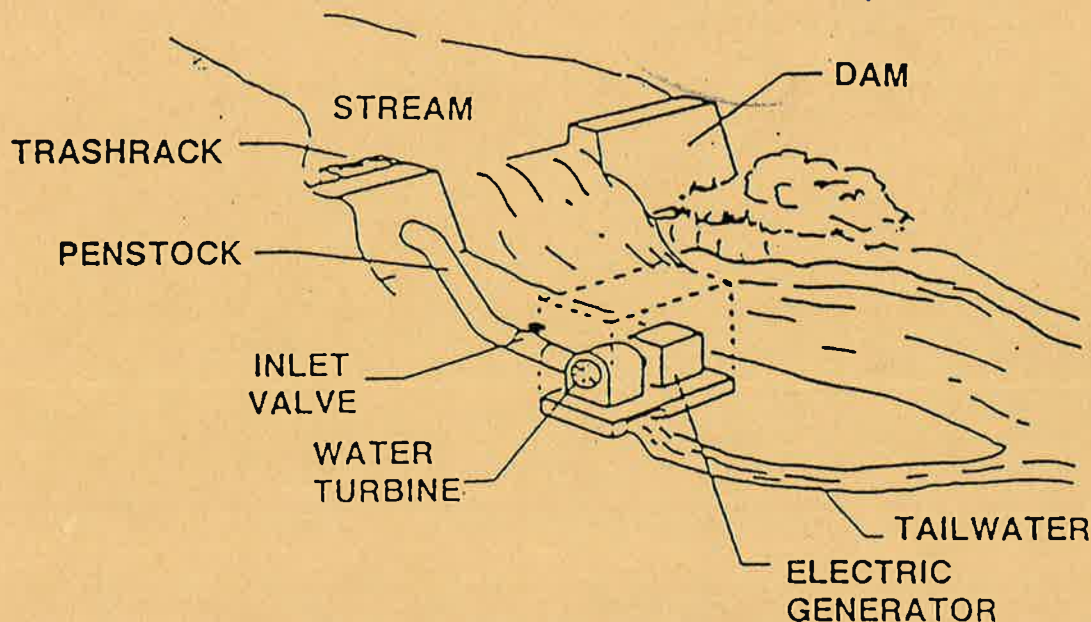
MICRO HYDRO POWER



WATER TURBINE INSTALLATION

DEPARTMENT OF ECONOMIC AND
COMMUNITY DEVELOPMENT

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Chapter 1
INTRODUCTION
6/6/99

This document has been written by Frederick J. Munster Jr. with regard to Micro-Hydroelectric systems. These are small hydro electric systems which take advantage of the falling or flowing water of brooks, streams, rivers, or as waste hydraulic energy recovery systems. They are used to produce electric energy which can be used to generate power for homes, cabins and other facilities which are not connected to the utility grid; for electric utility bill reduction or elimination for grid connected facilities; for backup power and for commercial generation of electricity. Used in conjunction with an electrolyzer, hydrogen fuel can also be produced from the very water used to operate the hydroelectric system. A publication available from D.E.C.D. entitled "FUEL CELLS" addresses this technology.

As with any renewable energy system, <u>One must carefully evaluate each such system and proposed use with due diligence. Pay very close attention to regulations and permitting issues especially with regard to construction of any hydro facility.</u>

A general rule of thumb for the successful use of any renewable energy source is to first minimize your energy use. There are several ways you reduce your electrical consumption. Eliminating high demand appliances either by switching to another, less expensive energy source or by not using them at all is an option for some appliances, such as electric heat, water heaters, refrigerators, and cloths dryers. Installing energy efficient appliances and fluorescent lighting should also be considered. Taking care to turn lights and other appliances off when not in use can have a significant, but difficult to estimate impact on electrical consumption.

By investing several hundred to several thousand dollars in energy conservation improvements to your home or business, you might be able to substantially cut your electric use and may or may not decide that a microhydro system would be economical for you.The author has arranged this document in a manner that addresses the basic approach of micro-hydro planning. Micro-Hydro use is governed by many regulations at the local, state and federal levels. Although some systems might qualify for certain exemptions, regulations regarding this method of energy production are quite extensive.

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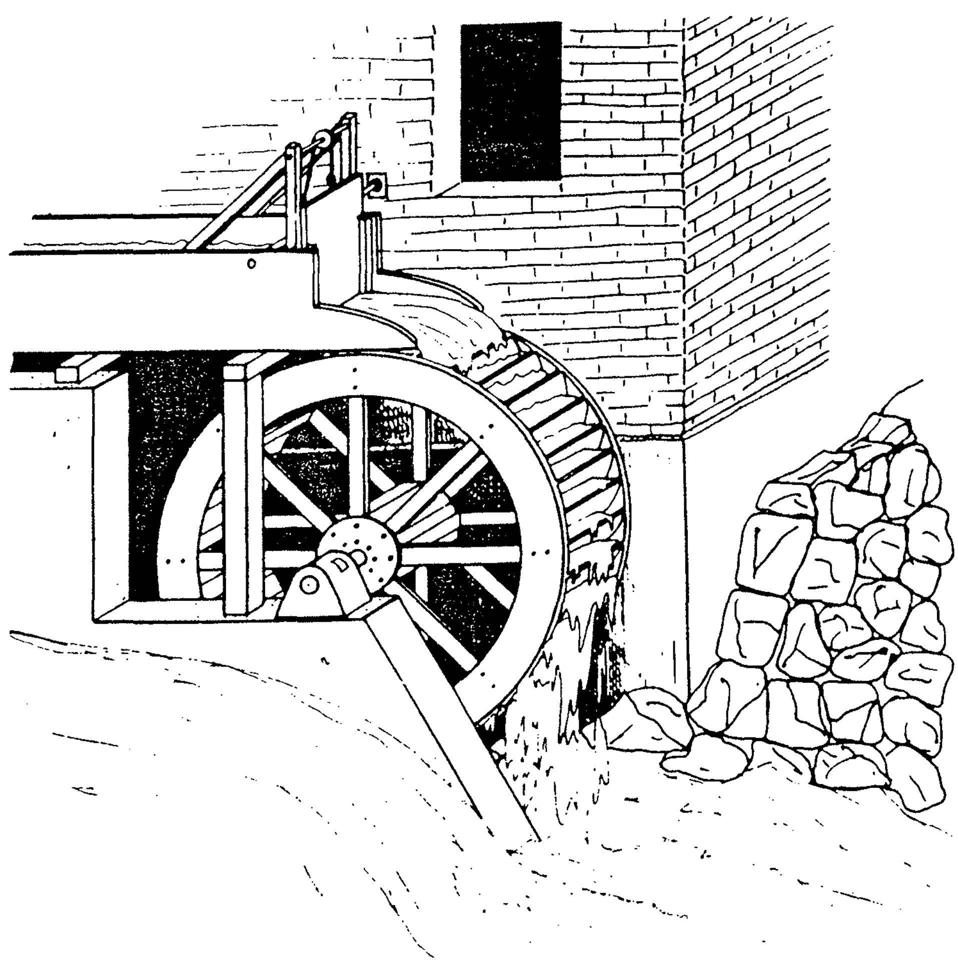
Chapter 2
HISTORY OF HYDROPOWER IN MAINE

In 1625, Fernando Gorges used hydropower to generate the mechanical energy contained in the moving (falling) water to operate a sawmill in Kittery to mill lumber for houses and boats. [1]

Early hydro systems utilized wooden water wheels to generate the mechanical energy required to operate mills of that era. When required, a small dam was built to channel and/or control the water flow. Small dams of the time were generally of wooden crib construction (like lincoln logs) that were filled with loose stones. Three popular water wheels of that era are the Undershot, Overshot and Poncelet wheels. The overshot wheel shown in Figure 2

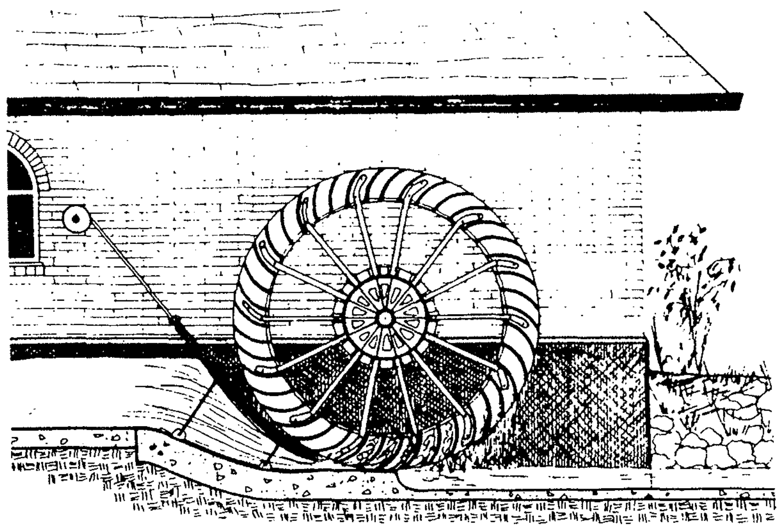
Figure 2 [2]



has water fall from a chute into buckets on top of the wheel. The dead weight of the water causes the wheel to rotate. The undershot wheel operates much in the same way, only that the water enters the wheel from below rather than above and is less efficient than the overshot system.

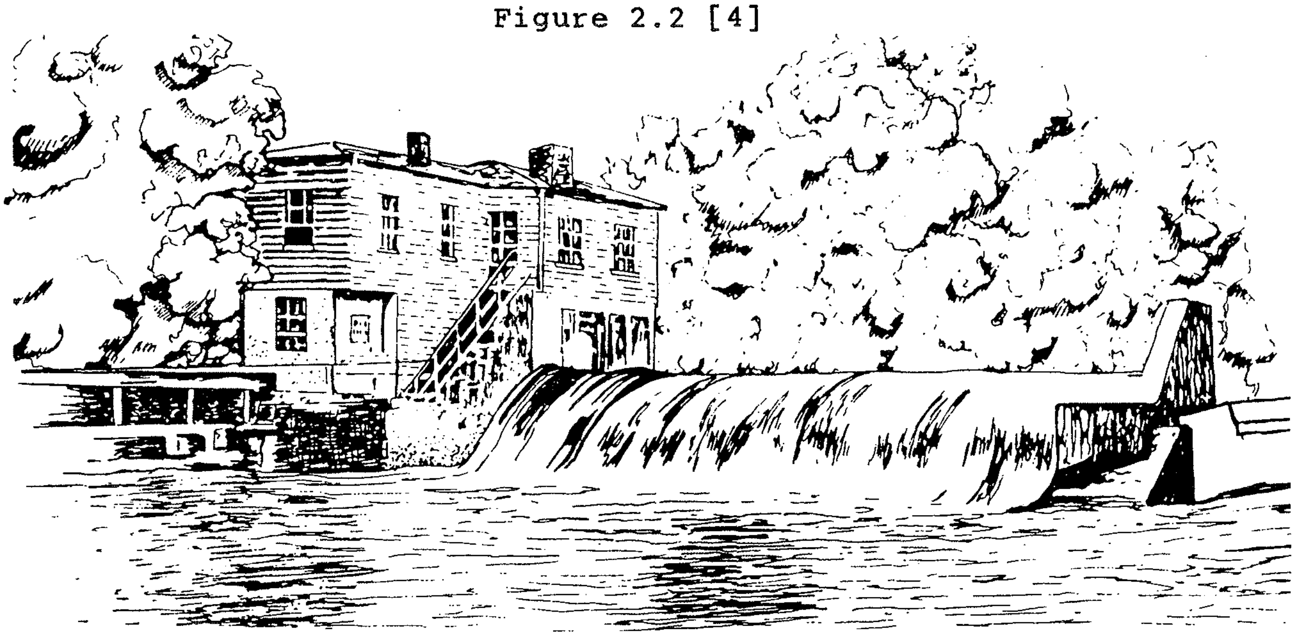
The Poncelet wheel shown in figure 2.1 is an upgraded version of the undershot wheel. Water would rush in below the wheel to fill the curved buckets forcing the wheel to turn. These were also susceptible to damage from debris carried in the water.[3]

Figure 2.1 [3]



As Maine developed, mills became commonplace along most rivers and streams. Dams were built which allowed more energy to be harnessed and controlled. Figure 2.2 shows what most small mills of the era looked like. [4]

Figure 2.2 [4]

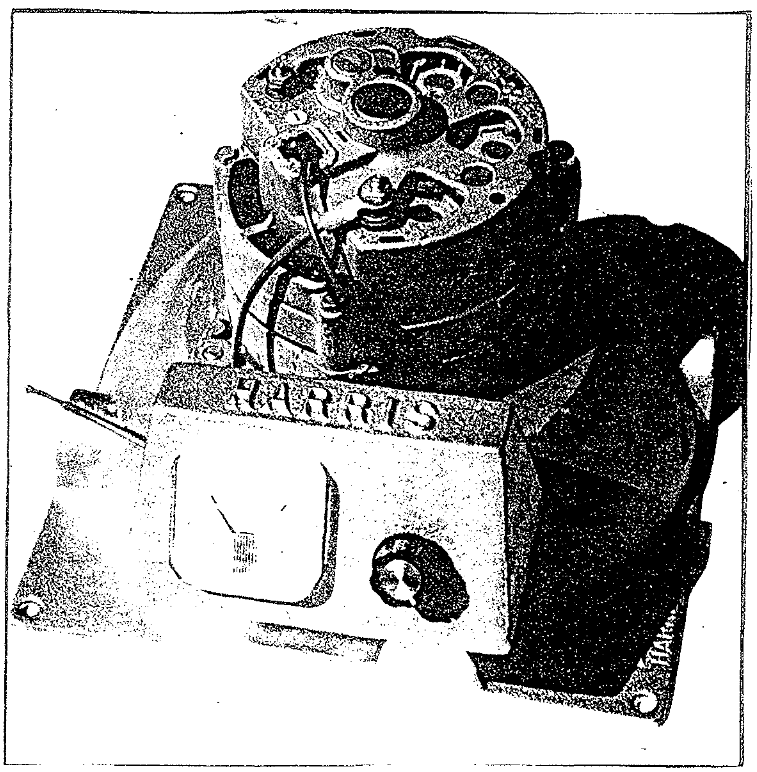


During the Industrial Revolution, many advancements in turbine design occurred. The Francis, Pelton and Propeller turbines (discussed later) were invented using theoretical calculations. After the turn of the century, power companies began to use hydropower to generate electricity. As Maine became more industrialized and the paper industry expanded, the number of electric companies increased. In the following years many of these companies merged or were absorbed by other companies until the present (and still changing) electric utility structure emerged.

In the last 50 years, electric companies expanded their generation by building power plants which utilized other technologies and fuels. Most of the small "mill sites" were abandoned as purchased electricity became more convenient.[5]

However, widespread concern regarding past oil shortages; petroleum supplies and prices; nuclear power and environmental issues have had an effect where production of electricity is concerned. Within the last decade, some of the "inactive hydro sites" and flood control dams have been retrofit with hydroelectric turbines for the commercial production of electric power. With deregulation of the electric utility industry in Maine, hydroelectric power may play a significant role. This also may include small systems like that shown in Figure 2.3 that can also power remote camps and homes not hooked to utility lines. They can also be used to reduce the electric bills of homes and small businesses connected to utility lines. Hydro by definition is a renewable resource. This will be discussed in the next chapter.

Figure 2.3



Courtesy: Canyon Industries Inc.

Chapter 3
RENEWABLES [27]

When considering any renewable system, the first rule of thumb is carefully evaluating resource availability, the intended use, legal/permitting issues, maintenance/reliability and finally the economics of the system. Guessing almost always results in disappointments.

In May of 1997, the State of Maine enacted H.P. 1274-L.D.1804, An Act to Restructure The States Electric Industry. The definition of "renewable resource" means a source of electrical generation that can be physically be delivered to the control region in which the New England Power Pool, or its successor (ISO-NE) as approved by the Federal Energy Regulatory Commission, has authority over transmission and that:

A. Qualifies as a qualifying small power production facility under the Federal Energy Regulatory Commission rules, 18 Code of Federal Regulations (CFR), part 292, Subpart B, as in effect on January 1, 1997;

B. Qualifies as a qualifying cogenerating facility under the Federal Energy Regulatory Commission rules, 18 CFR, Part 292, Subpart B, as in effect on Jan. 1, 1997 and was constructed prior to Jan. 1, 1997; or

C. Whose total power production capacity does not exceed 100 megawatts and that relies on one or more of the following:

1. Fuel cells;
2. Tidal power;
3. Solar arrays and installations;
4. Wind power installations;
5. Geothermal installations;
6. Hydroelectric generators;
7. Biomass operators; or
8. Generators fueled by municipal solid waste in conjunction with recycling.

