EAEE 3999: Black Rock Forest Micro Hydro Design

EAEE 3999: Undergraduate Senior Design Project

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Acknowledgements

During the design process from September until now many people in the department of Earth and Environment Engineering and at Black Rock Forest helped make our project possible. We would like to thank Professor Gavin Gong for establishing this project and guiding us through it from start to finish. Whether driving us up to Black Rock or staying late to teach us about hydrology, he was always eager to help and full of encouragement. We also appreciate the support of the Earth and Environmental Engineering Department, which provided us with critical research during our research and design. The folks at Black Rock Forest were also very helpful and a pleasure to work with. Thanks to Bill Schuster for showing us around the forest, answering questions, and putting us in touch with helpful resources. We also appreciate the help of Matt Munson and Jack Caldwell, both of whom connected us with critical forest information.

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1. Introduction

"Each spring... I heard the lambent voice of the brook as it flowed through the sugar bush, singing a song which to my ears said: 'kilowatts, kilowatts'." (Butler, 4) Similar to the author's situation in *How to Design and Operate Your Own Small Hydroelectric Plant,* the Black Rock Forest Brook presents an opportunity for power derived from hydro resources.

1.1 Black Rock Forest Consortium

Black Rock Forest, located near the Village of Cornwall-on-Hudson is an approximately 1600 hectare forest reserve maintained by the Black Rock Forest Consortium. The consortium operates out of two buildings, the Forest Lodge and the Science Center. Both buildings contain characteristics of "green" building so as to exist more harmoniously within the forest, minimize energy consumption, and also to be used for education. This aligns with the consortium's tri-part mission of research, education, and active management.

To follow with the consortium's mission, there is a desire to investigate the possibility of a hydroelectric facility which would supply power to one or both of the buildings. The consortium tries to maximize its use of renewable energy for the reason of having a smaller overall footprint and to help educate the students about the benefits of renewable energy. Currently a photovoltaic array supplies the bulk of power to the Science Center, making the Forest Lodge the prime candidate to be the beneficiary of a hydroelectric scheme. However, the specifics of which building would be better suited to benefit from hydro power needed to be investigated.

The Forest Lodge and the Science Center are used for reception and educational purposes. The Forest Lodge is equipped to accommodate day guests as well as up to sixty overnight guests. The Science Center contains wet and dry laboratories to aid in research and education for groups ranging from elementary schools to university level. A hydroelectric energy scheme would allow either building to operate in an even more environmentally friendly manner than it is already doing. The energy facility would also be used for education and demonstration of alternative energies to lodge visitors. Ideally the additional source of power would also decrease the yearly expenditure on purchasing energy from the gird for Black Rock Forest.

The consortium currently operates multiple measurement stations within the forest. The data from these stations can be used by education groups in the area and can be used to track forest conditions. There is an open lowland station, a ridgetop station, stream station at cascade brook, a fire tower station, and two snow/energy balance stations. The consortium also keeps record of the photovoltaic panels they operate and can make that data available if groups request it. The hydro power could be integrated into theses sources of data and provide information on how much power is produced at different levels of water behind the weir or information on the seasonality of the hydro power. This could add to the number of educational activities that could be done with the Black Rock Forest data catalog.

1.2 Hydropower

Power generation from water takes advantage of the energy produced when moving water incurs a height drop. At the bottom of the height drop, this energy can be harnessed to produce useful mechanical or electrical work. Mechanical work can be directly retrieved through waterwheels, which are one form of a turbine. Another type of energy conversion is to use the turbine to drive a generator which produces electricity. The consortium would like to use the energy to produce electricity, rather than mechanical work. The approximate goal of power delivered from the hydro power generated for the Black Rock Forest Consortium is slated at one to ten kilowatts. Because the scheme is going to produce less than 100 kilowatts of power the scheme would be classified as "micro-hydro." No electricity will be supplied to the national grid, and will be used only for electricity generation for the Lodge and/or Science Center.

As mentioned earlier, power for the consortium can be derived from two different layouts, either a storage or run-of-river scheme. A storage scheme uses a dam to build up the water height, giving a height drop necessary to energy production. A turbine is situated near the bottom of this height drop. Storage schemes often make it possible to have water flow even when the stream or river would normally run dry, however, using a dam may have adverse affects on the ecology of the downstream as well as upstream environment.

The run-of-river type of hydropower generation diverts water along a hillside and then lets it drop to the turbine. While this type of scheme does not keep water available for power during dry seasons, it generally has less environmental issues associated with it.

Associated with either type of general hydropower scheme (storage versus run of river) is how the energy from the scheme is converted to useful energy. A few of the components which make this conversion possible are a penstock, turbine, generator, and associated electrical equipment.

Hydro power schemes have been employed for many years and come in several forms, depending on the demand and use. Because of its widespread use and various adaptations, there are many valuable examples and resources available on hydropower. Different hydropower schemes can be chosen and varied to fit the conditions presented. Having already established research and applications brings even more confidence to applying hydropower for use by the Black Rock Forest Consortium.

2. Scheme

The Black Rock Forest consortium wished to install a hydropower scheme using the Black Rock Brook, which the Consortium possesses the water rights to. The brook offers a range of flow from no flow during the summer months, up to around 0.30 cubic meters per second (10 cubic feet per second). At a location near the Consortium's Lodge and Science Center buildings, the Black Rock Brook experiences a drop in elevation that the Consortium would like to use for hydropower. This change in elevation is approximately 85 meters, occurring over a length of about 410 meters.

Once the different types of hydropower schemes were investigated, the most suitable options for our site were determined. Integrating a type of hydro scheme to the surroundings is different for the conditions (terrain, amount of head, flowrate of the water source, etc) of the given site. A typical, cookie cutter option is not really possible for any site. Iterations and adjustments must be made with sound engineering judgment. To offer the best design, as many alternatives as possible should be explored.

2.1 Our Possibilities

For this micro-hydro project a storage scheme, a semi-storage semi-run-of-river scheme, and two run-of-river schemes were the possible designs.

2.1.1 Storage Scheme

The first scheme briefly investigated was a storage scheme. There is an existing weir in the Black Rock Brook, located at a point near the top of where the elevation drop starts. This weir already withholds some of the flow, and if we were to continue with a storage scheme, we would probably have a dam located at this point, but built higher to withhold more flow. Since the flow gets very low during the summer months (there is often no flow at all), the ability to have the water build up would be useful during those times.

However, using a dam may have adverse affects on the ecology of the downstream as well as upstream environment. Employing a storage scheme would flood the area upstream of the dam and would decrease water downstream of the dam. Installing a dam would almost guarantee that during the summer months the brook would be dry below the dam. The effects of a dam are especially important to the consortium, because in addition to their general concern for life in and around the brook, several pools of the brook are used for education and monitoring of certain fish and other aquatic species. Also, if the dam were built and the area upstream of the dam were to be more flooded than the amount the weir currently in place imposes, this may cause problems for the Consortium. The brook is located near the road which is used to access the Black Rock Forest Consortium headquarters. If the brook were flooded more than it already is, there is potential for high flow conditions to cause flooding onto the road. If conditions were so extreme so as to damage the road, this would be a serious safety thread to the Consortium.

2.1.2 Hybrid Scheme

A type of hybrid scheme, which was something in between a storage and run-of-river scheme, was also considered. This scheme would employ a storage component larger than a simple forebay tank, but of a smaller scale than that required for an explicitly "storage" scheme. Having this storage component would allow a more consistent supply to the pipe which would carry water to the turbine. However, the placement of such a tank would be difficult, due to the rocky and uneven terrain and limited space available.

2.1.3 Run-of-River

As is with many micro-hydropower schemes, a run-of-river scheme seemed most suitable for our project. The run-of-river type of hydropower generation diverts water along a hillside and then lets it drop to the turbine. Two possible run-of-river schemes were chosen as the best possibilities for the Black Rock Forest Consortium. Both schemes took advantage of the 85 meters of head, and would divert the water from the same point at the top of this elevation drop, with the turbine being located at the bottom of the head differential. The first case diverted the water, ran along a contour line, and then ran the remaining length along where the elevation drop was steepest. The second case diverted the water and ran the pipe approximately parallel to the brook. The first case would have a shorter length of pipe in the section of elevation drop and supply to the turbine, so friction losses may be less. However, the second case would probably be more feasible due to the type of terrain present in the Black Rock Forest. After comparing the advantages and disadvantages of the two cases, it was determined that for this project, the second case would be more feasible. Further explanation will be given in the yield analysis of this report.

3. Supply Analysis

When designing for a micro hydro facility it is necessary to have flow data on the site in question in order to properly analyze what the design flow for the system should be. In many cases it is known that the flow will more than satisfy the demand for electricity of the building or town that the hydro power scheme will provide power for. However, in a situation like that of Black Rock Brook it was known from the onset of the project that the micro hydro scheme would not be able to fully satisfy the power needs of the facilities. In that scenario it is necessary to fully analyze flow data in order to optimize the design flow for the system. Further complicating the situation was lack of long term flow data for the brook combined with the fact that the brook is known to have major seasonal flow variation and completely dries up during the summer months.

