A Study of Hydroelectric Power:
From a Global Perspective to a Local Application

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ABSTRACT

As energy becomes the current catchphrase in business, industry, and society, energy alternatives are becoming increasingly popular. Hydroelectricity exists as one option to meet the growing demand for energy and is discussed in this paper. Numerous consideration factors exist when building hydropower plants; whether the concerns are global or local, each has been measured when discussing this renewable energy source. From environmental and economic costs of constructing such plants to proposing the addition of hydropower generating capabilities in Pennsylvania, the authors have used personal experience from field studies and intensive research to cover the topic of hydroelecticity.

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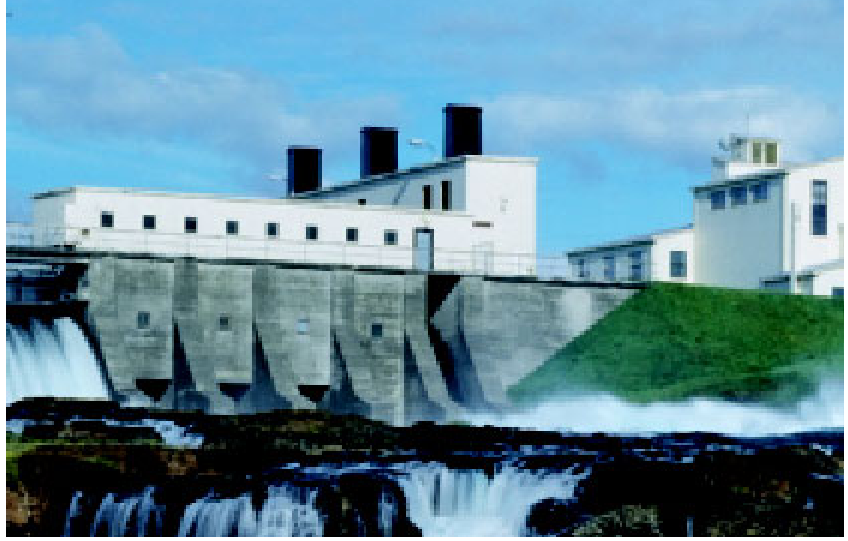
INTRODUCTION

Hydroelectric power captures the energy released from falling water. In the most simplistic terms, water falls due to gravity, which causes kinetic energy to be converted into mechanical energy, which in turn can be converted into a useable form of electrical energy. Ancient Greeks used wooden water wheels to convert kinetic energy into mechanical energy as far back as 2,000 years ago. In 1882 the first hydroelectric power plant was built in the United States using a fast flowing river. Humans in time began creating dams to store water at the most convenient locations in order to best utilize power capacity (Australia Renewable Energy). Additional engineering and structural changes have followed, providing for a much more complicated process in designing a hydroelectric power plant.

Hydroelectric power plants are categorized according to size. They fit into one of four different size ranges: Micro, Mini, Small, and Large. A Micro sized plant is one that generates less than 100 kW of electricity and would typically be used to power 1-2 houses. A Mini facility can serve an isolated community or a small factory by generating 100kW-1MW of electricity. A Small plant generates 1MW-30MW and can serve an area while supplying electricity to the regional grid. Lastly, a Large facility generates more than 30MW of power. Hydroelectric power accounts for about 10% of the total energy produced in the United States. The United States has the hydroelectric power potential to create 30,000MW of electricity by utilizing 5,677 undeveloped sites. This figure is based on environmental, legal, and institutional constraints. In Pennsylvania, we could potentially produce 5,525,646 MWhr of electricity annually; however, this would still only account for 3% of total electricity generation in the commonwealth.

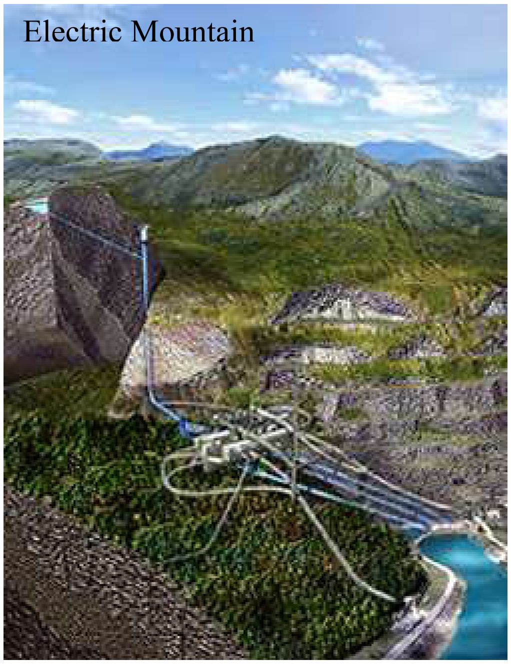
According to the US Hydropower Resource Assessment Final Report, there are a total of 104 projects that have a nameplate capacity of 2,218MW. One of these sites is the Flat Rock Dam in Manayunk, PA and this will be the site of our proposed hydroelectric power plant. It is located in Philadelphia County in the Delaware River Basin on the Schuylkill River and has a nameplate capacity of 2500kW. The canal and dam were first built in 1819 and rebuilt in 1977 after the dam collapsed. It is built on top of a naturally existing fall. The canal served to provide transportation for anthracite coal in the region by allowing boats to avoid the rapids; the water was also used to power mills on Venice Island, the island created by the canal. Boaters today use the "slack water" for recreation.

