4.5 Penstock and Valves

The penstock is a pipe that carries water from the intake to the turbine. Most microhydropower systems will include some type of penstock. Depending on the site characteristics, the penstock length may range from a few feet for manmade structures to several hundred feet for some run-of-the-stream sites. The exception is the manmade structure with an open flume (Figure 2-12). This type of site has no penstock. Developers with an open flume leading to the turbine can proceed to the next section. This section discusses location, design, and installation of the penstock and its associated valves.

If you have received a penstock recommendation from the turbine manufacturer, you should contact suppliers to obtain pipe specification and pricing information. If you plan to follow the turbine manufacturer's recommendation, you should review the contents of this section before ordering the pipe in order to facilitate making a design layout of the penstock and to make sure that you have considered all materials and costs.

4.5.1 Locating the Penstock

Run-of-the-stream developers determined a preliminary routing for the penstock in Section 3.4 Manmade sources generally do not allow much latitude in penstock routing. The developer using an existing dam has the option of a siphon penstock (Figure 2-13) or a power canal routed around the dam (see Subsection 4.4.3). Any modification to an existing dam is beyond the scope of this handbook.

In general, the optimum penstock is as short, straight, and steep as practical and has a continuous downward gradient. A power canal can be constructed to divert the water to give the best penstock alignment, (see Subsection 4.4.2). These characteristics will minimize construction costs and friction loss.

The following are some of the major factors that must be considered in selecting a penstock route:

- Accessibility. The route should be accessible to personnel and equipment required for pipe installation, inspection, and maintenance. In those areas where equipment access is difficult or impossible, installation and maintenance must be performed manually.

- Soil Conditions. Soils along the pipeline should be examined to identify rock outcroppings, soft or unstable soils, or other characteristics that would interfere with penstock installation or damage the penstock.

- Natural or Man-Made Obstructions. These include trees, roadways, buildings, stream crossings, and other features that require special care.

- Gradient. The penstock is best routed to take advantage of the natural downward gradient. If the line cannot be located so as to have a constant downward gradient, an air relief valve or equivalent device is required at every local high point, and a drain valve is required at every local low point.

- Above- or Below-Ground Installation. A buried penstock has certain advantages over an above-ground installation. Anchoring and supporting the pipe are simplified, ultraviolet radiation effects on PVC pipe are eliminated, and the effects of weather (thermal expansion, freezing) are reduced. In addition, physical damage to the pipe from falling rocks and trees or other sources is also prevented. On the other hand, an above-ground pipe will have a lower construction cost, may allow for more direct routing (fewer bends), and is readily accessible for inspection or repair. Another alternative is to have a combination of above- and below-ground installation.

4.5.2 Design Layout

To work with the penstock section, you will find a sketch of the proposed penstock routing helpful. In Subsection 3.4, the routing was surveyed. Take the information from that survey and on a sheet of graph paper sketch out the routing. Figure 4.5-1 is an example of such a sketch. You are encouraged to make a similar sketch of your site as well as an elevation view to confirm grades and elevations.

The sketch is helpful in identifying the number of elbows needed, in determining where the penstock will be above or below ground, and in locating anchors and thrust blocks (Subsection 4.5.5), etc. The sketch will also be helpful in the rest of this section for such items as estimating the cost of outside help, additional equipment, total material requirements, etc.

4.5.3 Material Selection

The turbine manufacturer may have recommended a certain material for the penstock. You may want to consider other material that might be less expensive. The most common penstock materials include:

- PVC (polyvinyl chloride)
- Steel
- Polyethylene
- FRE (fiber reinforced epoxy)
- Transite (asbestos cement).

For each of these materials, you must consider a number of factors:

- Cost
- Availability

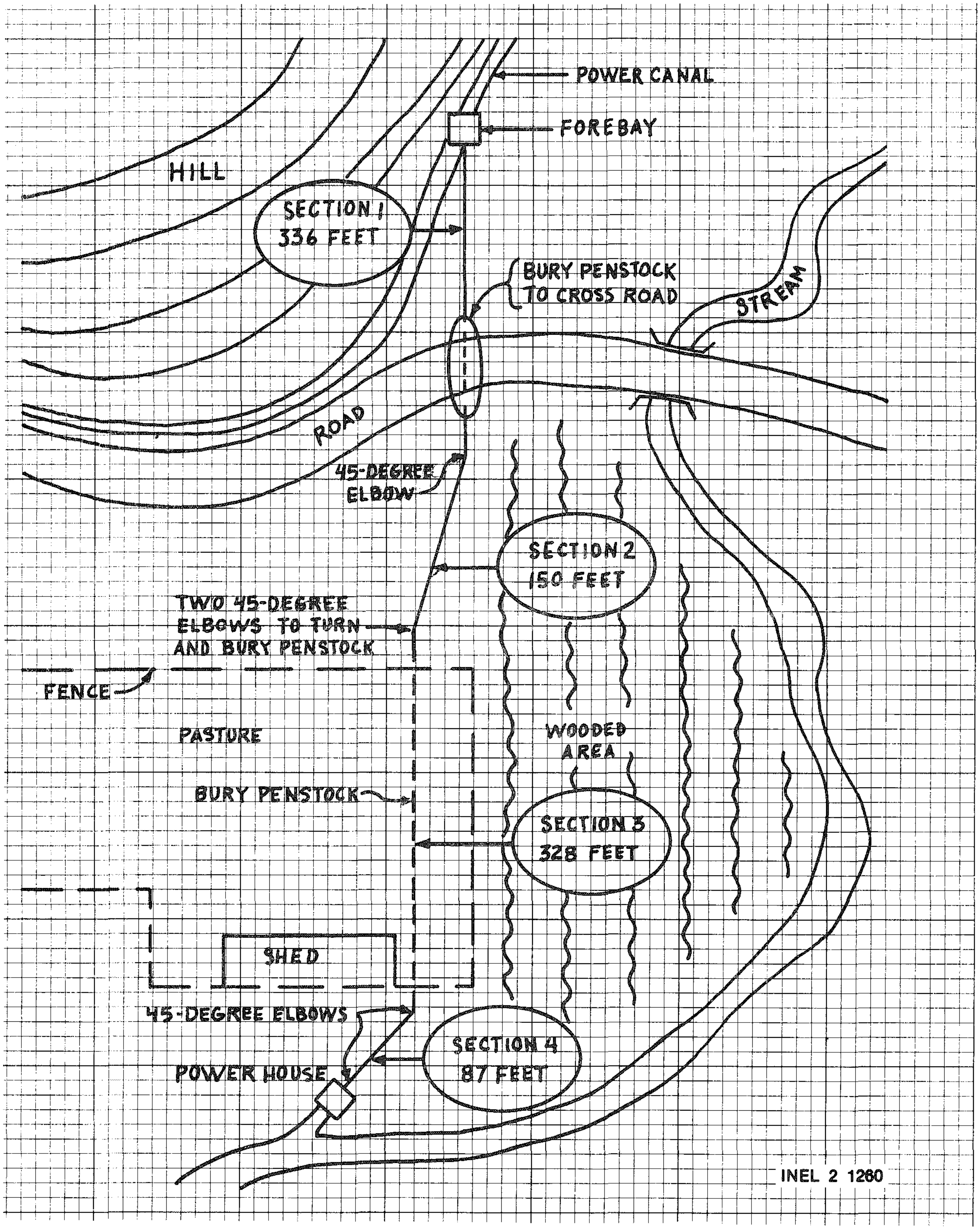

Figure 4.5-1. Sketch of proposed penstock routing.

- Physical properties (friction, strength, chemistry)
- Joining methods and installation limitations.

These factors are greatly influenced by a number of local and special conditions that are beyond the scope of this handbook. Certain observations, however, are in order.

Material costs vary with season, general economy, raw material surpluses or shortages, location, and other factors.

In some cases, used pipe materials may be locally available. Their use can reduce material costs, provided that the pipe is in satisfactory condition. You should attempt to establish the history of the pipe (length of service, material carried, maximum pressures) as well as to evaluate the uniformity of dimensions and wall thicknesses. Visual inspection of the stockpiled pipe is also recommended.

Material availability relates to manufacturing, marketing, and local economic demand. Certain materials are available only in specific size ranges. The head and flow conditions encountered will dictate the physical properties required in the material to be used and will thus influence the cost.

Each material alternative is governed by specific joining and installation requirements. Joining methods that require special skills or equipment will tend to increase construction costs. In addition, certain materials are not recommended for above-ground installation. In most instances, and especially for above-ground installations, some form of restrained joint will be required. Restrained joints include welding, concreting, or flanging of pipe to prevent joint pullout when the penstock is pressurized.

4.5.4 Penstock Sizing

A satisfactory penstock diameter depends on three factors:

- Energy (head) losses due to friction between the water flowing in the pipe and the inside pipe wall
- Pressure limitations of the pipe as a function of wall thickness
- Cost of the pipe and installation.

For a given flow rate, as the pipe diameter decreases the velocity of the water must increase, and the corresponding energy loss increases. This occurs because friction is a function of velocity. As velocity increases, friction increases. On the other hand, a larger pipe diameter would mean a decrease in velocity and a corresponding decrease in friction (head loss). The cost of the pipe however, increases drastically with the increase in size. The procedure presented here will help you balance energy loss with pipe size, material, and wall thickness. A velocity of 4 fps is recommended for the initial penstock design. Once the proper pipe size is selected, the material and installation cost can be evaluated to select the best buy.

The energy losses associated with friction can be expressed directly as feet of head loss.

EXAMPLE: Assume that a site has a measured head of 112 feet and that the developer calculates the energy loss in the penstock system as 8.6 feet. The actual head available to produce energy is not 112 feet but 103.4 feet (112 - 8.6).

Friction losses in the penstock system represent energy that is not available for power generation.

4.5.4.1 Selecting Pipe Diameter. The first requirement for sizing a penstock is to select the proper pipe diameter, using the design flow from Subsection 4.3. Figures 4.5-2 and 4.5-3 are graphs to help in making this

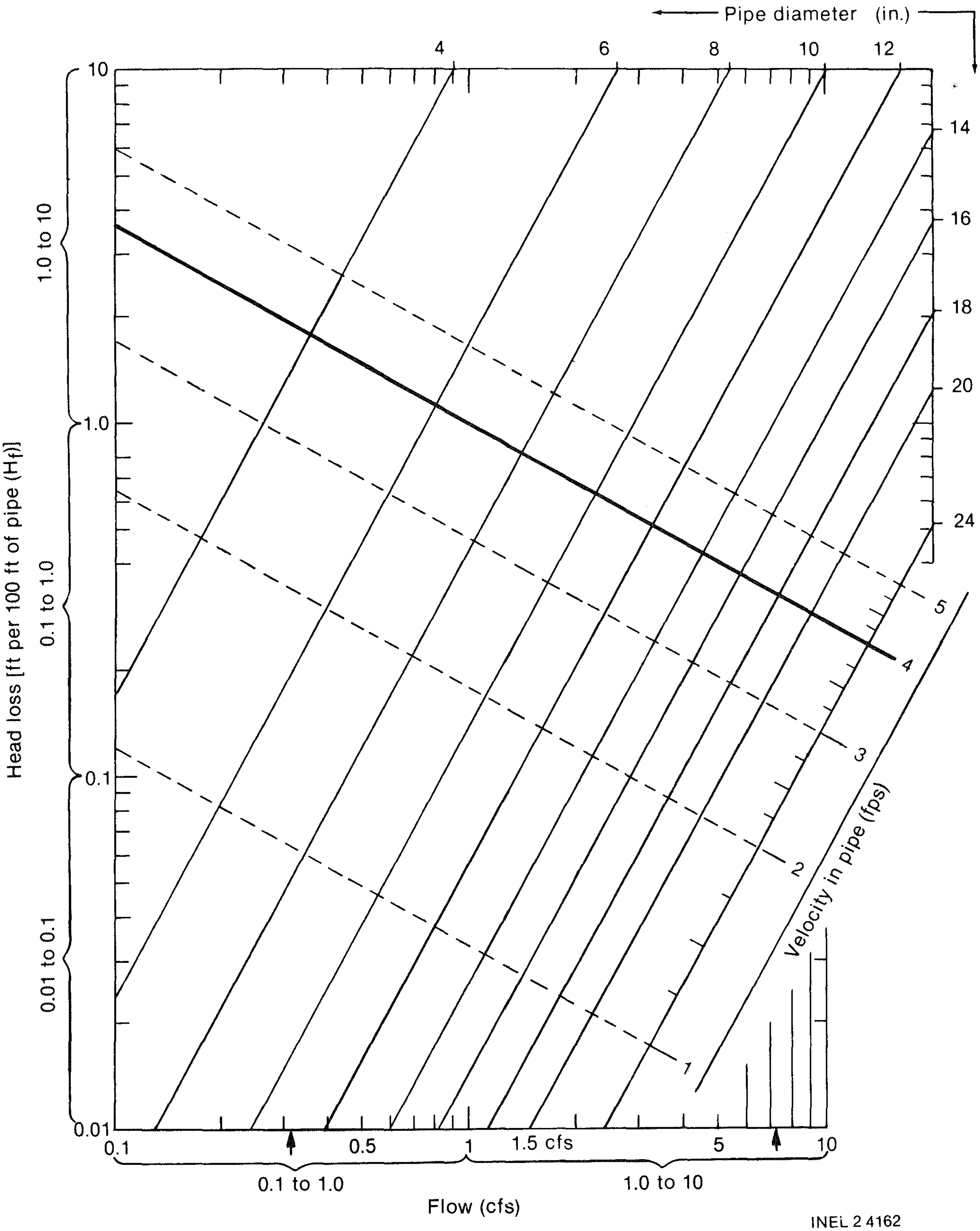

Figure 4.5-2. Pipe diameter selection graph.

