Chapter 8 MICRO HYDRO ENERGY RESOURCE

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CHAPTER 8 MICRO HYDRO ENERGY RESOURCE

8.1 Introduction

On Earth, water is constantly moved around in various states, a process known as the Hydrologic Cycle. Water evaporates from the oceans, forming into clouds, falling out as rain and snow, gathering into streams and rivers, and flowing back to the sea. All this movement provides an enormous opportunity to harness useful energy. Prior to the widespread availability of commercial electric power, hydropower was used for irrigation, and operation of various machines, such as watermills, textile machines, and sawmills. Compressed air was produced from falling water, which could then be used to power other machinery at a distance from the water.

Hydro power continued to play a major role in the expansion of electrical service around the world. Hydro electric power plants generate from few kW to thousands of MW and are much more reliable and efficient as a renewable and clean energy source than fossil fuel power plants. This resulted in upgrading of small to medium sized hydro electric generating stations wherever there was an adequate supply of moving water and a need for electricity. As electricity demand was increasing Mega projects of Hydro power plants were developed. The majority of these power plants involved large dams which flooded big areas of land to provide water storage and therefore a constant supply of electricity. In recent years, the environmental impacts of such large hydro projects are being identified as a cause for concern. It is becoming increasingly difficult for developers to build new dams because of opposition from environmentalists and people living on the land to be flooded. Therefore the need has arisen to evaluate smaller scale hydroelectric power plants in the range of mini and micro hydroelectricity power plants. Table 8.1 shows a classification of hydroelectric power plants based on power generation.

Table 8.1 Classification of Hydro Plants [H8]

Large	All installations with an installed capacity of more than 1000 kW.
Small	All installations in the range between 500 to 1000 kW.
Mini	Capacity between 100 to 500 kW
Micro	Hydropower installations with a power output less than 100 kW

8.2 *How is Hydro Electricity Generated?*

Most hydroelectric power comes from the potential energy of dammed water driving a water turbine and generator. In this case the energy extracted from the water depends on the volume and on the difference in height between the source and the water's outflow. This height difference is called the head. The amount of potential energy in water is proportional to the head [H1, H2]. To obtain very high head, water for a hydraulic turbine may be run through a large pipe called a penstock, see Figure 8.1.

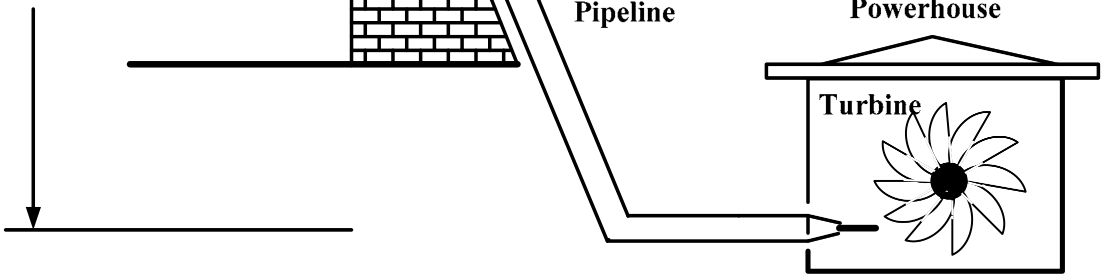

Figure 8.13. Hydroelectric Power Generation Diagram.

For a volume of a fluid which is not in motion or is in a state of constant motion, Newton's Laws states that it must have zero net force on it - the forces going up must equal the forces going down. This force balance is called the hydrostatic balance. The net force over one point is due to the fluid weight [H9]. In Figure 8.2 we can see the linear variation of pressure by water height, and then the basic hydrostatic equation is:

$$P = P_0 + \gamma h \tag{8.2.1}$$

Where γ = Specific Weigh of the fluid (lb/ft^3),
P_0= Atmospheric pressure (lb/ ft^2),
h = Height (ft).

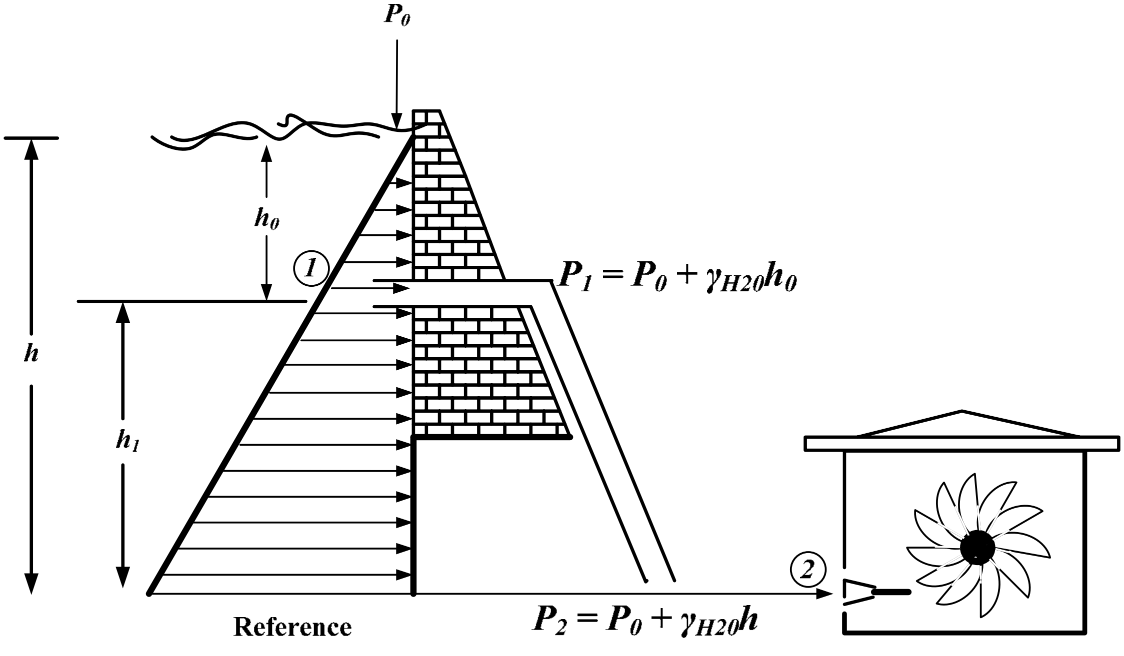

Figure 8.2. Variable Pressure by Water Height.

To determine the hydraulic power we use the Conservation Energy Law which states that the energy can neither be created nor destroyed. This means that the total energy of a system remains constant. The total energy includes potential energy due to elevation and pressure and also kinetic energy due to velocity. Considering the system in Figure 8.2 we can state that the total energy in point 1 is:

$$E_t = Wh_1 + W\frac{P_1}{\gamma} + \frac{1}{2}\frac{W}{g}v_1^{\,2} = cons\tan t \tag{8.2.2}$$

$$E_t = Wh_1 + W\frac{P_1}{\gamma} + \frac{1}{2}\frac{W}{g}v_1^{\,2} - H_l = Wh_2 + W\frac{P_2}{\gamma} + \frac{1}{2}\frac{W}{g}v_2^{\,2} \tag{8.2.3}$$

Equation 8.2.3 is also known as Bernoulli's Equation, where

Where v_1, v_2 = velocities at point 1 and 2 respectively (ft/s),
H_l = Represents losses in pipe (ft).

From Equation 8.2.3 we determine that the velocity at the intake of the system point 1 is the same as the velocity in point 2, but not necessarily the same at the turbine input. This is due to the use of nozzles at the pipe end in some cases.