Research Expedition Sites


Irafoss Power Station

On the trip to Iceland and the Untied Kingdom we saw two hydroelectric power plants – Irafoss and the Dinorwig Electric Mountain. Irafoss is located in Iceland and is one of three power stations on the River Sog. The power plants were designed to provide electricity to the capital city of Reykjavik. The Irafoss station harnesses power from two falls, the Irafoss and Kistufuss, located on the lower Sog. The combined head of the two falls is 38 meters. When it went online in 1953 it utilized 2 turbines that each generated 15.5 MW. In 1963 an expansion of the plant added a third turbine, which has a generating capacity of 16.7 MW. Interestingly, one of the brands of generators they use is Westinghouse Electric, International Co. of the United States.

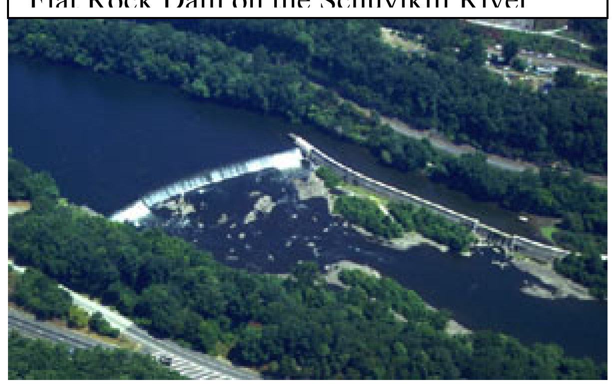
The Electric Mountain and Dinorwig Power Station in Wales in the United Kingdom is a pump-storage facility. The basic mechanics of a pump-storage facility is the use of two reservoirs at different altitudes. When water from the upper reservoir is released energy is generated. During non-peak hours when there is excess energy, the water is pumped from the lower reservoir back to the upper reservoir in order to fulfill peak demand once more. The picture on this page is a schematic of the inner workings of the plant. It can generate 1320MW of power and the pumps and turbines can reach maximum capacity in less than 16 seconds.


Electric Mountain

Scope of Project

While these are effective plants in their respective geographical areas, we wanted to research the effectiveness of building a hydroelectric power plant in a more local region of Pennsylvania. As mentioned earlier, we will take a look at the power potential of Flat Rock Dam in Manayunk, PA. We chose to address economic and environmental considerations and then propose a site in which to build a power plant and/or make modifications to the existing area. First, we wanted to address the general environmental concerns of any hydroelectric power plant. We decided to weigh the benefits and drawbacks to the flora and fauna affected by the construction of a plant. We

Flat Rock Dam on the Schuylkill River



then considered what economic impacts would be placed on the immediate area surrounding the plant, and also examined the historical and contemporary economics of the region. Finally, we studied the engineering specifications to satisfy as many environmental and economic concerns as is possible while building an efficient plant with the correct amount of power generation.

ENVIRONMENTAL EFFECTS

The implications of a hydroelectric power plant are quite varied and have significant effects on the physical, biological, and human environment in and near the site area. Complicating the matter even further, hydroelectric power generation is usually not the single reason why a dam is constructed along a river. A coal power station is not built for any other reason but power generation, whereas a hydroelectric dam may be constructed for other reasons such as flood control. Since hydropower is generated from the dam, however, some of the environmental implications should still be attributed back to the production of hydropower. As we have chosen a site with a pre-existing dam not all of the implications will directly apply. However, it is important to understand all the consequences of hydroelectric power and the existence of dams on rivers.

Physical

The physical environment is affected rather significantly by the construction of a hydroelectric power station. Both the river and ecosystem of the surrounding land area will be altered as soon as dam construction begins. Once the barrier is put in place, the free flow of water stops and water will begin to accumulate behind the dam in the new reservoir. This land may have been used for other things such as agriculture, forestry, and even residences, but it is now unusable. The loss of habitat may not seem severe but if this area was home to a threatened or endangered species, the dam construction could further threaten that species risk of extinction (Biswat, 1981).

The reservoir that has been rapidly filling up with water immediately begins filling up with sediment as well. Obviously the use of the reservoir is inhibited by sedimentation, so less water can be stored when more sediments fill in the bottom of the reservoir. The engineering problem with sedimentation is that less power is generated as the reservoir's capacity shrinks. Clean water stripped of its sediment load is now flowing downstream of the dam. This clean water has more force and velocity then water carrying a high sediment load and thus erosion of the riverbed and banks becomes problematic. Since this is unnatural and a form of "forced erosion" it occurs at a much faster rate then natural river process erosion to which the local ecosystem would be able to adapt. Environmentalists must work to slow down the water by creating barrages, although the effectiveness of these techniques is not exactly known (Thorndike, 1976).

An additional problem the sedimentation of the dam creates is erosion of the delta at the mouth of the river. All the sediments that are now trapped in the reservoir previously ended up in the delta. The Aswan Dam on the Nile River is a perfect example; the delta that is 1,000 km away is heavily eroded by winter waves. Sediments carried downstream during flood season would build the delta back up again before the dam was constructed. However, lacking sediments during flood season now, the delta is eroded nearly year round.

Oftentimes some of the most severe environmental implications of a project occur during the construction phase. The case of building a dam is no exception. Many new roads are built which requires the removal of vegetation and topsoil since dams tend to be built in undeveloped regions. The fill used for the dam often comes from the local area, in an effort to reduce transportation costs. The local impact becomes quite severe because of combining quarries with new roads and dam construction. Usually, environmental protection guidelines are followed during the construction phase to limit damage to the environment, even though damage cannot be completely avoided.