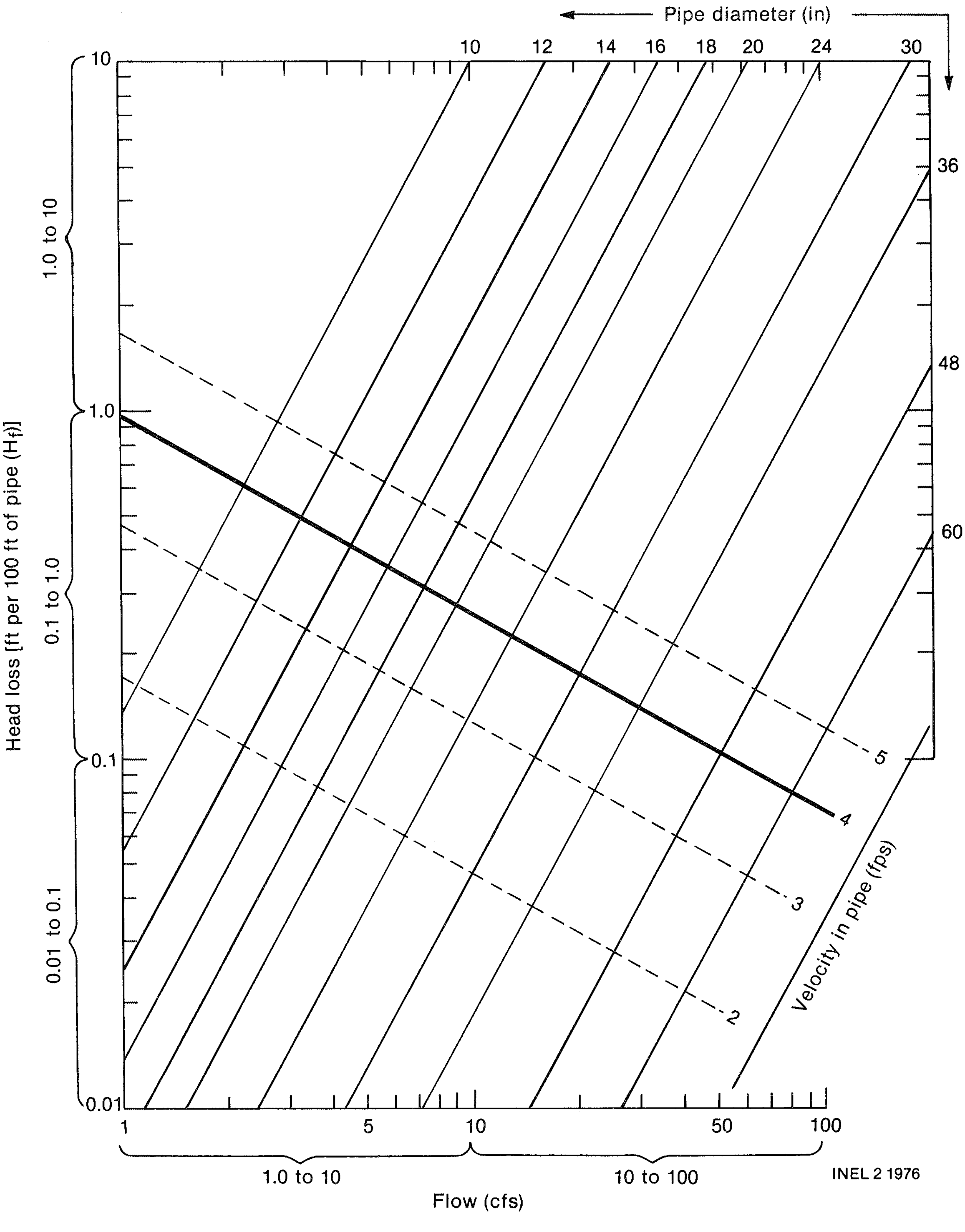

Figure 4.5-3. Pipe diameter selection graph.

selection. A range of flow values is shown at the bottom of each graph. If the design flow is between 0.1 cfs to 10.0 cfs, use the first graph, and if it is from 10.1 cfs to 100 cfs, use the second graph. Consult the manufacturer if the design flow is more than 100 cfs.

1. On the appropriate graph, find your design flow.

    NOTE: The graph is on log paper. The range of flow values is marked with brackets (i.e., 0.1 cfs to 1.0 cfs). As examples, flow readings of 0.32 cfs and 7.2 cfs are shown with small arrows at the bottom of the graph on Figure 4.5-2.

2. Draw a vertical line up from the design flow value to the recommended velocity line (the 4 fps line running diagonally line from the upper left corner to right center). The intersect point with 4 fps will be bracketed by two pipe diameter lines (diagonal lines running from the upper right to the lower left). Either of the bracketing penstock sizes can be used, but it is recommended that the larger size be selected to keep velocity (and head loss) low. Lower velocity will also result in less water hammer. A penstock head loss of 5 to 10% of the pool-to-pool head can be a reasonable design starting point.

    The actual velocity of water in the penstock will be the point at which the vertical line representing flow intersects the selected pipe size line and will probably be slightly lower than 4 fps if the larger pipe size is chosen.

    EXAMPLE: Referring to Figure 4.5-4, assume a design flow of 4 cfs. From 4 cfs (Point 1), draw a vertical line up to the 4 fps line (Point 2). Select the larger of the pipes--in this case, the 14-inch diameter pipe (Point 3). At Point 3, the velocity of 4 cfs in the 14-inch pipe can be estimated as 3.7 fps (Point 3 is approximately 0.7 of the way between 3 fps and 4 fps).

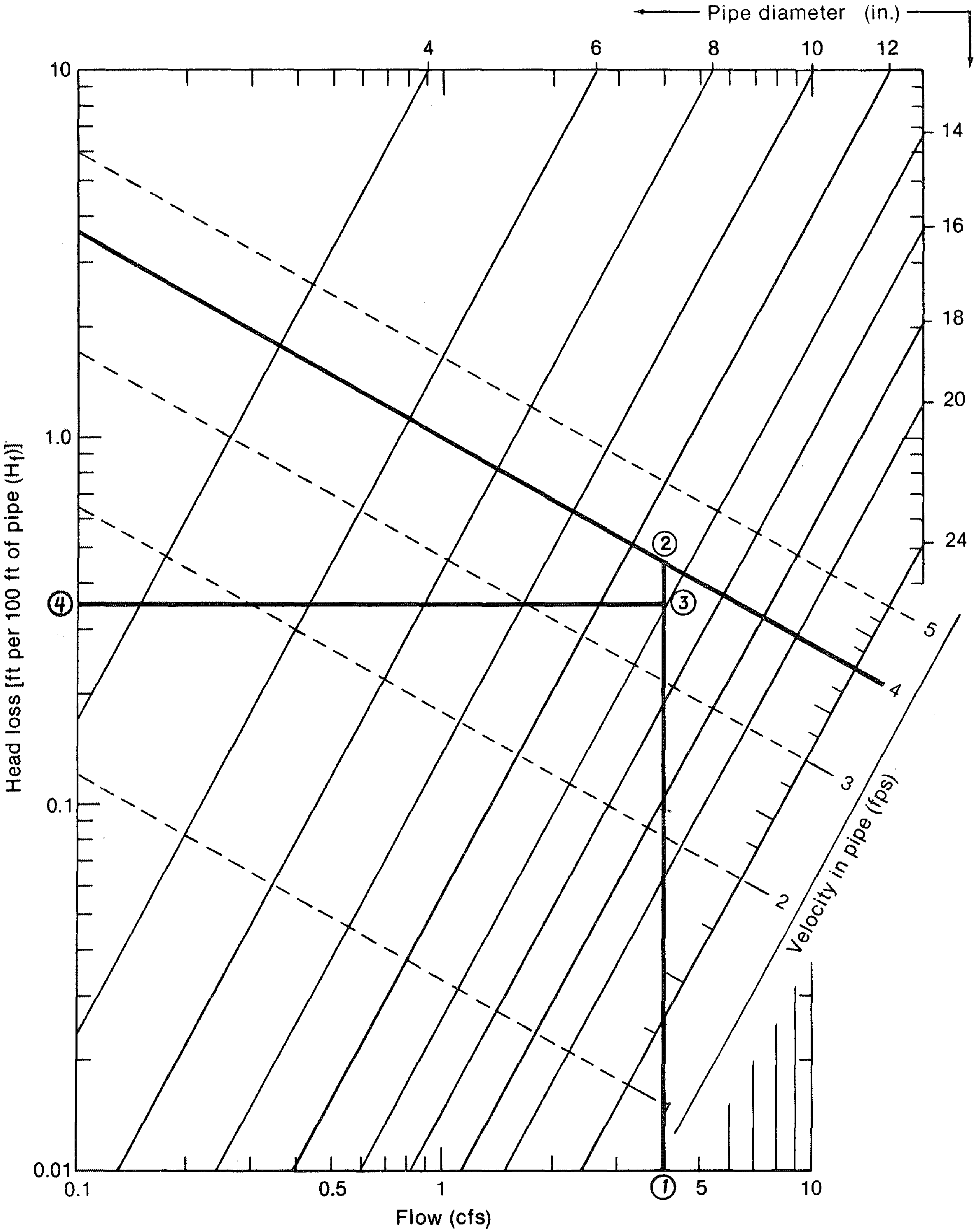

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Figure 4.5-4. Pipe diameter selection example.

3. From the pipe size intersect (Point 3), draw a horizontal line to the left side of the graph. The numbers on the left side of the graph represent the head loss per 100 feet of pipe length.

   EXAMPLE: From Point 3, draw a line to the left side of the graph (Point 4). At Point 4, read the head loss factor as 0.34 ft per 100 feet of pipe. The actual loss depends on pipe material.

4. Record the penstock diameter and actual velocity (Point 3 in the example) and the friction loss factor (Point 4).

4.5.4.2 Selecting Pipe Material. It is now time to consider various pipe material alternatives so that the actual friction losses can be calculated. Virtually any of the materials previously discussed can be used, but experience indicates that two materials, PVC and steel, stand out as the most likely choices for the greatest number of installations. As previously stated, local and site specific factors can influence material options and must be considered.

The selection of pipe material and pipe wall thickness depends on the pressure that the pipe will experience. There are two types of pressure to be considered:

- Static pressure, which is the pressure at the bottom of the pipe when the pipe is filled and the water is not flowing.

- Pressure waves, which are caused when the amount of water flowing is suddenly changed, as by opening or closing a valve.

Static pressure depends on the head in the penstock. Pressure waves depend on how fast the flow changes in the penstock.

To aid in determining the design pressure rating of the penstock and selecting the suitable pipe material, Table 4.5-1 lists the wall thickness (t_W), pressure rating (P_R), and surge allowance factor (S_A) for several sizes of commonly available pipe materials.

TABLE 4.5-1. PIPING ALTERNATIVES

Pipe material ↓ / Pipe size →	4 in.			6 in.			8 in.			10 in.			12 in.		
	t_W	P_R	S_A	t_W	P_R	S_A	t_W	P_R	S_A	t_W	P_R	S_A	t_W	P_R	S_A
Steel	0.24	1400	57	0.28	1200	56	0.25	800	54	0.25	640	52	0.25	540	51
							0.32	1100	56	0.37	1030	55	1.38	890	54
													0.41	1000	55
PVC (polyvinyl chloride)	0.11	100	12	0.16	100	12	0.21	100	12	0.26	100	12	0.31	100	12
	0.17	160	15	0.25	160	15	0.33	160	15	0.41	160	15	0.49	160	15
	0.26	250	18	0.39	250	18	0.51	250	18	0.63	250	18	0.75	250	18
PE (polyethylene)	0.265	100	9	0.39	100	9	0.51	100	9	0.63	100	9	0.75	100	9
	0.41	160	11	0.60	160	11	0.78	160	11	0.98	160	11	1.16	160	11
	0.62	250	13	0.91	250	13	1.18	250	13	1.47	250	13	1.75	250	13
A-C (transite—asbestos cement)	0.32	100	41	0.46	100	41	0.56	100	40	0.62	100	39	0.72	100	38
	0.41	150	44	0.53	150	43	0.63	150	41	0.83	150	42	0.96	150	41
	0.41	200	44	0.66	200	45	0.81	200	45	1.02	200	45	1.18	200	44
FRP (fiber reinforced epoxy)	0.07	225	17	1.11	250	16	0.14	225	16	0.18	225	15	0.21	225	15

Pipe material ↓ / Pipe size →	14 in.			16 in.			18 in.			20 in.			24 in.[a]		
	t_W	P_R	S_A	t_W	P_R	S_A	t_W	P_R	S_A	t_W	P_R	S_A	t_W	P_R	S_A
Steel	0.25	490	50	0.25	430	49	0.25	380	48	0.25	340	47	0.25	280	45
	0.38	810	54	0.38	710	52	0.38	630	52	0.38	570	51	0.38	470	
	0.44	970	55	0.50	990	55	0.50	880	54	0.50	790	53	0.50	660	
										0.59	950	54	0.69	940	54
PVC (polyvinyl chloride)	← PVC pressure pipe not available →														
PE (polyethylene)	0.82	100	9	0.94	100	9	1.06	100	9	1.12	100	9	1.41	100	9
	1.27	160	11	1.46	160	11	1.64	160	11	1.81	160	11			
	1.92	250	13												
A-C (transite—asbestos cement)	0.74	100	38	0.83	100	37	0.95	100	37	1.06	100	37	1.24	100	
	1.11	150	41	1.23	150	41	1.47	150	42	1.64	150	42	1.98	150	
	1.38	200	44	1.57	200	44	2.09	200	45	1.98	200	45	2.81	200	45
FRP (fiber reinforced epoxy)	0.26	225	15	0.29	225	15									

a. Above 24 inches, see manufacturer.