The Continuity Equation states that for steady flow in a pipeline, the weight flow rate (weight of fluid passing a given station per unit time) is the same for all locations of the pipe [H9, H10].

To illustrate the significance of the continuity equation, refer to Figure 8.3, which shows a pipe in which fluid is flowing with a weight flow rate W that has units of weight per unit time. The pipe has two different-size cross-sectional areas identified by stations 1 and 2. The continuity equation states that if no fluid is added or withdrawn from the pipeline between stations 1 and 2, then the weight flow rate at stations 1 and 2 must be equal.

$$W_1 = W_2 \tag{8.2.4}$$

$$\gamma A_1 v_1 = \gamma A_2 v_2 \tag{8.2.5}$$

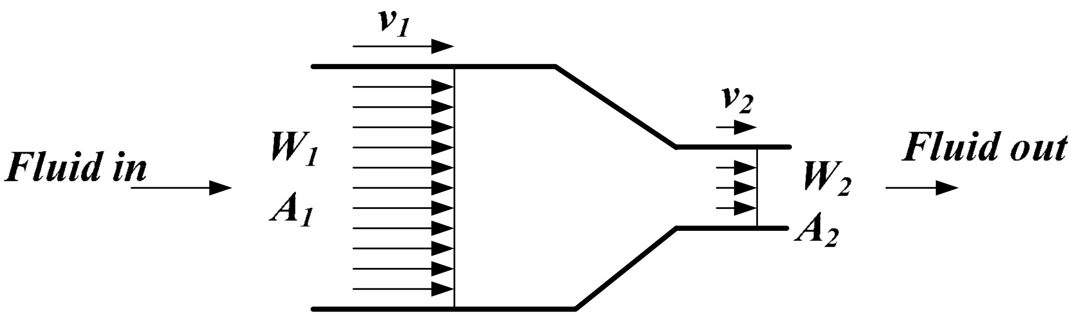

Figure 8.3. Continuity of Water Flow.

Where γ = Specific Weigh of the fluid (lb/ft^3),
A = Cross-sectional area pipe (ft^2),
v = Velocity of fluid (ft/s).

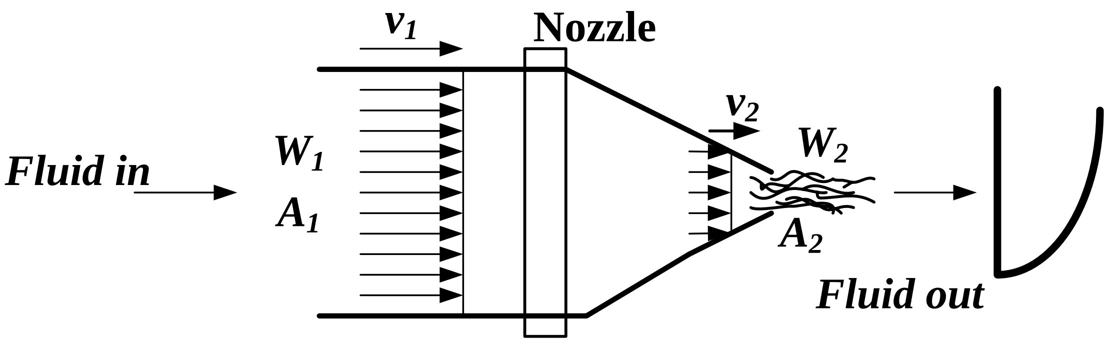

Figure 8.4. Nozzle Velocity Variations.

Once we have determined the velocity at point 1 in Figure 4, applying Equation 5 we find the velocity at point 2, then we know,

$$F = P(lb/ft^2).A(ft^2)$$

$$energy = F(lb).l(ft) = PAl$$

$$Power = \frac{energy}{time} = \frac{PAl}{t} = PAv$$

$$Caudal(Q) = Av,$$

$$HydraulicPower(ft.lb/s) = P(lb/ft^2).Q(ft^3/s)$$

$$HydraulicHousepower = HHP = P(lb/ft^2).Q(ft^3/s).\frac{1hp}{550\,ft.lb/s} \tag{8.2.6}$$

8.3 Head and Flow Measurements

The first step in designing a microhydro system is to evaluate ther water resource by measuring the head (vertical drop) and flow of your stream. These two measurements are necessary to calculate the energy potential of your stream. Also measurements must be made of pipeline and electrical transmission line length (from turbine to home or battery bank) to take into consideration the system losses.

The head and flow will determine the system's pipeline size, turbine type, rotational speed, and generator size. Nothing can be done until head and flow are measured [H3]. Inaccurate measurements of head and flow can lead to produce less electric power and increase the total costs of the system.

8.3.1 Head Measure

Head can be measured as vertical distance (feet or meters) or as pressure (e.g., pounds per square inch, Newton's per square meter). Regardless of the size of the stream, higher head will produce greater pressure and therefore higher output at the turbine.

An altimeter can be useful in estimating head for preliminary site evaluation, but should not be used for the final measurement. Low-cost barometric altimeters can reflect errors of 150 feet (46 m) or more, GPS altimeters are often less accurate. Topographic maps can be used to give an estimate of the vertical drop of a stream. But two methods of head measurement are accurate for design: direct height measurement and water pressure [H3].

8.3.1.1 Direct Height Measurement

To measure head, a laser level, a surveyor's transit, a contractor's level on a tripod, or a sight level can be used. The steps to do the measurement are: a) Subtract height of level from measurement on stick to determine head for each leg; b) Repeat multiple legs from intake location to turbine location; and c) Add the head of each leg together to determine total head. Figure 8.5 illustrates the method.

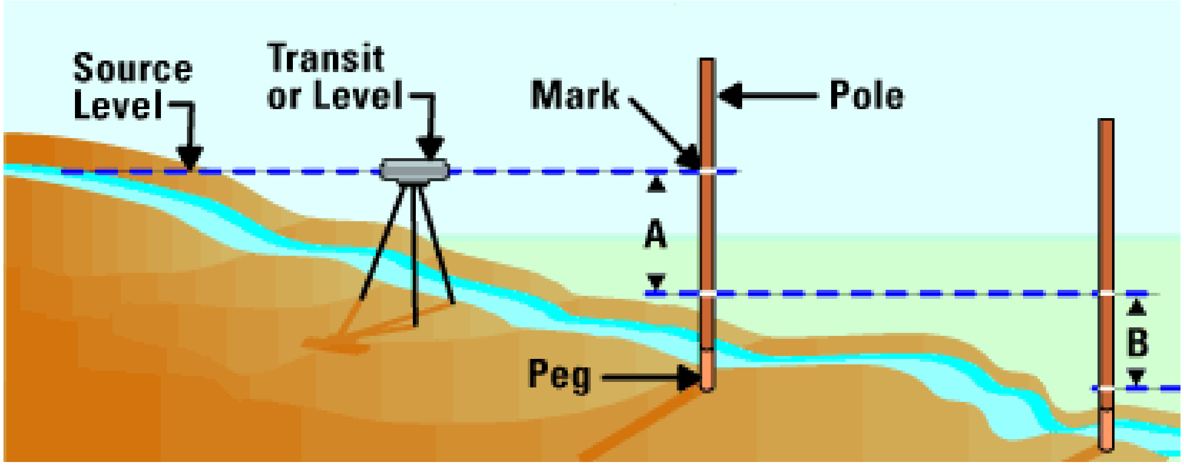

Figure 8.5. Measuring Downstream Source: EA Energy Alternatives Ltd.. Used with permission and as a courtesy from the owner [H12].