3.1 Basin and Brook Basics

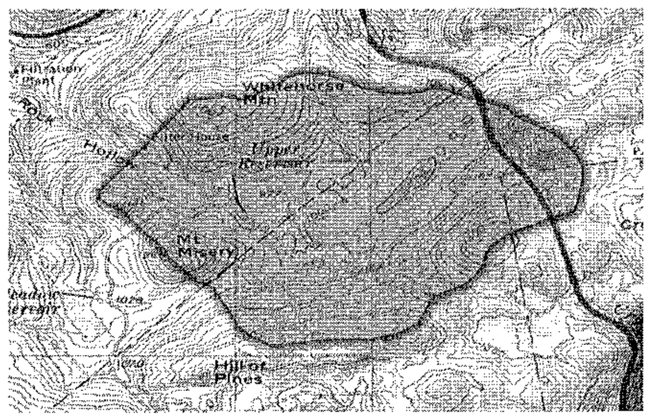


Figure 1. Topographical map showing the watershed for Black Rock Brook (Contour lines in feet)

Black Rock Brook starts at the outlet of the Upper Reservoir and continues to its confluence with the brook coming from the Aleck Meadow Reservoir. The approximate area of the watershed for Black Rock Brook is 170 hectares of land. This measurement was obtained by calculation using the topographical map. The majority of the land is within the boundaries of Black Rock Forest however, a small portion on the eastern edge crosses out of the Forest and across route 9W. The portion of Black Rock Brook and all the water that flows through it from the Upper Reservoir to the water treatment plant owned by the town of Cornwall-on-Hudson, NY is owned by the forest consortium. The village obtains its water from the Upper Reservoir through a ten inch pipe that connects directly to the Upper Reservoir, and runs parallel to the Black Rock Brook. The pipe ends at the town water treatment plant that is noted as the filtration plant on figure 1.

3.3 Cascade Brook and the Correlation Method

One way to solve the problem of lack of flow data for the brook or river is to look for correlations with nearby streams that have extensive flow data. This requires taking measurements of the flow of the brook that you want data for over the course of a year. If there is no flow during the dry season or it is known that wet season flows are fully sufficient to fulfill the need it may be only necessary to have flow measurements for part of the year. It is not necessary to ensure the year is an average year as far as precipitation because for the correlation to work it is assumed that the steams will react similarly to normal, drought, or flood conditions. It is however necessary to ensure that the choice of when to take the measurements is not biased towards only being taken during dry spells during the year or wet spells during the year.

Figure 2. Cascade Brook v-notch weir (photo taken by Rebecca Jarvis)

This method relies on that fact that streams near each other often experience similar environmental factors. The rainfall on average across their respective basins will be near equal. The kind of rock or soil in the basin will be similar which will lead to similar runoff patterns and similar timing of when the water from a rainfall event will reach the stream. A stream in a basin that contains mostly impermeable rock will react vastly differently to a rainfall event than a stream that is in a basin with mostly soft sand. In the case of rock the water will runoff quickly and the stream flow will peak soon after the rainfall event. The flow will than quickly decrease back to the base flow found in that stream. In the case of a soft sand or soil the rainfall will at least partially soak into the soil and sand and the runoff will be smaller. The water in the ground will slowly flow toward the stream and result in a later peak in stream flow and a slower return to the stream's base flow.

Black Rock Forest contains multiple streams and of particular interest to us was the Cascade Brook in the forest that had detailed measurements of stream flow going back to 2003. The Cascade Brook monitoring system includes a v-notch weir and automated recording equipment that measures and records data on flow, temperature, pH, conductivity, and dissolved oxygen. (http://www.blackrockforest.org/docs/scientist-resources/EnvironmentalMonitoring/index.html) This data is automatically transmitted from the measuring station to the science center in the forest.

The proximity of Cascade Brook to Black Rock Brook suggested that a possible correlation could exist. To test the correlation, measurements were taken of flow in Black Rock Brook between January 22, 2008 and November 18, 2008 on an approximately weekly basis. The Black Rock Brook flow

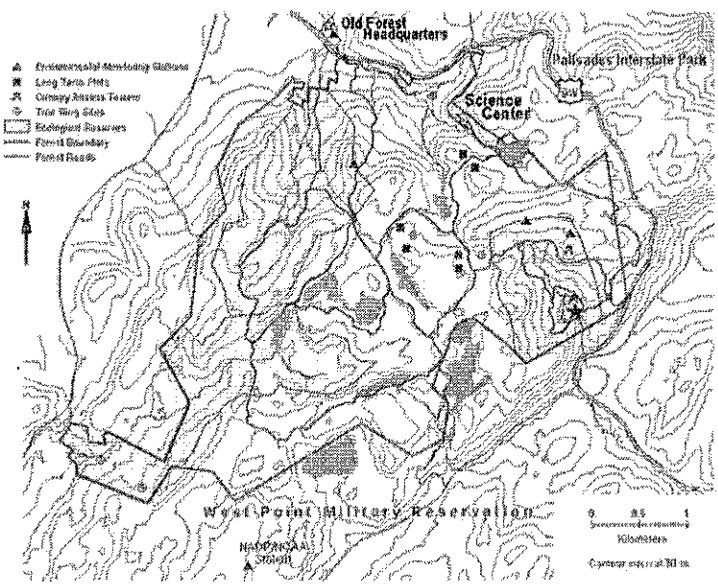
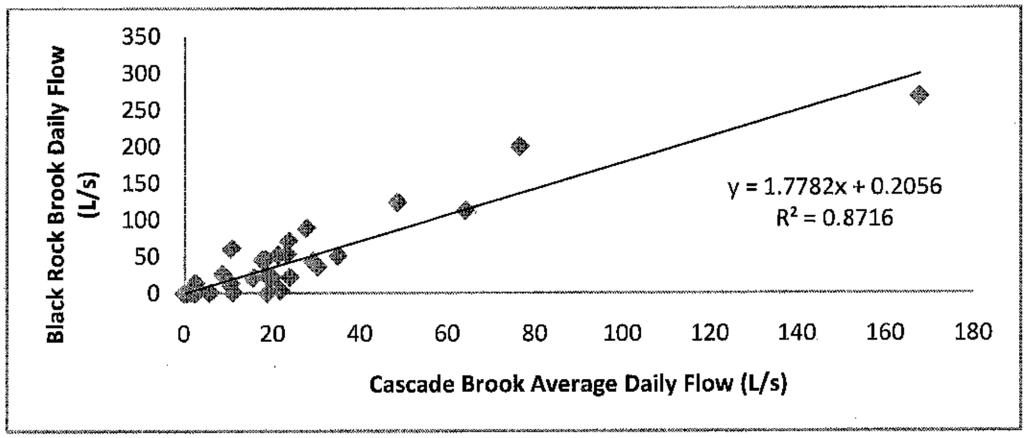


Figure 3. Map showing Cascade Brook measuring station with a purple star and the approximate location of Black Rock Brook based on its location next to the science center

measurements were taken just once in a day where as the Cascade Brook measurements are taken hourly every day. To account for this difference the hourly flow of Cascade Brook was average for the days that flow data existed for Black Rock Brook.

These flow measurements were plotted to test for a correlation. The correlation was found to have an R-squared value of .8716. We decided that this correlation was strong enough to use it to calculate historical flow records for Black Rock Brook. This gave us the long term data that was needed to properly calculate the design flow for the scheme.

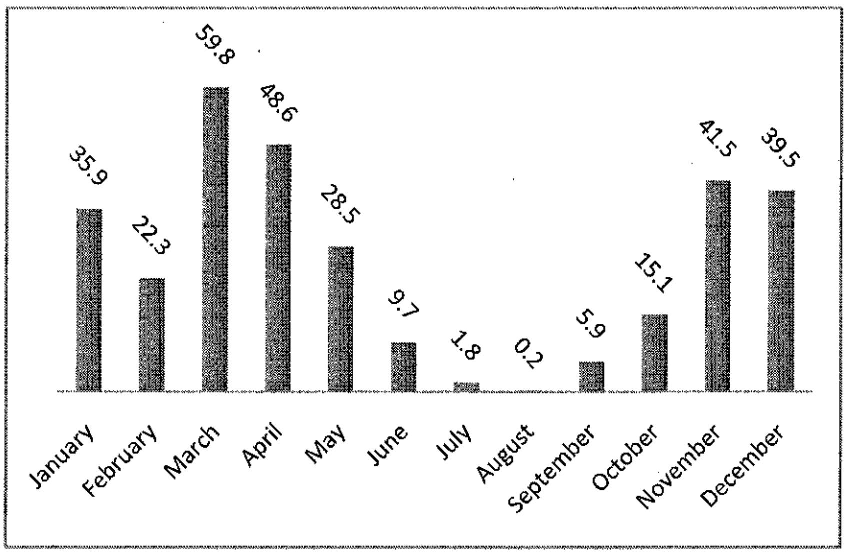


Graph 1. Flow Correlation for Cascade Brook and Black Rock Brook Jan 22,2008 through November 18, 2008 based on approximately weekly measurements.