Renewable Portfolio Standard (RPS)

PORTFOLIO REQUIREMENTS. As a condition of licensing pursuant to section 3203, each competitive electricity provider in this State must demonstrate in a manner satisfactory to the commission that no less than 30% of its portfolio of supply sources for retail electricity sales in this State are accounted for by renewable resources. By January 1, 1999, the commission shall provisionally adopt rules establishing reasonable procedures for implementing this requirement. Rules adopted under this subsection are major substantive rules pursuant to Title 5, Chapter 375, subchapter II-A. Other states have adopted or are reviewing similar rules. [27]

On the 10th of December 1998, The Maine Public Utilities Commission issued a ruling with respect to Chapter 313, Customer Net Energy Billing. This is applicable to facilities that are connected to the utility grid and use a renewable resource as defined by state law to generate electricity and does not exceed 100 kilowatts in size. The generating facility is to be used for providing some or all of the energy required by the customer to satisfy the customers own needs. (the customer will still have to facility will be metered against the customers use of utility electricity and will be netted on an annual basis effective March 1, 2000. In essence, the customer will be credited for energy production up to the point of electricity supplied during a one year period. Any production exceeding the customers usage at the time of netting will not be credited. However, the customer will still have to pay for delivery service (transmission and distribution charges).

In the past, netting occurred during each billing cycle (generally once a month) and excess electricity was purchased by the utility at the avoided cost rate, which was a fraction of what the customer paid on a retail basis. <u>If the customer produced more than was consumed, the entire utility bill was eliminated and the customer might have received a check back for excess production.</u>[a]

Since transmission and distribution utilities cannot engage in the sale or production of electricity when deregulation becomes effective[b], a utility interconnected system used to reduce the customers electric bill will only reduce it by the amount of electricity consumed. The customer must still pay the T&D charge[c].

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[a] This method will be eliminated for taxation purposes.

[b] Affiliates of T&D utilities can engage in the sale and generation of electricity when deregulation becomes effective.

[c] T&D utilities are still regulated and can petition the Public Utilities Commission for rate increases.

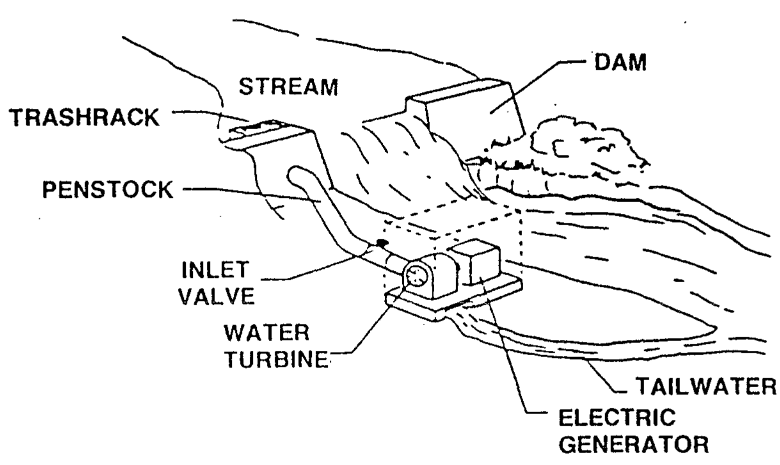
Chapter 4
WHY MICRO-HYDRO

Micro-Hydro may be an attractive method of electric power generation for utility interconnected applications such as utility bill reduction or elimination, for remote power where utility lines are either unavailable or to expensive to run in, for backup power in the event of a utility outage, for all of the above when other forms of renewable generation such as photovoltaics or wind prove too expensive or impractical. This method of energy production is also used to produce power on a small scale commercial basis.

Maine is blessed with an abundant hydro resource. Countless streams, brooks and many rivers have and will continue to be used to take advantage of this abundant resource. Many of you who hear of micro-hydro do not realize that small units can actually operate on lines not much bigger than common garden hose with water from a spring or artesian well located uphill from the generator. These systems are inexpensive and are great for camps and homes that are very energy conservative. Others might require part of a stream to be diverted or a small dam be built. In other cases existing dams can be retrofitted to accommodate a small hydroelectric system.

In all cases, careful planning and attention to detail is necessary. Some aspects of hydro development are complex, especially where dams and regulations are concerned. These and other issues will be addressed later in this document.

Whatever the application, a properly planned and designed micro hydro system should provide many years of enjoyment and economic benefits. The first part of understanding hydroelectric systems is understanding the source of its energy, water. The following three chapters focus on this subject.

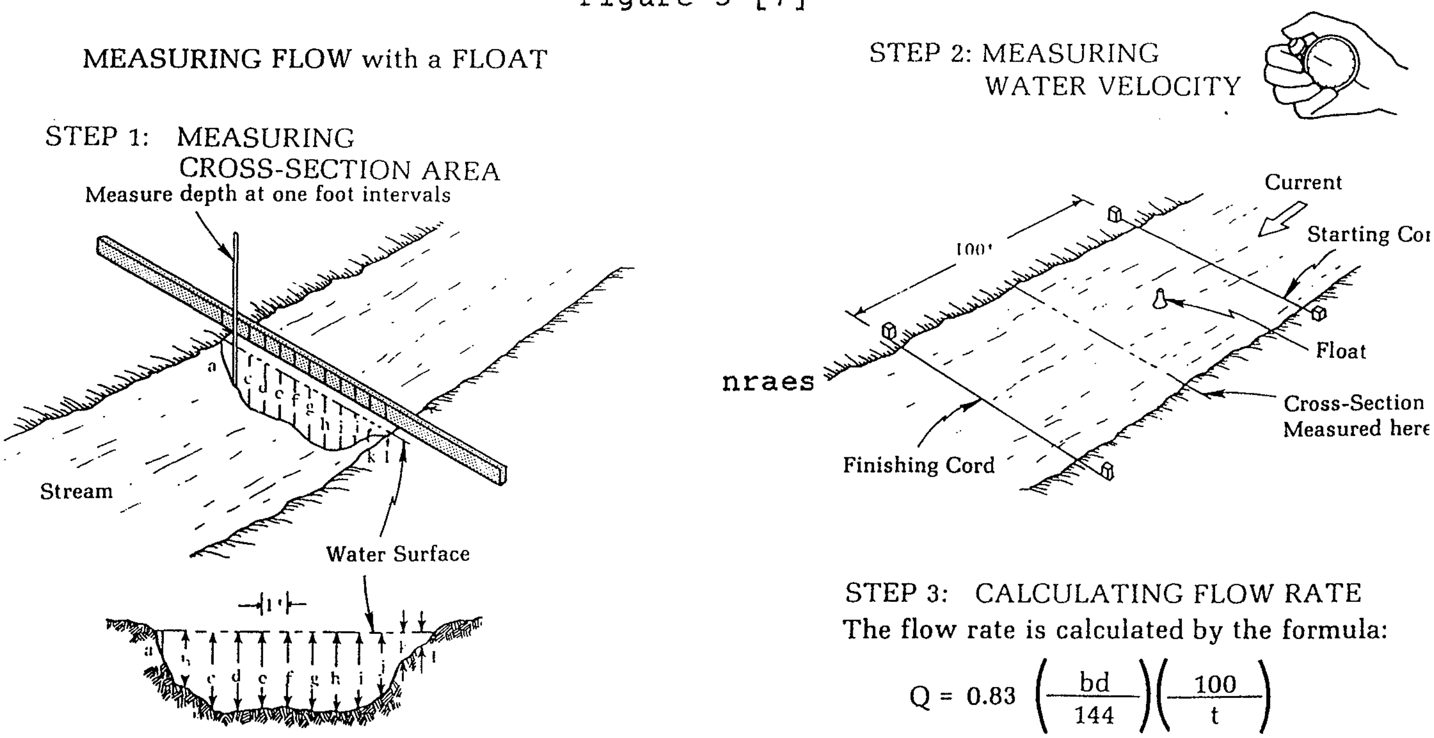


WATER TURBINE INSTALLATION

Chapter 5
DETERMINING FLOW

Flowing water contains energy. The amount of energy contained depends upon 2 main factors, flow and head. Long term flow data is essential for assessing hydro potential due to the seasonal variability of precipitation.[6] There are two common methods of measuring flow[a]. The first method is the float method. This is the easiest method of measuring flow and will produce satisfactory data, except in cases where a stream is shallow or rocky and impedes the movement of a weighted float. The float method of testing a stream is the easiest test to conduct[b].
Basically a cross section of an unobstructed area of a stream is measured for depth across and a weighted float (such as a large fishing bobber with a weight suspended underneath it) is timed as it floats down a 100 foot (or longer) course as shown in figure 5. [7]

Figure 5 [7]



$$\text{Average Depth} = \frac{\text{Sum of measured depths}}{\text{\# intervals measured}}$$

STEP 3: CALCULATING FLOW RATE

The flow rate is calculated by the formula:

$$Q = 0.83 \left(\frac{bd}{144}\right)\left(\frac{100}{t}\right)$$

Q = flow rate, cubic feet per second
b = stream width, inches
d = average stream depth, inches
t = time for float to drift 100 feet, seconds

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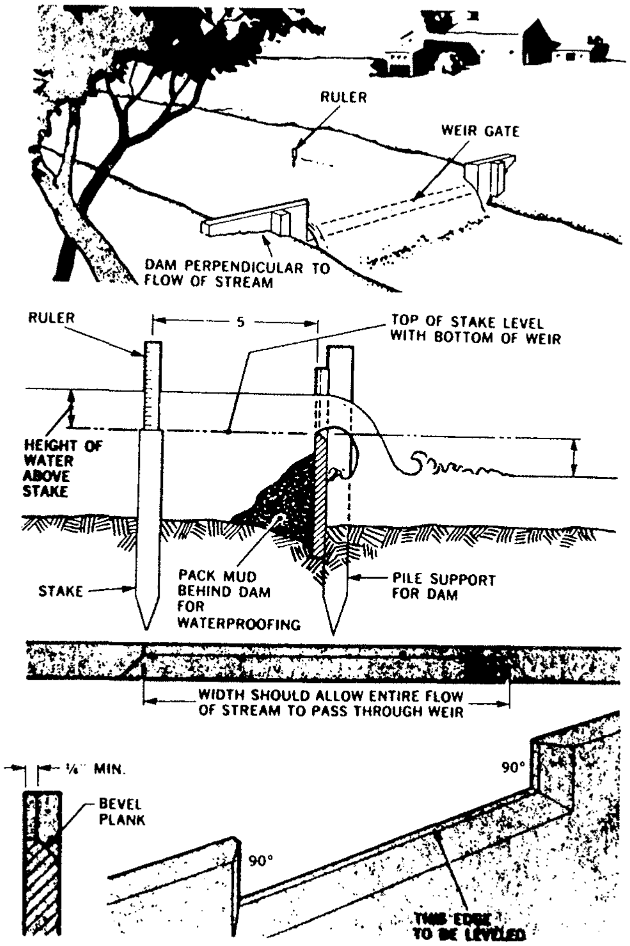
[a] large discharges are best left to an engineer.
[b] The USGS has stream gauges throughout Maine and may have flow information regarding a particular stream. Information concerning the USGS network is listed in a document entitled USGS Water Resources Data for Maine and can be obtained from the USGS or various libraries throughout Maine.

The weir method is more time consuming but may be the most satisfactory test if the stream is very small, rocky, or obstructed[a]. This test also works well if their is an existing dam.

The flow may be calculated by precisely measuring the depth of the water flowing over the crest of the weir as shown in figure 5.1.[8]

Figure 5.1 [8]

MEASURING FLOW WITH A WEIR



Construct weir gate and determine height of water above stake as shown above. Figure flow from chart below.

Courtesy: Canyon Industries Inc.

By using the chart and following the instruction of the chart shown on the following page (Figure 5.2) flow can be determined.

[a] Permit(s) may be required prior to constructing a weir.

Figure 5.2 [8]

WEIR MEASUREMENT TABLE

Table shows water flow (in cu. ft./min.) that will flow over a weir one inch wide and from 1/8 to 20-7/8 inches deep.

Inches		⅛	¼	⅜	½	⅝	¾	⅞
0	0.00	0.01	0.05	0.09	0.14	0.19	0.26	0.32
1	0.40	0.47	0.55	0.64	0.73	0.82	0.92	1.02
2	1.13	1.23	1.35	1.46	1.58	1.70	1.82	1.95
3	2.07	2.21	2.34	2.48	2.61	2.76	2.90	3.05
4	3.20	3.35	3.50	3.66	3.81	3.97	4.14	4.30
5	4.47	4.64	4.81	4.98	5.15	5.33	5.51	5.69
6	5.87	6.06	6.25	6.44	6.62	6.82	7.01	7.21
7	7.40	7.60	7.80	8.01	8.21	8.42	8.63	8.83
8	9.05	9.26	9.47	9.69	9.91	10.13	10.35	10.57
9	10.80	11.02	11.25	11.48	11.71	11.94	12.17	12.41
10	12.64	12.88	13.12	13.36	13.60	13.85	14.09	14.34
11	14.59	14.84	15.09	15.34	15.59	15.85	16.11	16.36
12	16.62	16.88	17.15	17.41	17.67	17.94	18.21	18.47
13	18.74	19.01	19.29	19.56	19.84	20.11	20.39	20.67
14	20.95	21.23	21.51	21.80	22.08	22.37	22.65	22.94
15	23.23	23.52	23.82	24.11	24.40	24.70	25.00	25.30
16	25.60	25.90	26.20	26.50	26.80	27.11	27.42	27.72
17	28.03	28.34	28.65	28.97	29.28	29.59	29.91	30.22
18	30.54	30.86	31.18	31.50	31.82	32.15	32.47	32.80
19	33.12	33.45	33.78	34.11	34.44	34.77	35.10	35.44
20	35.77	36.11	36.45	36.78	37.12	37.46	37.80	38.15

The U.S. Geological survey has an extensive stream gauging network in Maine. If a proposed site on or near a gauging station, the average annual, as well as daily, weekly and monthly flows can be determined from the record site[a]. Where no measured streamflow data for a particular site exists, streamflow may be estimated by knowing the drainage area of the project site. This requires getting information of the nearest gauged site of similar size and hydrologic characteristics. The flow at the project site is then proportioned according to the ratio of the project site drainage area to the record site drainage area.[9]

The drainage area of a proposed site can be found in one of two ways. Drainage areas have been calculated for a large number of sites in Maine, and are compiled in a series of reports published cooperatively by the USGS and Maine DEP. [10]

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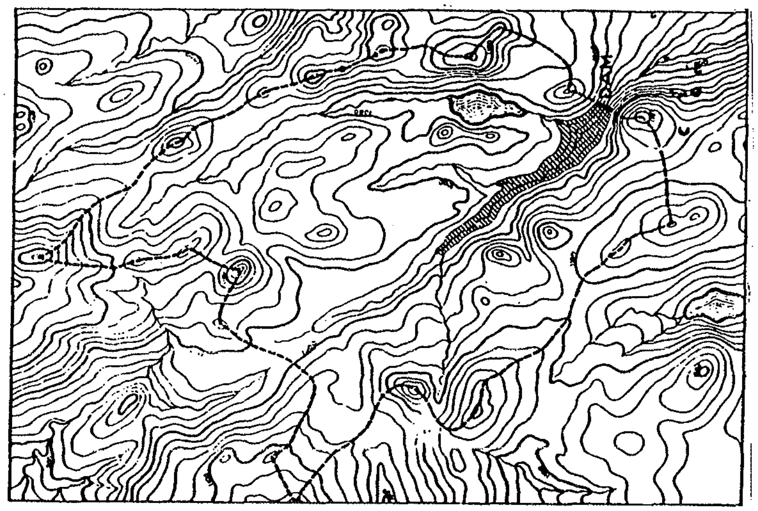
[b] Information concerning the USGS network is listed in a document entitled <u>USGS Water Resources Data for Maine</u> and can be obtained from the USGS or various libraries throughout Maine.

[b] These reports can be consulted at the USGS or Maine DEP.

Drainage areas may also be calculated by using a USGS quadrangle sheet of the project area as shown in figure 5.3. Draw a line around the ridges (boundary of high elevation) surrounding the area upstream of the proposed site[a]. The perpendicular to the contour at any point is the direction of the steepest slope and indicates the direction the water will flow. The area enclosed within the line is the drainage area of the site. This can be measured by re-plotting the area on a piece of graph paper and counting the number of squares within the plotted area and multiplying the scale. The area is usually indicated in square miles. [11]

Figure 5.3



By using the above method of drainage area calculation, another simple although approximate equation shown in equation 5.4 can be used. This method assumes that precipitation is the same throughout the State.[12]

Equation 5.4 [12]

$$Q = A\ (1.8)$$

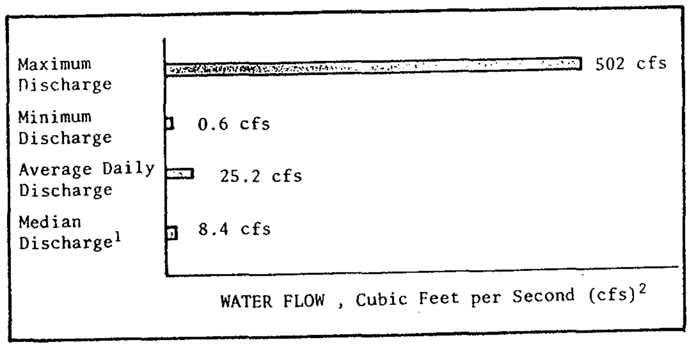
Where: A = Area of drainage basin in square miles.
Q = Mean annual flow in cubic feet per second.