8.3.1.2 Water Pressure Measurement

For short distances, flexible plastic tubing can be used to measure head. This method relies on the constant that each vertical foot of head creates 0.433 psi of water pressure. By measuring the pressure at the bottom of the hose, the elevation change can be obtained [H3].

8.3.1.3 Net Head

Net head is the pressure at the bottom of the pipeline when water is actually flowing to the turbine. This will always be less than the gross head measured, due to friction losses within the pipeline. Water flow figures are needed to compute net head. Longer pipelines, smaller diameters, and higher flows create greater friction. A properly designed pipeline will have a net head of 85 to 90 percent of the gross head measured.

Table 8.2. Head Loss in PVC Pipe [H3]*

Design Flow in Gallons per Minute & (Cubic Feet per Second)														
Pipe Size (in.)	**25 (.05)**	**50 (0.1)**	**100 (0.2)**	**150 (0.33)**	**200 (0.45)**	**300 (0.66)**	**400 (0.89)**	**500 (1.1)**	**600 (1.3)**	**700 (1.5)**	**800 (1.78)**	**900 (2.0)**	**1,000 (2.23)**	**1,200 (2.67)**
2	1.28	4.65	16.80	35.70	60.60	99.20								
3	0.18	0.65	2.33	4.93	8.36	17.90	30.60	46.10	64.40					
4	0.04	0.16	0.57	1.23	2.02	4.37	7.52	11.30	15.80	21.10	26.80	33.40		
6		0.02	0.08	0.17	0.29	0.62	1.03	1.36	2.20	2.92	3.74	4.75	5.66	8.04
8				0.04	0.07	0.15	0.25	0.39	0.50	0.72	0.89	1.16	1.40	1.96

*In feet per 100 feet of pipeline

8.3.2 Flow Measure

The second major step in evaluating a site's hydro potential is measuring the flow of the stream. Stream levels change through the seasons, so it is important to measure flow at various times of the year. The use of the stream by wildlife and plants must also be considered. Applicable permits should be sought from local agencies overseeing natural resources and wildlife preservation. Never use all of the stream's water for your hydro system [H3].

Flow is typically expressed as volume per second or minute. Common examples are gallons or liters per second (or minute), and cubic feet or cubic meters per second (or minute). Three popular methods are used for measuring flow: container, float, and weir.

The container fill method is the most common method for determining flow in micro hydro systems. Identify a spot in the stream where all the water can be caught in a bucket. If this is not possible, a temporary dam can be built that forces all of the water to flow through a single outlet. Using a bucket or larger container of a known volume, use a stopwatch to time how long it takes to fill the container [H3].

With the Net Head and Flow measurements one can determine the power output of a stream engine, as shown in Table 8.3. Higher head and flow bring out more power; however a right selection of the turbine is the critical stage of de design process and will determine the output capacity.

Table 8.3. Output Power (Watts) of Stream Engine [H5].

	Flow Rate (Liters per second)						
Net Head (m)	**0.67**	**1.33**	**2.50**	**5.00**	**6.67**	**7.50**	**9.50**
3		20	50	90	120	130	150
6	15	40	100	180	230	250	350
15	45	110	230	450	600	650	800
30	80	200	500	940	1100		
60	150	400	900	1500			
90	200	550	1200				
120	300	700	1500				
150	400	850	1900				

8.4 Hydro System Components

8.4.1 Water Diversion (Intake)

The intake is typically the highest point of a hydro system, where water is diverted from the stream into the pipeline that feeds the turbine. A water diversion system serves two purposes: provide a pool of water to create an air-free inlet to the pipeline, and remove dirt and debris [H2, H5]. See Figure 8.1.

Diversion System refers to the means used to divert water from the source and transport it to your turbine. There are various methods for diverting and transporting the water, but diversion systems can be grouped into two basic types: Open and Closed systems. Matching the correct type of diversion system to a particular style of micro hydro turbine is critical to the optimal performance of the turbine. In general, impulse turbines (which produce power primarily from head pressure) will utilize a closed diversion system. Reaction turbines (which produce power primarily from water volume) will normally work best with an open diversion system.

8.4.1.1 Closed Diversion Systems

In a closed diversion system (such as a pipe), the system is sealed and water is isolated from direct gravitational forces while in the pipe. The water surface at the inlet to the pipe is the point at which gravity directly affects the water, and is, therefore, the starting elevation for the system head. Closed diversion systems work well for developing high pressure head with relatively low water flow volumes [H11].

8.4.1.2 Open Diversion Systems

In an open diversion system (such as a canal), the water along the entire diversion system is directly exposed to gravity. In an open diversion system, then, the last point at which gravity directly impacts the water is the water surface directly above the turbine inlet. Thus, the starting elevation for the pressure head is often the water surface directly above the turbine. The ending point for pressure head is the turbine impeller. Open diversion systems work well for supplying large volumes of water to the turbine with low friction losses [H11].

8.4.2 Pipeline (Penstock)

The pipeline, or penstock, not only moves the water to the turbine, but is also the enclosure that creates head pressure as the vertical drop increases. The pipeline focuses all the water power at the bottom of the pipe, where the turbine is. In contrast, an open stream dissipates the energy as the water travels downhill [H6]. One or more bypass valves may be necessary. These should be installed at low points in the pipe to help get the flow going and to flush out air bubbles. Figure 8.6 shows an example of the location of a pipeline relative to point of use.

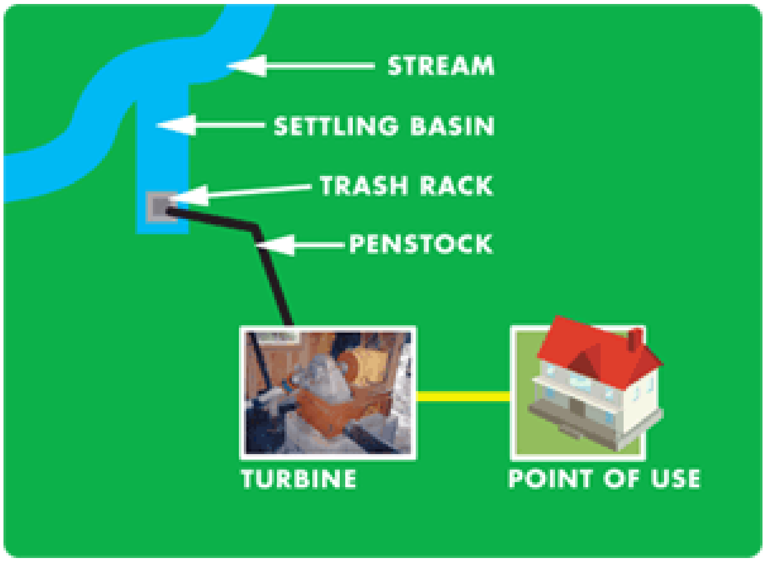

Figure 8.6. Pipeline Example Source: EA Energy Alternatives Ltd.. Used with permission and as a courtesy from the owner [H12]

8.4.3 Turbines

Water turbines generate very reliable power with very simple designs. Some kind of runner or propeller is attached to a shaft that operates an alternator to generate power when water turns the runner. There many types of turbines that include three major styles: impulse turbines, reaction turbines and submersible propeller turbines, each suitable for different types of water supplies [H11].

8.4.3.1 Impulse Turbines

These turbines are most efficient for high head and low flow sites. A narrow water jet impulse the blades of the turbine creating a momentum. A system using an impulse turbine drives the water into a pipeline. This pipeline leads the water to a nozzle, where the kinetic energy of the water is used to push or impulse the blades coupled to an alternator.

Sites with 25 ft of head or more are used commonly for these types of turbine, which are very simple and inexpensive. The Pelton and Turgo turbines are classified as impulse turbines. Figure 8.7 shows an impulse turbine system.