Another often-ignored environmental effect of dam construction is the impact on the microclimate level. Recent research has suggested that man-made lakes in tropical climates tend to reduce convection and thus limit cloud cover. Temperate regions are also impacted with "steam-fog" in the time period before freezing. In addition, depending on the size of the dam created, a moderating effect may be noticed on the local climate. Since water cools and warms slower then land, coastal regions tend to be much more moderate then land-locked regions in terms of temperature. Research has found in Hubei, China, that the Danjiankau Reservoir has increased winter temperatures by about one degree Celsius and decreased summer temperatures by the same amount (Biswat, 1981).

Finally, one of the least studied and most disputed physical impacts of dam construction is the possibility of inducing earthquakes. Some scientists believe that seismic activity can be attributed to the creation of dams and their adjacent storage reservoirs. The theory is that added forces of the dam along inactive faults seem to free much stronger orogenic tensions. Early research indicates that the depth of the water column may be more important to inducing earthquakes rather then total volume of water in the reservoir. While more research is needed on this subject several disasters such as the Koyna Dam in India seem to provide some truth to this theory (Biswat, 1981). While these impacts can be quite severe often they do not receive the attention of the biological impacts that people tend to associate more with animals like fish.

Biological

Animal and plant life are impacted significantly by the dam construction. As mentioned earlier the large scale flooding destroys a large area of habitat for animals and destroys an equally large number of plants. If the region was forested prior to the construction of the dam the timber is harvested before the flooding begins. Reservoirs that in the future will be used for recreation such as boating or fishing tend to be completely cleared of trees. In addition, in very cold climates such as Canada, deterioration of fully submerged trees occurs very slowly – increasing the likelihood that the trees must be removed first (Biswat, 1981). The impact of tree removal is more logging equipment around the dam site which of course increases roads and pollutants into the region.

Flora

Another negative biological impact of dams is the growth of aquatic weeds. Tropical and semi-tropical regions seem to have the largest problem with weed growth. In Surinam, Lake Brokopondo has become inundated with *Eichhornia crassipes*, which is commonly referred to as water hyacinth. In just four years the water hyacinth has covered more then fifty percent of the reservoirs surface. The impacts of weeds can be significant to water loss. More weeds growing in the reservoir result in a higher rate of evapotranspiration. Also, more water must be released for irrigation purposes to ensure that an adequate supply makes it to the lower reaches of the irrigation channel if there are weeds growing in the channel as well. The weeds will compete with fish for space and nutrients that are already under stress living in an unnatural setting.

Some disease rates such as malaria and schistosomasis tend to increase as weeds provide a very favorable habitat for mosquitoes and other invertebrates that spread these diseases. How do we contain these problems? The weeds can be controlled, although the task is often very difficult and expensive. In shallow water mechanical or manual clearing is by far the most effective. However, in deeper waters this is not an option and either chemical or biological means must be used to remove the weeds. Chemical herbicides work very well but bring about a whole new set of environmental hazards to organisms, humans and the ecosystem in general. The scariest part about using chemical herbicides is that their overall effect is generally not known until they have caused a problem. Finally, biological controls can be used to combat the weed problem. This involves using fish or other aquatic organisms to eat the weeds (Biswat, 1981). The process of weed control often works best when mixing the three techniques described above. While biological impacts receive a great deal of press and publicity so do the human-environmental impacts of hydroelectric power.

Fauna

Animals tend to get the most attention from the press and public in general when dam projects are proposed. In Africa, before the construction of the Volta Dam, rescue operations began to catch and transport as many animals as possible to safer areas. Some animals such as elephants, giraffes, and rhinoceroses are so large that this process is quite difficult and expensive. Environmental laws are not international; therefore when unique or rare habitats are involved the hope is that design or location changes can be made to save these habitats, but this does not always occur. The creation of the dam does however create a new larger habitat for some species of fish. For example when the Lake Nasser dam was created fish production increased nearly four- fold (Biswat, 1981). The news for fish during dam construction is far from all good, though.

For some kinds of fish the building of a dam makes completing their life cycle nearly impossible. Anadromous fish, such as salmon, are hatched upstream in a freshwater environment but spend their adult lives at sea in the salt water. The eel, a kind of fish classified as catadromous, is hatched at sea but spends much of its adult life in freshwater streams (Biswas 1981). Since these fish rely on streams and rivers to get to and from different environments, creating a dam makes a large roadblock for these animals to overcome. This is especially true in the Pacific Northwest in the United States. Without features such as fish ladders these fish would die off. However, even the fish ladders do not work perfectly and many fish die due to the dams.

There are a number of measures that can be taken to help minimize fish mortality at hydroelectric power plants. The most obvious step is to lower the number of fish that pass through the turbine. This can be accomplished by using better screens to capture the fish or establishing diversion passageways. A more complicated and emerging technology involves making “fish-friendly” turbines.

It is thought that gap sizes, runner-blade angles, wicket gate openings, overhang, and flow patterns are the components that most lead to fish injury. Pelton turbines, which are small turbines designed for high head installations cause nearly complete mortality of fish passing through. Kaplan, Francis, and Bulb turbines tend to be safer for small fish with mortality rates of only about thirty percent. These types of turbines have much larger areas of water passage. Kaplan turbines are thought to be the most fish-friendly of the conventional turbines. These turbines are used on the Columbia and Snake Rivers in the Northwestern United States and have a low mortality rate of just twelve percent. Scientists and engineers hope to work together to make changes to the design of turbines to ensure fish safety. Research is showing that reducing gaps might help fish pass through turbines safely. By reducing the gaps there should be less shear stress and grinding. However, it should be noted that all of this research is too preliminary to be positively sure. Scientists are researching whether the route of passage through a turbine has any impact on survival rates. However, at this point the data is mixed and no definite conclusions can be reached (Cada, 2001).