3.5 Design Flow

To determine the design flow for our system we wanted to optimize the amount of the year the hydro scheme would be able to run without building too small or large a system. We need to figure out how high a flow we could design for without ending up with a turbine that would only run at capacity during a few months of the year or a turbine that was so small the project would be almost useless. Larger turbines and larger diameter penstock cost more so it is important to take that into account as well.

Black Rock Brook usually dries up completely during the summer so there is no base flow value that we could count on having year round. We decided to use the 25th Percentile values for brook flow to pick our value. 25th percentile values were optimal to use because they represent flows that will be exceeded 75% of the time. This means that we can count of having the flow we design for most of the time. The one thing that the 25th percentile values and the correlation method did not do a good job of representing is the dry summer months of July, August, and September. The correlation used does not generate flow values of zero so it makes the data seem like Black Rock Brook will have very minimal flow during the summer. We know from discussions with Black Rock Forest staff that the brook is usually dry during the summer.

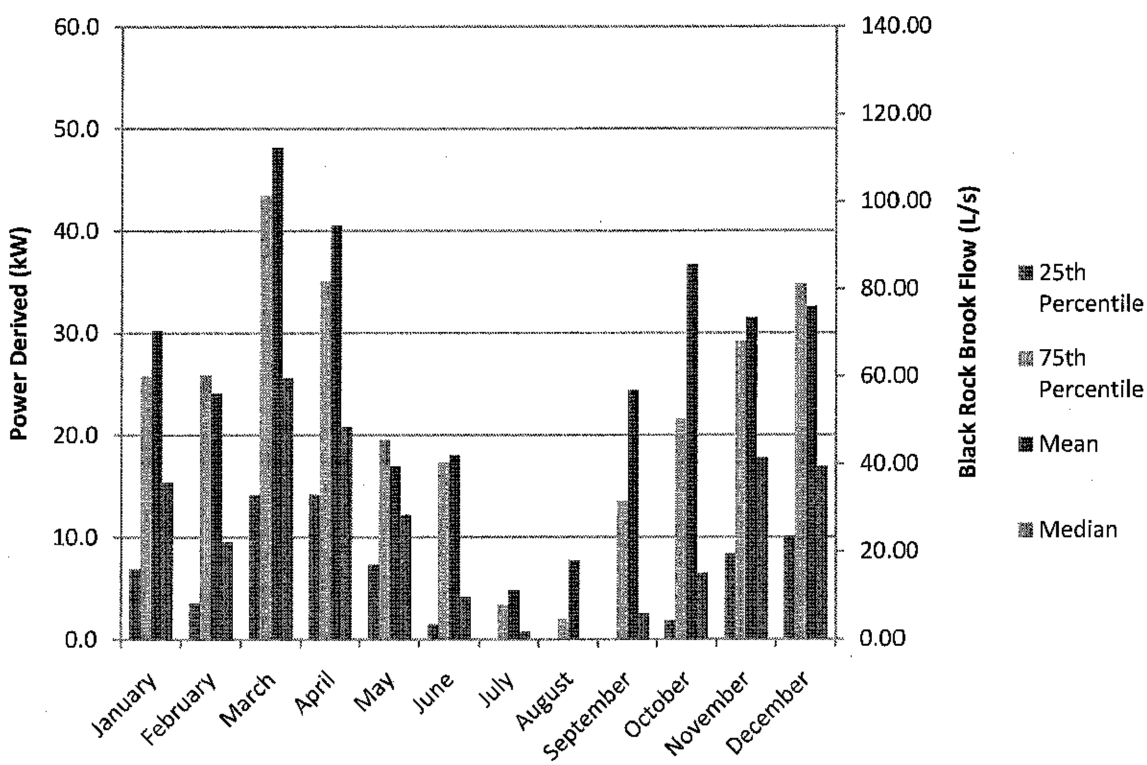


Graph 2. The 25th Percentile flow of Black Rock Brook in L/s.

A design flow of 4.4 L/s was chosen after investigating the options available to us. This is the value of the 25th percentile flow value for the month of October. The anticipated months that the turbine will, on average, be able to run at full capacity are October through May. In June the turbine will either be able to run at a reduced level or during wetter years be able to run at capacity.

The catchment that Black Rock Brook is in is relatively flashy. When storms come through they immediately add to the brook flow. To determine the design flood value we found the highest instantaneous (hourly) value of flow we had on record of 3,249 L/s to account for the fact that a larger flood could come through.

3.4 Derived Power



Graph 3. 25th percentile, 75th percentile, mean, and median power derived from Black Rock Brook and the associated stream flow.

Due to large fluctuations in the flow of Black Rock Brook the amount of power that can be derived from the flow also widely varies. Using a head of 85 meters and an assumed efficiency of 0.5 it is possible to calculate the power derived for different flow levels based on the flow that is known to exist in different months. Just as with the analysis of flow there is a large amount of power that could be captured. However, due to the variability of flow and the fact that it is not cost effective to install to big a turbine the design parameter for power derived is 1.8 kW and is based off of the 25th percentile flow and power derived values for the month of October.

3.5 Town Impact

One factor that influences Black Rock Brook but not Cascade Brook is the outflow of water from the Upper Reservoir, through a pipe, for the town of Cornwall-On-Hudson's consumption. The exact impact of this outflow is unknown. It is possibly that the variation in the magnitude of flow between Cascade Brook and Black Rock Brook that is not accounted for in the correlation is due to outflow for the town. There is however no way to currently quantify how that outflow impacts the brook.

We were unable to obtain flow data from the water treatment plant after multiple attempts to acquire the data. This made it impossible for us to even qualitatively look at the variation in the amount of water that the town is using. Through Bill Schuster we heard that the town may increase their water use in the coming years. To what extent they will increase their water use is unknown. Due to the fact that flow in Black Rock Brook is a result of overflow of the Upper Reservoir removing water via the town's pipe would impact the amount of overflow and therefore the amount of stream flow. Before progressing with the proposed design for the micro hydro scheme it would be necessary to discuss with the town their plans for water use and work to better understand how that will impact the brook and it's flow pattern.

Another unknown variable that the town introduces is that they have in the past expressed a desire to use the water in their pipe for hydro power. Their pipe currently follows a path that is very similar to our proposed location for the penstock but their pipe is buried. If the town were to decide in the near future that they wished to invest in such a plan it may be possible for Black Rock Forest to go in on the scheme with them.

3.2 Environmental Impact of Hydro Power on the Brook

A detailed environmental impact analysis has not been done relating to the installation of micro hydro on the health of the Brook. However, a preliminary analysis does not suggest that there will be any large detrimental impacts of the operation of the micro hydro scheme. Micro hydro schemes do not generally have a large environmental impact if they are properly constructed for the streams they are on. This statement especially applies to 'run of the river' schemes where water is diverted from the brook, run through a pipe to a turbine and then returned to the brook. In that case the natural ecology is not disturbed by damming of the river or holding back flows for use later.

The proposed scheme for Black Rock Forest is a 'run of the river' scheme. The portion of the brook that will experience reduced stream flow is quite large however, there has been no concern voiced by Black Rock Forest staff about this impacting the ecology of the brook. They have suggested that diverting a portion of the flow would be fine for the brook and would simply create a longer summer drought that the brook already experiences.

During the months of July, August, and September the Black Rock Brook is almost always completely dry. However, according to conversations with forest staff some small pools in the Brook do not completely dry up and sustain small fish populations. During heavy rainstorms in the summer the Brook will have instantaneous flow due to the flashy nature of the overall watershed. These brief rainstorms likely replenish those pools and allow them to survive the dry summer.

In most months that amount of flow that will be diverted for the hydro power is minimal in comparison to the flow coming through the Brook. In June and October, based on our calculations we will be diverting almost all of the flow 25% of the time. It is our opinion that due to periodic rainstorms that will cause flow to reach all parts of the brook it is unlikely that our induced drought will have an impact that differs from the natural lack of water in the summer.

While a portion of Black Rock Brook would experience permanent lower flows of water the brook downstream of Black Rock Brook would be unaffected. All water taken out of Black Rock Brook would be returned to the Brook at the outlet of the turbine. Before construction of the hydro facility it would be advisable to further study the species that use Black Rock Brook to ensure lower water levels would not negatively impact them. It would also be necessary to construct the facility in the most environmentaly friendly way as possible and not pollute the Brook during construction.

3. Demand Analysis

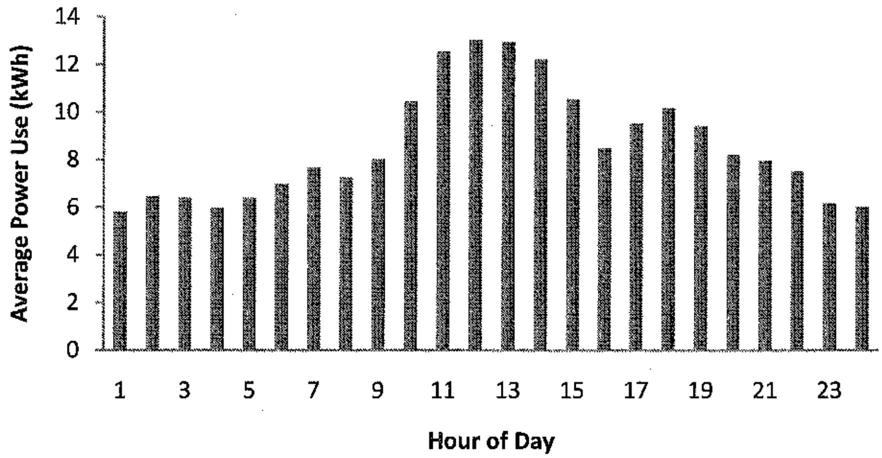
An important aspect of hydropower design is properly evaluating the demand for power. In order to maximize effectiveness of the installed hydropower system, it is important that no power goes to waste. This can occur if more power is produced than is required by the facilities at any given time. Excess power, unless stored or sold back to the grid, is then lost.

