble with generation | $634,660.04 | $644,179.94 | $653,842.64 | $663,650.28 | $673,605.03 | $683,709.11 | $693,964.75 | $704,374.22 | $714,939.83 | $725,663.93 |
| Operations and Maintenance Cost | -$126,067.62 | -$127,958.64 | -$129,878.02 | -$131,826.19 | -$133,803.58 | -$135,810.64 | -$137,847.80 | -$139,915.51 | -$142,014.24 | -$144,144.46 |
| Training Cost | | | | | | | | | | |
| Net Savings due to power generation | $901,768.28 | $915,294.81 | $929,024.23 | $942,959.59 | $957,103.99 | $971,460.55 | $986,032.45 | $1,000,822.94 | $1,015,835.29 | $1,031,072.81 |
| Benefits (in PV) | $500,400.69 | $481,428.15 | $463,174.95 | $445,613.82 | $428,718.51 | $412,463.78 | $396,825.34 | $381,779.83 | $367,304.76 | $353,378.52 |
| Benefits Cumulative Total | $7,493,478.04 | $7,974,906.20 | $8,438,081.15 | $8,883,694.96 | $9,312,413.47 | $9,724,877.25 | $10,121,702.58 | $10,503,482.41 | $10,870,787.18 | $11,224,165.69 |
| Costs | -$126,067.62 | -$127,958.64 | -$129,878.02 | -$131,826.19 | -$133,803.58 | -$135,810.64 | -$137,847.80 | -$139,915.51 | -$142,014.24 | -$144,144.46 |
| Costs (in PV) | -$69,956.25 | -$67,303.88 | -$64,752.07 | -$62,297.02 | -$59,935.05 | -$57,662.63 | -$55,476.37 | -$53,373.00 | -$51,349.38 | -$49,402.48 |
| Sum | $775,700.66 | $787,336.17 | $799,146.21 | $811,133.40 | $823,300.40 | $835,649.91 | $848,184.66 | $860,907.43 | $873,821.04 | $886,928.36 |
| Present Value | $430,444.44 | $414,124.27 | $398,422.88 | $383,316.80 | $368,783.46 | $354,801.15 | $341,348.97 | $328,406.83 | $315,955.39 | $303,976.04 |
| Net Present Value | $3,639,580.23 | | | | | | | | | |

| | Capital Cost | Net Benefits (with PV) | Net Benefits (without PV) | Costs (with PV) | Costs (without PV) | ROI (with PV) | ROI (without PV) | Savings | Simple Payback |
|---|---|---|---|---|---|---|---|---|---|
| TOTAL | -$5,315,149.82 | $4,303,872.29 | $10,763,131.11 | -$6,920,293.40 | -$7,970,058.42 | 62% | 135% | $11,224,165.69 | 7.91 |
| | | | | | | | | | 7.00 |

# Appendix


PLAN VIEW
NOTES
1) THIS PIPE TRAVELS ABOVE THE LOWER PIPE AND CONNECTS AT NOTE 2
2) CONNECT POINT FOR PIPE IN NOTE 1
CLIENT
Marble
MOUNTAIN
CONSULTANTS
Streamline
Engineering
Consultants
PROJECT NAME
HYDROELECTRIC DEVELOPMENT
PROJECT LOCATION
MARBLE MOUNTAIN, NL
DRAWING NAME
EXISTING PUMPHOUSE BUILDING
DESIGNED BY
CC
DRAWN BY
RD
APPROVED BY
AH
REV
A
SCALE
NTS
DATE
03/04/2013
DRAWING NUMBER
01-001-0001


1 PLAN
16000
16000
Office
Bathroom
Storage
2 FRONT ELEVATION
16000
3048 x 2438 OVERHEAD DOOR
3 SIDE ELEVATION
3048
16000
914 x 2134 STEEL MAN DOOR
4 REAR ELEVATION
914 x 2134 STEEL MAN DOOR
NOTES
1) ALL DIMENSIONS IN MILLIMETRES
2) CONTRACTOR TO VERIFY ALL DIMENSIONS ON SITE
CLIENT
Marble
MOUNTAIN
CONSULTANTS
Streamline
Engineering
Consultants
PROJECT NAME
HYDROELECTRIC DEVELOPMENT
PROJECT LOCATION
MARBLE MOUNTAIN, NL
DRAWING NAME
NEW TURBINE BUILDING
DESIGNED BY
CC
DRAWN BY
RD
APPROVED BY
AH
REV
A
SCALE
NTS
DATE
03/04/2013
DRAWING NUMBER
01-001-0002