For example, if the drainage area is 10 square miles, the mean annual flow (Q) is estimated to be 18 CFS

[a] There are some map programs for personal computers that can perform this as well.

As mentioned before, flow rates do vary in an unregulated stream depending on the size of the area the stream drains and the precipitation and runoff characteristics of the drainage area. For a regulated stream, the flow is also dependent upon regulation of upstream dams. Seasonal variations in precipitation as well as changing rainfall patterns within a particular season affect the flow. The runoff also has seasonal variations caused by different evaporation and infiltration rates. These factors combine to give flow rates that vary widely with time.[13] Figure 5.5 shows a typical discharge from a 22 square mile hilly to mountainous area in the Northeast during a year of normal precipitation.[14]

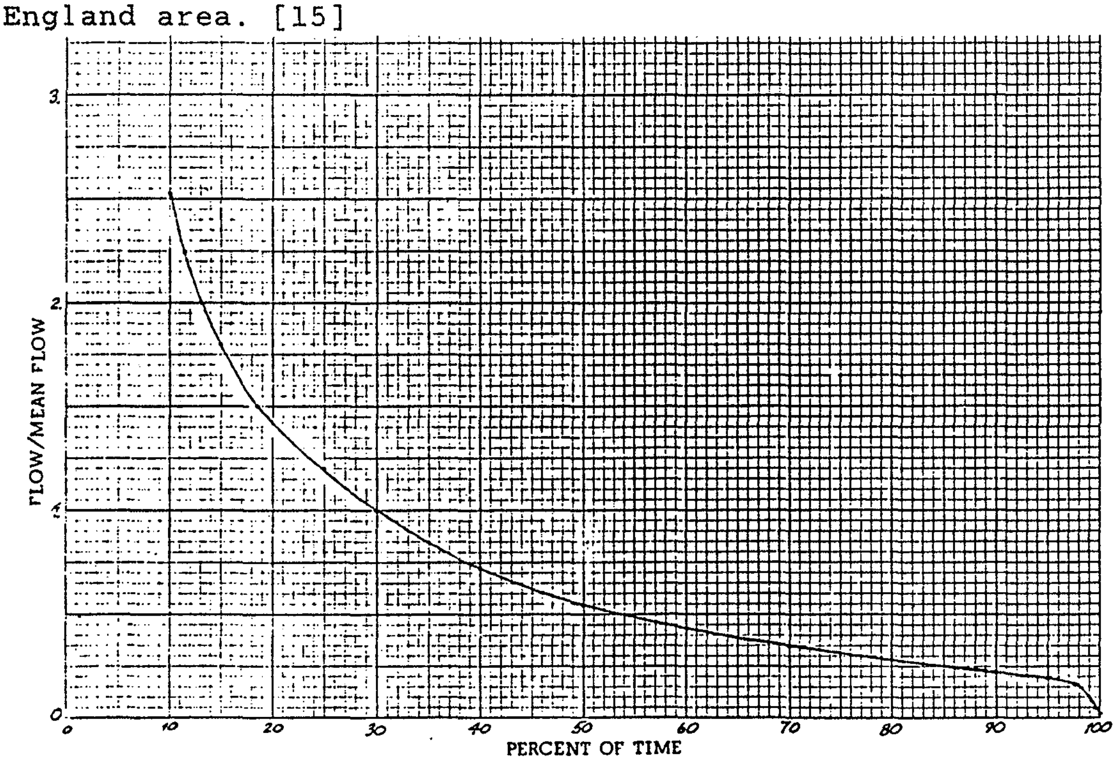
Figure 5.5



[1]Flow is 8.4 cfs or less for 183 days or half the year.

[2]1 cubic foot per second = 449 gallons per minute.

Figure 5.6 shows the generalized flow duration curve of the New England area. [15]



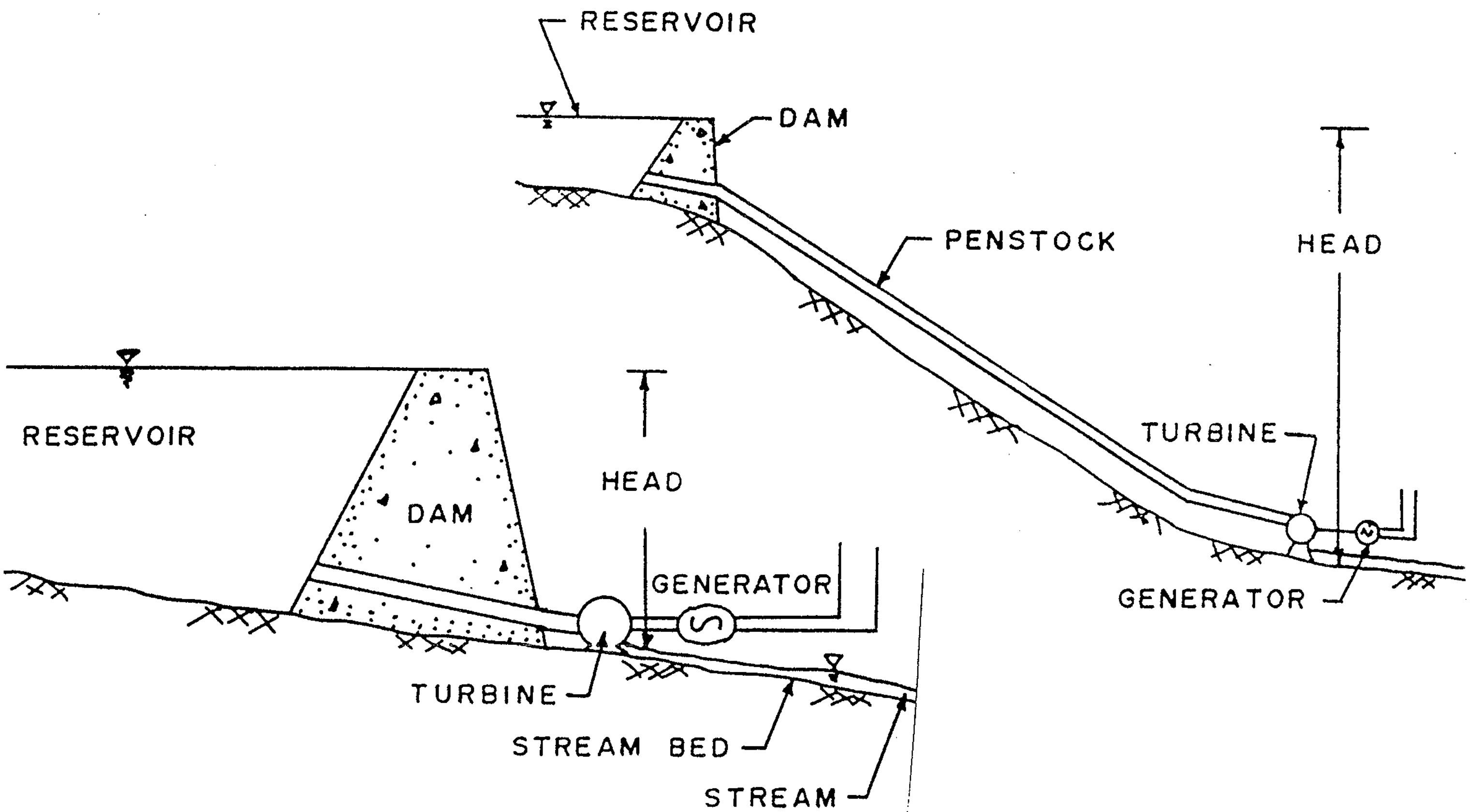
When evaluating flow for micro hydro use, design flow must be considered. This is the flow that should be expected for at least 2 to 3 months out of a year. Some systems should be designed for the maximum sustained flow of a stream. [16]

Chapter 6
DETERMINING HEAD

As discussed in chapter 5, flow is one of two critical items that need to be evaluated in determining energy contained in flowing water. This chapter will discuss the term head.

The available energy which exists in water depends on the change in elevation (head) that it undergoes. In a stream flowing over its bed, the energy derived from the change in elevation is dissipated through friction during flowing. If the water is pooled by a dam or channeled into a smooth pipe (penstock), energy will be available for use to drive turbines or water wheels. You can measure the value of head at your site to determine available energy. [17] The elevation difference between the headwater pool and the tailwater pool is the pool to pool gross head. The headwater pool at a dam is the reservoir behind the dam, and the tailwater pool is at the discharge of the turbine normally located near the downstream toe of the dam. The headwater pool for a penstock, which is a pipe that carries water from the intake to the turbine, is at the entrance to the penstock and the tailwater pool is at the turbine discharge. Both are shown in figure 6. [18]

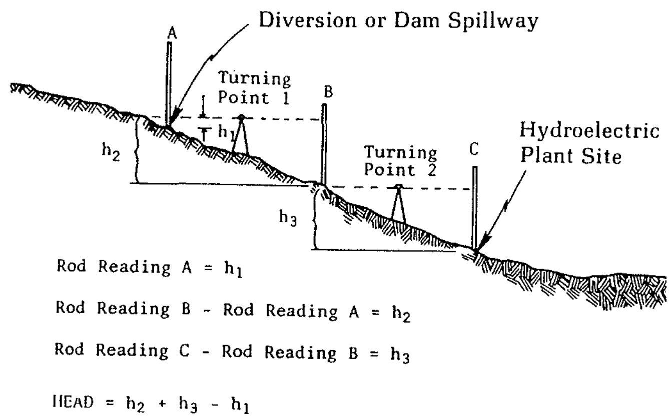
Figure 6 [18]



To measure pool to pool gross head, the best method is by using a surveyors level and leveling rod. Another method is using a transit with stadia lines and a leveling rod or by using a transit for trigonometric height determination. Figure 6.1 shows how to use the level and leveling rod to accomplish this. Accurate measurement is needed for final planning.

Figure 6.1 [19]

MEASURING the HEAD



Authors Note: This method may require quite a few setups, especially in the case of a long penstock run. Mark the spot where the rod was first held. (this assumes that you start from the diversion or dam spillway and keep marking every spot the rod was held (read) during the run) when you reach the hydroelectric plant site to measure the tailwater pool elevation, read the leveling rod at the pool elevation. Without moving the leveling rod, move the level and take another reading on the rod again. Proceed back to the diversion or dam spillway and take a final reading on the point you first held the rod on. This process is called closure and insures that the elevation of the tailwater pool is correct. If the starting elevation does not correspond to the final elevation, you will need to start the leveling run again.

If you are not familiar with surveying instruments, you may want to consider hiring a land surveyor, or someone like a construction worker, stone mason or carpenter who might know how to use this equipment. Other simple methods that could be used for estimating head are hand (pop) levels and estimating head from topographic maps.

Once gross head has been determined, you must now calculate the design (effective) head. This is the useable head at the turbine, and must be adjusted for pipeline and head losses. This can be determined by following the instructions and chart in figure 6.2 It is best to select a pipe diameter that will carry the design flow with no greater loss than 1Ø - 15% total gross head. [2Ø]

Figure 6.2 [2Ø]

Head loss for plastic pipe

Nominal Pipe Diameter,	Inside Diameter,	0.1	0.2	0.3	0.4	0.6	0.8	1.0	2.0	4.0	6.0	8.0	10.0
		Flow Rate, cubic feet per second[1]											
		Head Loss, feet per 100 feet of pipe											
160# PVC Plastic Pipe													
2"	2.193"	2.44	8.22	18.7									
3"	3.230"	0.37	1.34	2.84	4.83	10.2							
4"	4.154"	0.11	0.39	0.83	1.42	3.01	5.12	7.74					
80 psi Plastic Irrigation Pipe													
6"	5.900"		0.07	0.15	0.26	0.54	0.93	1.40	5.06				
8"	7.840"				0.06	0.14	0.23	0.35	1.27	4.58	9.70		
10"	9.800"						0.08	0.12	0.43	1.54	3.27	5.58	8.42
12"	11.760"							0.05	0.18	0.64	1.35	2.29	3.47

Flow rates to the right of the dashed lines have velocities over 7 feet per second and are not recommended.

[1] 1 cubic foot per second = 449 gallons per minute

Chapter 7
ESTIMATING ENERGY POTENTIAL

The amount of energy contained in water depends on the volume of the flowing water (flow) and the available difference in elevation (head) water can fall as discussed in the last 2 chapters. The measurement of head and flow is the basis for designing a system [21]. The amount of energy which you can recover in the form of electrical power is less than the available energy in the water. This is due to efficiency losses by the equipment which converts the hydraulic energy to electrical energy. Changes in either flow, head or efficiency affect the amount of electrical energy produced. This recoverable energy can be expressed in kilowatts by the following formula in equation 7. [22]

Equation 7 [22]

$$KW = (QxHxn)/11.8$$

Where: KW = Power potential in kilowatts
Q = Flow in cubic feet per second (CFS)
H = Head in feet
n = Efficiency of system

For most installations the head is relatively constant, but stream flow varies considerably during the year. The system efficiency also is affected by variations in the flow through the system. A typical efficiency of conversion accounting for losses in intakes, valves, draft tubes, turbines, generators, gears and transmission lines can be taken as Ø.6Ø [22]

Figure 7.1 lists the water flow and head required to run various small hydroelectric plants operating at 50% efficiency.[24]

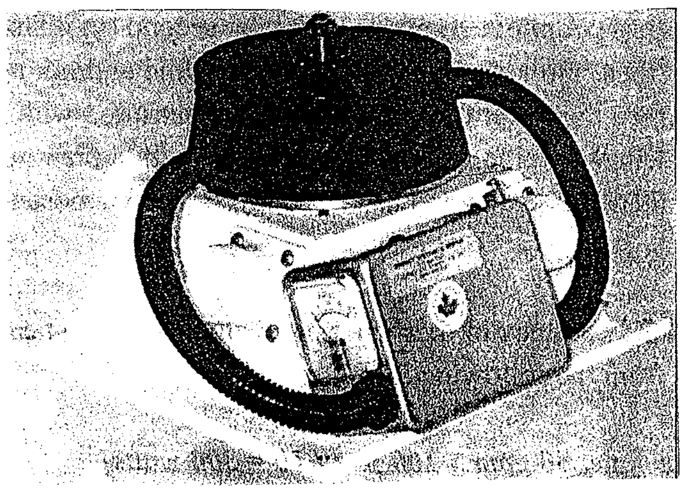
Figure 7.1 [24]

Generator Output, Kilowatts[1]	HEAD, feet 10'	20'	50'	100'	200'
	WATER FLOW, Cubic Feet per Second				
0.5	1.2	0.6	0.24	0.12	0.06
1	2.4	1.2	0.5	0.24	0.12
2	4.7	2.4	0.9	0.5	0.24
5	11.8	5.9	2.4	1.2	0.6
10	23.6	11.8	4.7	2.4	1.2

[1]Overall hydroelectric plant efficiency is 50%

When considering very small micro hydro systems rated at 1kW or less and shown in Figure 7.2, [25]

Figure 7.2 [25]



a simple yet approximate estimate can also be made with the equation listed in equation 7.3 [25] (this does not factor in losses).

Equation 7.3 [25]

$$\text{Head} \times \text{flow} / 10 = \text{watts}$$

Where: head = head in feet
flow = gallons per minute (gpm)

Example: 30 gpm x 100 feet /10 = 300 watts

Courtesy: Energy Systems and Design.