3.1 The two buildings and their power use

The power demand was determined by analyzing power records for each of the Black Rock Forest buildings: the Science Center and the Forest Lodge. The Science Center, which houses administrative offices in addition to laboratories, has a fairly predictable energy use due to forest employees using the facility on a daily basis. The Forest Lodge, on the other hand, has more erratic power use due to large fluctuations in visitors. The Forest Lodge is used to house visiting student groups, whose visits are determined by weather, school schedule, and other factors.

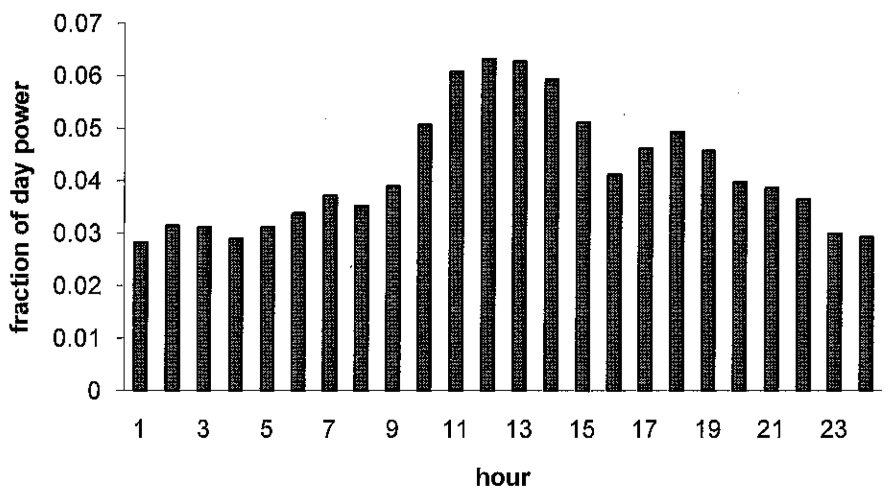
3.2 Data analysis and baseline power calculation

The data provided by the Black Rock Forest contains a good level of usage detail on an hourly, daily, and monthly basis for the period from 2006-2008. The hourly data is provided for the Science Center for the month of September of 2008. This data shows the energy used during each individual hour throughout the month. A typical daily energy usage plot was created by averaging the energy used at each hour of the day, as shown in graph 4. Since this is the only hourly power distribution data we have, we must assume that this is how power is distributed throughout the day for the whole year in both buildings.



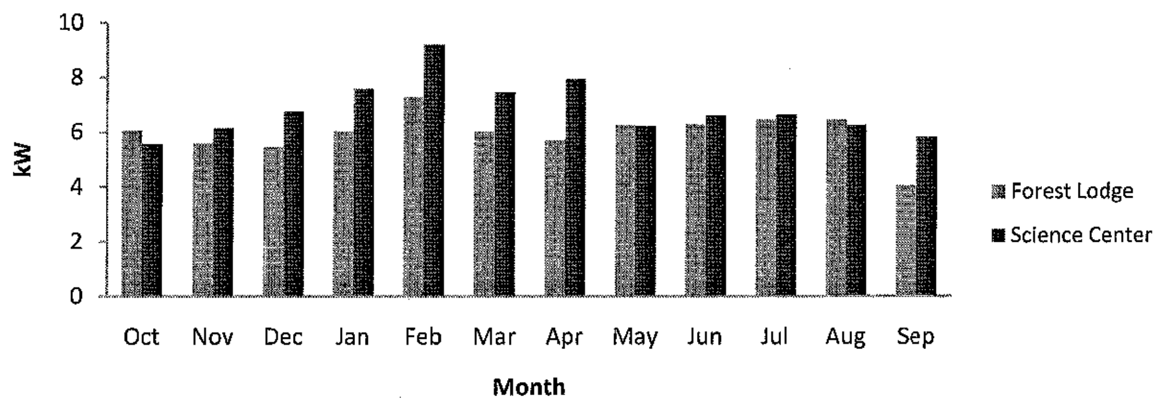
Graph 4. Science Center Power Use Per Hour for Sep 08.

To help with this, we have created a normalized power distribution, which shows the fraction of power consumed during each hour of the day and can be seen in Graph 5. As is clear from this distribution, the energy used from about 8 p.m. to 7 a.m. is a consistently low, baseline energy usage. Since hydropower runs around the clock, and we would like to utilize all the power being provided, the baseline power usage provides us with a good indication of the maximum power we should generate in order to avoid wasting any.



Graph 5. Daily Power Normalized Distribution.

Data was also provided on a monthly basis for both the Science Center and the Forest Lodge. By taking the total power used in any given month and dividing by the number of days in that month we are able to determine a typical day for each month of the year. Then, by applying our normalized power distribution to each day we are able to determine the typical baseline power needs for each month for both the Science Center and the Forest Lodge. The baseline power needs are shown in graph 6 for the Science Center and Forest Lodge. As the figures indicate, the minimum power requirement for each building is about 6 kilowatts. Therefore, as long as the power generated by the hydropower system is below 6 kW, it should be 100 % utilized.



Graph 6. Baseland (8pm-7am) Average Hourly Energy for the Science Center and Forest Lodge.

3.3 Existing Renewable Energy Resources

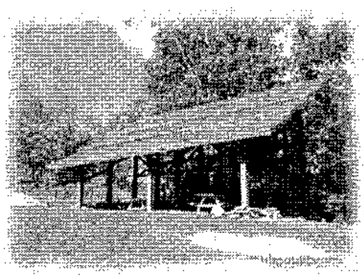
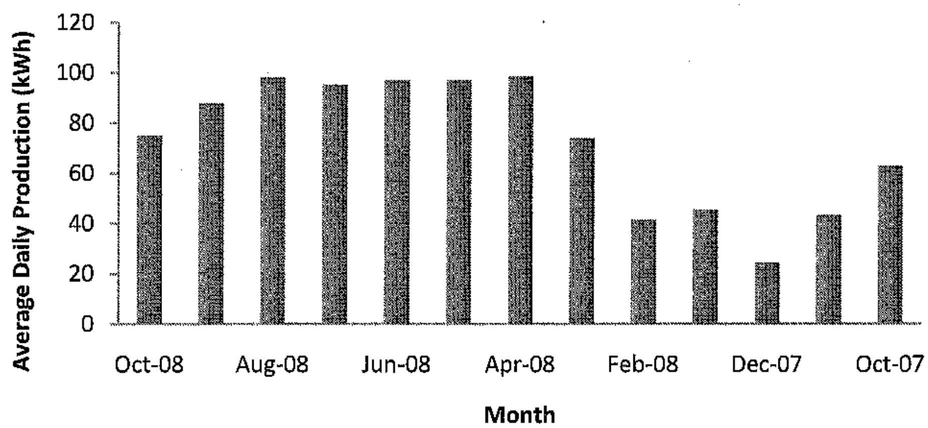


Figure 4. Photo of some of the solar panel at the Black Rock Forest.

In 2006 the Black Rock Forest installed a photovoltaic system that provides upwards of 100 kWh per day of electricity to the Science Center. The photovoltaic system is in keeping with the Forest's emphasis on sustainable energy and provides a sizable chunk of the required electricity to the Science center. The electricity that is generated in excess of demand is sold back to the grid on a net metering system. Solar power supply fluctuates throughout the year, with a maximum of about 100 kWh per day in summer and a minimum of about 25 kWh per day in winter, as indicated in graph 7. In addition to serving as a valuable energy source, the solar panels are located close to the Forest buildings, providing visitors with an opportunity to see photovoltaic power production up close. Therefore the solar panels, like the future hydropower system, serve both a functional and educational purpose.



Graph 7. Solar Production by Month

The Forest also has plans to install a small wind turbine, which would generate just a few hundred watts. This turbine would be located near the solar panels and would provide another opportunity to see renewable energy in action.

Due to an increase in stream flow in the winter/spring and a decrease in the summer/fall, it appears that the hydropower will fluctuate in a way that complements the solar power. As discussed earlier, the photovoltaic panels have a maximum output in the summer, when the sun is high, while the hydropower system will have a minimum value in the summer, when stream flow is low. Likewise, in the winter, the solar panels will have low output because the sun is low and the sky is cloudy, but the hydropower system will have a high output due to increased rain and snowmelt. Although the power from these sources may not go to the same building, the renewable energy sources complement each other well and result in a sizable year round contribution from sustainable sources.