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The procedure for determining penstock pressure rating (design pressure rating) is as follows:

1. Using the total design head determined earlier in Subsection 4.3, establish the static head on the penstock. From the relationship developed in Subsection 3.4.1 (1 foot of heat = 0.433 psi), the static pressure can be determined by using Equation (4.5-1).

$$S = 0.433 \times h \tag{4.5-1}$$

where

S = static pressure in psi

0.433 = converts feet to psi

h = design head in feet.

EXAMPLE: Assume that the head in Figure 4.5-1 is 325 feet. Use Equation (4.5-1) to find the static pressure in the penstock at the turbine.

$$S = 0.433 \times h$$

$$S = 0.433 \times 325$$

$$S = 141 \text{ psi.}$$

2. Using the penstock diameter previously established, select from Table 4.5-1 one (or more) potential pipe materials and select the t_w, P_R, and S_A factors for these materials.

NOTE: Select these factors for a pressure rating value (P_R) greater than the static pressure determined in Step 1 above. If the head is large, the pressure value should be significantly larger than the static pressure.

EXAMPLE: Assume a 14-inch pipe and static pressure of 141 psi. Select pipe materials from Table 4.5-1.

Steel: All have a P_R greater than 141 psi.

PVC: Not available.

PE: The P_R is above 141 psi for both 1.27 and 1.92 t_w, but only the 1.92, with a P_R of 250 psi, is significantly above 141 psi.

AC: The P_R is significantly above 141 psi only for the 1.38 t_w, with a P_R of 200 psi.

FRP: The 0.26 t_w has a P_R = 225 psi.

Therefore, consider the following pipe material and thickness:

Steel: $t_w = 0.25$, $P_R = 490$, $S_A = 50$

PE: $t_w = 1.92$, $P_R = 250$, $S_A = 13$

AC: $t_w = 1.38$, $P_R = 200$, $S_A = 44$

FRP: $t_w = 0.26$, $P_R = 225$, $S_A = 15$

3. For each pipe material selected, use Equation (4.5-2) to determine the penstock design pressure (P_d).

$$P_d = S + (S_A \times v) \qquad (4.5\text{-}2)$$

where

P_d = penstock design pressure in psi

S = static pressure in psi, from Equation (4.5-1)

S_A = surge allowance factor from Table 4.5-1

v = velocity of the water in the pipe in fps, from Figure 4.5-2 or 4.5-3.

NOTE: To use Equation (4.5-2), multiply S_A and v before adding to S.

EXAMPLE: From the previous example, S = 141 psi, and from Figure 4.5-4, v = 3.7; use Equation (4.5-2) to find the design pressure for the pipes to be considered.

$$P_d = S + (S_A \times v)$$

Steel: $P_d = 141 + (50 \times 3.7)$
$= 141 + 185$
$P_d = 326$ psi

PE: $P_d = 141 + (13 \times 3.7)$
$P_d = 189$ psi

AC: $P_d = 141 + (44 \times 3.7)$
$P_d = 303$ psi

FRP: $P_d = 141 + (15 \times 3.7)$
$P_d = 196$ psi

4. The design pressure rating, P_R, <u>must</u> be greater than the P_d value for the material and wall thickness selected. If it is not, recalculate the design pressure using the next thicker wall, or select another material.

EXAMPLE: From Steps 2 and 3 above, the following is known:

Steel: P_R = 490 psi, P_d = 326 psi

PE: P_R = 250 psi, P_d = 189 psi

AC: P_R = 200 psi, P_d = 303 psi

FRP: P_R = 225 psi, P_d = 196 psi

Since the P_R is larger than the P_d for steel, PE, and FRP, these materials can be used. AC, with a P_R smaller than the P_d, cannot be used in this example.

For pipe materials and wall thicknesses not included in Table 4.5-1, you should contact the pipe supplier for the necessary information. The data from the supplier will probably list wall thickness as (t), design pressure as (P), and allowable surge pressure as (W).

4.5.4.3 Calculating Penstock System Head Loss. The next step is to calculate the total penstock head loss. The total losses are a function of both turbulence and friction.

Turbulence is caused by the intake structure and by bends and obstructions in the pipe. Turbulence factors can best be considered by adding equivalent pipe length to the overall length of the penstock to get the adjusted length (L_a). This can be done by the following steps:

- Multiply the number of 90 degree bends by 30 feet
- Multiply the number of 45 degree bends by 15 feet
- Add 15 feet for the entrance at the intake

- Add 100 feet for the turbine isolation valve

- Sum all the additions and add to the total penstock length.

EXAMPLE: From Figure 4.5-1:

0 each 90 degree bends
5 each 45 degree bends
5 x 15 = 75 feet
Intake structure--15 feet
1 turbine isolation valve--100 feet
Total additions = 190 feet

The pipe length shown in Figure 4.5-1 is 336 + 150 + 328 + 87 = 901 feet; 901 + 190 = 1,091 feet. Adjusted length (L_a) = 1,091 feet

Friction losses are a function of pipe size, length, and material. The friction effect is accounted for with the pipe material correction factors shown in Table 4.5-2.

TABLE 4.5-2. FRICTION LOSS CORRECTION FACTOR (f_c)

Pipe Material	Factor (f_c)
Steel	1.16
PVC	0.77
PE	0.77
AC	0.87
FRP	0.77

To obtain the head loss due to turbulence and friction, multiply the adjusted penstock length (L_a) determined above by the material correction factor from Table 4.5-2. Multiply this number by the H_f factor previously determined from Figure 4.5-2 or -3 and divide the result by 100. This final number is the energy loss, in feet of head, for the flow, penstock length, and material selected. Use Equation (4.5-4) to determine total head loss.

$$h_l = \frac{f_c \times L_a \times H_f}{100} \qquad (4.5.4)$$

where

h_l = head loss in feet

f_c = f_c friction loss correction factor from Table 4.5-2

L_a = adjusted length of penstock in feet

H_f = head loss factor from Figure 4.5-2 or 4.5-3.

EXAMPLE: From the previous examples:

L_a = 1091 feet

H_f = 0.34 (Figure 4.5-4)

From Table 4.5-2:

Steel: $f_c = 1.16$

PE: $f_c = 0.77$

FRP: $f_c = 0.77$

For steel pipe

$$h_l = \frac{1.16 \times 1091 \times 0.34}{100}$$

h_l = 6.2 feet

For PE and FRP

$$h_1 = \frac{1.77 \times 1091 \times 0.34}{100}$$

$$h_1 = 2.9 \text{ feet}$$

This loss must be subtracted from the site's available head. Since it is a friction loss, it will not be available to produce power.

EXAMPLE: If the pool-to-pool head at the developers site is 42 feet, the net effective head for the site is 42 - 2.9 = 39.1 feet.

You must recognize that a number of pipe diameter and material combinations exist for transporting the desired flow from intake to turbine. The optimum pipe diameter tends to be a site-specific decision, and several alternative configurations should be evaluated. The following general suggestions may help with this evaluation.

- Penstock diameter (and cost) can be reduced until the maximum recommended velocity of 5 fps is reached. This will increase friction losses.

- Penstock friction (energy) loss can be reduced by increasing the diameter and therefore decreasing velocity. Offsetting costs may be realized if the reduced velocity reduces the pipe pressure class.

- Penstock friction loss can also be reduced by selecting alternative pipe materials having a lower loss coefficient.

The Category 2 developer may want to compare energy loss and pipe costs to arrive at an optimum pipe diameter.

NOTE: Higher friction in the pipe reduces the potential of freezing in the penstock. See Subsection 4.5.7.

4.5.5 Valves

During the life of the generating facility, it will periodically be necessary to stop flow to the turbine for maintenance and repair or to dewater the penstock for repair. Also, reaction turbines use valves to control flow and to prevent overspeed. For this reason, suitable valves or gates at either end of the penstock should be incorporated into the development plans.

Various types of valves can be used. For gates in canals or on corrugated metal pipe, slide gates are ideal (Figure 4.4-8). Butterfly valves work well at either end of the penstock. Figure 4.5-5 is a photograph of a butterfly valve body and disc, and Figures 4.5-6 and 4.5-7 present drawings of butterfly, gate, ball, and globe valves.

4.5.5.1 Penstock Intake. As discussed in the Intake subsection (4.4), a slide gate or butterfly valve can be incorporated into the structure at the intake of the penstock. The penstock inlet downstream from the valve must be open to the atmosphere to prevent the formation of a vacuum during penstock dewatering. This can also be a part of the inlet design, or an air admission valve can be added. This could consist of an open vent standpipe with the top elevation higher than the water surface at the forebay (Figure 4.4-13).

4.5.5.2 Penstock Upward Slope. At any point on the penstock where a high point exists, (that is, where the pipe has an upward slope) an air release valve should be installed. Similarly, a drain must be installed at any low point. Use Table 4.5-3 for approximate sizing of the air valves.

TABLE 4.5-3. SIZING OF AIR VALVES

Valve Diameter (inches)	Maximum Penstock Flow (cfs)
1	Up to 4
2	Up to 8
3	Up to 15

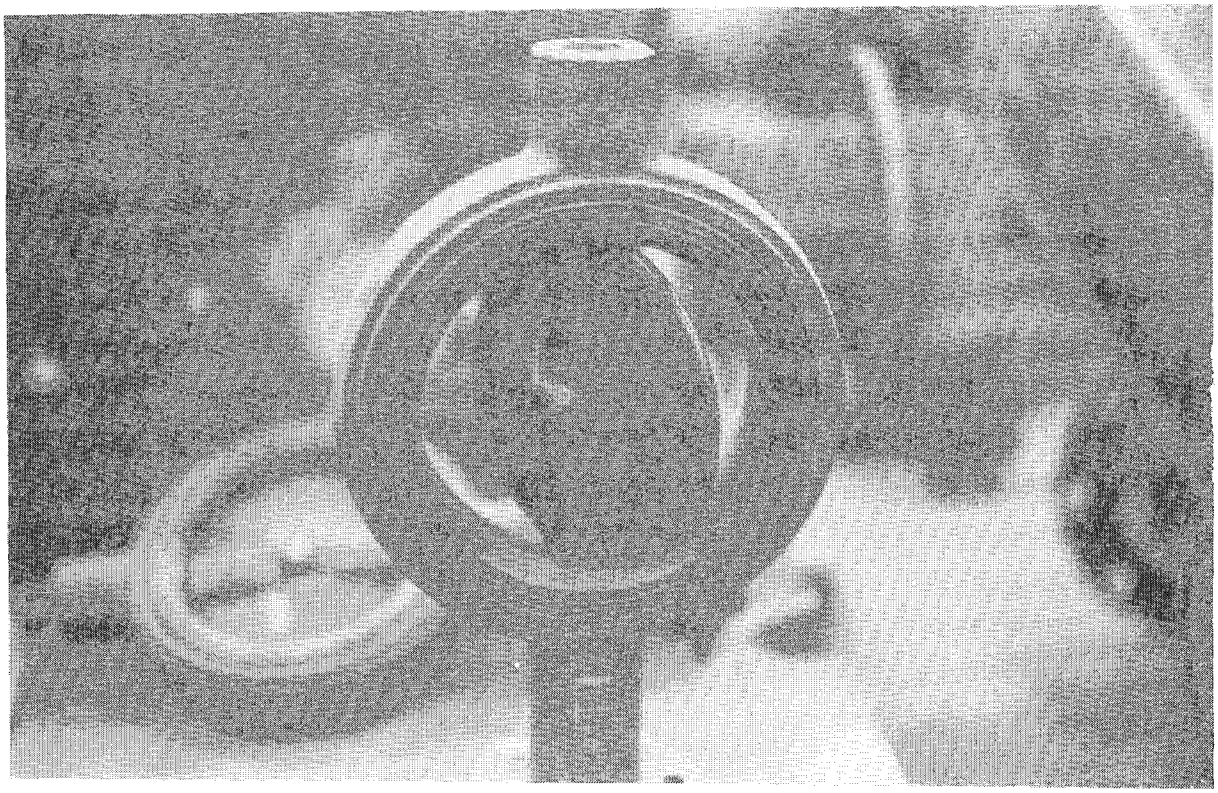

Figure 4.5-5. Butterfly valve body and disk.

4.5.5.3 Turbine Isolation Valve. At the lower end of the penstock, an isolation valve is required for stopping flow to the turbine. The turbine isolation valve should be connected (flanged) to the turbine to permit disconnecting the turbine from the penstock. The valve could be any one of a number of gate valves, globe valves, ball valves, or butterfly valves. However, the head loss is greater in a globe valve. The least expensive of these options are the butterfly and gate valves. The valve should be the same size as the penstock and have a pressure rating above the design pressure previously determined for the penstock.