Manufacturers of small hydro systems usually provide performance specification of their systems as shown in Figure 7.4 [26]

Figure 7.4 [26]

TURBINE SELECTION CHART

EFF. HEAD FEET	CANYON 751			CANYON 9513			CANYON 1220			CANYON 1525			CANYON 2435		
	CFS	HP	RPM	CFS	HP	RPM	CFS	HP	RPM	CFS	HP	RPM	CFS	HP	RPM
20	.196	.3	483	.44	.6	381	.77	1.2	302	1.20	1.9	241	2.35	3.7	151
30	.239	.5	592	.54	1.2	467	.94	2.2	370	1.47	3.5	296	2.88	6.9	185
40	.276	.8	683	.62	1.9	539	1.08	3.4	427	1.69	5.4	341	3.32	10.6	213
50	.309	1.2	764	.70	2.8	603	1.24	5.3	477	1.93	6.6	382	3.71	15.8	238
60	.338	1.6	837	.76	3.8	661	1.35	6.9	523	2.12	10.8	418	4.15	21.2	261
70	.366	2.1	904	.82	4.9	714	1.46	8.7	565	2.29	13.7	452	4.48	26.7	282
80	.392	2.5	967	.88	6.0	763	1.56	11.3	604	2.44	17.8	483	4.79	39.2	302
90	.415	3.1	1025	.93	7.6	809	1.66	13.6	641	2.59	21.2	512	5.08	41.6	320
100	.438	3.9	1081	.99	9.0	853	1.80	15.9	675	2.73	24.8	540	5.38	48.7	337
110	.458	4.5	1134	1.03	10.3	895	1.80	18.4	708	2.90	28.7	567	5.60	56.2	354
120	.480	5.1	1184	1.08	11.8	934	1.90	20.9	740	3.00	32.7	592	5.87	64.0	370
130	.498	5.7	1232	1.13	13.3	973	2.00	23.6	770	3.10	36.8	616	6.10	72.2	385
140	.518	6.4	1279	1.17	14.9	1009	2.10	26.7	799	3.17	41.2	639	6.22	79.2	399
150	.535	7.1	1324	1.21	16.5	1045	2.10	29.2	827	3.28	45.6	662	6.43	87.7	413
160	.553	7.9	1367	1.25	18.2	1079	2.20	32.2	854	3.40	50.4	683	6.64	96.6	427
170	.570	8.6	1409	1.28	19.8	1112	2.30	35.5	881	3.50	55.1	704	6.85	105	440
180	.587	9.4	1450	1.32	21.6	1145	2.30	37.6	906	3.60	60.0	725	7.04	115	453
190	.603	10.2	1490	1.36	23.5	1176	2.36	40.8	931	3.70	65.0	745	7.24	125	465
200	.618	11.0	1529	1.40	25.4	1207	2.43	44.2	955	3.79	70.3	764	7.43	135	477
210	.634	11.8	1566	1.43	27.3	1236	2.49	47.5	979	3.88	74.1	783	7.61	145	489
220	.648	12.6	1603	1.46	29.2	1265	2.54	50.8	1002	3.97	79.5	801	7.79	155	501
230	.664	13.6	1639	1.50	31.2	1294	2.60	54.7	1024	4.06	84.9	819	7.97	167	512
240	.678	14.4	1675	1.53	33.3	1322	2.66	58.1	1046	4.15	90.6	837	8.14	178	523
250	.691	15.3	1709	1.56	35.4	1349	2.71	61.6	1068	4.24	96.4	854	8.31	189	534
260	.706	16.3	1743	1.59	37.5	1376	2.76	65.4	1089	4.32	102	871	8.47	200	544
270	.720	17.2	1776	1.62	39.8	1402	2.82	69.2	1110	4.40	108	888	8.63	212	555
280	.732	18.2	1809	1.65	42.0	1428	2.87	73.1	1130	4.48	114	904	8.79	224	565
290	.745	19.2	1841	1.68	44.3	1453	2.92	76.9	1150	4.56	120	920	8.95	236	575
300	.757	20.1	1872	1.71	46.7	1478	3.00	81.8	1170	4.70	128	936	9.10	248	585
350	.819	25.4	2022	1.84	58.6	1596	3.30	105	1264	5.10	162	1101	9.80	312	632

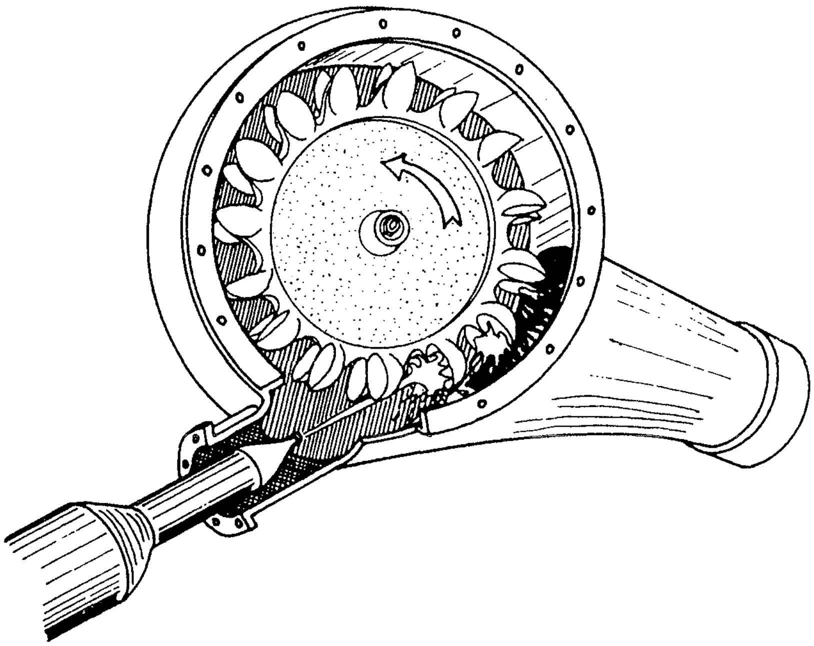
Courtesy: Canyon Industries Inc.

Chapter 8
HYDRO TURBINES

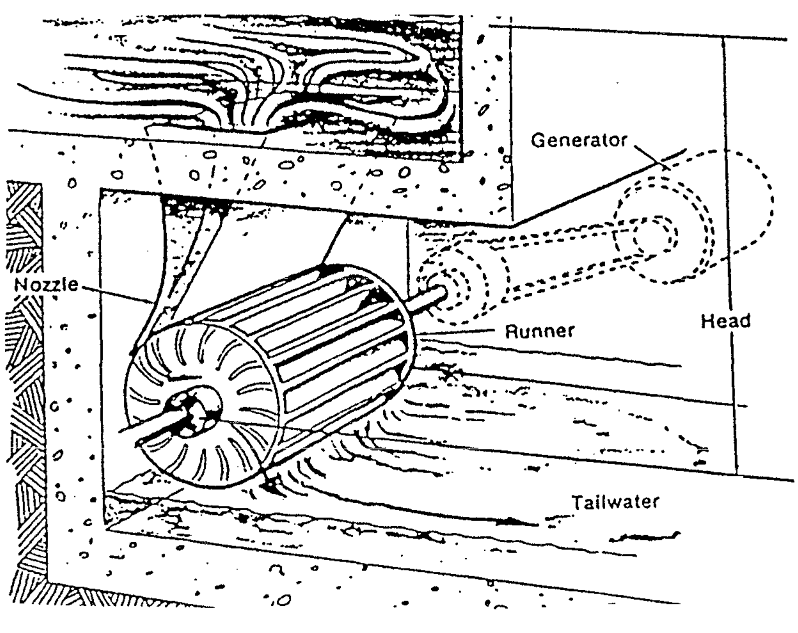
There are several types of turbine configurations available for micro hydro installations. If you are planning to build a micro hydro facility, some types of turbines can be eliminated immediately by knowing the characteristics of your site. Turbines are classified into two major categories: Impulse and Reaction.

Impulse turbines such as the Pelton, Turgo and Crossflow turbines are driven by the velocity of the water. Pelton and crossflow turbines are shown in figure 8.[29]

Figure 8 [29]



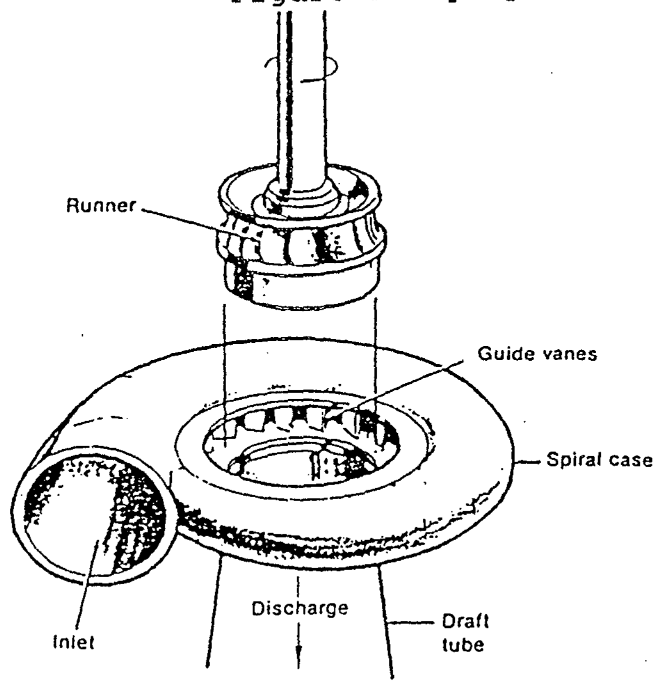
PELTON WHEEL



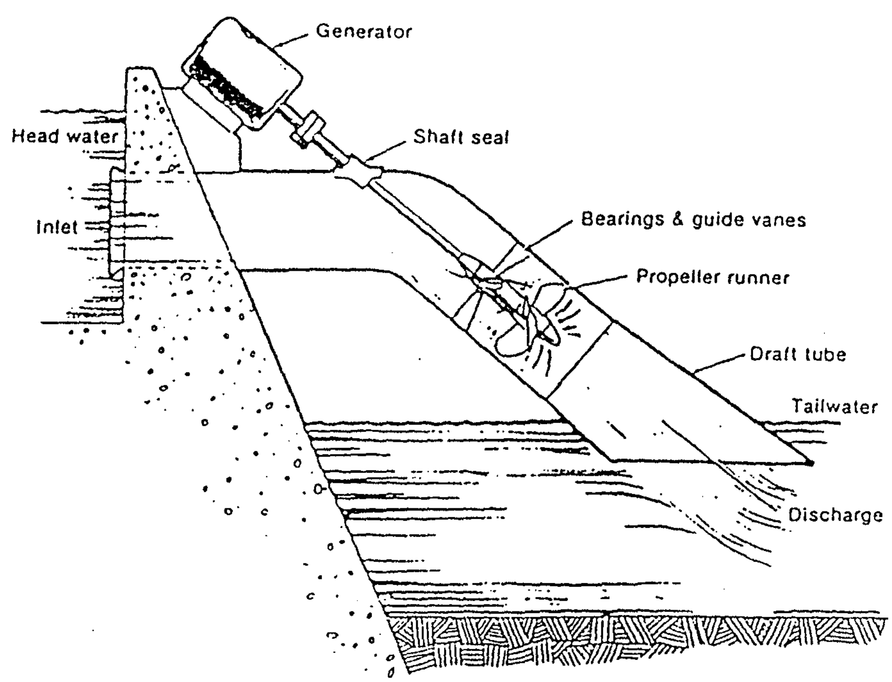
CROSS FLOW TURBINE

The Reaction Turbines, such as the Francis and Propeller turbines shown in figure 8.1 are driven by the pressure of the water. [30]

Figure 8.1 [30]



FRANCIS TURBINE

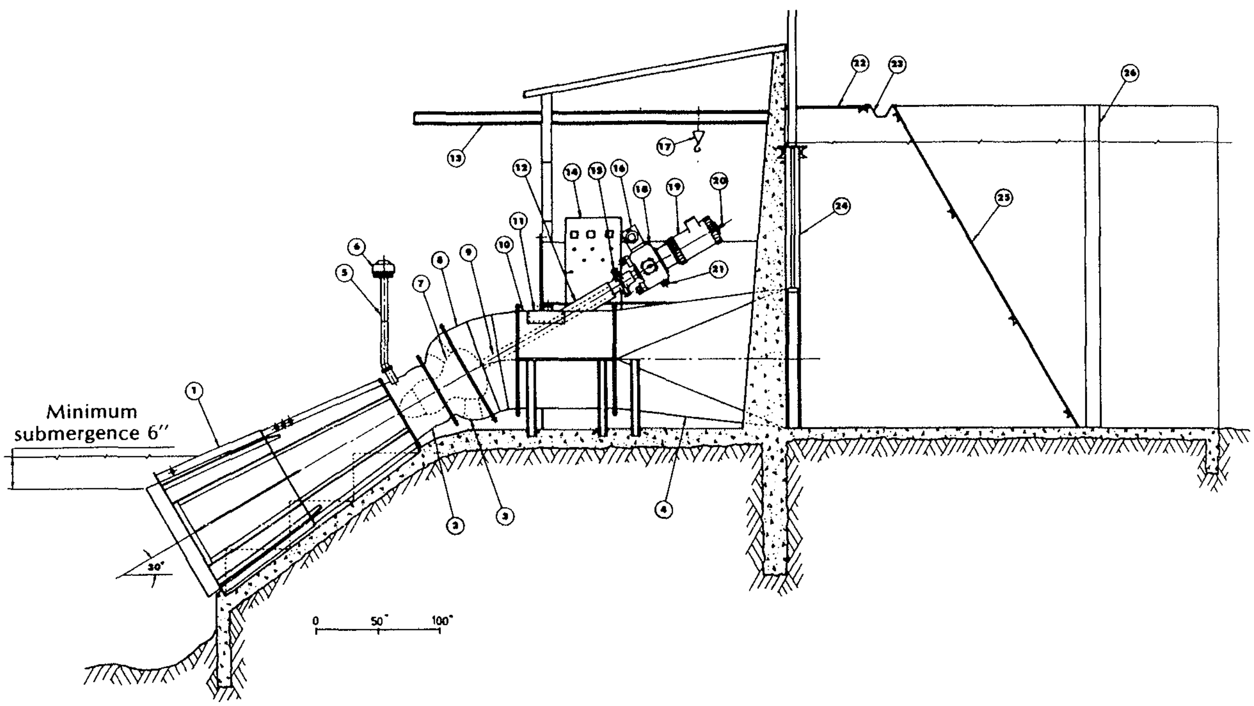


PROPELLER TURBINE

In general, the impulse turbines are installed at locations with high head and lower flow than the location of reaction turbines. Compared to impulse turbines, reaction turbines operate more efficiently, higher n, (see equation 7 on page 16) over a narrow range of head and flow, possibly lower PF (plant factor)[a] and have higher speeds. [31]

For reaction turbines to operate, the runners must be immersed. Either a draft (discharge tube) must be added as shown in figure 8.2. [32]

Figure 8.2 [32]

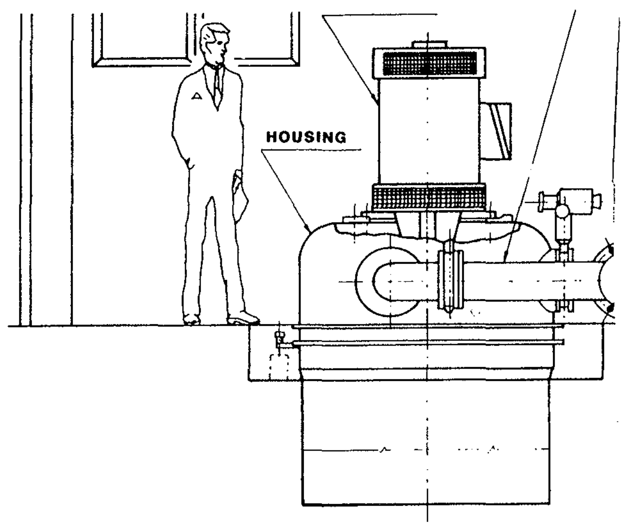


1. Draft Tube
2. Steel Turbine Throat
3. Cast Iron Guide Vane
4. Intake Transformation
5. Air Duct
6. Air Valve
7. Runner
8. 30° Elbow
9. Shaft
10. Adaptation Penstock
11. Inspection Door
12. Liquid Tight Seal
13. Beam
14. Control Panel

[a] Plant Factor (PF) is the ratio of the average annual power produced to the installed capacity annual power.

or provisions must be made to place the turbine below the tailwater level this might include installing a vertical generator and building a pit for the turbine (figure 8.3). [33]

Figure 8.3 [33]

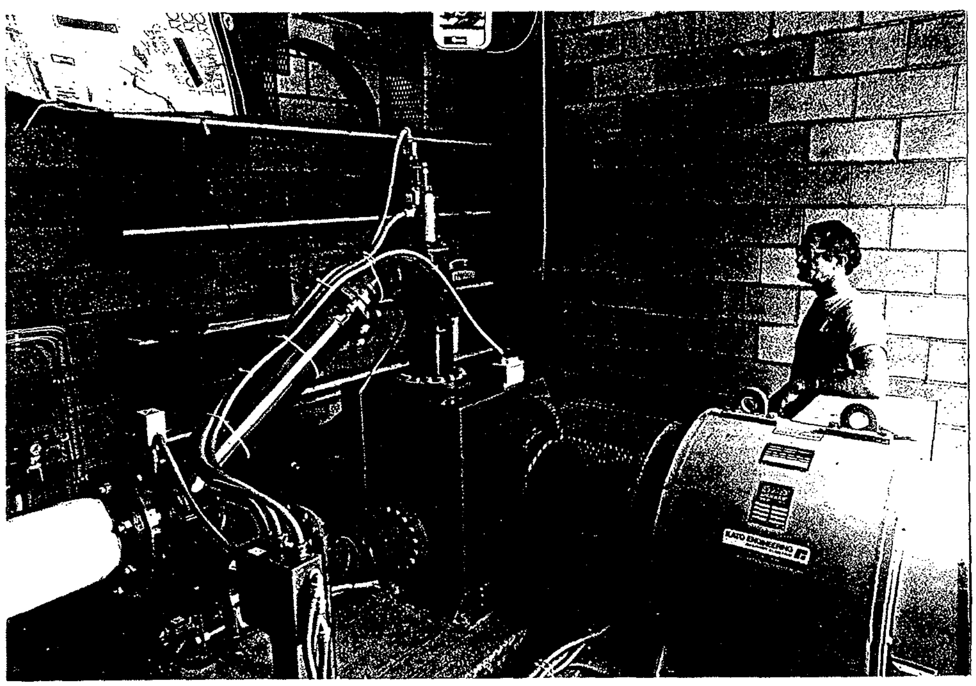


Since reaction turbines extract energy by reducing the pressure of the water, the pressure can be reduced until the water vaporizes (cavitation). Cavitation can occur at flows and head higher than design value and can result in damage to the turbine.