Humans

Often the most discussed topic of building a new hydroelectric power plant is the dislocation of large numbers of people. In China, for example, the Three Gorges Dam Project will force the dislocation of over one million Chinese people (China Online, 2000). While relocating may not seem problematic, consider the fact that many of these people come from small villages where different cultural values and beliefs are held and all of the sudden these villages are merged together in a new setting. Residents are forced to leave behind all their ancestral roots. This is especially troublesome in Africa where people have to leave behind gods, shrines, and graves of their ancestors, all of which are very important to the local culture (Biswat, 1981).

The human-environment is also positively impacted by such large-scale projects with flood control. A significant reason why the Three Gorges Dam was not stopped despite the environmental hazards was the benefits to those living downstream. The Chinese government claimed that over 15 million lives would be saved downstream with flood control measures being put in place (China Online, 2000). Some proponents of hydroelectricity have pushed the issue of increased recreation as a benefit to society. It is true that by turning a river into a lake a park can be built around the dam for campers, boaters and whoever else wants to use the lake. However, this may not be as beneficial as it seems in the United States. The United States already has a plentiful supply of lakes to use for recreational purposes but has few remaining rivers free of obstruction and still able to flow freely (Thorndike, 1976). Therefore, the recreational argument in favor of hydroelectric power is not very useful as many nearby residents will not want to see a free flowing river stopped in favor of a large reservoir.

While most of the environmental benefits to hydroelectric power are disputed, one is not. Hydroelectric power emits no air pollutants. A combined two billion tons of carbon dioxide are not emitted by burning fossil fuels thanks to hydroelectric power plants across the world.(Understanding Energy, 2003) While the environmental impacts of hydroelectric power are very far reaching and in some cases severe, they do not always receive the same amount of attention as the economic impacts. In the end, economics more often then not is the reason for the success or failure of a proposed project.

ECONOMIC ASPECTS OF HYDROPOWER

Economics is a branch of science concerning the distribution, production, and consumption of services and goods. Economics focuses on the financial aspects of a society on local, regional, and global scales. We need to learn about the economic structure and its function in order to fully understand (on a global scale) trade relations between countries, why and how (on a regional scale) a society works, and why (on a local scale) a business or factory fails or succeeds.

Thus when considering the construction of a hydropower plant in Pennsylvania it is necessary to have a basic understanding of the economics involved in building such a plant and how it would affect a local community economically. We also must consider the global economics of such a renewable energy source as hydroelectric. The global and local economics of hydropower will be explained throughout this analysis. The figures and statistics included in several surveys analyzed are too exhaustive and detailed to include in a regional economic analysis; thus we will examine the areas in which costs are high or low, without providing too many monetary examples.

<u>Global Hydropower Economics</u>

On a global scale, the majority of consumed energy is derived from oil. All forms of (other) energy sources are affected by oil prices; when oil prices are low, the demand for alternative energy is low. When oil prices are high, people turn towards alternative energy sources and are more likely to decrease their consumption of oil. This thesis was tested in the 1970s when the oil embargo was in place. Such energy forms as solar, wind, hydro, and nuclear increased in use; more plants were built, and a greater demand was placed on these renewables. This is a very important factor in considering globalization and the relations of countries. When the United States has a large dependence upon oil producing countries such as Venezuela, Kuwait, and Iraq, we are at the mercy of these countries' roller-coaster economies that fluctuate from day to day and remain unstable. The more dependent we are on a sole country the more vulnerable we become. Now, not only are we concerned with deriving energy resources from these countries, we are fully invested in assuring the stability of the economies, which requires enormous financial contributions on our part.

A national/regional economic factor which must be considered in the proposal of a hydroelectric plant is the effect on the Gross Domestic Product (GDP) of a country with consideration to the years of plant operation. The U.S. Commerce Department calculates GDP as a measure of total output of goods and services within the country based on the following items:

- Personal consumption
- Government expenditures

- Private investment
- Inventory growth
- Trade balance

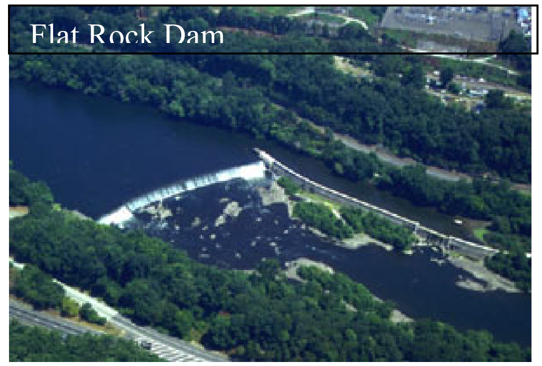
The GDP is calculated using a "chain-weighted" method. As deregulation increases business activity, relative prices for goods change quickly and dramatically. The "chain" system also recognizes that output for computers, telecommunications equipment and health services is growing much faster than other parts of the economy. The "chain" method forces the government to recalibrate the relative prices of these goods - and their relative importance to the economy - every year (USA Today).

A current thorough economic analysis of nationwide hydroelectric plant potential in the United States is available through a joint program between the U.S. DOE Office of Energy Efficiency & Renewable Energy, the Energy Information Administration, and The Idaho National Engineering and Environmental Laboratory. Using data across the United States, power plant sites were analyzed and assessed for economic cost and input to an area.