The butterfly valve is the most common in microhydropower use. A significant characteristic of the butterfly valve is its relatively quick rate of closure. Some reaction turbines use the isolation valve to prevent turbine overspeed. To accomplish this, they take advantage of the quick

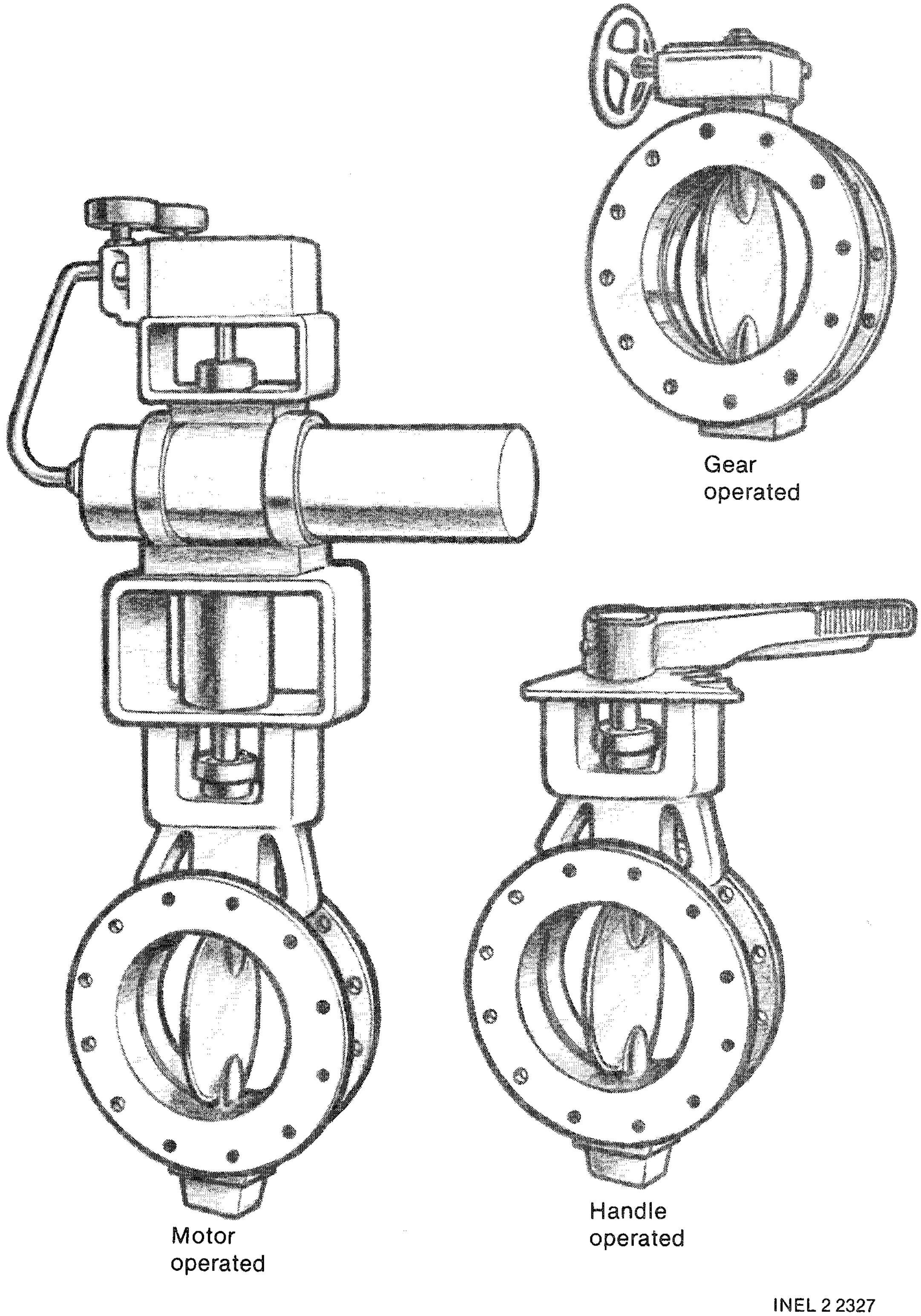

Figure 4.5-6. Butterfly valves.

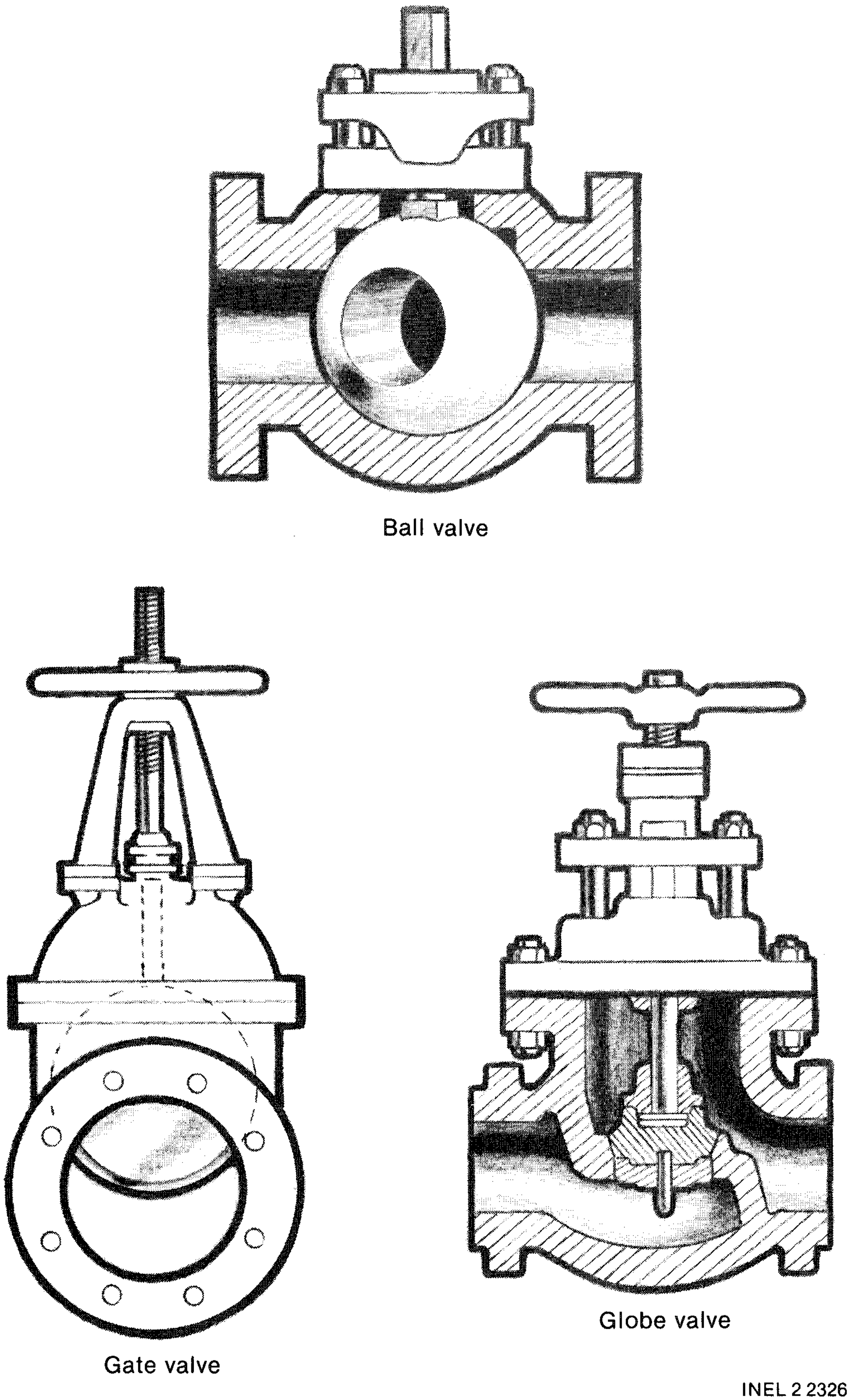

Figure 4.5-7. Ball valve, gate valve, and globe valve.

closing characteristics of the butterfly valve. When this is done, some other means must be designed into the penstock to eliminate surge pressure on the penstock. If no method is provided to eliminate surge, care must be taken to close the valve slowly. Providing a geared, motor-operated valve with backup power supply and with slow closure rate will reduce the potential for creating excessive surge pressures.

Surge pressure can create havoc with a penstock. It can cause a pipe to jump and send a wave of pipe movement up the length of the penstock. If the pressure is high enough, the penstock will rupture and cause other damage or even injury.

CAUTION: The water will actually force a butterfly valve closed after it is halfway closed; therefore, be very careful if you plan to use a handle type actuator (Figure 4.5-6). The handle has flown out of the hand of more than one unsuspecting operator. And, of course, a valve that is slammed shut will create surge pressure.

Many clever and innovative systems can be worked out to prevent surge pressure. Figure 4.5-8 is a drawing of such a system. An extension arm is welded on to the handle of the valve. In the open position, the handle is suspended by a solenoid hook or pin from the power house ceiling. A weight is attached to the handle to pull the handle down when the solenoid is released. The falling weight causes the handle to close the valve until the water pressure begins to assist in the closure. At that point, the shock absorber takes over and prevents the valve from slamming shut. Another approach is to prevent the surge pressure by opening other valves at the same time as the isolation valve is closed. Solenoid-operated valves that fail open can be used in place of the purge valve shown in Figure 4.5-9. When the generator loses its load and stops generating energy, the solenoid valve opens as the isolation valve closes. The solenoid valve should be at least half the size of the penstock.

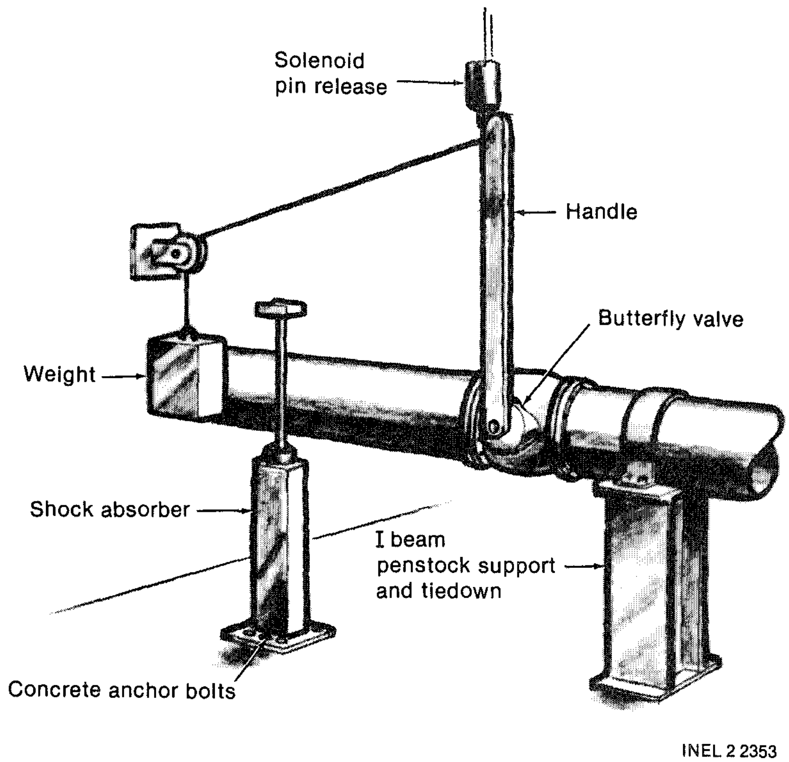

Figure 4.5-8. System to prevent surge pressure.

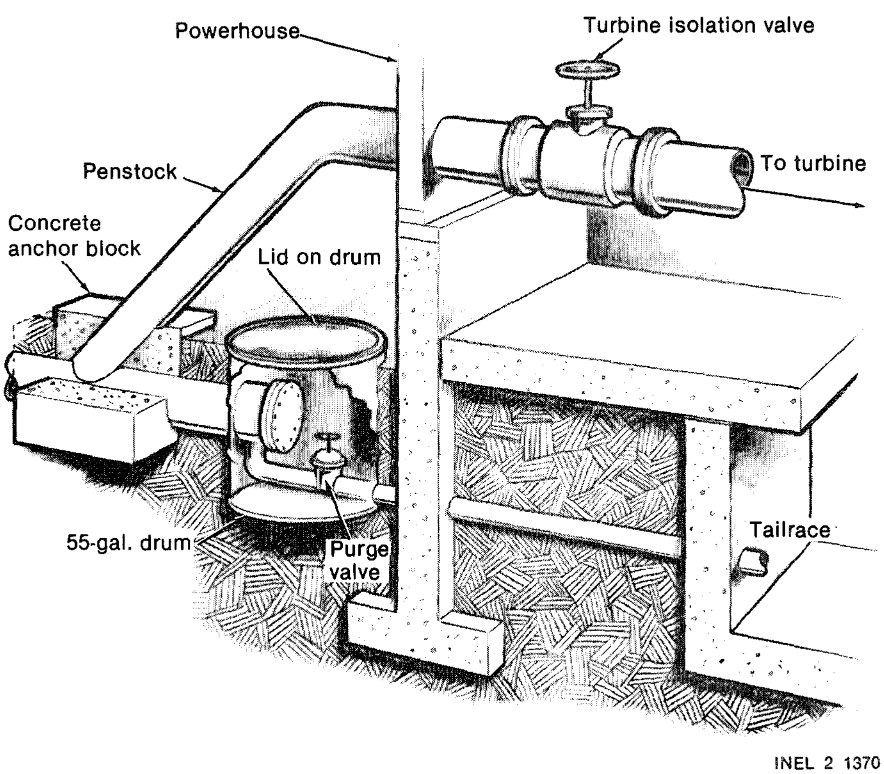

Figure 4.5-9. Arrangement showing turbine bypass "Y" and purge valve.

Another possibility with low head is a standpipe at the lower end of the penstock. The pipe can either be opened to the atmosphere or sealed with air in the pipe under pressure. The air in the pipe will act as a shock absorber for the surge pressure. If the pipe is sealed, provision should be made to check the water level in the pipe, since the air pocket may have to be replaced periodically. The air will be absorbed into the water over long periods of time. Also, standpipes have a tendency to freeze in the cold months because the water is stagnant. If a standpipe is used, heaters and insulation should be added to keep the water from freezing.

4.5.5.4 Turbine Bypass "Y". Figure 4.5-9 shows two additional recommendations for penstocks. To reduce the possibility of getting foreign material into the turbine, it is advisable to make a "Y" connection off the main penstock and have the turbine branch of the penstock above the bypass. To keep the turbulance of the "Y" out of the turbine, place the "Y" at least 10 pipe diameters above the turbine, e.g., place a 14-inch pipe 140 inches above the turbine.