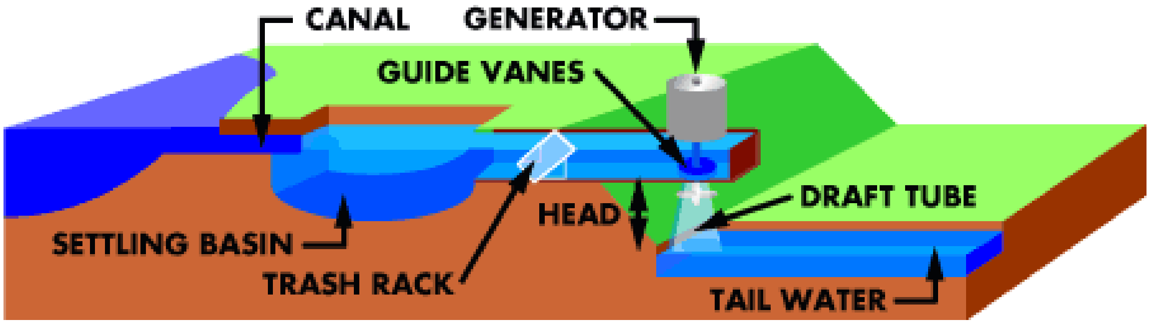

Figure 8.7. Impulse Turbine Hydro System
Source: EA Energy Alternatives Ltd.. Used with permission and as a courtesy from the owner [H12].

Figure 8.8 present an example of Pelton Turbines configuration, while Figure 8.9 shows the Turgo Turbines.

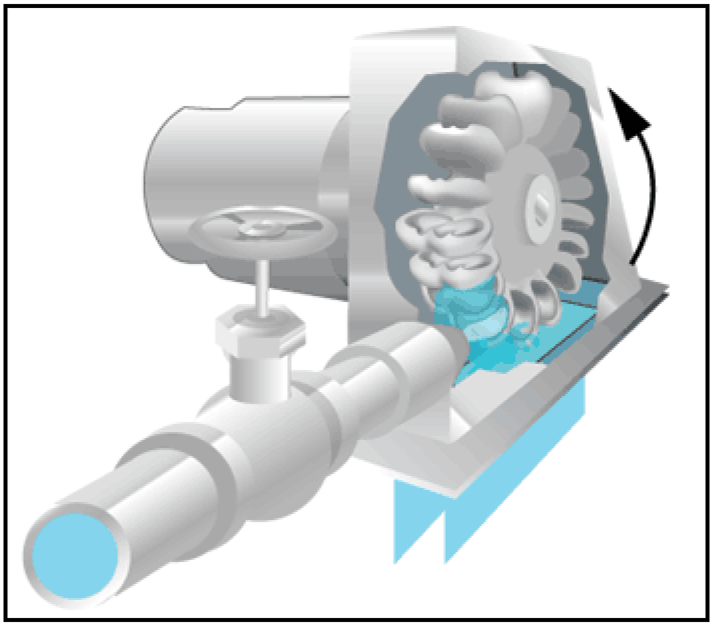

Figure 8.8. Pelton Turbines Configuration
Source: EA Energy Alternatives Ltd. Used with permission and as a courtesy from the owner [H12].

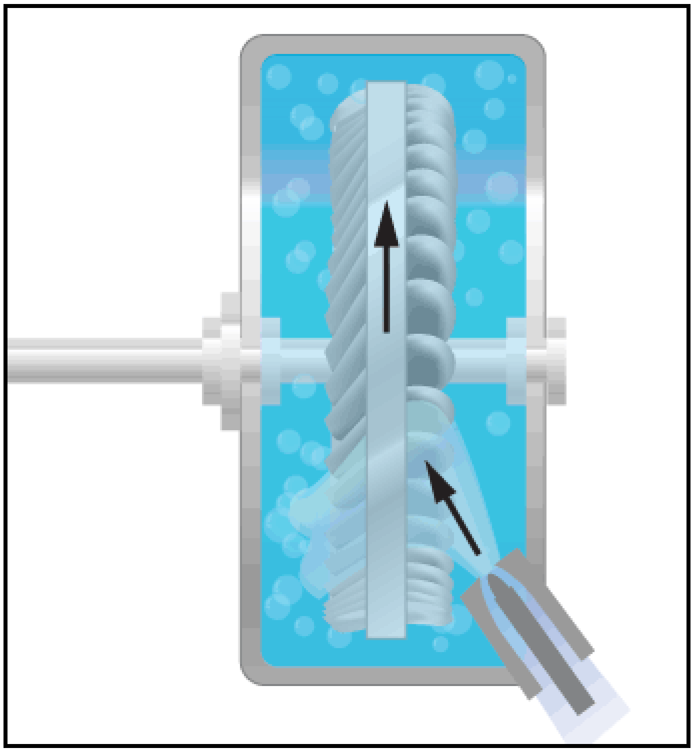

Figure 8.14. Turgo Turbines Configuration
Source: EA Energy Alternatives Ltd. Used with permission and as a courtesy from the owner [H12].

8.4.3.2 Reaction Turbines

Reaction turbines have a better performance in low head and high flow sites. In reaction turbines, there are no nozzles as such. Instead, the blades that project radially from the periphery of the runner are formed and mounted so that the spaces between the blades have, in cross section, the shape of nozzles [H2, H5, H11].

The efficiency of the reaction turbines is higher than the impulse turbines, and has slower operating speed. However, reaction turbines require a greater flow to operate. The Cross Flow, Kaplan and Francis are examples of reaction turbines. Figure 8.10 shows a sketch of a reaction turbine.

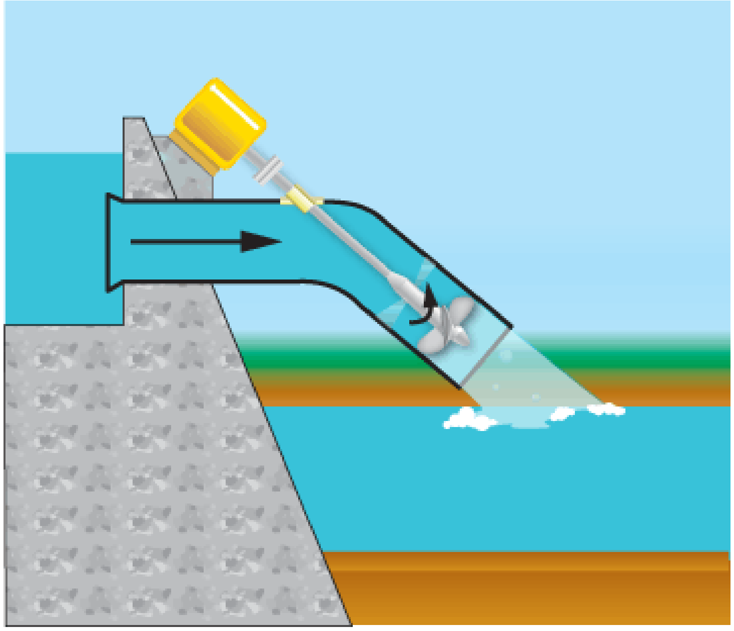

Figure 8.10. Reaction Turbine
Source: EA Energy Alternatives Ltd. Used with permission and as a courtesy from the owner [H12].

Table 8.4 and Figure 8.11 are useful to select the correct type of turbine according to the specifications of the site.

Table 8.4. Turbine Type Selection [H13, H14].