Local Hydropower Economics

When contemplating the local economics of a hydro plant, several things must be kept in mind: development, operating, and maintenance costs, and electricity generation. When evaluating a site, one must first consider whether it is already developed or not. If a dam does not exist, several imperative things to consider are: land/land rights, structures and improvements, equipment, reservoirs, dams, waterways, roads, railroads, and bridges. In an already developed area the only developmental costs that require consideration are structures, improvements, and equipment. Development costs may include factors for creating recreation, preserving historical and archeological sites, maintaining water quality, and lastly (but certainly not least) protecting fish and wildlife. Several graphical representations are available to demonstrate the increased costs associated with undeveloped sites. Operation and maintenance costs are considerably more exhaustive. They include water for power, hydraulic expenses, electric expenses, and rents.

<u>Flat Rock Dam Economics</u>



The site chosen for our current project is the Flat Rock Dam located in Philadelphia County Pennsylvania on the Schuylkill River, shown at right. This site is complete with a pre-existing dam; however, no electric generating power is present at the moment. In order to update the design and make amendments, we must understand the environment surrounding the area, as well as the economics of the process of maintaining the dam, distributing power, and providing employment opportunities. It is of interest to note that the town of Manayunk where the Flat Rock Dam is located was previously called “Flat Rock,” coined in 1810 because of an area of flat rocks in the Schuylkill River. Since its birth, the town has maintained its livelihood around the River as a means of travel and trade. By 1819, the completion of the Flat Rock Dam, had aided much in Manayunk’s prosperity and communication. Flat Rock Dam facilitated a difficult section of the Schuylkill River where "Rummell's Falls" was and had previously only been navigable when waters were high. It was in 1819 when the mills of Manayunk really started being built in large numbers and immigrants (mostly from England) began operating the mills. From an early time, the dam was a major leader in contributing to prosperity in Manayunk. Obviously jobs in conjunction or related to the dam were plentiful during the height of river travel and commerce. Lock operators, millers, and canalsmen were important occupations within the community.

In order to evaluate this site for a hydroelectric power plant, we must consider the fact that there is a pre-existing dam, the ownership of the dam (land use rights) and how much it will cost to modify and maintain the dam (covered in the site construction analysis). BAMR (The Pennsylvania Department of Environmental Protection's Bureau of Abandoned Mines Reclamation) has full ownership to the Flat Rock Dam. However, Lower Merion Township maintains a boat launch and picnic area that provides recreational access to the pool and dam. There is currently some controversy surrounding the use of powerboats in the pool area.

The debate surrounding the economics and environment of the dam provides us with the question of "Should the dam be used for maximum potential, or be maintained as is?" The dam has historically provided a means of livelihood; however, what is its future potential? The Flat Rock Dam was destroyed previously in a flood and rebuilt; the costs that accrued with rebuilding were substantial. Were they unnecessary? The dam is currently not providing any means of power to the residents of Manayunk. Historically it proved to be an invaluable asset to the community. When considering extensive technological improvements, the provision of power would not be of high interest to the citizens of Manayunk who now receive their power from Philadelphia based electric providers. Though the Flat Rock Dam is a historically important site, many environmental problems mentioned above have contributed to the idea that it should be removed. Alternatively, if the dam was not removed but rather upgraded and built upon as an energy provider for the community, what would it look like and what would the details involve? We will turn to these questions in the remaining section.

BUILDING A HYDROPOWER PLANT

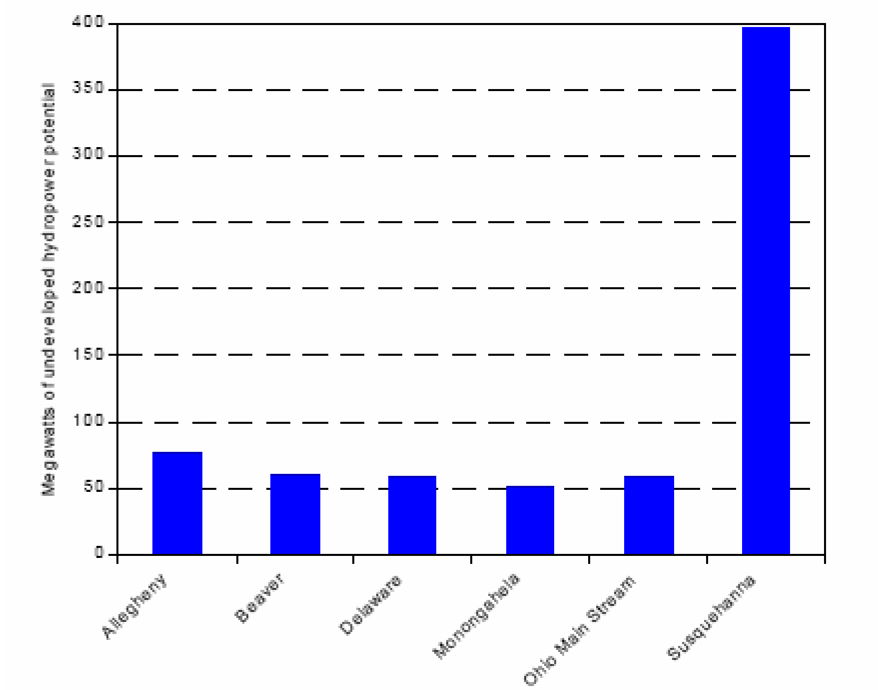
The task for this project now turns to developing a site for a proposed hydropower plant. With the environmental and economic knowledge gained above, a suitable location was found that will satisfy the numerous variables in designing a power plant. Now we will review our choice of the Flat Rock Dam site for engineering considerations. One factor that must be kept in mind is that the location will need to be geologically sound; the underlying rock formations must have the capability to hold the weight of a dam.