The second recommendation for the "Y" is a purge valve. This would consist of a 4- to 6-inch valve on a tee near the lower end of the bypass. In the case of the figure, the purge valve and the blind flange on the penstock are housed in a partially buried 55-gallon drum cut to fit. The drum with lid acts as a manhole and can help prevent freezing of the valve. This valve is piped to discharge into the tailwater and serves several functions. Among these are:

- A "blowoff" cleanout for silt or sand that has been carried down the penstock.
- A bypass valve to maintain flow in the penstock if the turbine is shut down (for example, to prevent freezing).

CAUTION: The water in the penstock is under pressure. The purge valve and discharge pipe must be anchored. In addition, the discharge pipe should be directed into the tailrace. If a reaction turbine is used, the discharge should be into the tailrace pool of water below the draft tube. The water in the pool will help to dissipate part of the energy. You can never be too careful when dealing with a pressurized penstock. Remember, there is more potential energy in a penstock than the electrical energy that the generator generates, and both can be very dangerous when not handled correctly.

Figure 4.5-10 is a photograph of a purge valve in operation.

4.5.5.5 Turbine Flow Control Valve. Control of flow to the turbine is usually a feature of the turbine package. If the rate of flow to the turbine is to be controlled (to control speed and generator output), this is typically accomplished by means of wicket gates on a Francis turbine, needle or spear valves on Pelton and Turgo turbines, and control gates on a

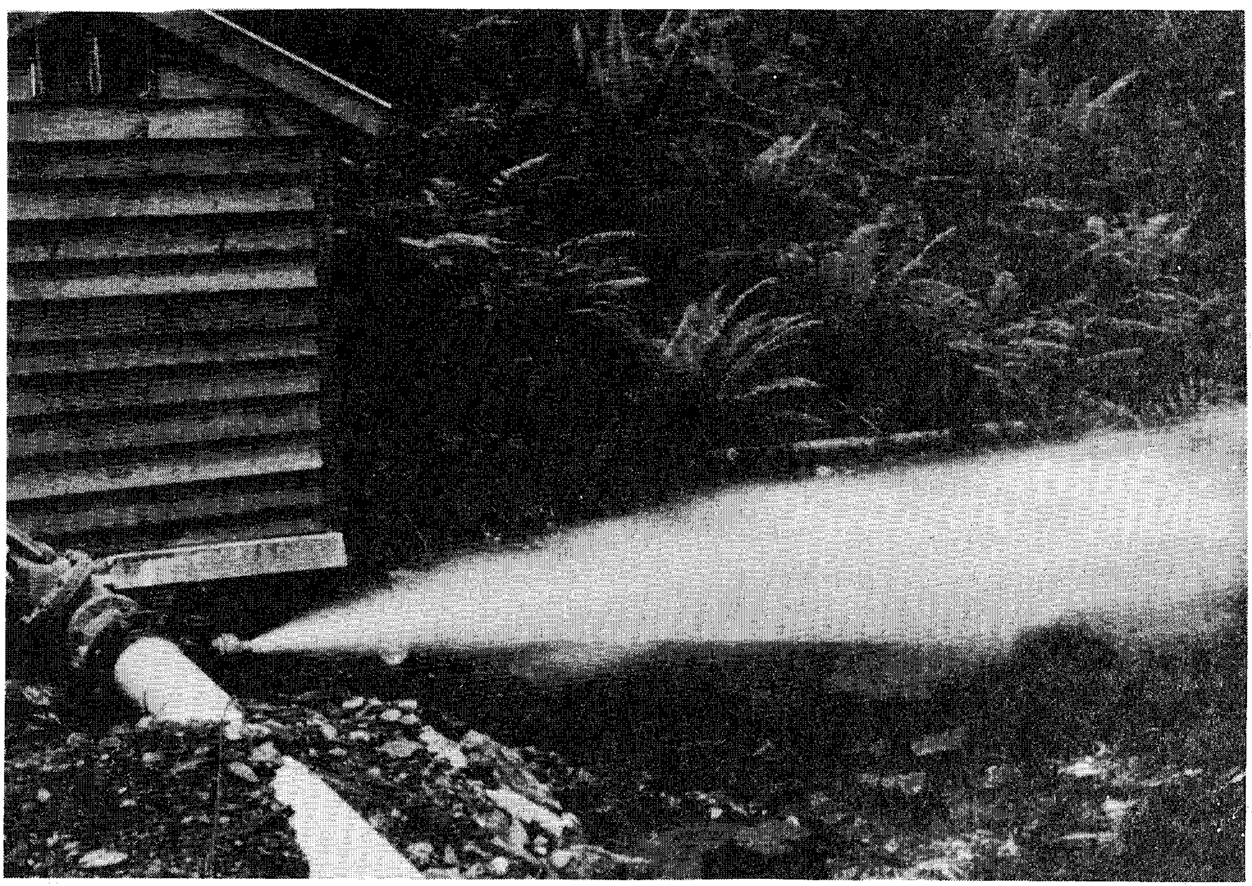

Figure 4.5-10. Purge valve in operation.

cross-flow turbine (see Figure 4.5-11). These valves and their associated governors are integral parts of the turbine unit and are provided by the turbine manufacturer.

Other turbines such as pumps used as turbines do not lend themselves to flow control. The best alternative is a load diverter where a constant flow is applied to the pump and the diverter controls the turbine speed (see Subsection 4.8).

4.5.6 Siphon Penstock

The siphon penstock is a good option where the lift is small and no other method is easily available to transfer the water to the turbine. If you plan to use a siphon penstock (see Figure 2-13), the hydraulic considerations already discussed (velocity and friction head losses) apply. Additional considerations include a means of starting the siphon. In order to start a siphon, the penstock must be completely full of water when the lower downstream valve is opened. For small diameter penstocks, a foot valve on the suction end can be used. For larger diameter penstocks, some form of automatic priming device must be used. A partial vacuum is drawn on the high point of the penstock until the pipe is filled with water. Once the penstock is filled, the water will start flowing to initiate the siphon action.

The maximum theoretical height to which a siphon can raise water at sea level is 34 feet. As a rule of thumb, the maximum practical lift a developer should design to is 20 feet at sea level. This lift could be even less at high elevations or when using siphons with high friction losses. At an elevation of 5000 feet, for instance, the maximum theoretical lift is 28 feet instead of 34 feet. With friction losses, the practical lift will be less than 20 feet. If you feel that a siphon penstock is the best choice for your site and you are not familiar with fluid flow calculation techniques, you should seek professional help for the design.

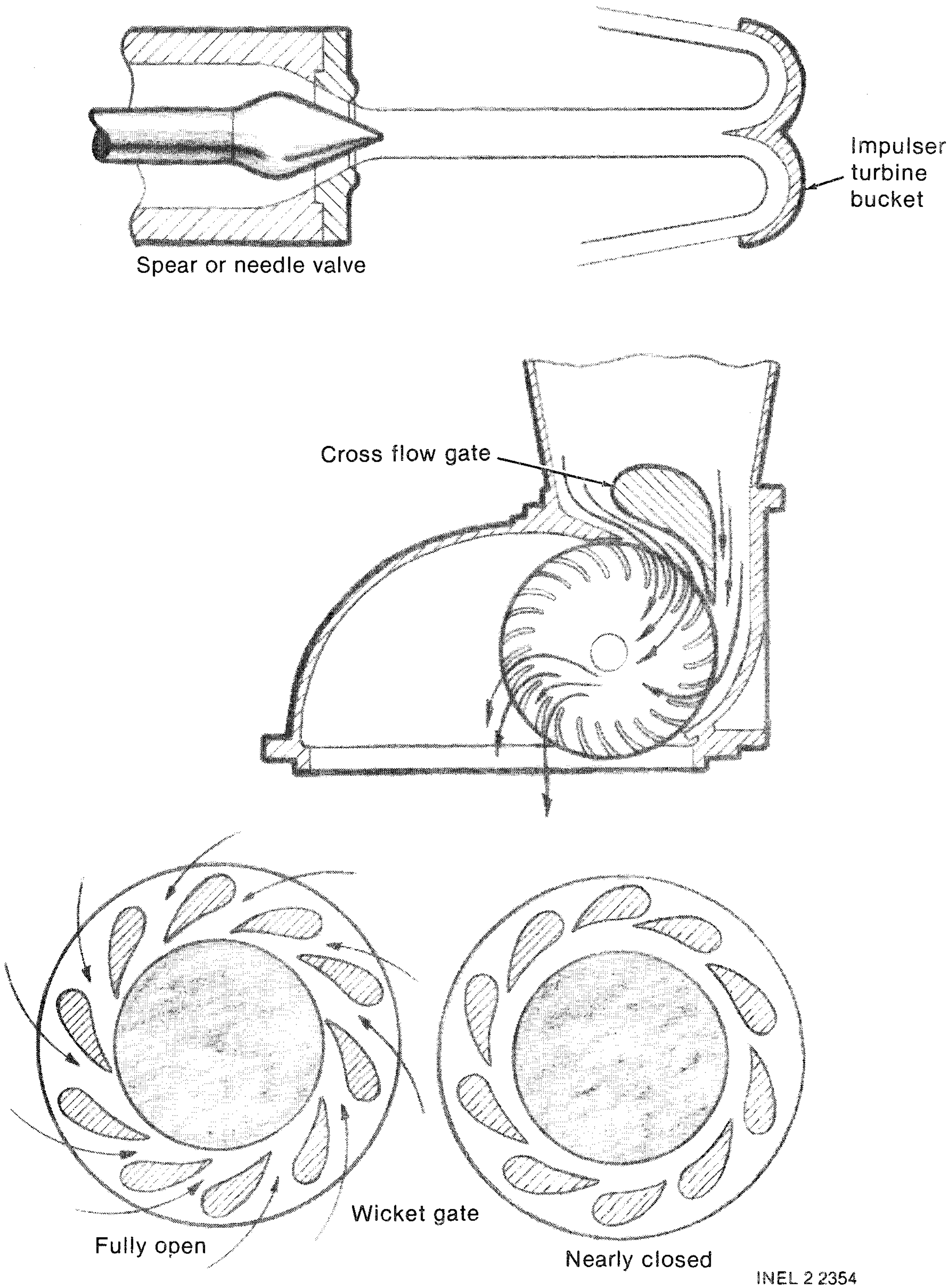

Figure 4.5-11. Types of turbine flow control valve.

In climates where the temperature occasionally drops below zero, the exposed portion of the penstock should be protected from freezing. The pressure at the top of the penstock is less than the atmospheric pressure and thus raises the freezing temperature of the water. A coat of spray-on insulation should suffice.

A rule of thumb in siphon penstock design is to keep the lift to a minimum. In other words, go no higher than absolutely necessary to clear the obstacle you wish to cross. This keeps the low (negative) pressure in the penstock to a minimum. If the lift is much over 2 or 3 feet and the penstock is large, some type of pipe stiffening is advisable. The stiffening can be ribs welded along the length of the pipe. They will help prevent the penstock from collapsing under the negative pressure.

In selecting a location for the penstock, try to locate it so that flood waters will have the least amount of effect on the penstock. If possible, design some type of protection around the pipe.

Some siphon penstocks have the upstream pipe flared out in a cone shape to reduce entrance head losses and the formation of vortices, which cause unstable turbine operation.

4.5.7 Additional Design Considerations

In addition to the specific design considerations--keeping the penstock as straight and short as possible; maintaining a continual downward grade; and using the proper pipe diameter, wall thickness, and material--other items such as thrust or pressure that tends to separate the pipe, thermal expansion, pipe span, pipe support, ultraviolet degradation, and freezing must be considered. Whether the penstock is above or below ground makes a difference on how these secondary considerations are handled.

4.5.7.1 Hydrostatic Thrust. From a safety standpoint, the most significant aspect of penstock design is the restraint of the pipe. Hydrostatic thrust will cause a penstock to move (crawl) and can even separate joints. The thrust is the reaction of a pressurized penstock to changes in flow direction or to outlet nozzles. For example, a garden hose with water flowing through a nozzle will move about freely if not held. Likewise, a 6-inch, 90-degree elbow with a 200-foot head will be subject to a force of nearly 3,500 pounds that tends to pull the elbow away from the connecting pipes. The following formula defines this thrust load for pipe bends.

$$T = 1.57 \times S \times D_p^2 \times \sin\frac{\theta}{2} \qquad (4.5\text{-}5)$$

where

T = thrust in pounds

S = static pressure in psi, from Equation (4.5-1).

D_p^2 = pipe diameter squared (multiplied by itself), in inches squared

$\sin\frac{\theta}{2}$ = trigonometric function, where θ is the angular change in direction; for a 45-degree bend, $\sin\frac{\theta}{2} = 0.38$, and for a 90-degree bend, $\sin\frac{\theta}{2} = 0.71$.

EXAMPLE: Assume a 6-inch pipe diameter, a 200-foot head, and a 90-degree bend. Find the thrust at the bend.

First, use Equation (4.5-1) to convert head to static pressure.

$S = 0.433 \times h$

$S = 0.433 \times 200$

$S = 86.6$ psi

Now, From Equation (4.5-5)

$$T = 1.57 \times S \times D_p^2 \times \sin \frac{\theta}{2} .$$

For a 90-degree bend, $\sin \frac{\theta}{2} = 0.71$. Therefore,

$$T = 1.57 \times 86.6 \times 6 \times 6 \times 0.71$$

$$T = 3475 \text{ lbs.}$$

To resist this thrust, you will either have to use restrained joints (glued PVC or welded steel) or push on or unrestrained joints with thrust blocks. Above-ground penstocks must always use restrained joints. Buried, unrestrained joints must include thrust blocks. A thrust block is a poured-in-place concrete mass bearing on the side of the trench to prevent movement of the pipe. Figure 4.5-12 shows a typical thrust block.