3.4 Which building should the hydropower be supplied to

The question remains whether to link the hydropower to the Science Center or the Forest Lodge. This question is simplified somewhat by a New York State Law which was proposed as bill number A05785 and "provides for the net energy metering of solar, wind, fuel cell and farm waste electric generating systems for both residential and business customers" (http://assembly.state.ny.us/leg/?bn=A05785). This law states that customers are allowed to sell excess power back to the grid when generated as "solar, wind, fuel cell and farm waste electric generating systems," but not for hydropower. This law is designed to prevent residents from flooding large areas of land to generate excess electricity, which could then be sold back to the grid at the expense of the ecology of the flooded area. The Science Center is already set up for net metering due to its large array of photovoltaic solar panels. This makes the Forest Lodge a better candidate because it does not already have a net metering system set up and can therefore utilize the hydropower without running the risk of breaking the law. Additionally, running the hydropower to the Forest Lodge ensures that there is no competition between PV power and hydropower and therefore maximum utilization of renewable energy.

4. Yield

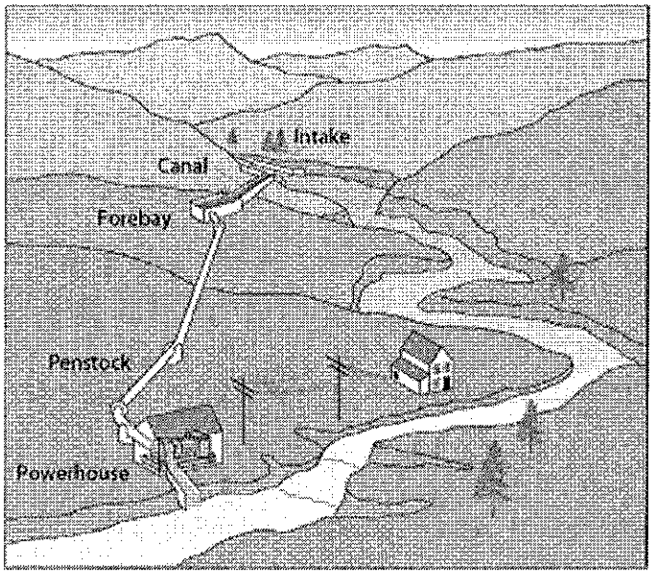


Figure 5. Illustrated example of the layout for a typical micro-hydropower scheme.

The design of the chosen run-of-river scheme was made in cooperation with the Black Rock Forest Consortium's electricity demand and hydrological data and correlations obtained. In order to simultaneously progress with the hydrological work as well as the design components, preliminary calculations were made with estimated design flows. After the hydrological data had been obtained, analyzed, and the correct correlations made, a design flow of 4.40 liters per second was decided upon (as stated previously in this report). The derived power from 4.40 liters per second is approximately 1.8 kilowatts, which satisfies the Black Rock Forest Consortium's desire of obtaining between one and ten kilowatts.

The components of the design fell into two major categories; civil works, and mechanical components. The civil works include the penstock, diversion weir, intake mouth, spillways, and the silt basin and forebay tank. The mechanical and electrical components include the turbine, electronic load controller, generator, and powerhousing. The civil works manage the flow of water supplied and the mechanical components mainly function to output the actual electrical power derived from the hydro scheme.

4.1 Civil Works

4.1.1 Penstock

The penstock contributes greatly to the function as well as the cost of the system, and thus is a key factor in the design process. The penstock is a closed pipe which supplies water to the turbine. Because it is a closed pipe, if blockage occurs, high pressure can develop inside the pipe, and so the penstock was designed with this in mind. For many systems the penstock consumes at least a quarter of the total capital costs. As will be explained further, because we had such a long required length of penstock, the cost amounted to over half of our estimated capital costs. Important features of the penstock which were considered included length, friction losses occurring in the penstock, cost of the pipe, whether it will be buried or above ground, and the physical characteristics of the penstock.

The length of the penstock depended greatly on what type of scheme (storage vs run-of-river) was chosen. Once a run-of-river system was selected for this project, two run-of-river designs were possible. Both schemes diverted the water at a point in the Black Rock Brook right before a fairly steep elevation drop occurred, so that the greatest difference in head could be taken advantage of. Supply to the turbine was located at point where the terrain began to level out. The difference in head from diversion to the point of supply to the turbine was 85 meters. Both options passed through this amount of head, and thus would have generated the same amount of power. Because both designs would generate the same amount of head and power, the defining factors under consideration were the length of penstock required and which would be physically and financially more feasible.

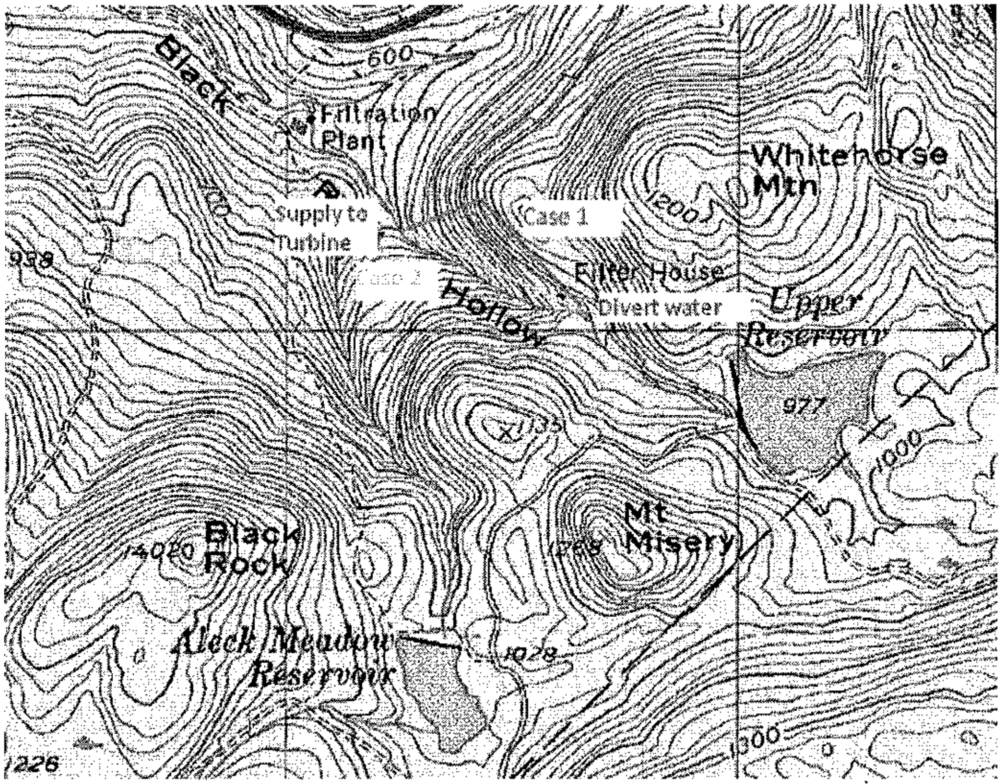


Figure 6. Two options for configuration of the penstock; Case 1 and Case 2.

Of the two designs being considered, case one diverted the water, ran along a topographic contour line for approximately 322 meters, then dropped down at a point in the landscape when the slope was steepest. Where the penstock dropped down the slope, the length was 182 meters. In addition to the portion running along the contour line, the total length of penstock for this scheme was 504 meters. The second option under consideration consisted of running the penstock parallel to the brook between diversion and reintroduction to the brook. There is an existing path along this length that the penstock could be located on or near. There is also a pipe running below this path. The buried pipe belongs to the town of Cornwall, and carries the town's water supply. The buried pipe gets water from the Upper Reservoir and delivers the water to the town's filtration plant. Due to the already made path and the pipe being buried along here, the terrain was somewhat less rocky and would be the most accommodating portion to place a pipe. The total length of penstock for this option was calculated as

411 meters. The length of penstock was calculated by adding any horizontal portions to the square root of the sum of the squares of the head and horizontal distance measured during changes in elevation.

$$\text{Penstock length} = \text{horizontal distance} + \sqrt{(\text{map distance}^2 + \text{head}^2)}$$

Both schemes diverted and reintroduced the water at the same points, but differed in the paths between these two points. The option in which the penstock ran along the contour line and then dropped down to the turbine at the steepest drop in elevation would have been more desirable had the terrain of the area been forgiving enough to be able to construct a channel along the horizontal contour line. In the black rock forest, the bedrock was extremely shallow, and was exposed at many points. While shallow bedrock would mean that infiltration of water would be kept to a minimum, it also meant that for our hydropower design purposes, constructing a channel would be near impossible. To build a channel in this type of terrain would require extensive excavation, most likely through blasting through the bedrock. In weighing the options of the project, having to blast through the bedrock to build a channel was an unattractive and unlikely solution.