Close tolerances between the runner and casing maintains good efficiency and are an important feature of the reaction turbine, however, entrained sand and silt may cause more of a loss in efficiency in this type of turbine than the impulse type. [34]

Pelton Wheels. The Pelton wheel is a higher head turbine and is normally used in conjunction with a penstock (pipeline). It can operate at sites with low or substantial variation in flow. The efficiency remains relatively constant even down to 20% of maximum flow. The turbine spins so rapidly that little to no gearing is needed to turn a generator. Since the turbine operates in a jet atmosphere, it is placed above the tailwater pool resulting in the loss of up to a few feet of head. The high velocity of the water will cause gradual wear of the jets and "buckets" of the turbine. Maintenance is often less than that of impulse turbines since there is no cavitation problem.[35] Figure 8.4 shows a typical 100KW Pelton system. [36]

Figure 8.4

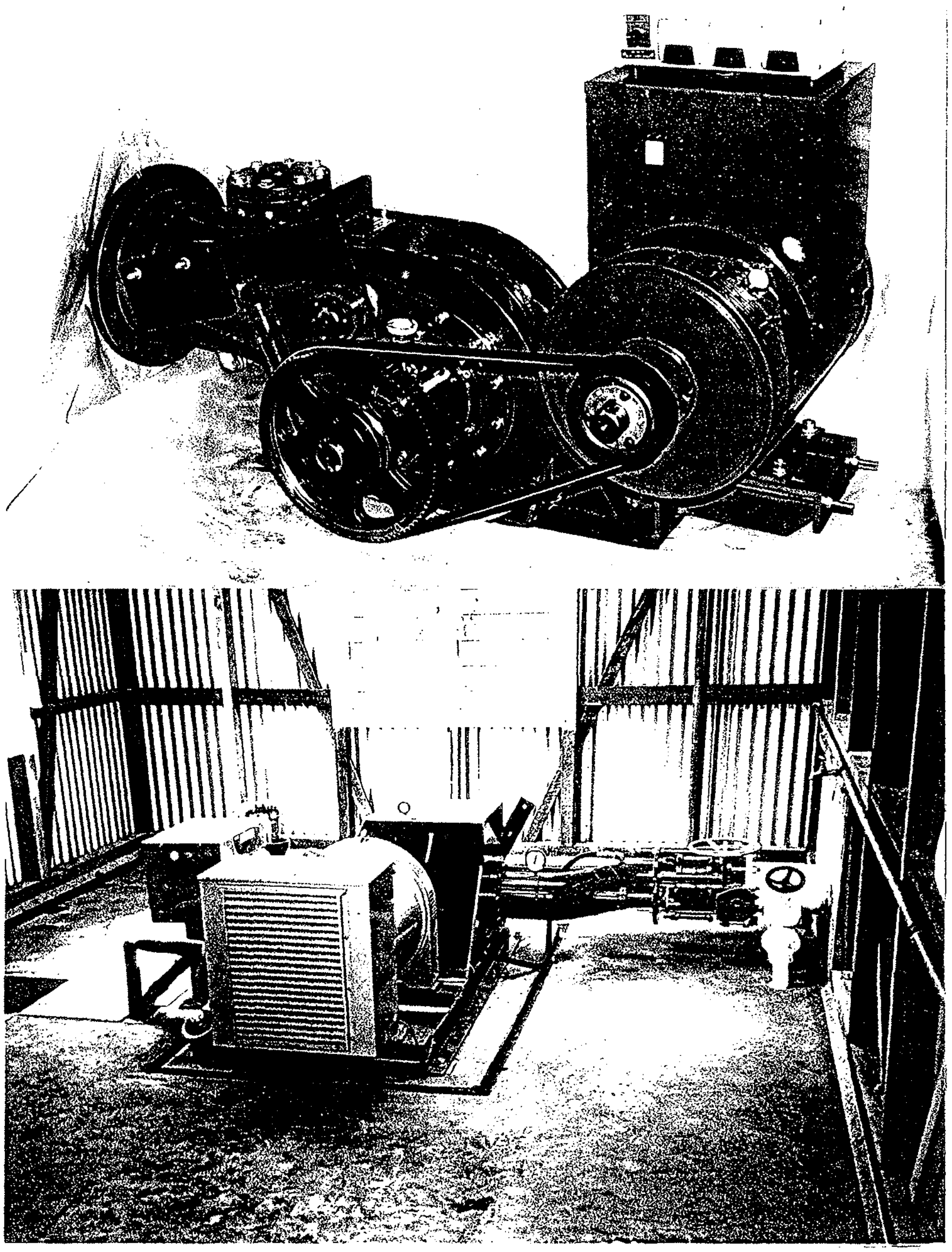


Courtesy: Canyon Industries Inc.

Turgo Impulse Wheel. The Turgo wheel turbine is like the Pelton wheel except that the shape of the wheel is different.[37]

Cross-Flow Turbines. A cross-flow turbine is designed to operate at partial flows, so that if a stream flow drops, guide vanes can block off part of the turbine. This feature allows it to operate with a relatively constant efficiency down to almost 10% of full flow. Since speed is a function of net head, low speeds will require gears be added to turn the generator at the proper speed to produce power. Cross-flow turbines are free from cavitation and are self cleaning. [38] Shown in figure 8.5 in their respective order are typical 40KW and 60KW cross-flow systems. made by Canyon Industries inc. [39]

Figure 8.5 [39]



Francis turbines. These operate over a wide range of head and flows because they have gates which control the inlet flows. The Francis turbine is has been used on large hydroelectric projects but are now becoming available for micro hydro use. Their gates termed "wicket gates," are complicated to repair as compared to other turbine systems. [38]

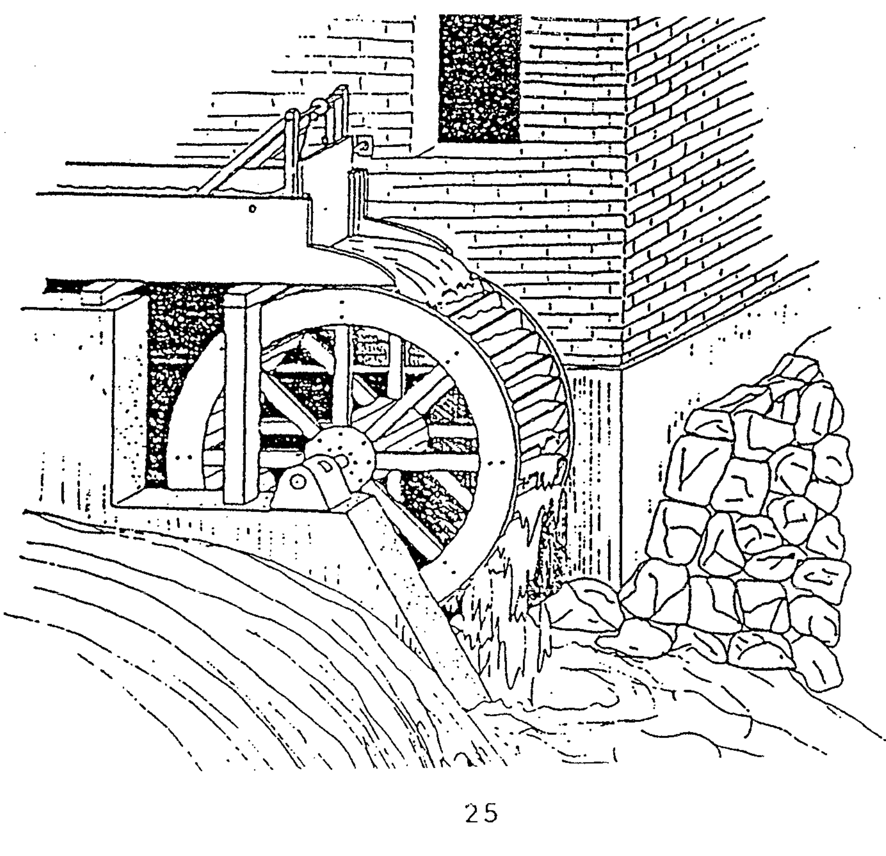
Propeller Turbines. Propeller turbines spin faster than Francis turbines even with low heads of water. The efficiency range of the fixed blade propeller turbine is narrower than the francis turbine and may result in lower plant factor (PF). The Kaplan turbine is a propeller turbine with adjustable pitch blades which widens its efficiency range. [38]

Waterwheels. Waterwheels have been used since Roman times to extract power from water. There are three main types of waterwheels; the Overshot, Breastshot, Undershot and/or Poncelet wheels (see figures 2 & 2.1 on pages 2 and 3).

Although less efficient than other turbine configurations, they can be less expensive and easier too maintain. Waterwheels cannot handle high heads but do perform well despite variation in flow rate. Although they are less susceptible to trash or grit in water, they are susceptible to ice problems in the winter months.

Waterwheels turn at between 2 and 2Ø RPM. While this slow turn rate is good for operating machinery, It is necessary to install the necessary gearing to produce the higher RPM rate needed to operate a generator. Since waterwheels produce tremendous amounts of torque, the gears must be heavy duty. The Overshot wheel shown in figure 8.6, is most commonly used since its efficiency is

Figure 8.6 [38]



higher and operates with higher head than other waterwheels. The Overshot wheel requires that water be brought to the top of the wheel by either a sluiceway or penstock. The Breastshot wheel has water brought to the mid-point of the wheel. The Undershot and Poncelet wheels are turned by the velocity of the water striking the lower part of the wheel [39]. Figure 8.7 shows typical efficiencies of power conversion devices. [39]

Figure 8.7 [39]

Component	Typical Efficiency, Percent
Waterwheel(1)	
– Undershot	25–45
– Breast	35–65
– Overshot	60–75
Turbine(1)	60–85
Reversed Centrifugal Pumps	60–85
Belt Drives(1)	95–97
Gear Boxes(1)	95+
Generators(2)	92.5–94.0
Main Power Transformers(2)	99

(1) Alward, et al. (1979)
(2) Wayne (1980)

The efficiency, n, of converting hydro energy into electrical energy is a composite of all components and accounts for energy losses throughout the conversion system. To find the net efficiency of a particular system, the individual efficiencies must be multiplied together. The above figure (8.7) show some typical individual efficiencies of certain components. For a system consisting of a turbine, 2 belt drives and a generator, the net efficiency is:

Net efficiency, n = Ø.89 turbine x Ø.95 (belt) x Ø.95 (belt) x Ø.93 (generator) = Ø.67

The plant factor (PF) is the ratio of the average annual power produced to the installed capacity annual power. The installed capacity annual power production in KWH (kilowatt-hours) is obtained by assuming that the installed capacity (KW) operates continuously throughout a year (8760 hours). The installed capacity is obtained from figure 8.8 [22]

Figure 8.8 [22]

$$KW = (QxHxn)/11.8$$

Where: KW = Power potential in kilowatts
Q = Flow in cubic feet per second (CFS)
H = Head in feet
n = Efficiency of system

The power developed by a flow less than the design flow is found by using the lower flow value (Q) in the above equation. When the flow is less than the design flow turbine efficiency is also lower. In some cases the efficiency drops to near zero when the flow is only 60% of the design flow, in others it drops significantly below 20% of the design flow. This can be minimized by selecting the proper size turbine for a particular flow rate keeping in mind the seasonal variation of flow rates. If you want to maximize the annual production rate, a design flow exceedance of 25% is recommended. For a dependable amount of power (high plant factor) a 90% exceedance is recommended. Flow exceedance is derived from a flow duration curve such as the one shown in figure 5.6 on page 12.

The generalized flow-duration curve of New England shows that the flow at 25% exceedance is slightly greater than the mean flow. Using equation 8.10 and the multiplier from the generalized curve gives an approximate design flow at 25% exceedance equal to A (2.0)

Equation 8.10 [12]

$$Q = A\ (1.8)$$

Where: A = Area of drainage basin in square miles.
Q = Mean annual flow in cubic feet per second.

For example, if the drainage area is 10 square miles, the mean annual flow (Q) is estimated to be 18 CFS

To find your annual average power production, Equation 8.11 is used.

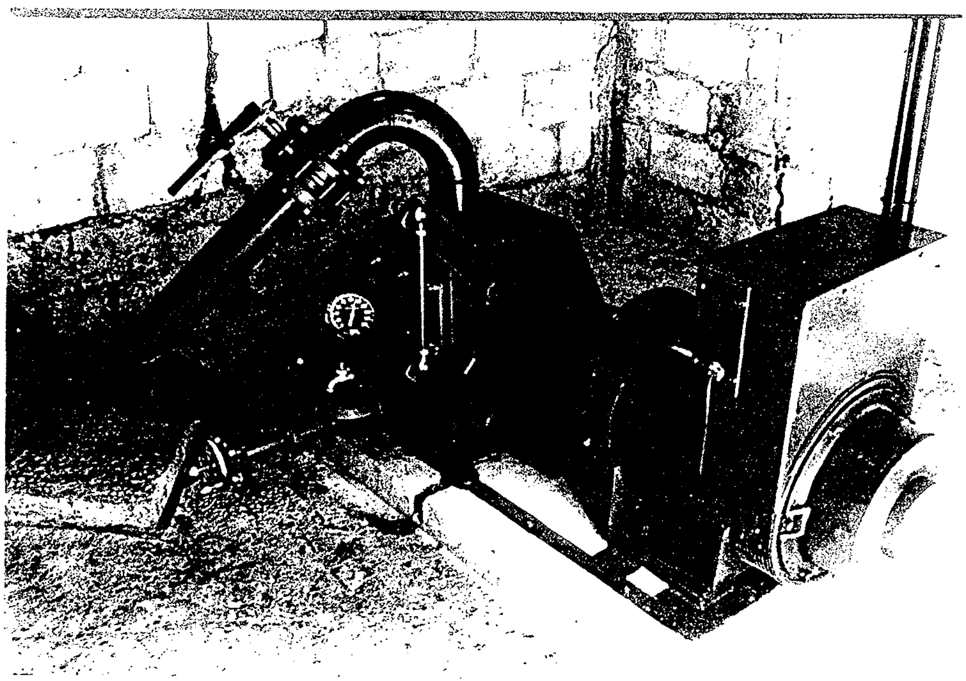
Equation 8.11

$$(KWHR)_{ann.ave.} = KW \times 8769 \times PF$$

where: $(KWHR)_{ann.ave.}$ = Average annual power production in kilowatt hours.

KW = Installed capacity in kilowatts.
8760 = Number of hours per year.
PF = Plant Factor.

Sometimes you can store enough water in a reservoir so that flow discharges to the turbine can be maintained at higher levels than the stream flow. This entails building a dam or renovating an existing one. This will result in increased costs and regulations. A consultant and/or engineer is highly recommended. The next chapter will focus on these aspects.