To design a thrust block, you must determine the area (A_t) that pushes against the undisturbed side of the trench. In Figure 4.5-12, it is the height (h_t) times the width (W_t). Table 4.5-4 provides a basis for finding the area required for the thrust block.

TABLE 4.5-4. AREA OF BEARING FOR CONCRETE THRUST BLOCKS

Pipe Size (inches)	45-degree Bend (area in ft^2)	90-degree Bend (area in ft^2)	Tee, Plug, and Cap (area in ft^2)
4	2	2	2
6	3	5	4
8	3	8	6
10	5	13	9
12	7	18	13
14	10	25	18
16	18	32	23

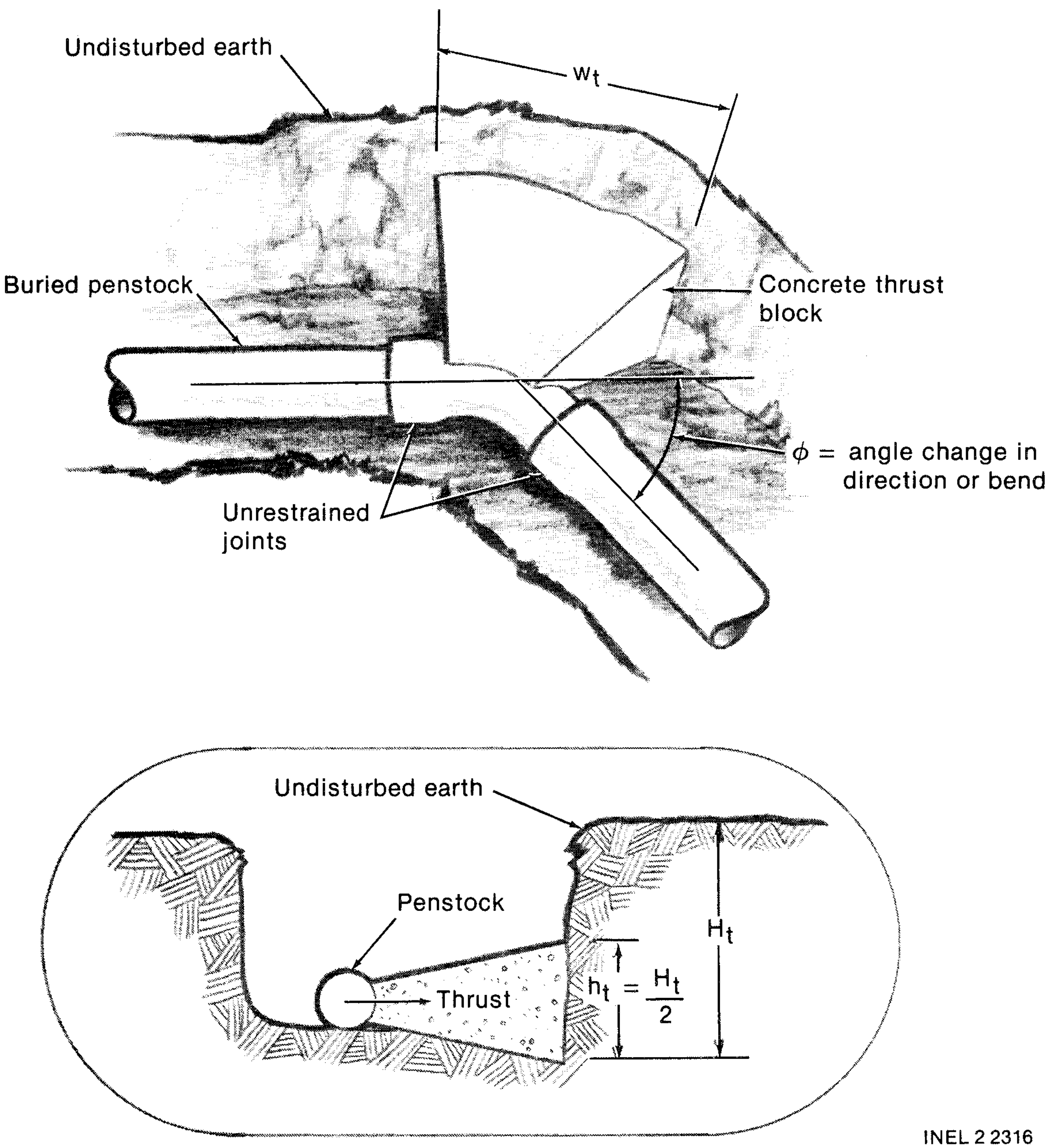

Figure 4.5-12. Typical thrust block.

To allow for soil condition, the areas given in Table 4.5-4 should be multiplied by the appropriate factor from Table 4.5-5.

EXAMPLE: Assume a 6-inch pipe with a 90-degree bend. Find the bearing area (A_t) of the thrust block when buried in sand and gravel.

From Table 4.5-4, the area is 5 ft^2.

From Table 4.5-5, the multiplier is 1.33.

Therefore, $A_t = 1.33 \times 5$

$$A_t = 6.65 \ ft^2 \ .$$

Now that the area is known and the height is set by half the depth of the trench, the width (W_t) can be computed.

$$W_t = \frac{A_t}{h_t} \qquad (4.5\text{-}6)$$

TABLE 4.5-5. SOIL CONDITION MULTIPLIERS

Soft clay	4
Sand	2
Sand and gravel	1.33
Shale	0.4

where

W_t = width of the thrust block in feet

A_t = area of the thrust block in ft^2

h_t = height of the thrust block, equal to half the depth of the trench in feet

EXAMPLE: Assume that the trench is 4-feet deep; find the width of the thrust block if the area is 6.65 ft^2

$$h_t = \frac{4}{2} = 2 \text{ feet.}$$

From Equation (4.5-6)

$$W_t = \frac{6.65}{2}$$

$$W_t = 3.33 \text{ feet, or 3 feet 4 inches } (12 \times 0.33 = 4 \text{ inches})$$

4.5.7.2 Thermal Expansion and Contraction. The penstock will most likely be continuously full of water at a relatively constant temperature. Temperature changes that occur due to a drained pipe or extreme climatic conditions will cause expansion or contraction of the pipe. PVC pipe will expand (contract) at the rate of 0.36 inches per 100 linear feet for every 10°F temperature change. For steel, the expansion coefficient is 0.08 inches per 100 linear feet per 10°F. This means that a 1000-foot PVC penstock will increase in length by about 4 inches for a temperature change of 10°F. In some cases, deflection at elbows will accommodate this change. If larger temperature changes are anticipated, care should be taken in the routing and anchoring of pipes. (Consult the pipe supplier for assistance in this case.)

4.5.7.3 Pipe Spans and Support. The maximum unsupported span for a PVC pipe is from 6.5 feet for a 6-inch diameter pipe to 8 feet for a 12-inch diameter pipe. For steel pipe, the maximum span should be limited to about 15 feet for the smaller diameters and 25 feet for anything over a 14-inch pipe. The pipe should be allowed to expand and contract longitudinally (due to temperature changes) at the supports without abrading or cutting the pipe material. Figure 4.5-13 shows a typical concrete support saddle for above ground piping. If the pipe is layed on the ground, assure that the soil under the pipe is free of rock and debris and that the soil is firmly packed to support the pipe. The sides of the pipe should be bermed to keep surface water from eroding the soil underneath.

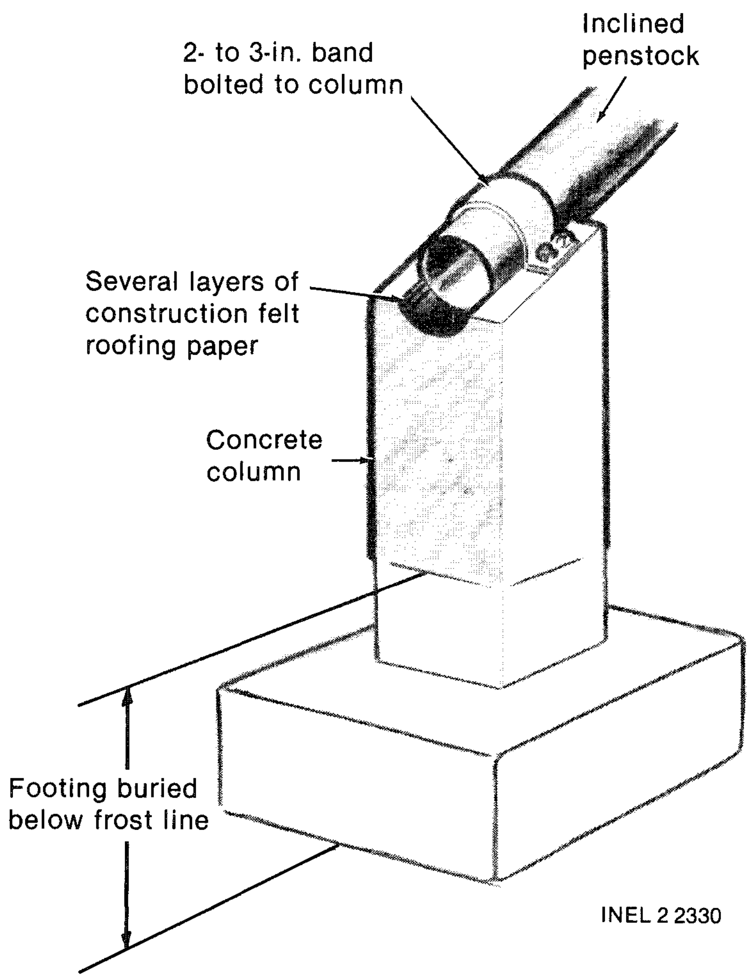

Figure 4.5-13. Typical concrete support saddle for above-ground piping.

4.5.7.4 Ultraviolet Degradation. PVC is susceptible to damage by sunlight, and above-ground use of PVC pipe in areas exposed to direct sunlight is typically not recommended unless the pipe is painted or otherwise covered. Below ground, PVC is good for 10 to 15 years.

4.5.7.5 Penstock Anchoring. If the penstock is more than 100 feet in length, it should be anchored. To anchor a penstock, a mass of concrete can be poured around the pipe. Before pouring the cement, coat the pipe with a material similar to tar and wrap with several layers of felt roofing paper. A rule of thumb is a yard of concrete for each 12 inches of pipe diameter; therefore, a 12-inch pipe would have a 3 ft x 3 ft x 3 ft block of concrete for an anchor.

The primary location for the anchor is just before the penstock enters the powerhouse (Figure 4.5-9). The anchor restricts movement of the penstock at the powerhouse, avoiding the possibility of the penstock separating from the turbine and eliminating loads on the turbine casing. The installation of the anchor is an important additional safety factor to prevent penstock failure because of movement of the penstock.

For long runs of above-ground pipes on steep slopes, intermediate anchors should be provided to reduce pipe stresses from the weight of the pipe and water. The anchor block should be firmly attached to the slope so that its weight will not add to that already on the pipe.

4.5.7.6 Freezing. A hydropower system does not produce energy. Rather, it transfers energy from one form to another. If water flows down a stream from Point A to Point B, the water has dissipated the same amount of energy that you can recover in a turbine.

In a free stream, energy is dissipated in the form of heat. Heat is generated by the friction of water within itself and with the stream bed. Likewise, if the water is piped from A to B, the friction between the water and the pipe will generate a certain amount of heat. The less the friction, the less the heat generation, and conversely, the more the friction, the more the heat. An old steel pipe with riveted sides has a lot of friction and will very seldom have a freezing problem. PVC, on the other hand, has a very low friction factor, and ice will usually build up in the pipe in freezing temperatures. If your site is in the mountains or in the northern half of the U.S. and you plan to use PVC, you should consider burying the penstock to reduce or eliminate the freezing problem.

If for some reason flow in the penstock must be stopped in the winter, drain the penstock or use the purge valve to keep some water flowing.

4.5.8 Design Layout

After you have decided on the type and length of penstock, make a sketch or sketches of the system. If earthwork or concrete is involved, calculate the volume as in Subsection 4.4.4. Be sure to include all valves and other associated equipment required to make the system functional.

4.6 Powerhouse

It should be noted that not all hydropower plants will require a powerhouse. Projects using a "bulb" turbine will have the turbine-generator package located directly in the water. In these cases, space should be provided only for the location of the electrical switchgear. Other turbine units may be designed for outdoor installation of the generator and switch gear.

The purpose of a powerhouse is to house the turbine-generator set and electrical components. The powerhouse protects the equipment from the elements, limits access for safety and security, and provides space to maintain and service the mechanical and electrical equipment. The powerhouse should be constructed to fit the equipment. Consequently, the equipment should be selected before the powerhouse is planned. Some powerhouse details will be supplied by the turbine-generator manufacturer.

The location of the powerhouse depends on the local site conditions. A Category 1 developer who has sufficient head and flow may decide to locate the powerhouse next to the load source and thus reduce the transmission distance. Since the powerhouse is generally located adjacent to the stream it should be located above the high water mark of the stream or flooding will result during spring runoff. If the high water mark results in the house being too far above the stream (so that the vertical distance from the house to the stream is not available as head to an impulse turbine), then the house can be set lower and a long tailrace used so that the elevation of the floodwater at the tailrace exit is lower than the powerhouse, as shown in Figure 4.6-1. Or, you can use a reaction turbine with a draft tube installed as discussed in Section 4.1.6, which will allow the turbine to be set higher and still use the head.

The physical orientation of the powerhouse should be set to keep the penstock straight. A straight penstock is much more important than a perpendicular powerhouse parallel to the stream. Notice the location of the powerhouse in the sketch in Figure 4.6-1.