Turbine Style	**Head (H) Range in Meters**
Kaplan and Propeller	$2<H<40$
Francis	$10<H<350$
Pelton	$50<H<1300$
Banki-Michell	$3<H<250$
Turgo	$50<H<250$

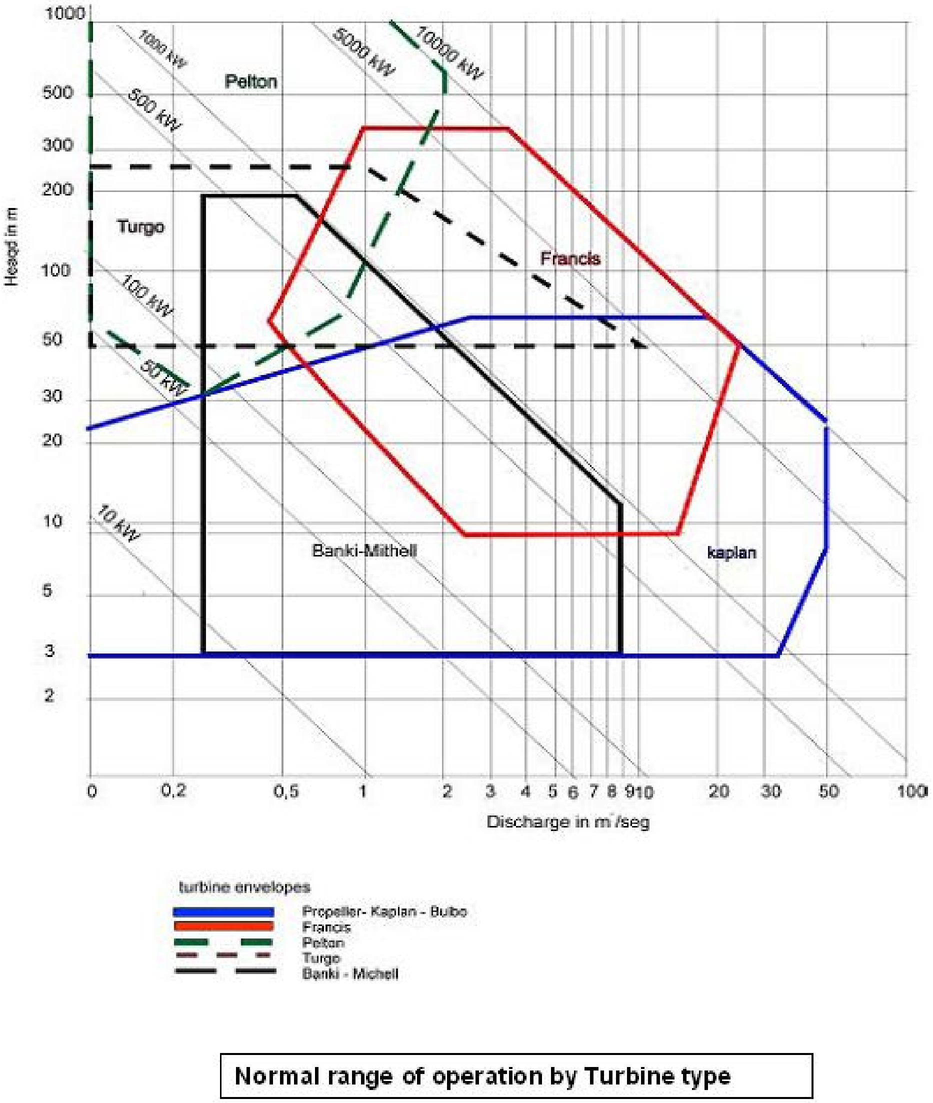

Figure 8.11. Turbine Application Chart
Source: St. Onge Environmental Engineering, PLCC. Used with permission and as a courtesy from the owner [H13].

8.4.4 Drive System

The drive system couples the turbine to the generator. At one end, it allows the turbine to spin at the velocity that delivers the best efficiency. At the other end, it drives the generator at the velocity that produces correct voltage and frequency (frequency applies to alternating current systems only). The most efficient and reliable drive system is a direct, 1 to 1 coupling between the turbine and generator. This is possible for many sites, but not for all head and flow combinations. In many situations, especially with AC systems, it is necessary to adjust the transfer ratio so that both turbine and generator run at their optimum (but different) speeds. These types of drive systems can use gears, chains, or belts, each of which introduces additional efficiency losses into the system. Belt systems tend to be more popular because of their lower cost [H2].

8.4.5 Generator

Alternators with brushes work well, and are still used for their low cost. The major drawback is that the alternator's brushes need regular replacement. These days, brushless permanent magnet (PM) alternators are available, and are a better choice, since they eliminate the need for brush replacement. In addition, brushless permanent magnet alternators perform at higher efficiencies, increasing the hydro system's output [H4].

8.4.5.1 Alternator Configuration

Utilizing different wiring configurations (field configurable by a qualified technician), the alternator can produce 12V, 24V, 48V, or 120V (3 phase AC) [H5].

Standard Configuration: Extra Low Voltage (12V, 24V, 48V). If system is extra low voltage and the distance from the hydro turbine site to the balance of the DC system is minimal, use the standard factory DC turbine configuration. The alternator wiring is configured for the desired voltage and a rectifier converts the AC to DC. The Rectifier is incorporated into the turbine control so that DC power of the correct voltage is provided.

Externally Rectified: Extra Low Voltage (12V, 24V, 48V). If the system is extra low voltage but the distance from the hydro turbine site to the balance of the DC system is far enough that wire loss becomes a concern, the Rectifier can be removed from the turbine control box and installed externally at the end of distribution wire. The voltage produced by the alternator is the same, but it is travelling as 3-phase AC to the rectifier so the current is distributed over three wires instead of two.

Long Transmission: Low Voltage (120V). A low voltage unit is typically required because the power needs to be transmitted a long distance from the hydro turbine site in which case the alternator is wired for 120V (3-phase AC) for easier transmission of the power.

8.4.6 Controls

AC Controls: Pure AC hydro systems have no batteries or inverter. AC is used by loads directly from the generator, and surplus electricity is burned off in dump loads (usually resistance heaters). Governors and other controls help ensure that an AC generator constantly spins at its correct speed. The most common types of governors for small hydro systems accomplish this by managing the load on the generator [H2, H5, H6].

With no load, the generator would “freewheel,” and run at a very high rpm. By adding progressively higher loads, the generator is slowed down until it reaches the exact velocity for proper AC voltage and frequency. As long as you maintain this level of design load, electrical output will be correct. A governor performs this action automatically.

By connecting a hydro system to the utility grid, energy can be drawn from the grid during peak usage times when the hydro system does not provide enough power, and feed excess electricity back into the grid.

DC Controls: A DC hydro system works very differently from an AC system. The generator output charges batteries. A diversion controller shunts excess energy to a dump load. DC systems make sense for smaller streams with potential of less than 3 KW [H2]. AC systems are limited to a peak load that is equivalent to the output of the generator. With a battery bank and large inverter, DC systems can supply a high peak load from the batteries even though the generating capacity is lower.

Figure 8.12 shows a typical diagram of Battery Based Hydro Power systems.