The fact that the bedrock was extremely shallow was an important terrain feature which affected many of our design considerations. In terms of the penstock, this meant that the portion along the horizontal contour line which would normally be a channel would have to be a closed pipe. At 322 meters, this horizontal portion was a significant contribution to the pipe length. If this extra horizontal distance of pipe did not have to be included, the length of penstock in which the pressure drop occurred in was 182 meters. This would have been much less than the other run-of-river option under consideration, which ran the penstock parallel to the brook and had a penstock length of 411 meters. However, because the scheme which ran along the contour line had to include the extra length of penstock along the contour line, the total length of penstock for that option came to 504 meters, almost 100 meters longer than the other option under consideration. While 411 meters of pipe seems like a very long length of pipe, 504 meters is even longer, and would not be beneficial for generating the same amount of head.

4.1.1(a) Friction Losses

Friction losses which occur in the penstock decrease the amount of power delivered to the turbine, and these losses are proportional to the length of the penstock. Friction losses were calculated using the equation

$$h_{wall\ losses} = (fL0.08Q^2)/D^5$$

f = friction factor obtained from Moody (Stanton) diagram

L = length of penstock over which pressure drop occurs [m]

Q = flow rate [m^3/s]

D = inner diameter of pipe [m]

This equation is the Darcy-Weisbach equation, commonly used in fluid dynamics[1]. Friction factors obtained from the Moody (Stanton) chart used, as well as the chart itself can be found in the appendix.

Losses were calculated for both of the possible penstock configurations. In the case where the penstock ran along the contour line, then along an elevation drop, the length over which the pressure drop occured was 182 meters, and this was the length used to calculate the friction losses. The head friction losses for this case were calculated to be 0.62 meters. For the alternate case under consideration, in which the penstock ran parallel to the brook, the length over which the pressure differential occurred was 411 meters. The friction losses calculated in this option were 1.39 meters. Losing 0.62 meters of 85 meters of head is 0.73%, and the loss of 1.39 meters of head would be 1.63%.

[1] Harvey 1993, p 124

4.1.1(b) Cost

With increase in penstock length also comes increased costs. At $179.55 per ten foot length, keeping the penstock to a minimum for cost considerations was very important. For the first option, in which the total length of pipe needed came to 504 meters (1,653 feet), this would require 166 ten foot lengths of pipe, amounting to a cost of $29,805, not including freight costs. For the second case, the length of penstock was 411 meters (1,348 feet), requiring 135 ten foot lengths of pipe, and cost $24,205, again not including shipping and handling costs.

Although the head losses in the second option were more than double the first option, taking all factors under consideration, the second case still outweighed the first. The price difference between these two options is $5,600. The difference in power due to friction losses of the two cases would be approximately 16.6 watts. This amounts to 0.92% of the total power. In the course of a full year, the case with the smaller penstock length would produce 96 kWh more due to less friction losses. This would amount to a savings of $8.64 per year. The difference in cost of the longer pipe length greatly outweighed the fact that its shorter penstock length would have less friction losses.

In addition, the longer penstock would be at a greater risk of damage, just due to the fact that it is longer and would have more exposure. The option with the total required pipe length of 504 meters would have a section of that pipe approximately following a contour line. Although a contour line is an average constant elevation, the terrain which the pipe would follow is by no means even and smooth. A path would have to be cleared, and this would be quite difficult, considering the dispersement of trees and large rocks in the area.

4.1.1(c) Burying the Penstock vs. Locating It Above Ground

Penstocks can either be buried or located above ground. Buried under ground, penstocks are not exposed to sunlight and are less likely to encounter contact by people, unless digging for some other project is necessary. However, if the penstock is buried and damage somehow occurs (through human or natural causes), it is more difficult to access and fix a buried pipe than one above ground. Also, during the winter, the penstock could possibly freeze in the very cold temperatures, and again, it would be much more difficult to address the problem in a pipe buried under ground versus one locate above ground.

Also, as previously mentioned, the bedrock was extremely shallow. If this fact prevented including a channel in the design of this system, it follows that burying a pipe would not be a feasible option either. The water supply pipe belonging to the town of Cornwall was buried along the same location which was considered for the penstock of this project, so it was a possibility to bury the penstock in this same area. The town's pipe being buried here would make it easier to dig a trench for the penstock. Cooperation with the town would be very important. The option of burying the pipe with consent from the town would have been furthered, but after weighing the pros and cons of burying the penstock, it was decided to locate the penstock above ground.

4.1.1(d) Physical Characteristics of the Penstock

The size (diameter) of the penstock was chosen to most easily interface with the other components of the hydropower scheme. A four inch diameter pipe would result in a water velocity inside the pipe of 0.52 meters per second (1.70 feet per second). This size pipe also was the most appropriate size for connection to the turbine.

The material of the penstock was either going to be galvanized steel or polyvinyl chloride (PVC). It is desirable to have the pipe material be as smooth as possible to decrease turbulence affects, but also to have a pipe that will be able to withstand the internal pressures and the external environment conditions, while keeping costs at a minimum. Much of the decision of what material pipe to use rested on our previous decision to locate the penstock above ground. Located above ground, the penstock is exposed to sunlight, rain, falling leaves (and other debris), etc. It is subject to general threats from the environment. The biggest concern was that, while the penstock would be in a pretty well shaded forest, there would still be random and substantially large patches where the penstock would be in direct sunlight. If the material of the penstock were to be PVC, there would be a very high potential of cracking and splitting of the penstock due to sun exposure. It was decided that a stronger pipe material was necessary, and galvanized steel was chosen.

Although galvanized steel is a rougher material than PVC, the difference between the two in friction losses turned out to be small. The indicator of the roughness of the pipe is a length called the "roughness value." This parameter is the average height of roughness on the pipe walls. The PVC pipe had a roughness value of 0.01 millimeters, and the galvanized steel pipe had a roughness value of 0.15 millimeters (Harvey 1993, p 125). The steel pipe had a roughness value fifteen times as large as the PVC pipe, but because this was on the order of millimeters, it became almost negligible in the calculation of friction losses. The PVC pipe incurred friction losses of 1.18 meters, and the losses in the steel pipe were 1.39 meters. The difference of losing 0.21 meters of head over an overall 85 meters of head definitely did not outweigh having to repair and replace the PVC penstock much more frequently than the steel pipe. It was concluded to use galvanized steel pipe for the type of penstock material.

4.1.1(e) Final Penstock Decisions

After weighing all options and factors contributing to the penstock, the layout, length, location, size, material, and cost of the penstock was designed. Between diversion from the brook to supply to the turbine, the penstock would run approximately parallel to the brook. The total length of penstock required came to 411 meters. The penstock would be located above ground. The inner diameter of penstock would be 4 inches. The material chosen for the penstock would be galvanized steel. The cost for this type, diameter, and length of penstock would be $24,205.

4.1.2 Design of the Other Civil Works (Harvey 1993, pg 81-83, example 3.3.1)

The penstock is one of the most important components of the design of a hydropower system, but there are other components under the civil works which contribute to the cohesive design of the project. Other parameters of the design in the civil works include the weir, headrace, spillway, and forebay tank.

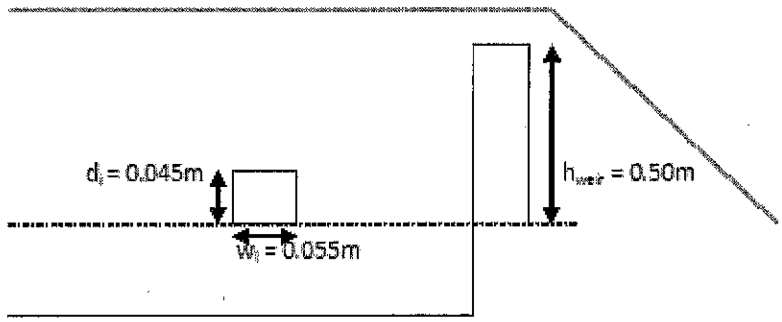


Figure 7. Dimensions of weir and intake as seen looking into the intake.

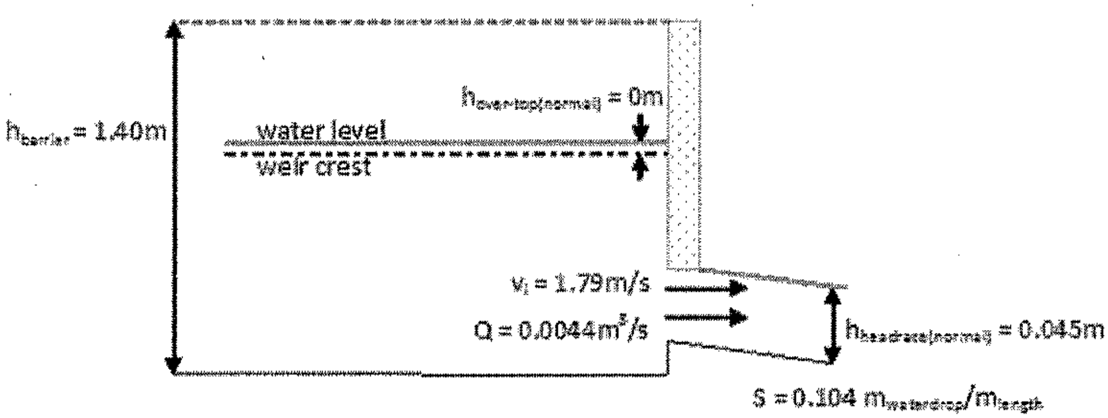


Figure 8. Headrace dimensions, seen from upstream of the weir during normal flow conditions

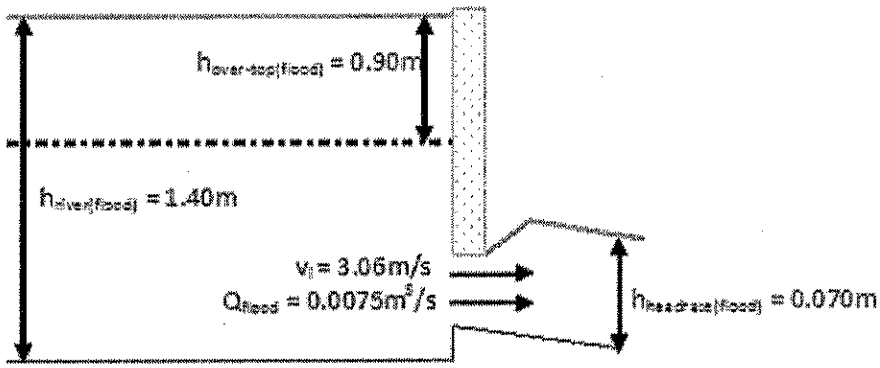


Figure 9. Headrace dimensions, seen from upstream of the weir during normal flow conditions.