NOTES

CLIENT

Marble
MOUNTAIN

CONSULTANTS

Streamline
Engineering
Consultants

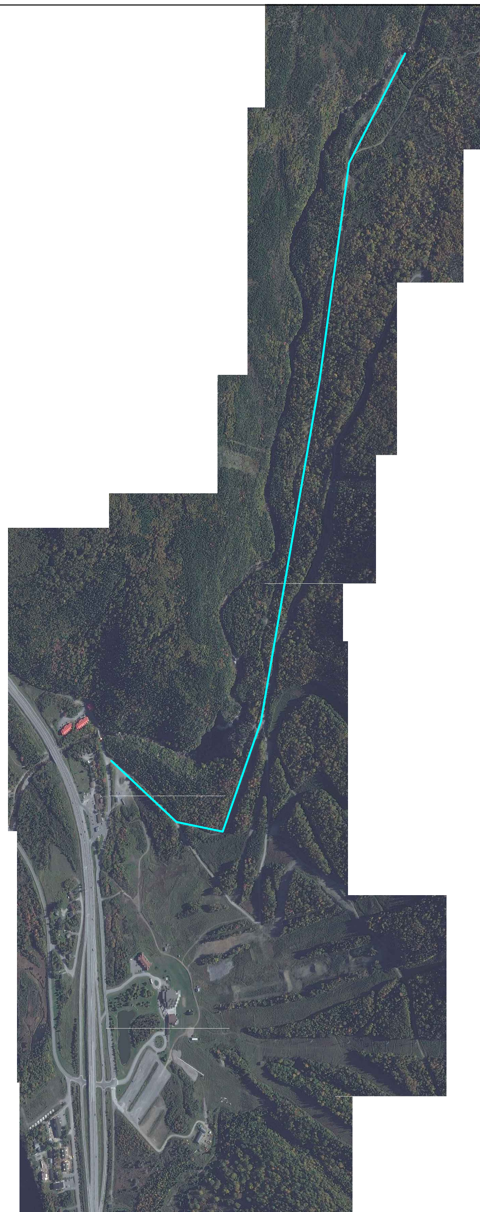
PROJECT NAME
HYDROELECTRIC DEVELOPMENT

PROJECT LOCATION
MARBLE MOUNTAIN, NL

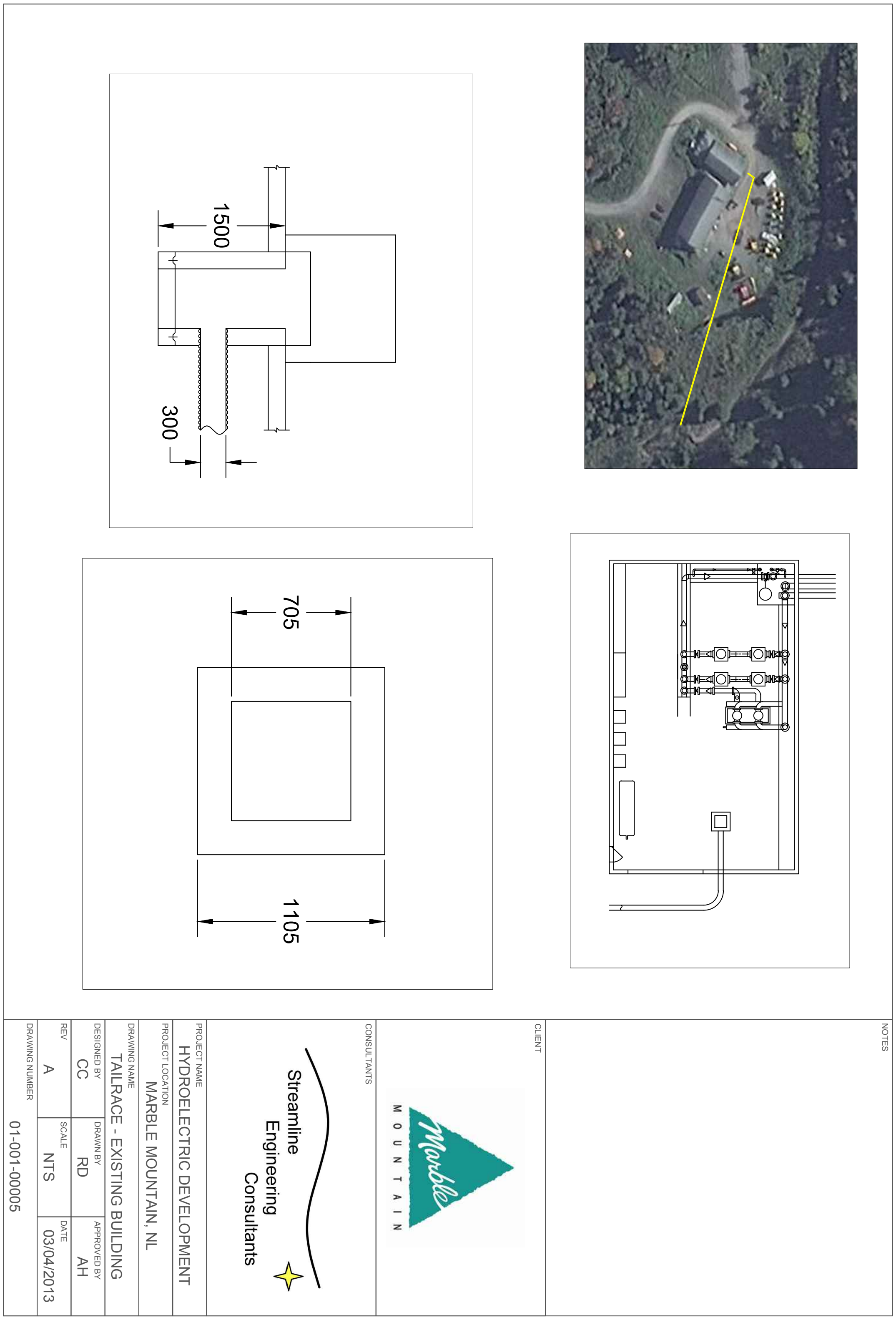
DRAWING NAME
EXISTING PIPELINE LAYOUT

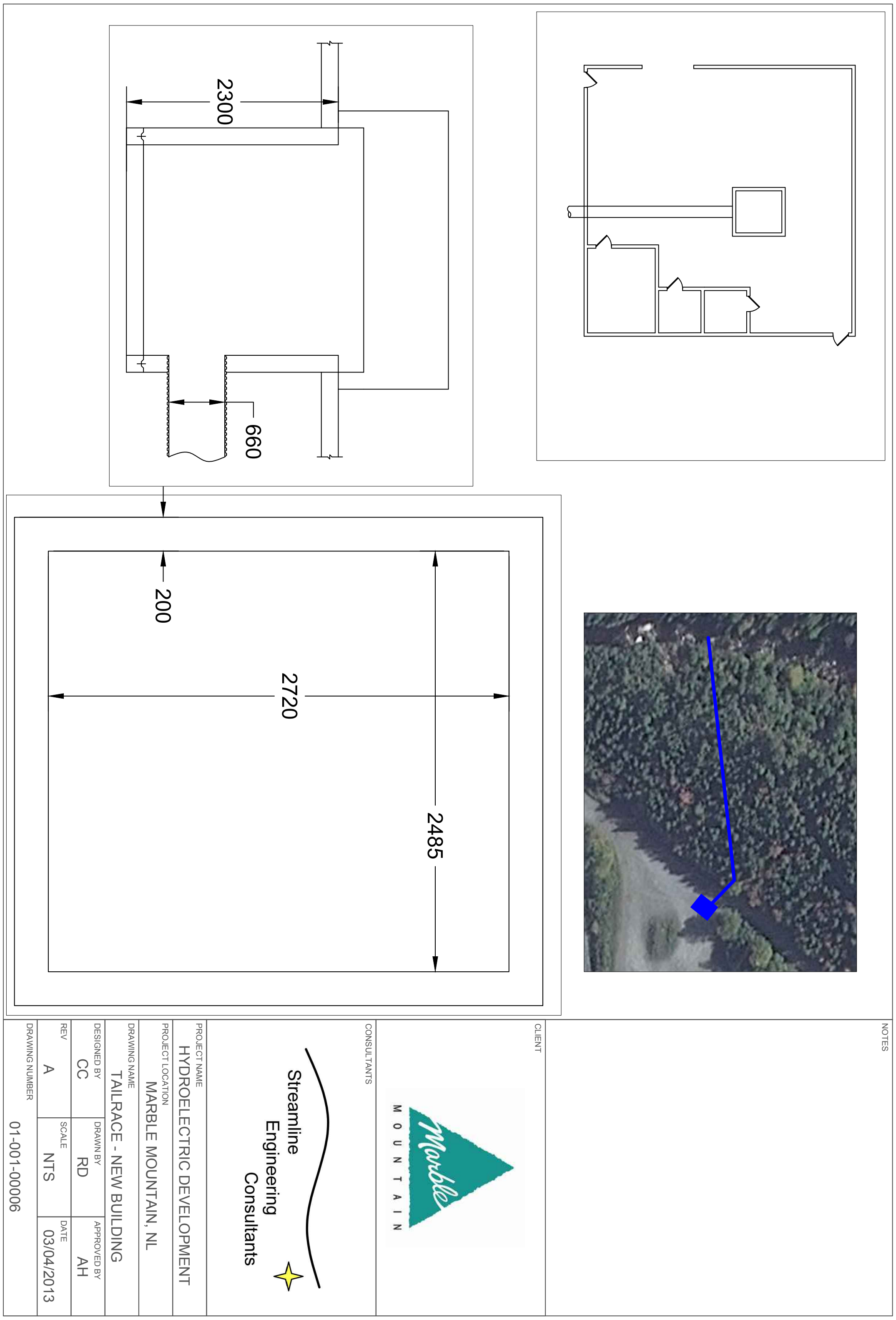
| DESIGNED BY | DRAWN BY | APPROVED BY |
|---|---|---|
| CC | RD | AH |
| **REV** | **SCALE** | **DATE** |
| A | NTS | 03/04/2013 |

DRAWING NUMBER
01-001-0003



| | |
|---|---|