Chapter 9

DAMS, IMPOUNDMENTS, PENSTOCKS AND POWER HOUSE

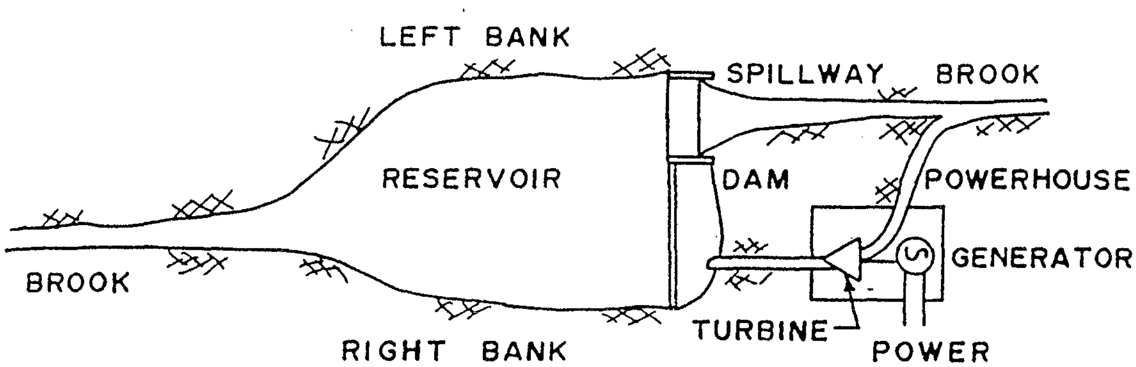
Generally speaking, a micro-hydro project will be easier to construct and obtain permits for if stream disruption is kept to a minimum. Many successful small hydro projects take advantage of natural pools or backwaters for siting the intake structure. Others have maximized the usefulness of natural pools by adding a simple diversion. But in some instances small dams may be necessary to maximize head or to provide storage. A word of warning. There is more to building a dam than piling up a wall of rock. [42]

The dam creates a reservoir which creates head and/or controls water flow to the turbine. In designing a dam, you must control for leakage, stability, settlement, flows and flooding periods. At a low head site the depth of water in the reservoir provides the head to drive a turbine. A higher the reservoir will result in greater head. However, reservoirs greater than 10 feet deep begin to pose safety concerns and should be designed by a qualified professional. this also applies to impounding a stream with design flows of more than 1 CFS.

If available an existing dam saves time and money since environmental changes are minimized. An existing dam demonstrates that the dam and spillway design has been adequate for flows encountered historically. Sometimes the dam and spillway may need upgrading to meet possible larger future flows and/or for safety reasons. In any event a qualified professional should inspect the dam prior to conducting any work on such a facility.

Water in a reservoir must be contained and replenished so consequently, the developer will utilize the existing terrain for three sides of containment as shown in figure 9. [40]

Figure 9 [40]



Dams must be built to withstand the forces of water and resist erosion from rainwater and percolation from the reservoir. Water losses can occur not only through the dam but sometimes water can seep through the foundation. This results from the foundation being placed on soils or rocks that are larger than sand size. Either the material must be removed down to a more impervious material such as rock or hardpan, or, a one to two foot layer of clay or silt can be used to line the reservoir. Plastic liners are also quite effective. [40]

Although there are many different materials that are used in constructing a dam, materials such as concrete, while more expensive, will save much labor and time.[a]

Dams must also be stable against large soil movements. for earth dams, an upstream slope of 4 feet horizontal to 1 foot vertical and a downstream slope of 2.5 feet horizontal to 1 foot vertical should be sufficient for most materials encountered in Maine. Fine materials may require a flatter slope.

Stone-earth, timbercrib, gabions, and precast concrete segments form vertical downstream walls. They are buttressed on the upstream side with sloped earth. A slope of 4 feet horizontal to 1 vertical should be sufficient.

Poured concrete dams eliminate the need for upstream earth slopes. Reinforced concrete saves on the amount of concrete needed but normally requires professional design.

Soil erosion must also be controlled on dams, deep rooting grass will help stabilize soil. Riprap (large boulders) placed on the upstream side of the dam will help reduce the erosive effect of the stream on the dam itself. Earth dams must be built to resist settling as well as erosion. Soil must be placed in 8 inch layers and then compacted. The soil should not contain large rocks, stumps or other vegetation. You can compact a small dam by running a bulldozer back and forth six times over each layer.[40]

A good book on dam design is entitled Design of Small Dams (1973) U.S. Dept of the Interior, Bureau of Reclamation, U.S. Government Printing Office.

Dams must be protected against destruction of floods. Earth dams require a spillway to carry off the overflow in periods of high water. The top of the spillway is lower than the top of the dam. The spillway can be made of concrete or wood planks. The rock crib, gabion, precast concrete and concrete dams don't require spillways as water goes over the top, however, provisions must be made to protect the powerhouse.

Many failures of dams are attributed to spillways being too small or improperly designed. A spillway of ample capacity generally costs moderately more than one that is too small.

---

[a] According to a program sponsored by the U.S. Dept. of Energy, a small hydro facility was built in Enfield Maine. The dam was a 75 foot long, 8 foot high rock crib dam. The grantee thought it would be inexpensive and easy to build. It wasn't... The grantee and about 40 friends had to cut and peel 200 logs, build the 8 x 8 x 8 foot cribs and fill them by hand - with about 4,000 cubic feet of rocks. In retrospect the grantee reported that he would opt for a concrete dam, in spite of the extra cost. [41,42]

The size of an overflow spillway is made by the following formula shown in equation 9.1.

Equation 9.1 [43]

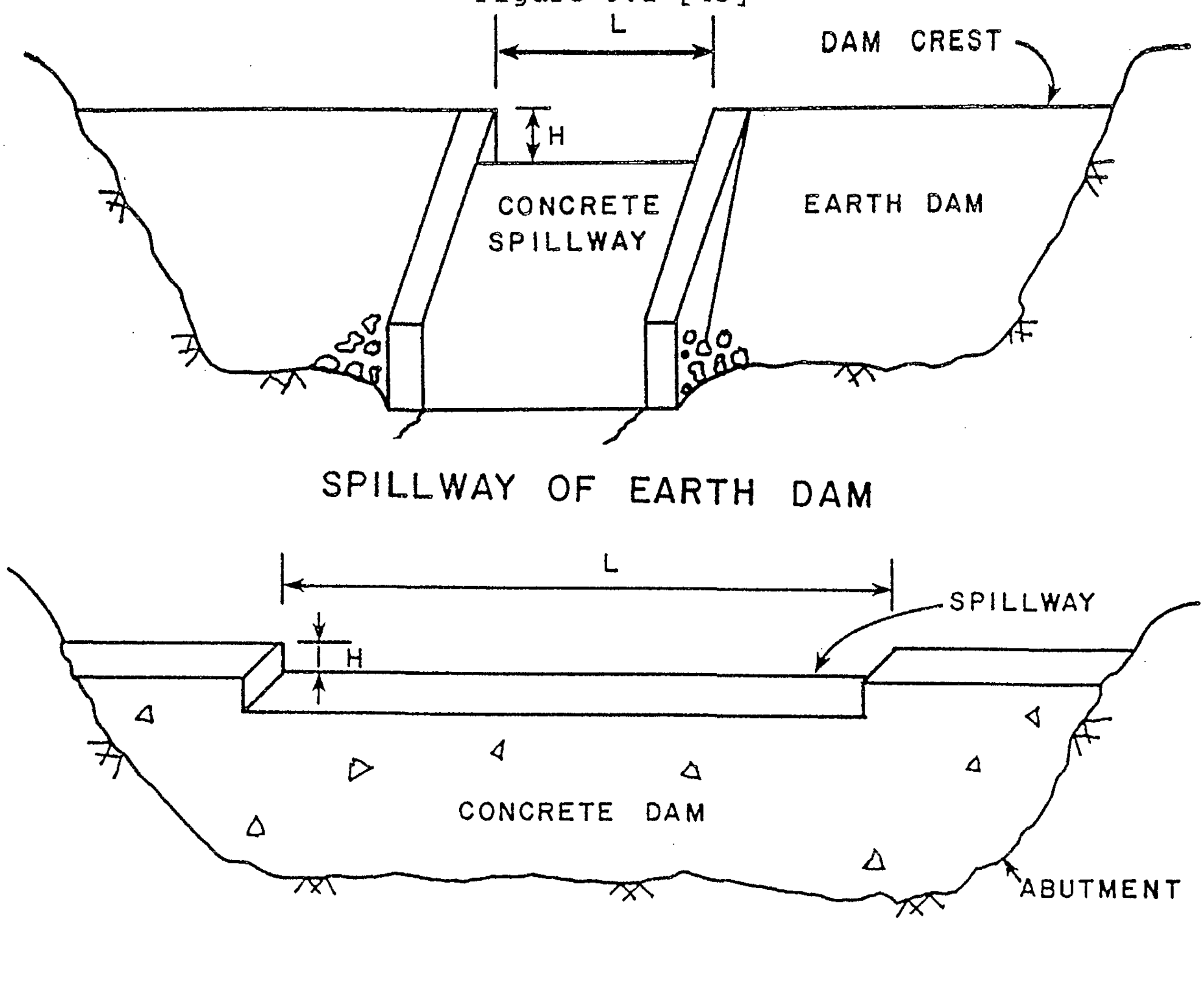
$$Q = CLH^{3/2}$$

Where:

C = 3.3 (constant for small dams)
L = Length of spillway in feet
H = Height of spillway in feet
Q = Flow Capacity, CFS

The capacity must be equal to or greater than the flow for a specified periodic flood. If the spillway capacity (Q) is less, increase the dimensions of the spillway. You should design for a flood level that recurs in 25 years or longer. Regulatory agencies will probably specify a recurrence period for the spillway design flood. Figure 9.2 shows the spillway of earth and concrete dams. [43]

Figure 9.2 [43]

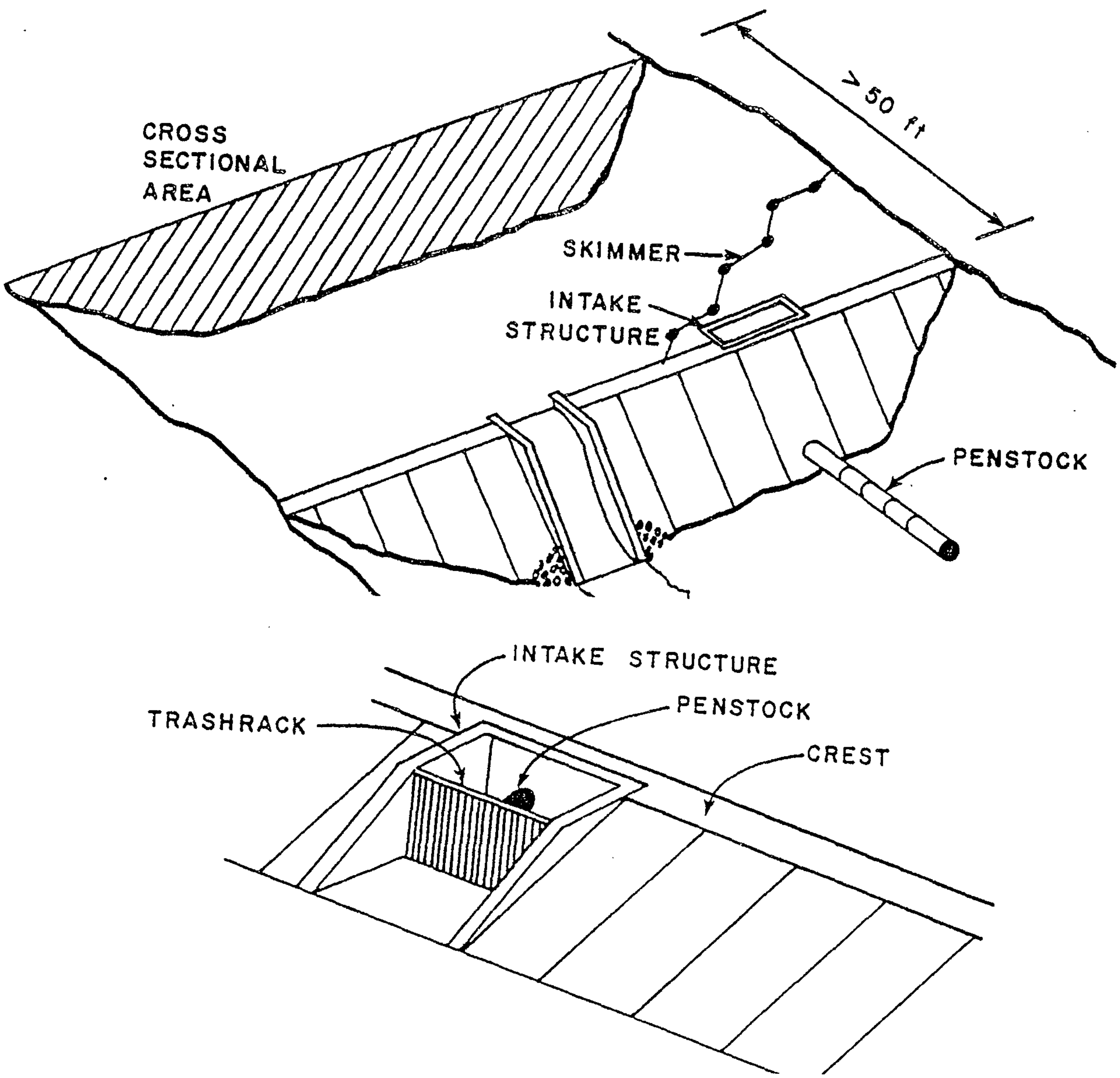


SPILLWAY OF CONCRETE DAM

In addition to providing sufficient spillway capacity, the spillway must have a non-erodible lining along the waterway. The downstream toe of the dam must be protected with armor stone so that the discharge will not erode or undermine it. Planning a dam must include downstream interests. The possible loss of property and/or life in the event of a failure, as well as future development in the downstream flood plain, should be considered.

Water is brought to the turbine through a penstock (pipeline) or a conduit through the dam. To prevent debris from damaging the turbine, a skimmer, which is a floating line or string of floating logs upstream of the intake conduit or penstock helps diverts floating debris away from the inlet. A trash rack, which is a metal grate is also placed in front of the inlet. Suspended sand and silt which could pass through the trash rack are removed by settling in a quiet basin upstream of the inlet known as a forebay. Figure 9.3 shows all of the above. [44]

Figure 9.3 [44]



The forebay should be large enough so that the water velocity is less than Ø.25 feet per second. For most installation with a reservoir behind a dam, the reservoir will be large enough to trap the sand and silt particles. If the water is being diverted to a penstock, the water velocity must be checked and if too swift, a forebay must be designed. To obtain a velocity below Ø.25 feet/sec. the cross sectional area of the forebay should be larger than the area calculated in equation 9.4.

Equation 9.4 [45]

$$A_{FB} = 4 \times Q$$

Where: A_{FB} = Cross sectional area of the forebay in square feet
Q = Design flows in cubic feet per second.

If the design flow is 8 CFS, The area of the forebay should be greater than 32 square feet. The length upstream of the pipe inlet should be greater than 5Ø feet as shown in figure 9.3 on page 33.

The trashrack is a grating which stops debris but must not restrict the flow with openings that are too small. They must be of rugged construction and designed for easy cleaning. The trashrack is designed so that the water velocity is less than Ø.5 feet per second. The open area must be greater than that given in equation 9.5 [45]

Equation 9.5 [45]

$$A_{TR} = 2 \times Q$$

Where: A_{TR} = Area of open space in trash rack in square feet
Q = Design flow in cubic feet per second.