4.1.2(a) Weir

The length of the weir is determined by the width of the brook. Since the weir must span the width of the brook in order to control the desired amount of flow, the width of the brook sets the length of the weir. The width of the brook at the desired point of diversion was measured during a site visit, and was measured as 2.5 meters. The weir height must be at least as high as the intake depth. Though the weir must be reasonably higher than the intake, it is very undesirable to set the height of the weir too high. This would cause an unnecessary excess of water to be stored upstream of the weir. Since unnecessary flooding upstream of the weir should be avoided, it is important to give the weir a height that will be enough to divert water to the intake, but not too high.

For this project, an initial weir height of 1 meter was chosen. After performing initial calculations for the intake, headrace, spillway, etc it was found that is was not necessary to have a weir as high as 1 meter. It would also result in having very tall headrace barriers. The weir height was then set at 0.5 meters.

4.1.2(b)Intake and Headrace

4.1.2(b.1)Flood conditions

The intake is where the water diverted by the weir enters the hydropower scheme. Once it has gone through the intake, the water flows through the headrace. The headrace is a channel which connects the intake to the spillyway and siltbasin. The velocity of the water in the headrace is relatively fast. The headrace also helps control the water during flood conditions.

As exemplified by disastrous cases where barriers were not properly designed, it is very important to choose a flood flow that would ensure safety during extremely high flow conditions. The average design flow was 0.0044 cubic meters per second. From the range of historic data available, the maximum hour flow recorded was 3.42 cubic meters per second. This is 777 times our average design flow, an even higher estimate than recommended by literature (Harvey, pp 81).

4.1.2(b.2) Intake barrier

During normal flow conditions, it is assumed that the water upstream of the weir is at the same height of the weir. Therefore, the height of water above the weir, $h_{over\text{-}top(normal)}$ is zero. The important $h_{over\text{-}top}$ is during flooding conditions, as this will determine the proper height of headrace barriers. Using the chosen flood flow, the length of the weir, and the weir coefficient of discharge, the height of water above the weir during flooding conditions could be determined. The weir coefficient of discharge is a characteristic of the weir crest shape chosen. The weir crest can be sharp-edged, broad with sharp edges, round, broad with round edges, round overfall, or roof-shaped. The chosen weir crest for this project was broad with rounded edges. The weir discharge coefficient for this shape weir is 1.6. The maximum height of water over the weir could then be calculated according to the equation

$$h_{over\text{-}top(flood)} = [Q_{flood}/(c_w L_{weir})]^{2/3}$$

Q_{flood} = Flood flow

c_w = Weir coefficient of discharge

L_{weir} = weir length

With our design conditions, the height of water over the weir during flood flow would be 0.90 meters. Summing the height of water over the weir during flood flow with the height of the weir gives the required height of the intake barriers. For this project, the intake barriers would be 1.40 meters high.

4.1.2(b.3) Intake dimensions

Next, the dimensions of the intake were calculated. Several iterations of calculations were performed to obtain a reasonable headrace width and depth. By setting the depth of the intake, the velocity of the water through the intake could be found. Using this velocity and the average design flow rate, the width of the intake was calculated. The velocity of the water as it passed through the intake was calculated using

$$v_i = c_d \mathrm{sqrt}[2g(h_{r(normal)} - h_{h(normal)}]$$

c_d = coefficient of velocity

$h_{r(normal)}$ = height of water upstream of the weir during

normal conditions = h_{weir}

$h_{h(normal)}$ = height of water into headrace = depth of intake

The coefficient of velocity is a factor which takes into account the turbulence which the water encounters as it passes through the intake. It usually ranges from 0.6 for a sharp-edged intake, to around 0.8 for a carefully finished aperture. Allowing for a sharp-edged intake, a coefficient of velocity of 0.6 was used (Harvey 1993, p 82).

The width of the intake could then be found using the fact that the area of the intake multiplied by the velocity is equal to the flow rate. The area of the intake is the intake depth multiplied by the intake width. Therefore, the intake width is

$$w_i = Q/(d_i*v_i)$$

w_i = intake width

Q = average design flow

d_i = intake depth

v_i = velocity through intake

Several iterations were made so that the width and depth were not too different from one another. It would not be desirable to have an intake depth of a few centimeters and the width be orders of magnitude larger. Through these iterations, a depth of 0.045 meters and a width of 0.055 meters was decided upon.

4.1.2(b.4) Headrace Slope and Width

As mentioned previously, the velocity through the headrace is somewhat fast. This is so that the water is able to sweep silt, leaves, and debris from the headrace and does not let the material accumulate and clog the headrace. The velocity through the headrace is set at a certain value; the headrace slope and width are calculated in a way to ensure the desired velocity. The velocity chosen to be maintained within the headrace was 1.50 meters per second. This value was close to the velocity of the water through the intake, so the change from the intake to headrace would not be too abrupt. Also, this velocity would be fast enough to generate enough force to move silt and such from the headrace to the forebay.

The width of the headrace could then be calculated in a method similar to how the width of the intake was calculated. During normal conditions, the flowrate through the headrace is going to be the same as through the intake (0.0044 cubic meters per second). The height of water in the headrace is equal to the depth of the intake (0.045 meters). The area of the headrace (headrace width multiplied by headrace depth) is the flowrate. Rearranging for the headrace width:

$$w_h = Q/[v_h * h_{h(normal)}]$$

Q = average design flow

v_h = velocity of water in the headrace

$h_{h(normal)}$ = height of water in the headrace during normal flow conditions = d_I

Under our given conditions, the width which the headrace should be was calculated as 0.065 meters.

The headrace must be sloped correctly to keep the water flowing at the desired velocity. To find the slope as a function of the desired velocity and size, the following equation was used:

$$S = [(n * v_h)/R^{0.667}]^2$$

n = roughness value

R = wetted perimeter = $(w_h * h_h)/(w_h + 2h_h)$

The roughness value is the roughness value for the material of the headrace. The value for concrete, which is what the headrace would be constructed of, is 0.015. To maintain the desired velocity of 1.50 meters per second would require a slope of 0.1008 meters of water drop for each meter of headrace length.

4.1.2(b.5) Height and Velocity of Flow in the Headrace During Flood Conditions

During high flow conditions, the amount of water forced through the intake will increase, increasing the height of water flowing in the headrace. To obtain the values for the height of the water in the headrace during flood flow, two equations were solved simultaneously. The two equations used were the discharge orifice equation, and the second was Manning's equation.

Discharge orifice equation: $Q_{hflood} = d_h*w_h*c_d*sqrt[2g(h_{r(flood)} - h_{h(flood)})]$

Q_{hflood} = flow of water in the headrace during flooding conditions

$h_{r(flood)}$ = height of brook water during flooding conditions

$h_{h(flood)}$ = height of water in headrace during flooding conditions

It is significant to note that Q_{flood} here is not the same as the stream flood flow.

Manning's equation: $Q_{flood} = h_{h(flood)}*w_h*(S^{0.5}/n)*(w_h*h_h)/(w_{h(flood)}+2h_h(flood))^{2/3}$

The discharge orifice equation and Manning's equation were set equal to each other, and iterated with different values of $h_{h(flood)}$ until unity was obtained. The predicted height of river water in the headrace during flood conditions was calculated to be 0.069 meters. This indicates the minimum height that the headrace walls must be between the intake and spillway. The headrace must be able to control the full flow of water from the intake during flood conditions, up until the water reaches the spillway. The excess flow, which is the flowrate in the headrace during flooding conditions subtracting the normal flowrate, will be removed by the spillway.

4.1.3 Flood Spillway

The spillway allows excess water in the headrace to overflow and be rediverted back to the brook. The spillway crest is set at a height equal to the height of water in the headrace during normal conditions (0.045 meters). This ensures that water needed by the system will not be lost, but that flows which would overwhelm the system can be rerouted safely.