| NOTES | |
| CLIENT | MARBLE MOUNTAIN |
| CONSULTANTS | Streamline Engineering Consultants |
| PROJECT NAME | HYDROELECTRIC DEVELOPMENT |
| PROJECT LOCATION | MARBLE MOUNTAIN, NL |
| DRAWING NAME | NEW PIPELINE LAYOUT |
| DESIGNED BY | CC |
| DRAWN BY | RD |
| APPROVED BY | AH |
| REV | A |
| SCALE | NTS |
| DATE | 03/04/2013 |
| DRAWING NUMBER | 01-001-0004 |


1500
300
705
1105
NOTES
CLIENT
MOUNTAIN
Marble
CONSULTANTS
Streamline
Engineering
Consultants
PROJECT NAME
HYDROELECTRIC DEVELOPMENT
PROJECT LOCATION
MARBLE MOUNTAIN, NL
DRAWING NAME
TAILRACE - EXISTING BUILDING
DESIGNED BY
CC
DRAWN BY
RD
APPROVED BY
AH
REV
A
SCALE
NTS
DATE
03/04/2013
DRAWING NUMBER
01-001-00005


2300
660
200
2720
2485
NOTES
CLIENT
MARBLE MOUNTAIN
CONSULTANTS
Streamline
Engineering
Consultants
PROJECT NAME
HYDROELECTRIC DEVELOPMENT
PROJECT LOCATION
MARBLE MOUNTAIN, NL
DRAWING NAME
TAILRACE - NEW BUILDING
DESIGNED BY
CC
DRAWN BY
RD
APPROVED BY
AH
REV
A
SCALE
NTS
DATE
03/04/2013
DRAWING NUMBER
01-001-00006