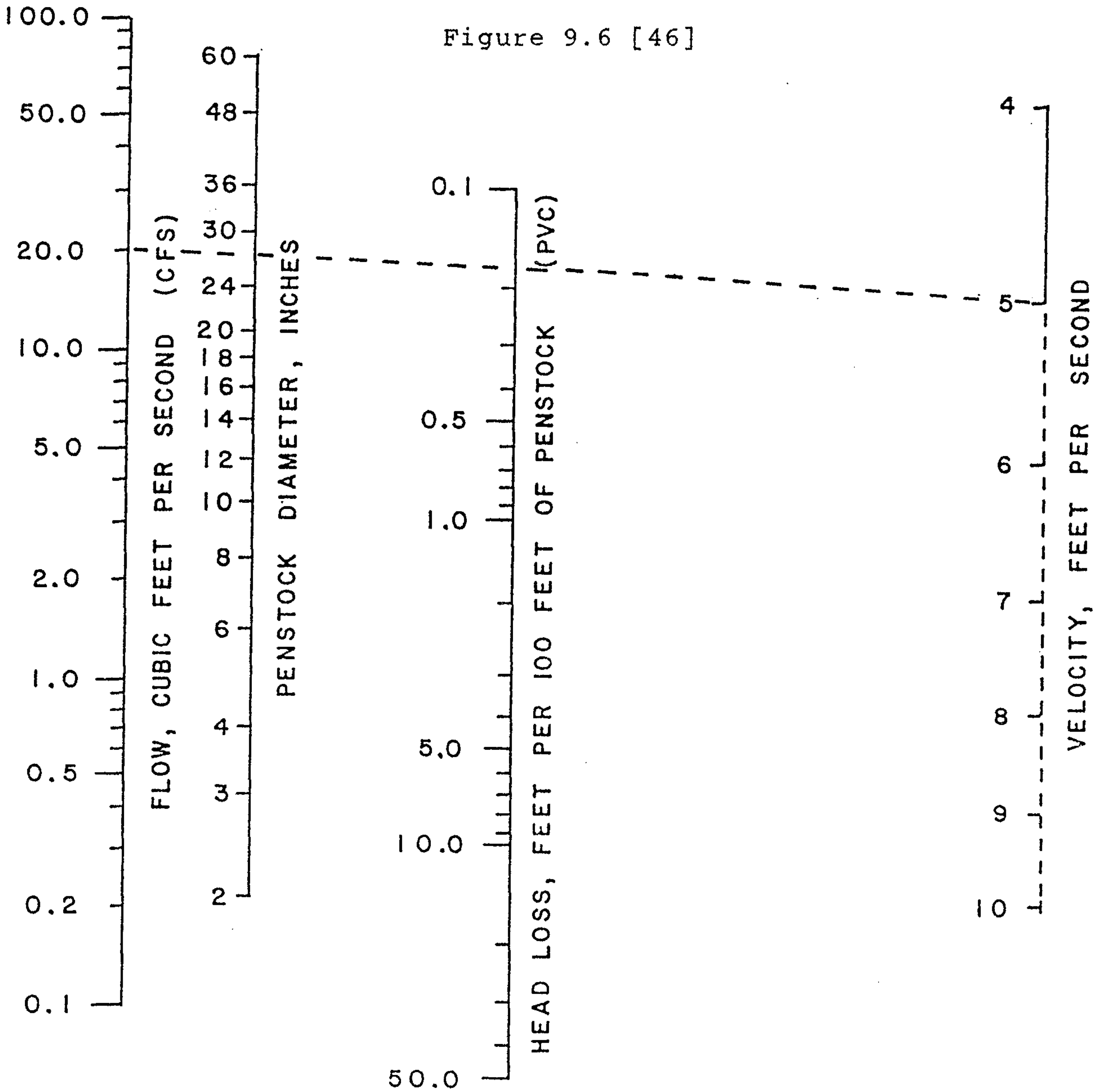
The total width of the trash rack will be the width of the open area plus the total width of the bars. For racks with 1/4 inch bars and 1/2 inch spaces, the total rack width is 5Ø% larger than the width of the open spaces. For example, if the design flow is 8 CFS, the needed open space area using equation 9.5 is 16 square feet. For a 5 foot minimum depth of water, the trashrack open space width is 3.2 feet. The total trash rack open space width is 3.2 feet. The total trash rack width is then 4.8 feet, which is 5Ø% greater than 3.2 feet. For bar sizes other than the 1/4 inch and different opening sizes, the total trash rack width will have a different ratio to the open space width than 5Ø%. [45]

The intake structure at the inlet to the penstock provides the framework for the trash rack (shown in figure 9.3 on page 32). The intake structure can be constructed with reinforced concrete, wood or other materials might also be used. The penstock should be located far enough from the bottom as not to pick up debris from the bottom. It also be at least 1-1/2 times the pipe diameter below the low water elevation or below the normal ice level. [45]

The penstock is a pipe that conveys water with head from the intake to the turbine. It must be large enough to convey the intended flow and strong enough to resist the water pressure and should be protected from sunlight, cold, and falling debris such as trees and branches. The penstock should be adequately supported and resistant to the thrust developed by water moving inside as well as heaving of the supports which may be caused by frost.

The size of the penstock is related to the design flow of the turbine. First you must know the design flow of your stream as discussed in chapter 8. Turbine manufacturers can use this information to assist you in determining proper penstock size and material. Figure 9.6 shows how to determine proper penstock size using the stream design flow and desired flow velocity using PVC pipe. By drawing a line across the graph from the known stream design flow to the desired water velocity, head loss and proper penstock size can be determined (this is where the line crosses each respective scale). [46]

Figure 9.6 [46]



If the proper pipe size is unavailable, use the next greater available size. Items affecting head loss also include: inlet design; bends; valves and penstock material type (steel, polyethylene, PVC etc.). An engineering text, turbine manufacturer or Microhydropower Handbook (listed in section entitled "For more Information" in the back of this document) should be consulted.

For a design flow of 1.0 CFS through a penstock 2400 feet long and a gross pool to pool head of 160 feet, the head loss of the penstock is derived from figure 9.6 (page 34) at 1.1 feet per 100 feet of penstock resulting in a loss of 26.4 feet. Additionally, you must calculate the loss of 1 intake, 5 bends and 1 valve. This assumes losses for one intake (loss of 0.5); 5 bends (loss of 0.5 each) and one valve (loss of 1.0). The head loss from these items is 4.0 feet. Thus the head loss of the penstock, intake, bends and valve is 30.4 feet. To determine net head, you subtract 30.4 feet from the gross pool to pool head of 160 feet. This results in a net head of 130 feet.

The penstock must be able to withstand the water pressure when the valve near the turbine is closed. This pressure equals the static pressure of the water plus a surge pressure when the valve is closed. Equation 9.7 is used in determining pressure.

Equation 9.7 [47]

$$P_D = 0.4333 \times H + P_s$$

Where:
P_D = Penstock design pressure, psi
H = Design head, feet
P_S = Surge pressure, psi

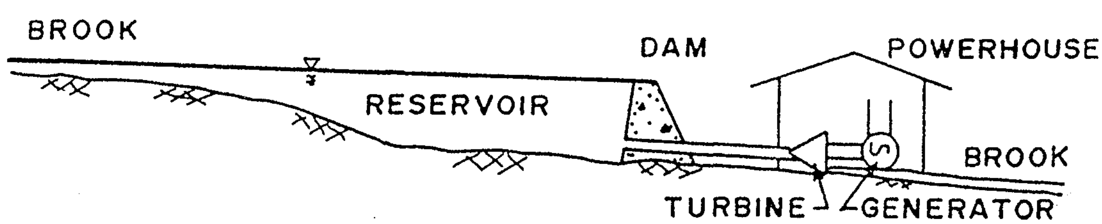
The design head is the elevation difference between the intake pool and the turbine intake. The surge pressure for plastic pipe (polyethylene or PVC) is approximately 60 psi. You must select the plastic pipe which will withstand the calculated design pressure. Steel penstocks with 0.25 inch wall thickness will handle most pressures encountered in microhydro installations. [47]

A penstock can be either above ground or buried. Both have advantages and disadvantages. One is cost. The above ground penstock is less expensive as it eliminates the excavation of a trench and can be cleaned and maintained without hiring equipment to dig it up. However, the buried penstock which costs more, is less susceptible to freezing, vandalism and is not affected by falling branches and trees. On the down side the buried penstock might have to be dug up in the event a problem develops such as clogs or breaks. Dips and humps in the pipeline might result in serious problems, so great care must be taken when planning the penstock route.

The power house is essentially a shelter for the turbine and associated electrical equipment. It also acts as a protective workspace and limits access for safety and security reasons.

Placement of the powerhouse with respect to the stream is important. It should be high enough so that it won't be damaged by spring runoff, yet low enough so that head is not lost at the turbine. Submerged turbines may be located below floor level. The building should be large enough to accommodate all necessary equipment and workspace. For ease of installation and maintenance, the turbine should be placed in the center of the building. A concrete floor is advisable, however, if wood is used for the floor it should be framed with pressure treated Wolmanized lumber. Insulating the building helps keep it warm in winter months with excess generator heat. In the event of a shutdown, another heat source should be planned for. A few windows will allow additional light in, and also aid in ventilation during the summer months.[47]

As with any building, the powerhouse must be built in compliance with respect to all electrical, plumbing and building codes.



Chapter 1Ø
UTILITY INTERCONNECTED SYSTEMS

When used for reducing or eliminating utility bills, the utility interconnected system is the best. Since it is connected to the utility lines (usually through the owners main panel), energy is still available even when the microhydro system is not operating. This insures a reliable energy supply. The main components of such a system include the turbine and associated power control/conditioning equipment.

In addition to average power needs it may be helpful to analyze usage patterns. Depending on whether you are considering conservation methods, utility interconnected or off grid systems, analysis of energy consumption is critical. [48]

In describing Utility Interconnected Systems, certain methods are used to evaluate electrical consumption for basic system sizing. For existing households and small businesses, the easiest method to analyze electrical consumption is to review your past electric bills. By graphing monthly kilowatt hours used during the past year, you will see your average monthly use and seasonal variations such as higher use in the winter months as compared to lower consumption in the summer. This is valuable in determining what size system is best. This result then can be compared to the available hydro resource (taking into consideration the seasonal variation of the hydro resource) and allows proper sizing of the system to the resource and energy requirements of the customer. Incorporating energy conservation measures into the design will aid in longer system life and faster payback.

Another method of evaluating your electrical usage is to make a list of appliances that you have, then add up the estimated annual energy consumption using the chart shown in figure 1Ø on the following page. [48]

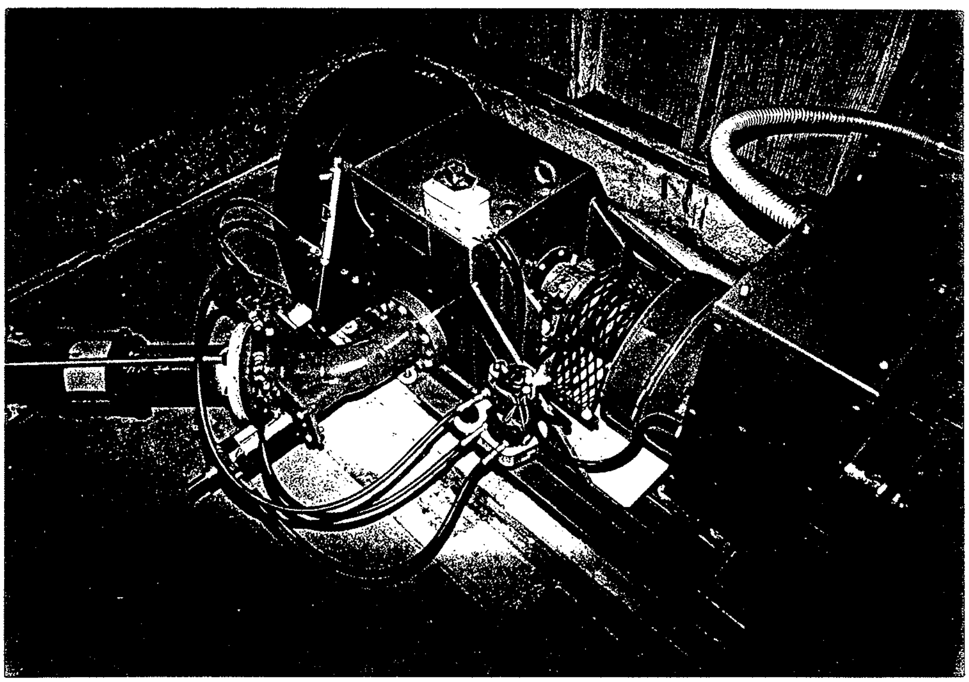
Figure 1Ø [48]

Item	Average wattage	Est. kwh consumed annually
Blender	3ØØ	1
Coffee Maker	12ØØ	14Ø
Deep Fryer	1448	33
Dish Washer	12Ø1	363
Hot Plate	12ØØ	9Ø
Mixer	127	2
Microwave Oven	145Ø	19Ø
Range with Oven		
(self cleaning	122ØØ	73Ø
Toaster	1146	39
Trash Compactor	4ØØ	5Ø
Freezer		
Automatic Defrost 16.5 "		182Ø
Refrigerator/Freezer		
Automatic Defrost 17.5"		225Ø
Clothes Dryer	4856	993
Hand Iron	11ØØ	6Ø
Washing Machine (Auto)	512	1Ø3
Water Heater		
Quick Recovery	4474	4811
Dehumidifier	257	377
Humidifier	177	163
Fan (circulating	88	43
Fan (window)	2ØØ	17Ø
Air Conditioner (rooms)		
1ØØØ hours annual use	96Ø	96Ø
Hair Dryer	6ØØ	25
Color Television		
(solid state)	145	32Ø
Radio/Record player	1Ø9	1Ø9
Clock	2	17
Vacuum Cleaner	65Ø	46

Source: Central Maine Power Co., Lamplighter, January 198Ø

There are many "hidden" appliances in Maine homes such as electric water pumps, and heat. To estimate annual energy consumption, you would look at the nameplate (found near where the electric wiring enters the appliance or on the back of that appliance) The nameplate usually has appliance electrical consumption data listed on it. If the watt rating is not listed on the nameplate, the voltage and amp rating will be. To determine its kilowatt hour rating, you would multiply the voltage rating times the amp rating. The result will be its watt rating. For example, an electric water pump might be rated at 11Ø volts, 2 amps. (11Ø X 2 = 22Ø watts) If used 3 hours per day, Multiply (22Ø X 3) = 66Ø watt hours used daily. In a one year period, (66Ø watts X 365 days), 24Ø,9ØØ watt hours would be consumed. By dividing 24Ø,9ØØ watt hours by 1ØØØ the result would be 24Ø.9 Kilowatt hours consumed.

By knowing what your electrical consumption is, you will have a good idea of approximately what size and type of system would be most appropriate. By comparing electrical consumption, hydro resource availability and power curves provided by turbine manufacturers, proper system sizing can be achieved. These utility interconnected systems can be designed to charging batteries as a form of back-up in the event of a power failure on the utility side.



Chapter 11
BATTERY CHARGING SYSTEMS

These systems are popular when one desires not to be connected to the utility, or where utility lines are not run in or too expensive to do so. Used at remote telecommunications sites and popular with homeowners who have camps or homes in remote areas, these systems have made remote living quite comfortable. With readily available AC appliances, inverters that convert DC electricity to AC allow owners of remote facilities to enjoy every convenience that their grid connected counterparts do. This also simplifies wiring the home or small business.

Since battery charging systems obviously require batteries to store energy, You must determine what your electrical consumption will be. The microhydro turbine voltage and the battery voltage must correspond. Since a 24 volt battery bank is composed of 12, 6 or 2 volt batteries, a 115 volt system may have 57 to 60 battery cases.

The sizing of the bank should meet the electrical load demands and average length of low hydro periods. (solar panels, wind generators and/or fossil fueled generators can also be installed to offset these periods). Charging rates may vary so battery banks need to be relatively large, therefore, industrial heavy duty deep cycle batteries are best.

The battery bank is exactly like a holding tank for electricity. If it is too small it will be continually overflowing or running empty and could fail prematurely due to large charging currents available from different systems. Plan enough amp-hour capacity for unexpected problems such as maintenance shutdowns.

It would be a good idea to have enough storage back up (4 to 6 days) in the event a component needs to be ordered. (this allows time for shipping and installation).

Figure 11 (on the next page) can be used to estimate how many amp-hours per day your household needs as a minimum during the low flow season. Multiply by the number of days storage you need to determine the amp-hour battery capacity required. The amp-hour usage of an appliance is determined by multiplying its wattage by the hours of use and dividing by voltage.[49]

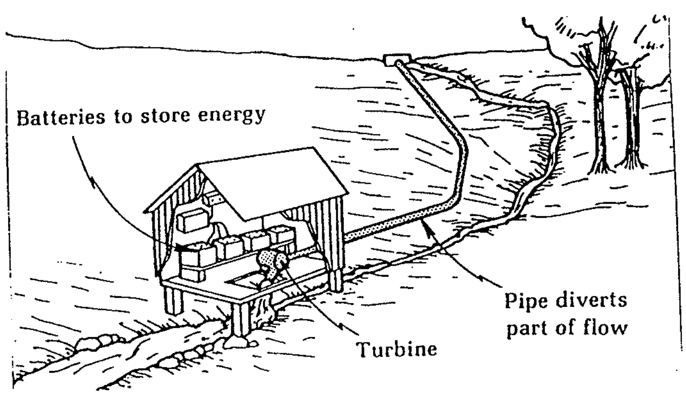


Figure 11 [49]

EXAMPLE OF BATTERY CAPACITY (AMP-HOURS) CALCULATION

Stereo Cas.	30 watts	x	3 hours	=	90 watt-hours
Fan	55 watts	x	4 hours	=	220 watt-hours
Skill Saw	450 watts	x	20 minutes	=	150 watt-hours
Computer/mono	110 watts	x	1 hour	=	110 watt-hours
Coffee Brew	600 watts	x	10 minutes	=	100 watt-hours
Coffee Warm	75 watts	x	1 hour	=	75 watt-hours
Microwave	600 watts	x	15 minutes	=	150 watt-hours
Lights	150 watts	x	3.5 hours	=	525 watt-hours
Water Pump	225 watts	x	3 hr/wk	=	96 watt-hours
TV/VCR	125 watts	x	1 hour	=	125 watt hours
Hair Dryer	1200 watts	x	10 minutes	=	200 watt-hours

TOTAL WATT-HOURS PER DAY USAGE 1841 watt-hours

b. Add 20 percent for battery and inverter losses:
1841 x 1.2 = 2209.2 watt-hours per day usage

c. Divide by the battery voltage, say 12 volt system
2209.2 / 12 = 184.1 amp-hours per day usage

d. Multiply by the number of days storage desired, say 5 days
184.1 x 5 = 920.5 amp-hour capacity, 12 volt battery required

e. If this is a 24 volt battery, divide watt-hours per day by 24 and multiply by 5. For 32 volt battery divide by 32 and multiply by 5, etc.