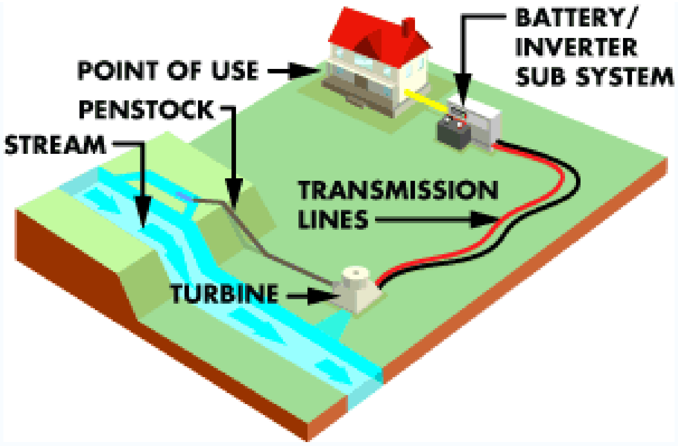

Figure 8.12.Diagram of Typical Battery Based Hydro Power System Source: EA Energy Alternatives Ltd. Used with permission and as a courtesy from the owner [H12].

Series charge controllers, like those used with solar electric systems, are not used with hydro systems since the generators cannot run without a load (open circuit). This can potentially damage the alternator windings and bearings from over speeding. Instead, a diversion (or shunt) controller must be used. These normally divert energy from the battery to a resistance heater (air or water), to keep the battery voltage at the desired level while maintaining a constant load on the generator [H2].

8.5 Available Micro hydropower Technology

8.5.1 Pelton Turbine

- Can produce over 1.5 kW of power
- Operates most efficiently on high head (Above 25 ft)
- Effective operation with ultra low flow (3GPM and grater)
- Reliable, year- round electricity at low cost

8.5.2 Stream Engine Turbine

- Can produce over 1kW of power
- Operates efficiently on low head (down to 5 ft)
- Easy installation and low maintenance

8.5.3 Water Baby Turbine

- Operates efficiently on ultra low flow (3 GPM)
- Super lightweight and compact design
- High quality turbine at low price

8.5.4 The LH-1000 Turbine

- Produces up to 1 kW of electricity
- High quality turbine at a low price
- Ultra low head (2 ft to 10 ft)

8.5.5 The Nautilus Turbine

- Produces over 3kW of power
- Operates efficiently on low head (4-18ft)
- High quality design with expected life of 50 years

8.5 Micro Hydropower Costs

For small turbines between 2000 watts (2kW) and 30,000 watts (30kW) the turbine hardware will cost between $1.00 and $2.00 per watt. That price includes the turbine, generator, electronic load control, manual shut-off valve, and resistive dump load. Very small turbines will cost more per watt, and very large turbine may cost less. The price will also vary with turbine style; generally impulse turbines cost less than reaction turbines [H13]. Table 8.5 and 8.6 shows the price lists for Stream Engine, LH-1000 and Water Baby Turbines as of September 2007.

Table 8.5. Price List for SE, LH1000 and Water Baby Turbines [H6].

Stream Engine Turbine (SE)	
1 Nozzle SE Standard	$2345
2 Nozzle SE Standard	$2495
4 Nozzle SE Standard	$2795
High Voltage Option	$275 Extra
High Current Option	$275 Extra
All Bronze Machine	$700 Extra
Low Head Propeller Turbine (LH1000)	
LH1000 With Draft Tube	$2975
High Voltage Option	$275 Extra
High Current Option	$275 Extra
Water Baby	
Baby Generator, 1 Nozzle (12/24V)	$1945
Extra Nozzles (Installed)	$150 Each
High Voltage (48/120V)	$150 Extra

Table 8.6. SE, LH1000 and Water Baby Parts Lists [H6]. Effective September 1, 2007.

Parts List for SE, LH1000 and Water Baby	
Turbine Housing (Unmachined)	$375
Turbine Housing (2 Nozzle)	$450
Turbine Housing (4 Nozzle)	$525
Universal Nozzle	$35
Bronze Turgo Wheel (Stream Engine Wheel)	$825
Bronze Pelton Wheel (machined and balanced)	$400
Plastic Pelton Wheel	$150
Bearing Kit (SE & LH1000)	$35
Rotor, Shaft and Hub Assembly (SE & LH1000)	$450
Rectifier with wiring (SE & LH1000)	$35
Junction Box with Multimeter	$300
Bronze Water Baby Wheel	$290
Plastic Water Baby Wheel	$110
Bearing Kit (Water Baby)	$35
LH1000 Propeller	$325

8.6 Micro Hydropower Resource in Puerto Rico

The hydrology of small tropical islands differs from that of temperate, continental areas. The precipitation in the Caribbean, the origin of all freshwater resources, is controlled principally by the easterly trade winds, the passage of tropical storms, and orographic effects in the islands with high relief. The geology, topography, and relative size of the islands determine the degree to which they collect and retain the rainfall that ultimately provides island water supplies [H16]. Figure 8.13 shows the annual precipitation per year in Puerto Rico.

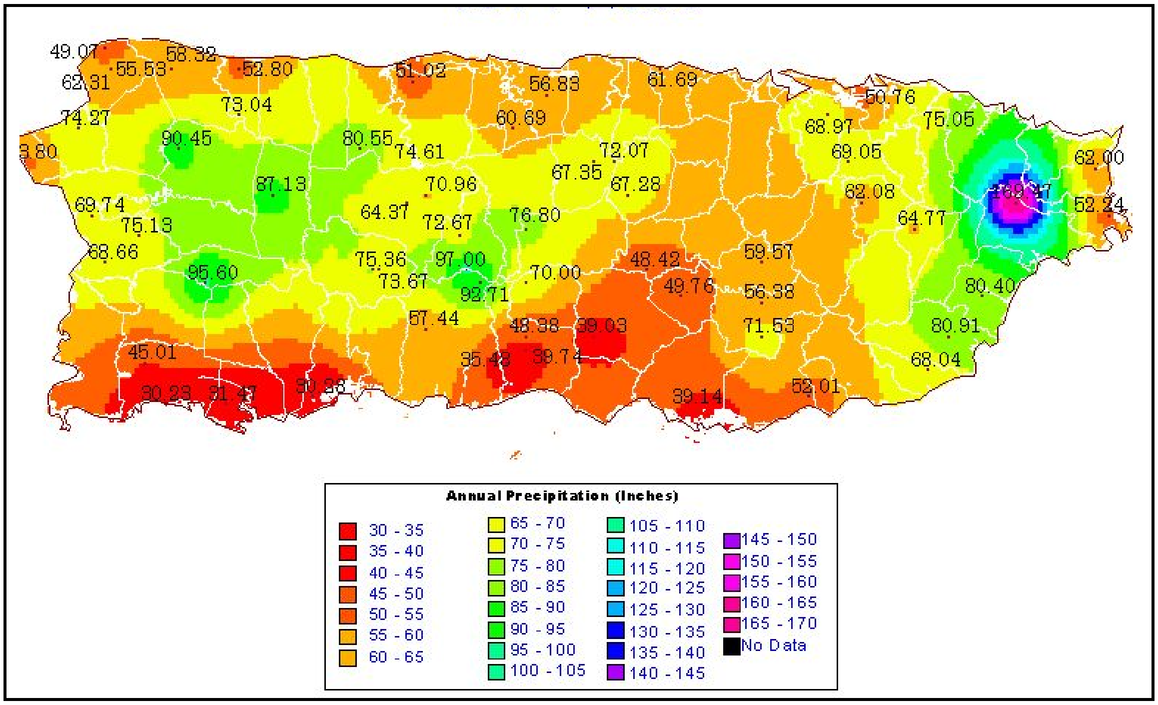

Figure 8.13. Annual Precipitation per Year in Puerto Rico (1971-2000) [Source: NOAA 2008].

The water flow in a river is critically affected by annual precipitation in a particular zone. The USGS has different stations in all Puerto Rico's territory, shown in Figure 8.14. The precipitation can be used to estimate the stage of a year with less hydropower generation.