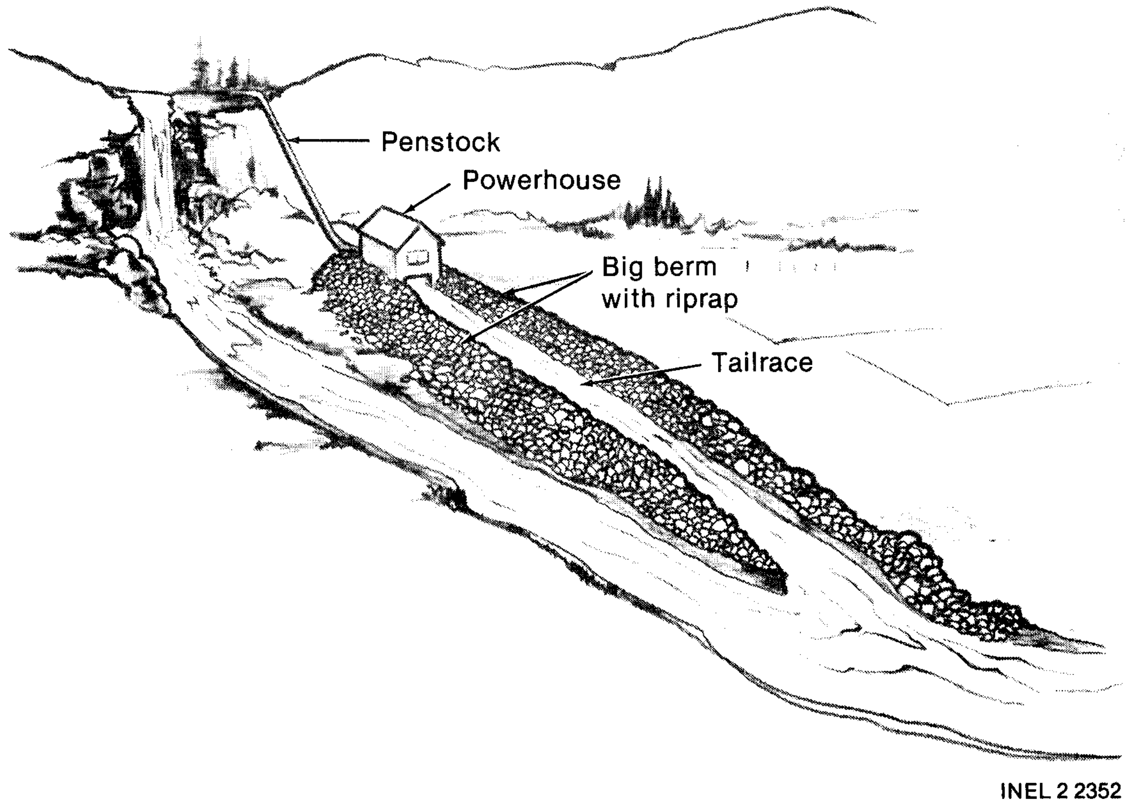

Figure 4.6-1. Powerhouse installation with long tailrace.

4.6.1 Physical Features of the Powerhouse

The powerhouse must be designed to accommodate the equipment and provide adequate room for personnel to work on it. Detailed powerhouse requirements can only be obtained from the equipment manufacturer. Powerhouses can be constructed of wood (Figure 4.6-2), metal (Figure 4.6-3), or masonry depending on the availability and cost of material. In all cases, the footings, foundation, floor slab, and equipment pad should be constructed of concrete.

The powerhouse should include an opening or access for the penstock to connect to the equipment and an opening for the water to exit the powerhouse in the tailrace. Other accesses or openings may be:

- A door large enough to handle the largest single item. The dimensions of the various components can be obtained from the manufacturer. The door should have a lock to control access.

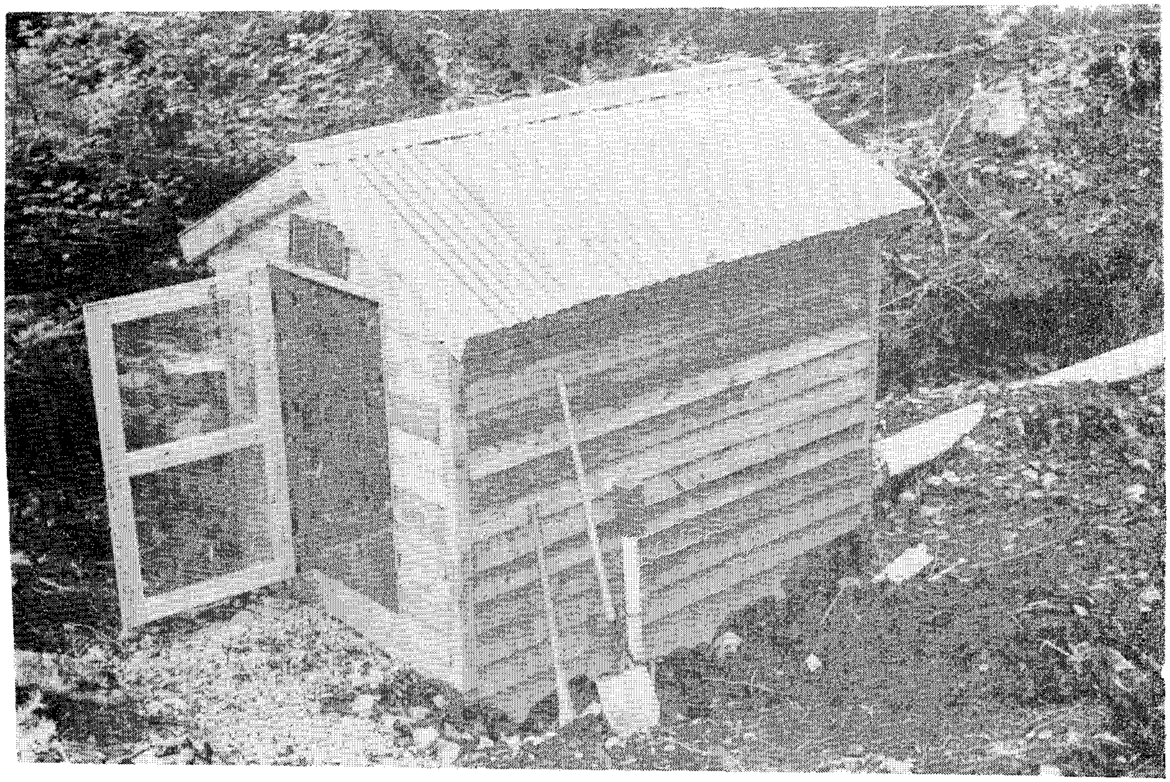

Figure 4.6-2. Wooden powerhouse.

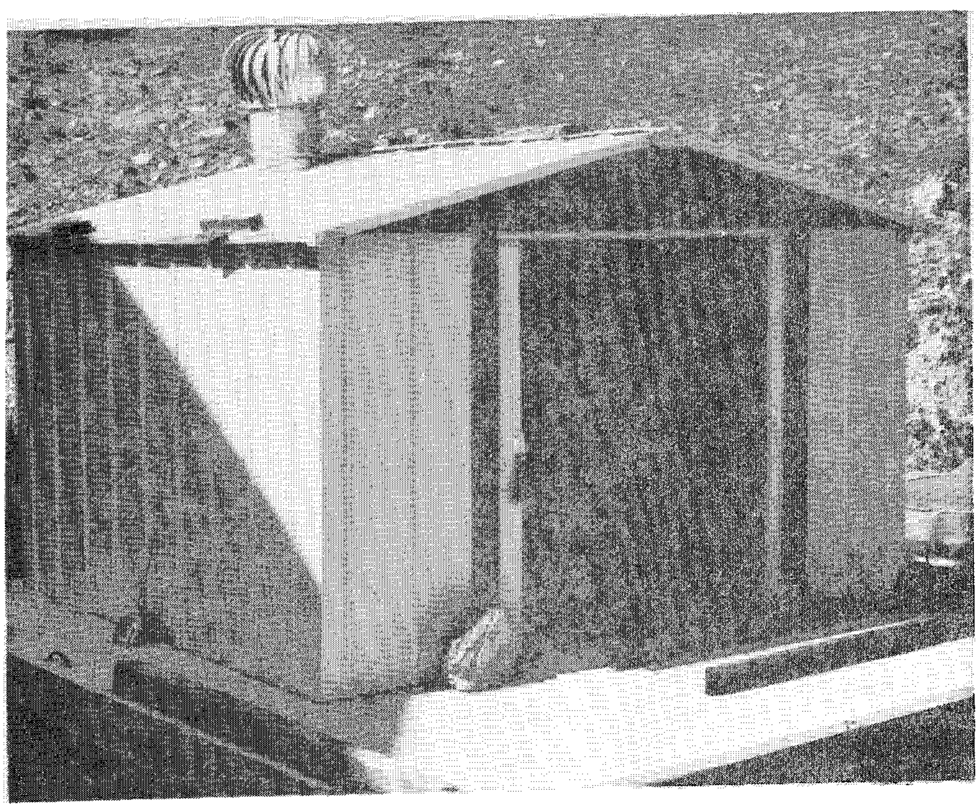

Figure 4.6-3. Metal powerhouse.

- Windows, louvers, and roof vents to provide good cross-ventilation for temperature control and removal of dampness. Since most generators are designed to operate in a temperature range of 20 to 100°F, the number and size of ventilation openings should be adjusted to the climate.

- Conduits for electrical wires to allow the connections between the control equipment in the powerhouse and the distribution lines outside the powerhouse.

- Floor drains to allow water from leaks, condensate, or repair and maintenance activities to drain from the building.

- Small pipe openings for piping or tubing since some generators may be water cooled.

The powerhouse should include other features such as lighting and electricity. Thought should be given to how equipment can be installed and removed. It may be worth while to incorporate a beam into the powerhouse structure for this purpose. A temporary "A" frame structure or oversized doors to allow a forklift to enter could accommodate equipment placement without a beam. Figure 4.6-4 illustrates some of the typical features of the powerhouse. The illustration shows a turbine with a draft tube. If the turbine is an impulse turbine, the draft tube will not be included. The draft tube must discharge below the water level. The tailrace can be equipped with a weir to provide a pool of water for discharge of the the draft tube. The weir can be a simple metal plate slipped into an angle iron frame bolted to the precast concrete tailrace wall (Figure 3.9). See Subsection 4.7 for the design and size of the tailrace.

4.6.2 Powerhouse Size and Dimensions

The powerhouse should be sized for sufficient and safe clearance around the turbine and generator equipment. Once the size of the turbine-generator set is known, it is recommended that the minimum

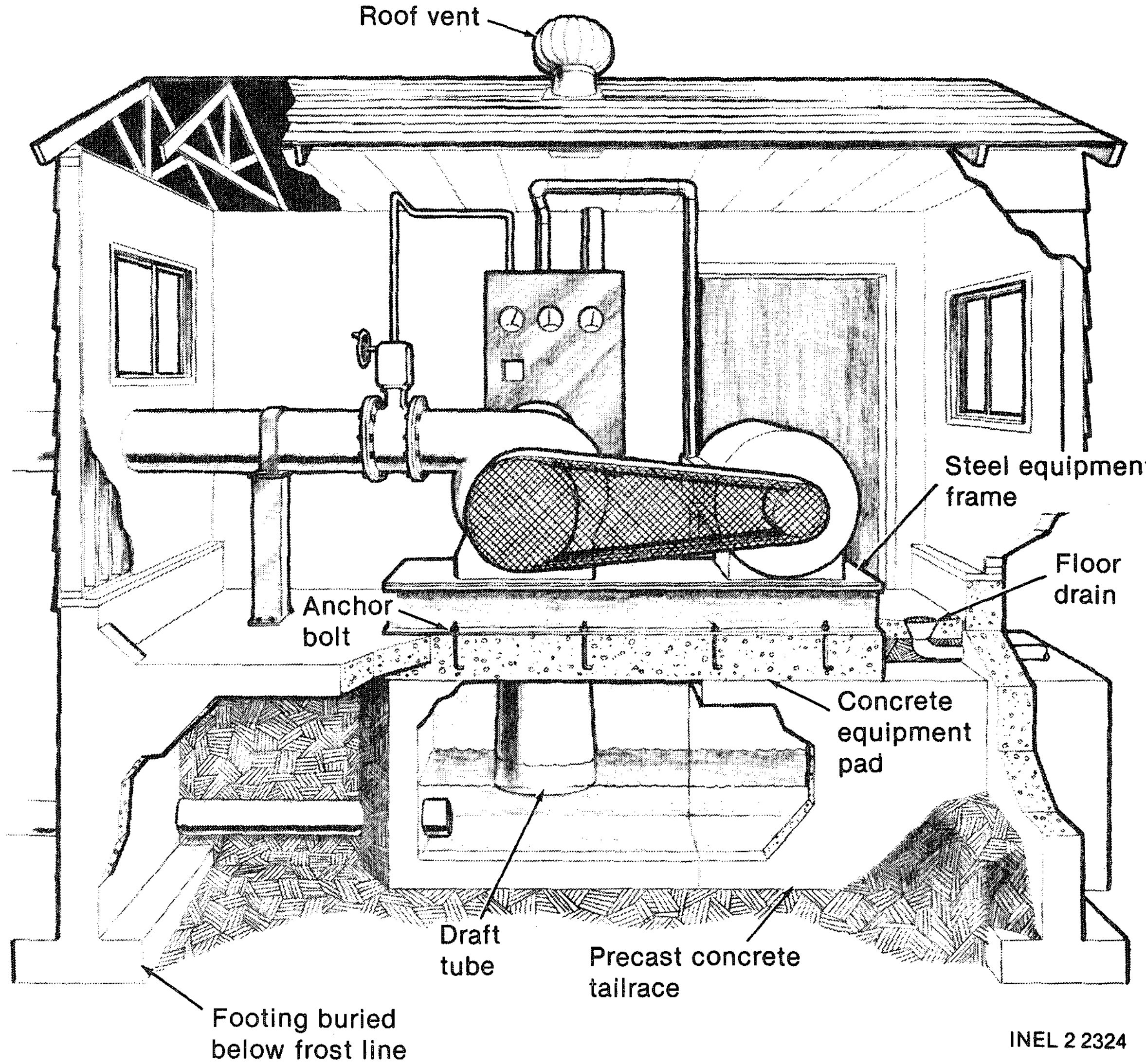

Figure 4.6-4. Typical powerhouse.

powerhouse width be at least two times the equipment width and the length be at least three times the equipment length. Additional considerations would be storage space for spare parts and space for repairs and maintenance. The inside height should be sufficient to allow movement while standing.