(2209.2 / 24) x 5 = 460.25 amp-hour capacity, 24 volt battery required (2209.2 / 32) x 5 = 345.2 amp-hour capacity, 32 volt battery required.

Make certain that the charging voltage of the system matches the voltage of the battery bank !

BATTERIES

Batteries also need to be carefully selected. Your standard automotive type should never be used. Deep cycle batteries are recommended because of they can be discharged and recharged many times over. The Lead-Acid type is the most common and has distinct advantages and disadvantages. Lower cost is the primary advantage as well as their ability to accommodate "large start up loads". This occurs when appliances that use electric motors (i.e. a table saw) that require large amps to start that appliance operating.

On the down side, They need to be "Maintained". About once a month an equalizing charge should be done. This is when the battery is overcharged by a couple of volts to keep the voltage of all the cells equal. The "water" (acid) level needs to be checked and specific gravity of the electrolyte measured (ability to hold a charge). Lead, which is highly toxic and Sulfuric acid which is corrosive, requires special care when handling and are difficult to dispose of when the batteries are no longer useful. They also are prone to freezing in cold weather. It is best to place the batteries in a heated environment such as the powerhouse. Special vent caps and tubing are needed to vent the gasses associated with charging outside.

Other popular types of batteries are the Gell-Cell, Nickel Fiber and the Nickel Cadmium type. Although more expensive, each has its pro and cons and should be evaluated on a case by case basis. Disposal of the batteries is an issue that needs to be evaluated. Make certain that the retailer or manufacturer will accept old batteries for recycling. Your community may have a recycling program for batteries as well. Make certain that they will accept the type of batteries you may want to use.

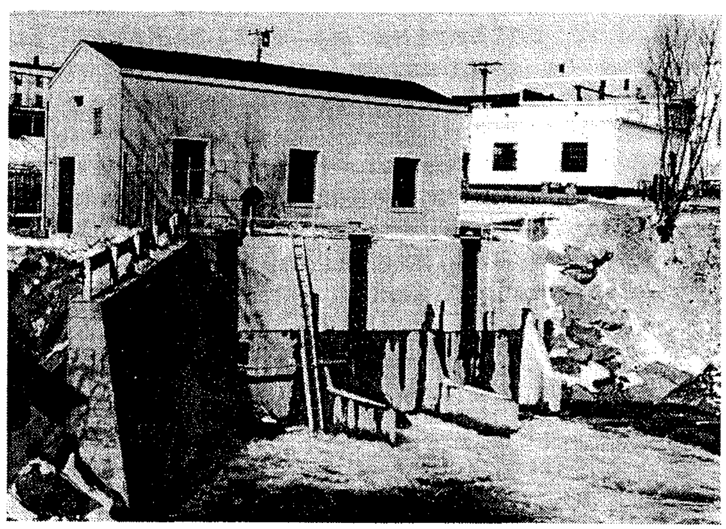
In the not so distant future, fuel cells may provide an option to conventional batteries.

In designing a remote system, many now prefer to use inverters for changing the DC output of the battery bank to AC for all of their energy needs. This simplifies wiring the home or cabin because DC needs to be wired differently than AC. The fact that AC fixtures are less expensive and are more readily available make this a popular choice.[49]

Chapter 12
OPERATION AND MAINTENANCE

A small hydro system must be operated in a manner which will insure long system life and comply with all applicable license article requirements and project conditions (including exempted facilities).

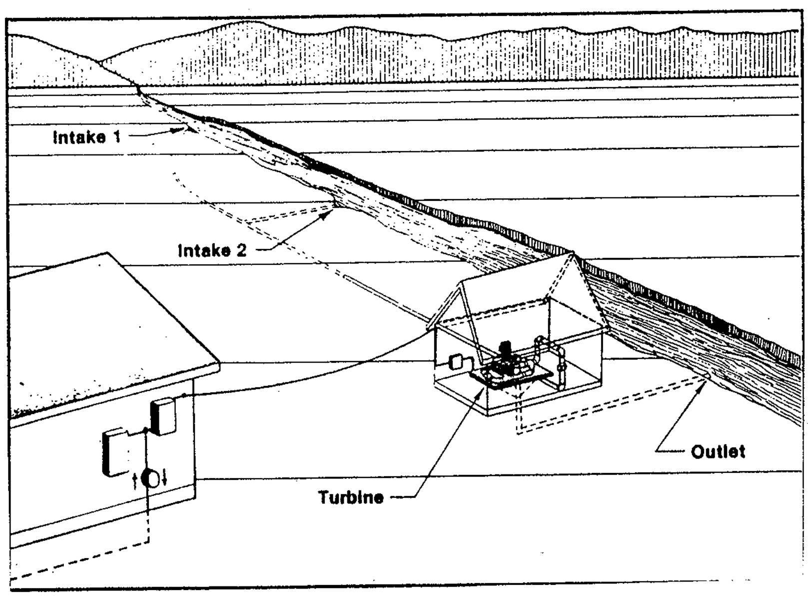
In certain instances, one must carefully monitor and control the flow of water from a hydro facility. Technically known as minimum flow compliance, this is the amount of water that must be discharged from the facility which maintains a certain flow level downstream of the facility. In some cases, different minimum flow levels may be required on a daily basis. More importantly, violations of this requirement could result in civil penalties and be considered during the relicensing process. [51]



The dam or diversion structure should also be well designed and maintained. Always check for cracks or leaks. If found, a competent licensed engineer should be consulted and repairs made immediately.

The skimmer and/or trashrack must be inspected and cleaned frequently. Foreign material in the trashrack or intake structure may significantly restrict the flow of water to the turbine. Ice buildup should be removed frequently during winter months from all intake structures and trashracks.

If a penstock is used it should be checked for cracks or leaks on a regular basis. Small systems which are not used in the winter months should have their penstocks drained completely. Those with small systems in remote areas in Maine that are inhabited by animals should be aware of this fact. Bear will chew on plastic pipe. Serious damage was done by bear to black plastic pipe in the Munsungan area. Pipe up to 2 inches in diameter is damaged and requires repair annually.



It is a good idea to have extra penstock (pipe) and fittings on hand to repair unexpected damage. Other items that may damage or reduce flow in a penstock are falling trees, ice, frost heaves and buildup of debris inside the penstock. By monitoring flow frequently you can detect any damage or obstruction that may have occurred.

The generator, turbine and gearbox (if the system incorporates one) must be serviced according to the manufacturers recommendation.

If the system is utility intertied, the utility might perform tests to insure system safety and performance prior to operation. This may also include annual or semi-annual tests after the system is in operation.

Chapter 13
ECONOMICS

Renewable energy is usually considered because either it offers potential cost economic advantages over utility supplied electricity, or because utility supplied electricity is not available. Some people also prefer to use renewable energy sources to provide their electricity or for other applications previously discussed. In general, most small hydro facilities cost about $1000 to $3000 per developed kilowatt of power. Some economic analysis is needed to help determine whether or not to purchase a microhydro system, and to help analyze which system best suits your situation.

Microhydro systems may require a large initial capital outlay. Over its years of service the system will provide "free", or at least very inexpensive energy. Installed costs vary depending upon factors such as site characteristics, resource availability, cost of materials, costs of components, legal fees, property taxes, insurance, permits, licenses and labor.

Analysis of your electrical consumption or projected needs, hydro resource availability and determining what size or type of system best suits your needs is critical. One important cost factor is whether or not your system will be interconnected to the utility. When new net energy billing rules go into effect on March 1, 2000, (Chapter 313, Customer Net Energy Billing) your electric bill will be reduced up to the amount of electricity you may have consumed from the energy provider you have selected or by the standard offer provider. However, if you have produced more than you have consumed during a billing cycle, the excess will be rolled over into the next billing cycle and credited in the event you may have generated less electricity than you have consumed from the utility.

Known as annualized netting, this allows you to take advantage of the cyclic nature of the hydro, wind or solar resource during a one year period. After a one year period, any excess you may have generated is no longer credited and the annualized net billing process starts over. This eliminates certain taxation issues to the benefit of all those concerned. You will however, still have to pay the Transmission and Distribution provider for delivery service. For further information on chapter 313, please contact the Maine Public Utilities Commission.

There are two kinds of economic analysis that are helpful. The first looks at "simple payback"; how long it takes for the energy cost savings to repay the initial cost. The second looks at "life cycle costs"; a comprehensive analysis of all costs and savings over the expected life of the system.

Simple payback is determined by dividing the total initial cost by the annual energy cost savings:

$$\frac{\text{Initial Costs}}{\text{Annual Energy Cost Savings}} = \text{Payback in years}$$

Energy cost savings is an estimated figure that should account for actual wind system performance, utility rate schedules, and the cost of any back-up power purchases. The advantage of simple payback analysis is its simplicity, enabling a quick comparison of the cost effectiveness on different energy supplies.

Life cycle cost analysis attempts to account for all incurred costs and savings associated with the investment over the systems operating lifetime. Such factors as the inflation based cost of electricity vs general inflation, maintenance costs, interest paid on borrowed money, interest lost on savings used for the investment, replacement costs of shorter lived components, and system salvage value can be considered. These costs and savings are discounted back to the net present value of the money invested.

Equation 13 shows a simplified version of the Life Cycle Cost formula.

Equation 13 [52]

$$LCC = I - S + M + R + E$$

Where:

- LCC = Life Cycle Cost
- I = Investment
- S = Salvage value
- M = Maintenance and Repair Cost
- R = Replacement Cost
- E = Energy Cost (for back-up power)

For a more detailed discussion of Life Cycle Cost methods, refer to an economics, microeconomics, project feasibility assessment or energy economics text. [52]

Project viability is an important aspect to any renewable energy project. A viable project is generally considered any project that can pay for itself in 10 or less years. Equation 13.1 can be used to determine the payback period excluding interest. [53]

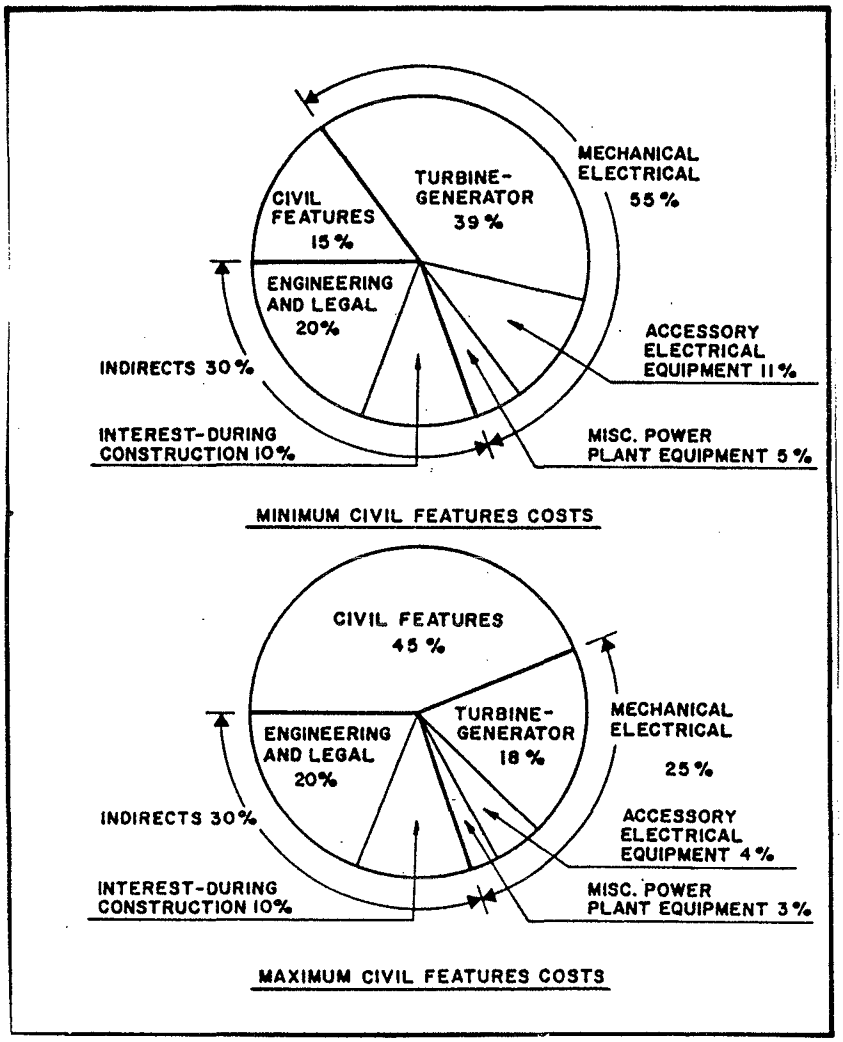
Equation 13.1

Payback Period, Years = Project Capital Costs/ Net Annual Revenue

The net annual revenue is your gross annual income minus annual recurring expenses. Another measure of project viability is to determine if there will be sufficient income in the early years to meet annual expenses. If tax consideration and interest payments are complicated, see a consultant who can provide detailed cash flow analysis. [53]

Figure 13 on the next page shows an indicator of percent of total costs for each component of a hydro project.[54]

Figure 13 [54]



Chapter 14
REGULATION OF HYDRO DEVELOPMENT

Rules governing hydro development can be extensive depending on the type of project being considered. Local, State and Federal agencies will need to be contacted preferably in that order with regard to any proposed project. Although you may live next to a stream or river doesn't necessarily mean that you have the right to install a dam, divert it or even use the water in any form. Water is protected by many rules and regulations that either limit or even prohibit its use.

Developing any hydro project without proper permits and licenses may result in serious and costly legal problems. While some smaller hydro units may be exempt from certain regulations, it is a good idea to contact all concerned agencies first and foremost in planning any hydro project.

Locally your project may be affected by zoning laws regulating land usage and building codes regulating design of structures.

The State regulates many areas of public interest which include; public trust laws, environment effects, water resource matters, wildlife and scenic river protection. You may need to demonstrate that you are consulting with state agencies when you apply for federal licensing so it is a good idea to consult the appropriate state agencies first.

The Federal Energy Regulatory Commission (FERC) has authority over almost all of the hydroelectric projects in the country. You will probably need FERC authorization to proceed with project development. The Federal government sometimes overlap or supersedes the State in regulating navigable waterways, fishing and conservation. Due diligence is required when applying to FERC for licenses/permits. Even your writing style could result in the application being rejected. The license application you request should include a writing style manual.

For more specific information on hydro development you should contact:

The State Planning Office
Attn: Betsy Elder
38 State House Station
Augusta, Maine 04333
(207) 287-8927

The Federal Energy Regulatory Commission
Office of Hydropower Licensing
Washington D.C. 20426
(202) 208-1371

FOR MORE INFORMATION

Canyon Industries Inc.
5346 Mosquito Lake Road.
Deming, WA 98244
(360) 592-5552
e-mail: CIT Turbine @ aol.com

Company manufactures 5kw - 8 mw pelton turbines and 5kw to 1 mw crossflow turbines for stand alone and utility interconnected applications.

Energy Systems and Design, P.O. Box 1557, Sussex, New Brunswick, Canada EOE 1P0

Contact for further information on products and services offered.

Burkhardt Turbines
P.O. Box 1436
Ukiah, CA 95482
(707) 961-0459

Contact for further information on products and services offered.

Harris Hydroelectric Systems
632 Swanton Road,
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Manufacturers small DC battery charging systems.

Jack Rabbit Marine
425 Fairfield Ave.
Stamford, CT 06902
(203) 961-8133

Manufacturers a small turbine for yacht applications that can be used in streams.

Lil Otto Hydroworks
P.O. Box 203
Hornbrook, CA 96044
(916) 475-3402
http://www.snowcrest.net/econet

Manufacturers small DC battery charging systems.

Rocky Creek Hydro
Box 90B Alladin
Colvill, WA 99114

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Dependable Turbines
Port Moody
British Columbia, Canada
(604) 461-3121

Contact for further information on products and services offered.

Microhydro Hydropower Handbook
Available from:

The National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
(800) 553-6847
Volume 1, 428 pp. order # DE83006697, $71.50
Volume 2, 408 pp. order # DE83006698, $71.50

This handbook contains detailed information on system design, construction, operation, economics, legal and environmental issues.

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