Puerto Rico has 224 rivers. The main rivers drain the north and south areas. A hydrology analysis indicates that 67% of the superficial drain is from Central Mountain Ranges to Northern cost (Aguadilla to Fajardo) [H18-H19].

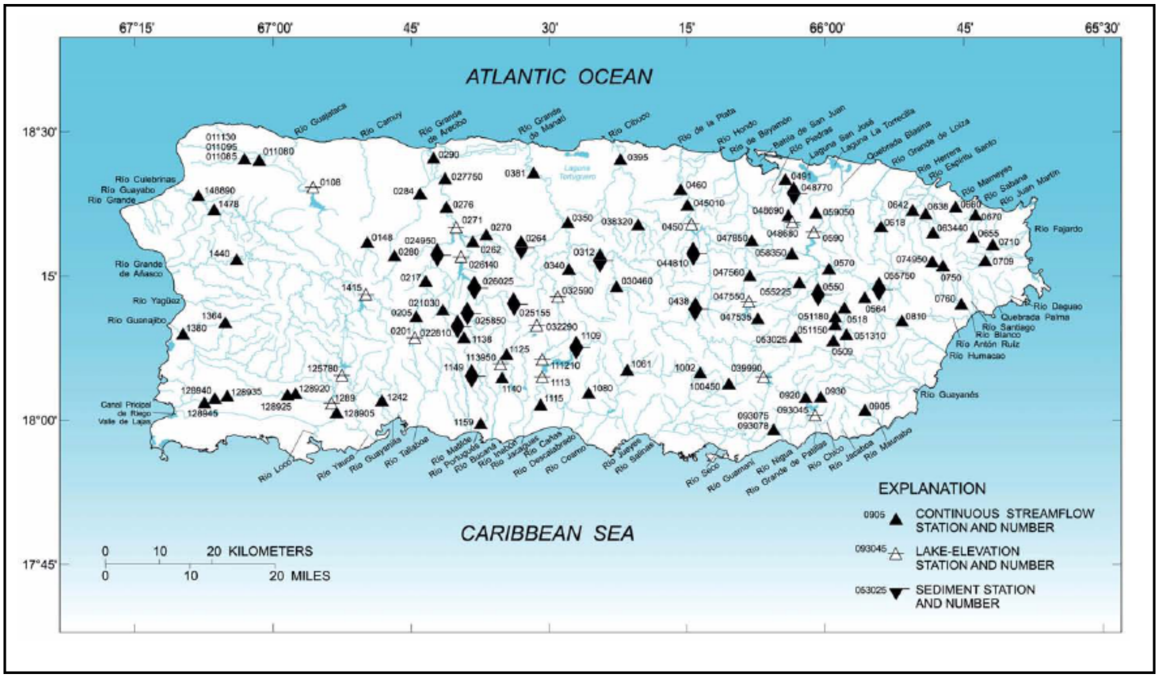

Figure 8.14. Location of surface-water stations in Puerto Rico [Source: USGS 2008].

The US Geological Survey Divide PR in 4 Hydrologic Units (HU) shown in Fig. 8.15. Each HU provides data regarding to a specific area (e.g. Average Discharge per year). The data for this assessment of 44 rivers was downloaded from http://waterdata.usgs.gov/pr/nwis/annual. Table 8.7 specifies the hydrologic unit extension and identification number.

Table 8.7 Hydrologic Units enumeration and location.

Hydrologic Units	
21010002	Cibuco-Guajataca
21010003	Culebrinas-Guanajibo
21010004	Southern Puerto Rico
21010005	Eastern Puerto Rico

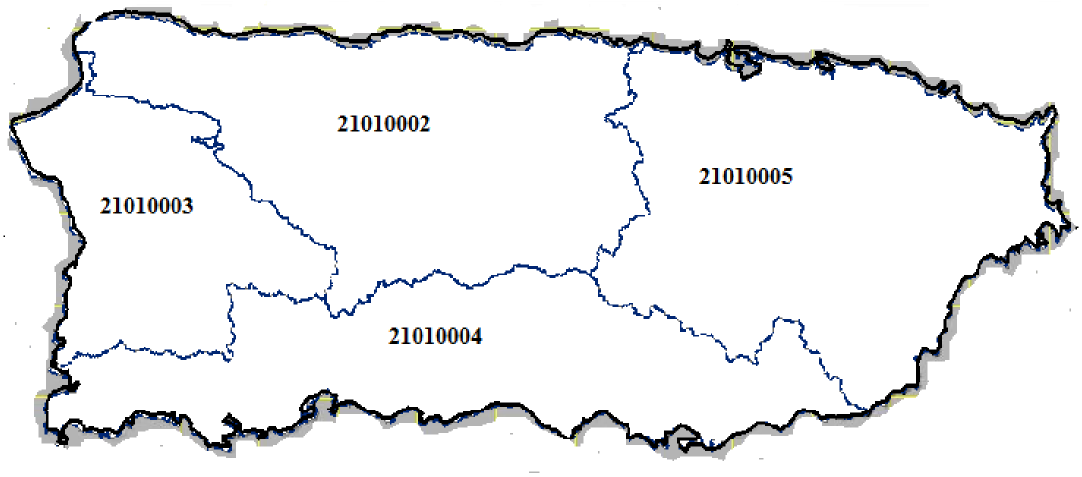

Figure 8.15 Puerto Rico Hydrologic Units map [Source: USGS 2008].

The USGS data was analyzed to obtain the average discharge of a river in a period of time. Fig. 8.16 shows the fluctuation presented in Rio Grande de Arecibo's data from 1970 to 2007 in cubic feet per seconds. The average flow is employed to obtain a rough idea of Micro Hydropower potential of that river to different Water Heads. However, if data is available for a particular location, discharge per days, months and years can be analyzed in order to determine fluctuations in hydropower generation.

The Hydropower generation is basically determined by Water flow and Net Head. The height variation can be considered looking for higher points and lower point's difference, but for the same river may exist random locations for turbines operation; therefore the net head depends on the site specifications. Figure 8.17 shows the highest points in Puerto Rico's Topography.

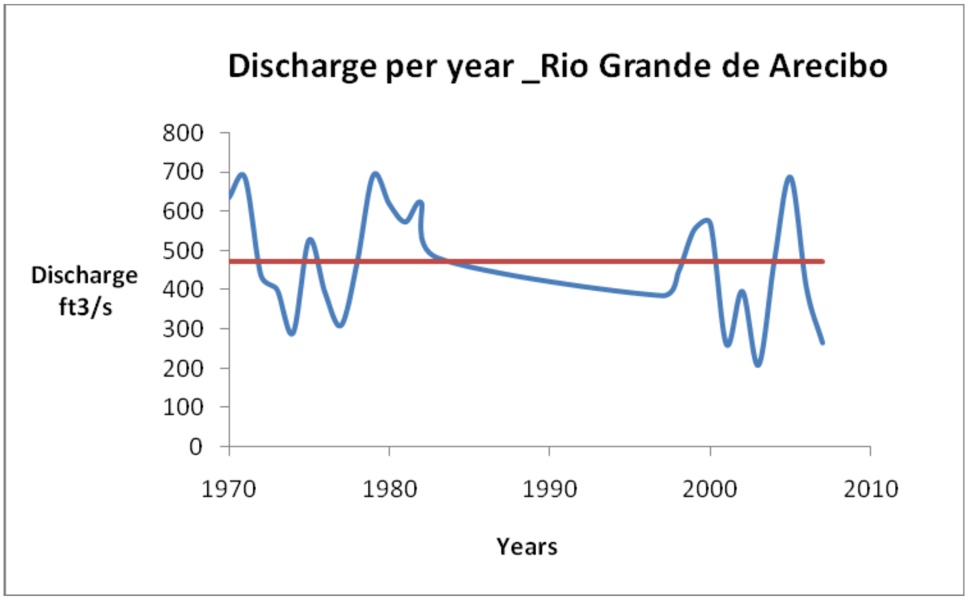

Figure 8.16 Rio Grande de Arecibo Discharge per Year.