The surrounding area must also be able to hold the water behind the dam in a manner that will not extensively damage the surrounding area scenically or physically. This is a major concern that must be addressed since most of Pennsylvania's rivers have been developed.

The daily routines of the general public require a fluctuating need for power, with the most electricity used during 'peak demand' times. Meeting peak demand is one issue that has been addressed by electricity providers with generally the same response. Most producers of electricity in the United States use natural gas-fired power plants to quickly meet the surge; however, combustion of natural gas produces numerous gasses that pollute the environment. Using water instead of natural gas to meet this demand decreases reliance on non-renewable fuel and does not produce volatile organic compounds, SOx or NOx emissions.

The United States Department of Energy subcontracts the Idaho National Engineering and Environmental Laboratory (INEEL) to study hydropower throughout the country. Information on all possible sites in each state has been compiled and listed with numerous site variables taken into consideration when determining available power at each location. In Pennsylvania, major rivers available for damming include the Allegheny, Beaver, Delaware, Monongahela, Ohio, and Susquehanna. **Figure 1**, below, summarizes the power available in each river.

Figure 1: Potential power in Pennsylvania rivers (Conner, 1997)



INEEL provides a detailed listing of sites on each river available for power generation. The Flat Rock Dam in Manayunk, PA proved to be a solid match with the environmental factors described below. (Flat Rock Dam Information).

<u>Consideration Factors</u>

The Flat Rock Dam site was chosen based on the characteristics from the INEEL database. These nineteen points are detailed in Table 1, below, and provide a solid argument for developing hydropower in Manayunk. Sustainability Factors range from a low of 0.1 to 0.9, with 0.9 having the least impact on land and being the most likely for development.

Table 1: INEEL PESF (INEEL)

Project Environmental Sustainability Factors	
Wild/Scenic Protection	0.9
Wild/Scenic Tributary or Upstream/ Downstream Wild/Senic Location	0.9
Threatened/Endangered Fish	0.9
Cultural Value	0.9
Fish Presence Value	0.9
Geologic Value	0.9
Historic Value	0.9
Other Value	0.9
Recreation Value	0.75
Scenic Value	0.9
Wildlife Value	0.9
Threatened/Endangered Wildlife	0.9
Federal Land Code 103	0.9
Federal Land Code 104	0.9
Federal Land Code 105	0.9
Federal Land Code 106	0.9
Federal Land Code 107	0.9
Federal Land Code 108	0.9
Federal Land Code 198	0.9

The Manayunk location in Southeastern PA remains an ideal candidate for construction of a hydropower dam. Effects of building the generating station near the dam are minimal; environmental impacts are especially low. Actually constructing this facility will require precise knowledge of the site and dam dimensions.

Construction

When designing a hydroelectric power plant a number of elements and equipment need to be taken into consideration. Dam size, retention basin size and depth, inlet valves, weir and control gates, penstock length and diameter, turbines, generators, transformers and excitation equipment, and efficiency all have to be examined. Elevation or head and stream flow have to be established as well. In our case we can achieve a maximum drop of 21 feet or 6.4 meters and have an average stream flow of 9070 cubic feet per second or 256.83 cubic meters per second. According to the INEEL hydropower resource database we can achieve 2500kW of electric power. Using this information we can find out how much of the flow we need to achieve 2500kW. The following is the calculation:

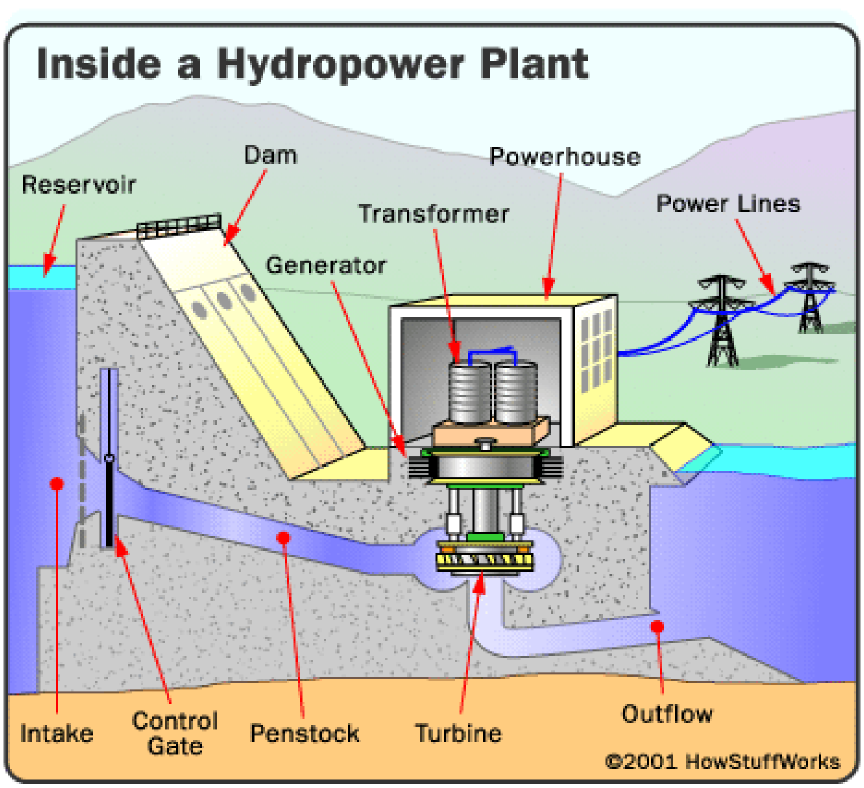
Power equation: P=eHQg	<u>Solve for Q:</u>
P=electric power output in KW	2500=(0.81*6.4*Q*9.81)
e=efficiency (.81 for small scale hydroplants)	Q=49.15 m^3/s
H=Head in meters	%of flow used: 49.15/256.83=19%
Q=design flow, m^3/s	
g=gravitational constant, 9.81m/s^2	

According to the calculation we will only need to divert 19% of the stream flow to create the needed amount of electricity. We will not divert much more than the needed 19% as to not take away from the aesthetics of the dam and the rushing water. As this is a highly recreational area, we do not want to greatly disturb the environment.