The length of the spillway is determined a function of how much water needs to be diverted during a minor flood. A minor flood is estimated as 1.5 times the normal flow conditions. This was calculated to be 0.00506 cubic meters per second. The flowrate through the spillway is the difference between the flowrate of water in the headrace during normal conditions and the flowrate of water during the minor flood conditions. The standard weir equation was used and rearranged to obtain an equation for the length of the spillway.

$$L_{spillway} = (Q_{minorflood} - Q)/[c_{w,s}(h_{h(minorflood)} - h_{spillway})^{1.5}]$$

$Q_{minorflood}$ = flowrate in headrace during minor flood conditions

$c_{w,s}$ = weir coefficient for the spillway

$h_{h(minorflood)}$ = height of water in headrace during minor flood conditions

$h_{spillway}$ = height of spillway crest

The weir coefficient used for the spillway was 1.6. The length of the spillway found was 0.74 meters.

4.1.4 Forebay Tank

The forebay tank is the small storage area which is a medium between the headrace and point of supplying water to the penstock. In some schemes, if space and surroundings permit, there can also be a silt basin before the forebay tank. In our scheme, it was chosen to have one tank, serving as a forebay tank and silt collection. The tank was sized taking into account the silt that would accumulate. The forebay tank must be deep enough to ensure that the penstock is fully submerged. Where the penstock joins the forebay tank there should be an air vent. This prevents collapsing of the penstock due to lower pressure within it.

Since the forebay tank is connected to the headrace, it must have tapered sides so that the flow is introduced somewhat gradually to a larger width. The widest width of the tank is called the width of settling. The tank width was set at 0.3 meters. With this set width, the length of the forebay tank at this width can be calculated. Along with the width, the length of settling is a function of the average design flow and the vertical velocity of silt particles (how fast the silt settles).

$$L_{settling} = Q/(w_{settling} * v_{vertical})$$

$w_{settling}$ = width of settling

$v_{vertical}$ = vertical velocity of particles

The vertical velocity is dependent on the average size of particles in the tank. For particles with an average size of 0.1 millimeters, the vertical settling velocity is 0.02 meters per second. The length of settling would then need to be at least 0.73 meters.

With the dimensions of the forebay tank, characteristics of silt collection can be investigated. If collected daily, the silt load would be 190 kilograms. This assumes a silt density approximately the same as sand, and a brook carrying capacity of 0.5 kilograms of silt per cubic meter of water.

Silt collection in the forebay tank would not be the only means of controlling debris in the system. Especially during the Fall, leaves travel with the brook. There would have to be a grate or some other type of barrier over the intake to stop leaves from blocking the intake. There would also be an inclined trash rack over the penstock.

4.2 Mechanical and Electrical Components

Once the water has been diverted by the weir, sent through the intake into the headrace, the forebay tank, and the penstock, it is supplied to the turbine. It is here that the kinetic energy of the water begins to be converted to electricity. Different types of turbines available include crossflow, Francis, Pelton, Turgo, and propeller turbines. The selection of the turbine depends on the shaft power, amount of head, and cost (if more than one type of turbine fits the system). The shaft power of the turbine can be calculated using

$$\text{Turbine Shaft Power} = e_{turbine} * g * Q * H$$

The turbine efficiency, $e_{turbine}$ is different for different types of turbines. Typical efficiencies are around 0.65 for crossflow turbines, 0.75 for the Pelton turbines, and 0.80 for Turgo turbines. Using the above equation, the shaft power calculated was 2.38 kW, 2.75 kW, and 2.93 kW for the Crossflow, Pelton, and Turgo turbine types, respectively[2]. With the shaft power and amount of head for the system, a nomogram was used to get a rough idea of what type of turbine to select. From the nomogram, a Pelton (single or multi jet) or Turgo turbine would be appropriate. Some turbines can also be used at variable flows, by changing a nozzle, or, for larger flows, by shutting some of the jets off.

Many of the details of a turbine's operation lie in the manufacturer's data. To investigate further

[2] It should be noted that the shaft power is higher than the average power calculated, because the average power calculated takes into account losses in efficiency from other parts of the scheme.

the type or turbine and its respective specifications, companies offering turbines for micro-hydro schemes were researched. Initially, a representative at Canyon Hydro Eric Melander had recommended a single nozzle Pelton turbine. However, this was based on a design flow chosen before the flow data had been properly analyzed. When the final design flow (0.0044 cubic meters per second) was chosen, it turned out to be significantly less than our first estimate (0.0327 cubic meters per second). This difference in design flow called for a turbine size smaller than the packages offered by Canyon Hydro. We were then referred to a representative Lee Tavener from Solar Plexus, an alternative energy company.

Given the design flow of 0.0044 cubic meters per second and 85 meters of head, the "Stream Engine" Turgo turbine was recommended. The turbine with its base measures 12" by 12" by 12," and would put out an average of 1.8 kilowatts. It also called for a four inch pipe, which perfectly fit the penstock design we had previously chosen. However, the electricity of the Stream Engine was put out in direct current (DC) power, and for the Black Rock Forest Consortium to be able to use the power would require the power to be alternating current (AC) power. The recommended turbine package included the necessary components to do so. The necessary parts and costs (not including the power house or electric tie-in) are as follows.

Turbine Costs

Stream Engine turbine	$	2,495.00
High-voltage option	$	275.00
Base assembly	$	450.00
Manifold	$	275.00
DC controls	$	650.00
Xantrex XW inverter panel	$	6,295.00
Step-down transformer	$	3,450.00
4 8G8D batteries	$	2,370.00
Freight (estimated)	$	500.00
Total Turbine Costs	$	16,760.00

Turbine Replacement Parts

Universal Nozzle	$	35.00
Bronze Turgo Wheel	$	825.00
Bearing Kit	$	35.00

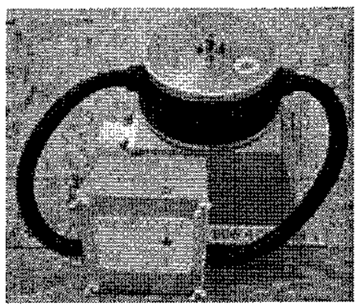


Figure 10. The "Stream Engine" Turbine, approximately 12"x12"x12", will produce an average of 1.8 kilowatts.

The electrical connection would be done through a private contractor as hired by the Consortium.

4.3 Basic Economic Analysis

The feasibility of a project lies not only in the design, but also largely in the financial demands of the project. A basic cost comparison was done as a preliminary analysis of the cost versus benefits of the project. The average annual electricity costs for the Black Rock Forest Consortium is $7,700 per year. The amount of power produced by the project would be 1.8 kW. Assuming this would be produced 8 months out of the year, 10,404 kWh per year would contribute to the electricity demand of the Black

Rock Forest Consortium. The Consortium uses 64,000 kWh per year on average, so the hydropower could contribute 16% of this demand. At this percentage of the cost, the hydropower project would contribute $1,251 per year in benefits.

The total principal cost for the turbine and penstock totaled $42,965. This included the total cost of the turbine package and the penstock. The construction costs (Of the civil works) and electricity tie-in would be done by private companies chosen by the Black Rock Forest Consortium. This portion of the capital costs would have a pay off period of thirty-five years.

Besides the principal costs, there would also be costs for operation and maintenance. Fortunately however, hydropower schemes require relatively low-maintenance. A cost for maintenance was estimated assuming that about two hours each week of maintenance would be done when the turbine was operating (8 months of the year) , and that labor would be paid at $15 per hour. The estimated annual costs of maintenance were found to be $1040. Replacement parts for the turbine were researched, and the average cost of yearly replacement parts was estimated at $200. Once installed, hydropower schemes are pretty resilient and easy to maintain. Also, the Black Rock Forest Consortium would be using all the energy produced by the scheme. None of the electricity produced by the system would be wasted. This means that the plant factor, which is the ratio of the amount of energy used to the energy installed, would be pretty high. It is desirable to have a high plant factor.

5. Conclusion

The design of a hydropower scheme was made for the Black Rock Forest and the feasibility of the design was investigated. Although the project is feasible from a physical standpoint and beneficial for educational purposes, it would not be recommended for the purpose of economic benefit. The amount of power produced would aid the electricity consumption of the Black Rock Forest Consortium. It would be partnered with the other alternative energy methods already employed by the Consortium. With the existing photovoltaic panels, and the soon to be installed wind turbine, the Consortium would have several types of alternative energy schemes working simultaneously. These contribute to the energy usage and costs of the Consortium, but what is more important to the Consortium is that these are also very beneficial educational tools. This does not mean that the economic reasoning is unnecessary. The cost of the proposed project is very high with a long pay off period. It is at the Consortium's discretion to implement the design.

Regardless of whether or not the Consortium chooses to use the design, many educational benefits have already been gained through this senior design project. Obstacles in obtaining data and learning what assumptions to make were especially important learning points. By nature, engineering is not a cookie-cutter profession, so it was important for us to learn that no project is perfect. It was a challenge to overcome the road blocks, but it became apparent that this is part of the long learning curve for engineers. It is important to make several iterations and explore all the options of a design. We also learned to appreciate more the importance of working on a team, where your calculations, reasoning, and sanity can be checked.

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