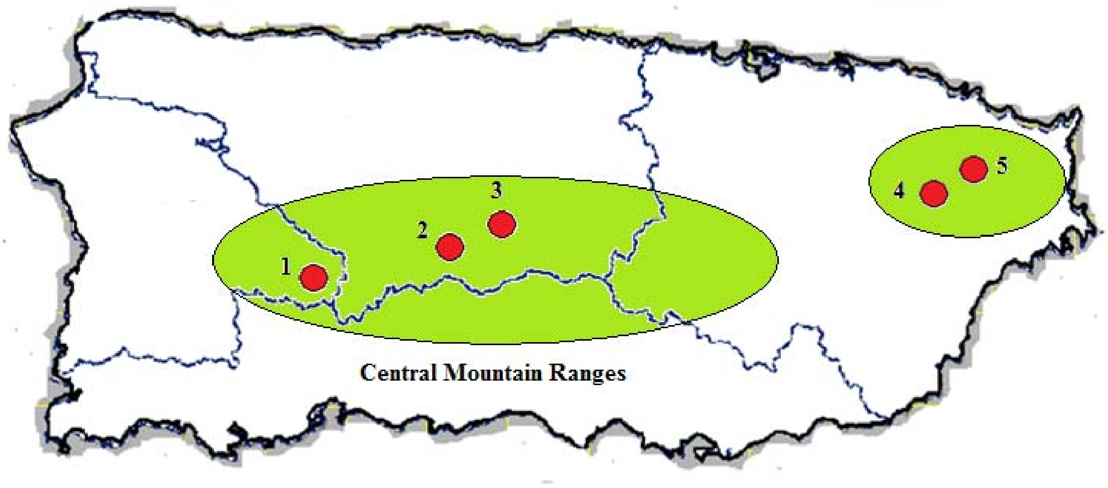

Figure 8.17 Puerto Rico Highest points [Source: DRNA 2008].

Table 8.8 Puerto Rico Higher points location.

	Location	Height (ft)
1	**Cerro Guilarte**	3952
2	**Cerro Punta**	4389
3	**Tres Picachos**	3953
4	**El Toro**	3464
5	**Pico el Yunque**	3523
PR Higher Points Average (1-5)		**3856.2**

A range of (10-400) ft was selected to take into consideration different positions to the same river in a particular area. Although PR higher points average is 3856.2ft [H18] Micro Hydropower is in a range of (0-100) kW, in order words, a combination of Net Head and Flow that exceeds 100 kW is out of the Micro hydropower range.

The assessment of Micro Hydropower potential for PR can be done by rivers or specific regions. Every river has different paths in different locations, just as every location have different rivers, and some locations common rivers. Table 8.9 shows an example for Rio Grande de Arecibo and Rio Blanco, where

Site Number: Indicate the number of the station where the measurements were done.

From yr- to yr: The period of time to recollect the data.

The water flow (ft^3/s): Is the average into the period of time under consideration.

Each river is measured in different locations (e.g. Rio Blanco in Adjuntas and Naguabo). And by county in different stations (e.g. Naguabo has 50077000 and 50076000).

This assessment considers the Micro hydropower generation by county. Thus, all the available data was rearranged taking into consideration the amount of rivers in a region. Table 8.15 shows the amount of rivers by county for Hydrologic unit 21010003. Each river is analyzed at (10-50-400) ft to simulate different turbine positions in the same stream. Red squares indicate power that does not qualify into Micro hydropower range.

Table 8.9 Rio Blanco and Rio Grande de Arecibo Average Discharge.

Rio Blanco		
Adjuntas Municipio 21010002		
Site Number	**From yr-To yr**	**ft3/s**
50141000	1947-1984	38.26
Naguabo Municipio 21010005		
50077000	1973-1977	84.86
50076000	1983-2006	92.37
Rio Grande de Arecibo		
Adjuntas Municipio 21010002		
Site Number	**From yr-To yr**	**ft3/s**
50020500	1948-2006	57.26
Arecibo Municipio 21010002		
50027750	1983-2002	342.17
50029000	1970-2007	471.22
Utuado Municipio 21010002		
50021700	2000-2006	115.87
50024950	1997-2006	179.39

In Table 8.10 is considered for each county only one turbine by stream. Because there is no way to know the amount of Micro hydro systems that might be implemented without a detailed supervision of the particular area under study (i.e. number of turbines, net head and flow by turbine). Then, adding the power generated by hydrologic unit there's an approximation of Micro hydropower potential.

Table 8.10 Potential Kilowatts production by area in Hydrologic Unit 21010003.

Hydrologic Unit 21010003			**10**	**50**	**400**	**kW by Area**
Aguada Municipio						
Rio Culebrinas						
Site Number	**From yr-To yr**	**ft3/s**				
50148890	**1999-2006**	**351.61**	**209.49**	**1047.43**	**8379.42**	
Anasco Municipio						
Rio Grande de Anasco						
Site Number	**From yr-To yr**	**ft3/s**				
50144000	**1986-2006**	**557**	**331.85**	**1659.27**	**13274.18**	
Sabana Grande Municipio						**31.10**
Rio Loco						
Site Number	**From yr-To yr**	**ft3/s**				
50129000	**1964-1966**	**52.2**	**31.10**	**155.50**	**1244.01**	
Hormigueros Municipio						**31.35**
Rio Guanajibo						
Site Number	**From yr-To yr**	**ft3/s**				
50138000	**1974-2005**	**192.84**	**114.89**	**574.46**	**4595.68**	
Rio Rosario						
50136400	**1986-2006**	**52.62**	**31.35**	**156.75**	**1254.02**	
San German Municipio						**38.71**
Rio Guanajibo						
Site Number	**From yr-To yr**	**ft3/s**				
50131990	**1992-2001**	**64.98**	**38.71**	**193.57**	**1548.58**	
Rio Rosario						
50136000	**1961-1986**	**50.34**	**29.99**	**149.96**	**1199.68**	
			POTENTIAL POWER (kW)			**101.16**

To estimate the Micro Hydropower potential for Puerto Rico the next formula was considered,

$$P(kW) = \frac{H(ft).Q(ft^3/s).(62.412)(0.7)(0.75)}{550}$$

Where H is the rough Head, Q the flow, 62.412 the specific weight of water in (lb/ft^3), 0.7 is a factor to consider the net head (losses by friction), 550 is a factor to convert to horse power, and 0.75 the conversion factor from hp to kW. Table 8.11 shows the potential Micro Hydropower production by HU.

Table 8.11. Approximate Hydrologic Units Power Production.

POTENTIAL POWER (kW) 21010002	**1067.15**
POTENTIAL POWER (kW) 21010003	**101.16**
POTENTIAL POWER (kW) 21010004	**766.41**
POTENTIAL POWER (kW) 21010005	**1147.7**
Total Micro Hydropower Potential (kW)	**3082.42**

The sum of all Hydrologic Units Micro Hydropower potential electricity is approximately 3.08MW, which is a 3% of total PR hydroelectricity capacity and less of a 0.1% of the total PR electricity generation. It's important to see that the major power is located in HU 21010002 and 21010005, which corresponds to the north part of the island and drain a 67% of superficial water.

8.8 References

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