<u>Plant Specifications</u>

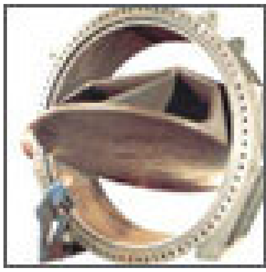
The next task is actually choosing the specifications for the plant. The main dam is already in place, as we chose a site with a pre-existing dam. However, in the spot where our power plant will sit, there will be a head of 21 feet. The dam is an integral part of the power plant. It is what controls the water; by damming up the water, the amount of water used to create power can be determined. When building a power plant from the ground up, the building of the dam would be the first step. Building a dam requires much research, approval, time, and money. The geology of the area must be taken into account (as was mentioned previously) so to avoid collapse due to geologic activity such as earthquakes. The size of the retention basin, or where the water sits behind the dam, must also be considered. Flow rate of the river and sediment load must also be determined in order to establish an estimate on the dam lifetime. If the river carries a large sediment load, sediment will build up behind the dam more quickly than if there is less of a load. There are also mitigation techniques for removing sediment that can be considered for the project to lengthen lifetime. The dam also must go through an extensive approval and permit process. The Federal Energy Regulatory Commission is the main government body that provides the license for such a project as a hydroelectric power plant. Building dams and power plants takes a lot of time and money as well. There is always the chance of holdups and delays and sometimes projects can even run out of money. By choosing a site with an existing dam, all that needs to be done is some modifications – a choice that will require a lot less time and money (Woodward).

Upon approval and completion of the dam the actual power plant needs to be built and each component fashioned. The following picture is a schematic of a power plant and all of its component parts.



Intake

The intake is the entrance to the system for the water. The inlet valves and control gate control how much water is going to enter the system. There are a number of different inlet valve designs. Three types that TOSHIBA Company of Japan offers are spherical or rotary, butterfly,



and thruflow. GE Power Systems offers butterfly and rotary designs, as well as 6 others. We chose a thruflow (pictured left) as it has less head loss and leakage than the butterfly and rotary (pictured right) designs (GE Power Systems and TOSHIBA).

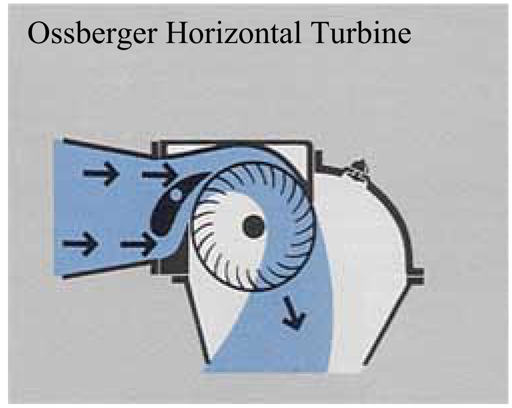
The next step is the intake weir and where the water will enter the power plant. The weir also is responsible for diverting the water. It also must help keep solid material from entering the system. Three examples of intakes are the side intake without weir, side intake with weir, and bottom intake. A side intake without a weir is relatively cheap requiring no complex machinery, but asks for regular maintenance and repairs. At low flows very little water will be diverted so this type of intake is not suitable for rivers with great fluctuations in flow. The side intake with weir is a set-up in which the weir can be partially or completely submerged in the water. This design requires little maintenance but low flow cannot be diverted properly. The weir is completely submerged in the third design, the bottom intake. It is very useful with fluctuating flows and allows excess water to pass over the weir. With our location and dam we would use the side intake with weir design. It allows us the most flexibility and will be the most effective and economic (Micro Hydropower Basics).

Penstock

The Penstock is a tunnel that caries the water from the intake to the turbines. There are a number of factors to consider when deciding which material to use in the building of the penstock. They are: surface roughness, design pressure, method of jointing, weight and ease of installation, accessibility of the site, terrain, soil type, design life and maintenance, weather conditions, availability, relative cost, and likelihood of structural damage. When considering soil type, you have to choose a material that will not be degraded or eroded by the surrounding soil. Economically speaking, the penstock can account for up to 40% of total cost of the plant. This is why efficient planning is critical (Micro Hydropower Basics).

Turbines

Once the water flows down the penstock, it passes and turns the turbines. There are a number of different models of turbines depending on which company the turbine is purchased from. However, there are common designs. Two different types of turbines are impulse and reaction turbines. Impulse turbines include Pelton, Turgo, cross-flow, and multi jet Pelton designs. Reaction turbines include the Francis, propeller, and Kaplan turbines. There are different designs specified for different head values. High head requires either a Pelton or Turgo, medium head calls for cross-flow, multi-jet, or Francis, and low head requires cross-flow, propeller, or Kaplan. In our situation, we have medium head so the cross-flow is going to be the best design for us. Also, the cross-flow has to be horizontal and that will work the best with our set up. "Also called a Michell-Banki turbine a cross-flow turbine has a drum-shaped runner consisting of two parallel discs connected together near their rims by a series of curved blades. A crossflow turbine always has its runner shaft horizontal (unlike Pelton and Turgo turbines which can have either horizontal or vertical shaft orientation)" (Micro Hydropower). A specific type of cross-flow turbine is the Ossberger. It has an efficiency of up to 86%. It can operate in head ranges of 1-200m and with water flows of 0.025-13 cubic meters per second.



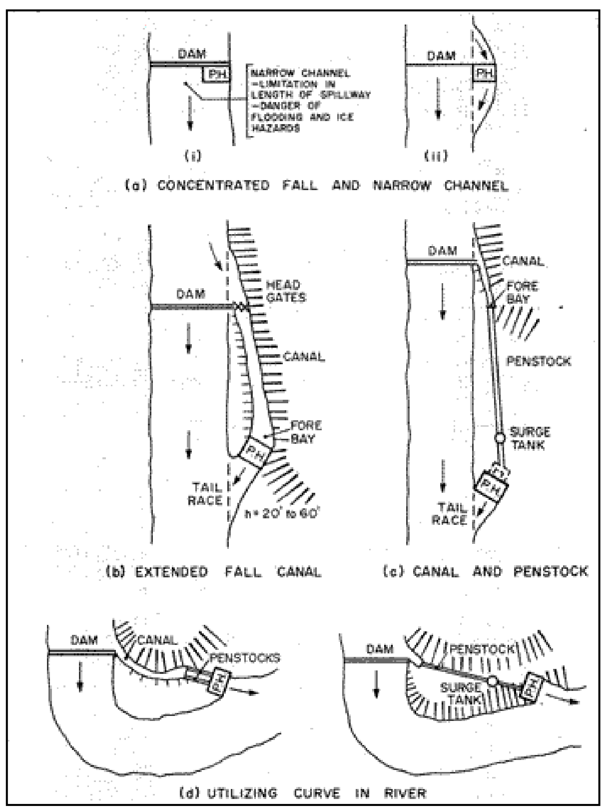
Due to these specifications, we will need to use four turbines at our location to generate the maximum amount of power. Ossberger turbines are relatively slow moving at 20-80 revolutions per minute. "The Ossberger turbine is a radial and partial admission free stream turbine. From its specific speed it is classified as a slow speed turbine. The guide vanes impart a rectangular cross-section to the water jet. It flows through the blade ring of the cylindrical rotor, first from the outside inward, then after passing through the inside of the rotor from the inside outward. Where the water supply requires, the Ossberger is built as a multi-cell turbine. The normal division in this case is 1:2. The small cell utilizes small and the big cell medium water flow. With this breakdown, any water flow from 1/6 to 1/1 admission is processed with optimum efficiency. This explains why Ossberger turbines utilize greatly fluctuating water supplies with particular efficiency" (Ossberger).

Generators, Transformers, and Electricity Production

Water flows through the turbine to turn it and its shaft to create mechanical energy that is transformed into electrical energy by the generators and transformers. Depending on the company purchased from, there are a number of different models of generators. Two main designs are the vertical or horizontal arrangements (TOSHIBA). There are four major components to the generator; they are the shaft, exciter, rotor, and stator. The water turns the turbine, which turns the shaft and causes the exciter to send an electrical current to the rotor. The rotor is comprised of a series of large electromagnets that spin inside the stator, which is a tightly wound coil of copper wire. This process creates a magnetic field, which creates an alternating current, AC, by the moving of electrons. The transformer then converts the AC to a higher voltage current. The generator and transformer sit in what is known as the powerhouse. This is the main building of the hydropower plant. From the powerhouse there are four main wires that leave. There are three for the three phases of produced power and a ground wire common to the other three. These power lines are connected to the regional power grid (How Stuff Works, inc). The last component to the system is the tailrace. The tailrace is simply the pipelines that carry the water back out to the river.

Development Configuration

The diagram on the right shows some development configurations that the river and canal with the powerhouse can have. Based on how the dam and canal look in our scheme, design b, the extended fall canal, looks to be the best option. This design allows us to best utilize our given area.



CONCLUSION

After investigating the various impacts of a hydroelectric plant, we were able to determine the feasibility of implementing a hydroelectric plant at the Flat Rock Dam. Since most environmental concerns stem from construction of the dam, this location would not be greatly affected by the installation of a hydropower generating facility. Also, taking into the consideration that this is a highly scenic site of recreational value, we will only partially disrupt the volume of water over the dam, using about 19 percent of the flow. Most environmental concerns are mitigated by the fact that the area is already partially developed for a project such as this.

Economically speaking, this project would benefit the community by providing energy as well as employment opportunities. Construction costs are relatively low, especially when compared to the high price of building a new dam. Because the residents of Manayunk will benefit, any economic costs incurred by the building of a hydropower plant are justified.

Based on the environmental and economic considerations discussed, Flat Rock Dam would be a promising potential site for a hydropower plant. It would be classified as a small hydro project generating 2.5 MW of electricity. All materials involved in the construction would be readily available. There are many companies that service small hydropower plant projects and component parts would be easily accessible. Overall, the Flat Rock Dam site appears to be a good candidate for a hydropower plant due to its environmental, economical, and engineering feasibility. Through our research we have seen numerous applications of hydroelectric power from large scale projects to those on a smaller scale. From international power generating stations to a potential local opportunity, we have realized the vast opportunities of this natural resource.

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