4.6.3 Minimum Powerhouse Standards

The powerhouse should be a weathertight enclosure with a strong roof structure to handle snow and rain. The building should be locked to discourage theft and vandalism. The concrete used in the construction should have a strength of at least 3000 psi. If ready-mix concrete is ordered, specify the maximum strength. The floor level should be at least 1 foot above the highest maximum water level of the tailrace.

4.6.4 Location and Mounting of the Equipment

A concrete pad is necessary to mount the turbine-generator equipment or the metal equipment frame. Equipment mounting specifications, details, and requirements must be obtained from the equipment manufacturer to plan for the construction of the mounting pad. The pad serves as a base for mounting the equipment and as a mass (dead weight) to dampen the vibration created by rotating machinery. The weight of the concrete pad should be at least two times the weight of the equipment plus the weight of the water in the turbine. Once the weight of the equipment and water has been determined, the size of the pad can be determined since concrete weighs approximately 110 pounds per cubic foot. To support any equipment, the concrete pad should be at least six inches thick. To support heavy equipment (more than 2000 pounds) the thickness of the pad should be increased.

EXAMPLE: Assume that the weight of equipment plus water is 1000 pounds

Weight of concrete = 2 x 1000 = 2000 pounds

Amount of concrete = 2000 lb ÷ 110 lb/ft^3 = 18 ft^3

Size of 6-inch-thick pad = 18 ft^3 ÷ 0.5 ft = 36 ft^2

The 36-square-foot, 6-inch-thick pad should be made to match the length and width of the equipment. For example, if the length and width of the equipment is basically square, then the pad should be square, or in this case 6 x 6 feet.

Normally, the equipment pad should be placed on compacted soil or rock and poured separately from the floor pad. Expansion joints should be placed between the equipment pad and floor pad. This will minimize the transfer of vibration into the floor pad and building. It will be necessary to use reinforced steel bars in the equipment pad to maintain the integrity of the concrete. The reinforcing should be at least Number 4, located 12 inches on center each way. To aid the grounding of the generator, the reinforcement should be welded together and a lead brought out for a ground attachment.

The turbine package will be bolted directly to the equipment pad with bolts. These bolts can be cast into the pad as it is poured or welded to an angle iron cast into the concrete. The arrangement and spacing of the bolts must match the holes drilled in the equipment frame see Subsection 5.3.2.

Electrical panels are generally mounted on the wall, high enough from the floor so that flooding will not cause serious damage.

4.6.5 Powerhouse Costs

The average material costs per square foot of building space for a typical powerhouse as discussed in this section are shown in Table 4.6-1.

TABLE 4.6-1. POWERHOUSE COSTS

Item	Costs per Square Foot of Building[a] ($)
Concrete--Includes footings, foundation, equipment pad, floor, and tailrace under powerhouse	5.00
Building Structure--Based on wood frame with metal exterior includes walls and roof	5.00
Miscellaneous--Includes door, windows, vents, and electrical equipment	2.00
TOTAL MATERIAL COSTS PER SQUARE FOOT OF BUILDING	12.00

a. 1982 dollars.

A 10- x 12-foot building would contain 120 square feet of building space. The average material costs for this powerhouse would be 120 x $12 per square foot = $1440.

If the powerhouse is constructed by a building contractor, the average cost per square foot of building will be twice the material costs. In this example, 120 x $24 per square foot = $2880. Costs may vary depending on the site location and availability of local material and labor.

These costs are for the powerhouse structure and do not include costs for the penstock, turbine-generator, control equipment, and any tailrace beyond the powerhouse. These costs are covered in the appropriate sections.

4.6.6 Design Layout

Once the size of the powerhouse is determined, sketch the layout of the powerhouse on a sheet of graph paper.

4.7 Tailrace

A tailrace is a canal or conduit that carries water from the powerhouse to the next desired location (usually back into the stream).

4.7.1 Size of the Tailrace

The tailrace should be large enough to carry the design flow. The velocity in the tailrace can be 2 fps. In parts of the country where fish migration is a consideration, the velocity at the tailrace exit should be reduced to less than 0.5 fps. Migrating fish will be attracted into the tailrace if the velocity is too high.

For sizing the tailrace for 2 fps, refer to section on power canals, Subsection 4.4.2.2. The power canal and tailrace will have the same cross-sectional area. Note that the slope for the tailrace must also be equal or greater than that of the power canal. If the reduced velocity is needed at the stream entrance, make the end of the tailrace four times wider. If the same depth is maintained, the velocity will be reduced to 0.5 fps.

4.7.2 Tailrace Intake

Generally, the tailrace will start below the powerhouse and is an integral part of the powerhouse design. The width and depth is set by the area for 2 fps. As in Figure 4.6-4, the powerhouse footings and the tailrace intake are usually constructed from concrete. The concrete can either be precast or poured in place. Since the equipment pad is usually directly on top of the tailrace, the concrete must be structurally sound. If you pour the cement yourself, be sure and use a sufficient number of reinforcing bars. If you are not sure how to do that, then a precast concrete box culvert purchased from a manufacturer is strongly recommended.

Figure 4.7-1 shows two types of precast concrete box culverts connected together. The open top is the "U" shape type, and the closed top is the box type. In the culvert, both ends are open; therefore, an end

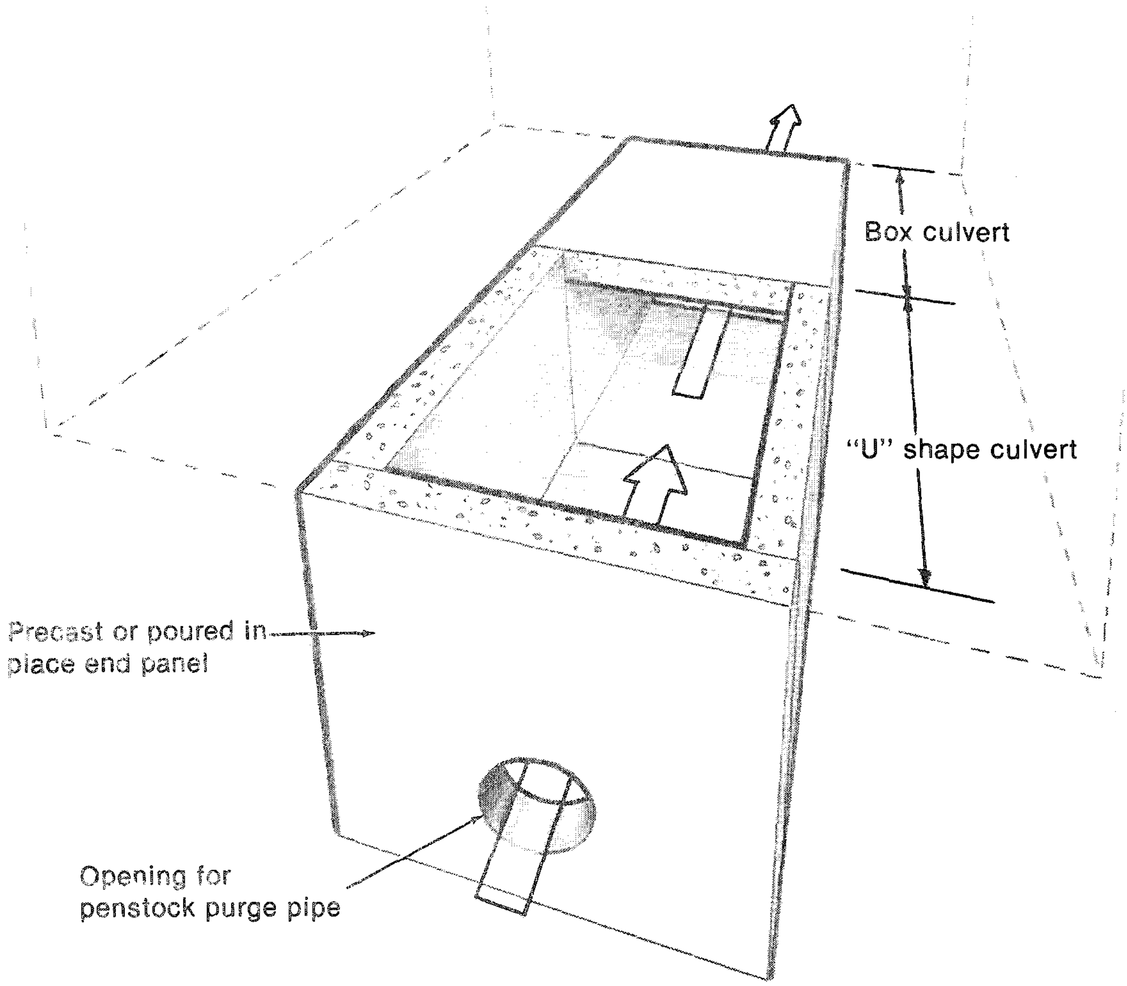

Figure 4.7-1. Tailrace intake structure.

panel will either have to be poured in place or precast with the culvert. In either case, an opening for the purge pipe should be cast into the panel. If you decide to pour your own intake, the physical arrangement can be similar to that shown in Figure 4.7-1 or can resemble just the "U" shape.

As mentioned in Section 4.6.1, if a draft tube is used, a pool of water must be maintained in the intake. The pool should also be drainable and cleanable. A metal weir can be installed near the end of the tailrace intake. The weir is held in place by angle iron bolted to the side of the tailrace. The height of the weir should be less than half the height of the tailrace. This will ensure that the weir can be inserted and removed.

Also, when the purge valve is opened, there will be a high-pressure stream of water exhausted into the tailrace pool. The weir mounting must be strong enough to withstand that force.

4.7.3 Design Considerations

The area and size of the tailrace was determined by the design flow and the velocity. Figure 4.6-1 showed a powerhouse set lower than the high-water mark of the stream. A long tailrace is used to lower the elevation of the tailrace exit to a point where flood water cannot back up the tailrace and flood the powerhouse. In this case, a berm and rip rap will have to be constructed to protect the powerhouse and the tailrace from flood waters. The berm should be at least 3 feet above the high water mark. The higher the berm, the less the possibility of washing out the powerhouse and all the equipment.

An additional advantage to a long tailrace is that the flood waters will not raise the water level on the reaction turbine draft tube. If the tailwater rises on a draft tube, the effective head is reduced and less power is produced.

If the excavation involves a large volume of soil, a backhoe will be necessary. The cost of equipment rental and operating time must be estimated. Survey the potential location for the tailrace for rock outcrops and other obstacles that will increase the cost of construction. If these obstacles are too severe, an alternative location for the powerhouse should be considered.

4.7.4 Design Layout

If the tailrace is a significant activity, sketch the tailrace on a sheet of graph paper and estimate the material to be excavated. The cost of the excavation can be determined in the same way as the cost of the intake structure (Subsection 4.4.3.)

4.8 Generators and Electrical

A generator is an electromechanical device that converts mechanical energy, "torque," into electrical energy. This is accomplished by driving a coil through magnetic lines of force and so that the coil interacts with those lines of force to produce a voltage at the coil terminals.

The electrical distribution system for a microhydropower installation is selected for transmitting the power developed in the generator to the point of use.

This section is written with the assumption that the developer has some background in electricity and the terminology of electrical construction and generator operation. Electrical and generator terminology and the theory of a generator are discussed in Appendix A-6, which contains the following.

- A description of synchronous and induction generators and their associated equipment
- Standard voltage characteristics
- Connection diagrams for a 12-lead generator to match standard voltage characteristics
- Standard nameplates and an explanation of terms
- Standard generator insulation ratings and enclosures.

You may want to study Appendix A-6 on electrical theory and standard generators before studying this subsection of the handbook.

4.8.1 Electrical Safety Considerations

The National Electrical Code (NEC) should govern the installation of any electrical equipment from the terminals of the generator to the point of consumption. The NEC is a legal document and is enforced by local electrical inspectors. However, the NEC is also a document based on common sense and on electrical installation practices that have been found to be safe and to minimize the risk involved in the use of electricity. You should comply with all requirements of the NEC. A copy of the regulation can be obtained from bookstores or from equipment suppliers.

CAUTION: If you have questions on electrical requirements or the connection of any piece of electrical equipment, you should get help from a licensed and qualified industrial electrician. Electricians have various areas of expertise; therefore, make sure the one you hire is qualified to work with generators and protection equipment. An electrician not qualified to handle a power system can be as much of a hazard as a nonelectrical person making the installation.

You should obtain wiring and connection diagrams of all equipment. Study these connection diagrams before installing equipment to make sure that you understand how the system is wired and how each wire and piece of equipment relates to the system. These diagrams will be helpful for final checkout and for future trouble shooting.

You should always get an electrical permit and have your electrical system inspected. The electrical inspector will verify that the electrical installation meets the intent of the NEC and can operate in a safe manner. The electrical inspector will probably not verify that the controls and wiring are connected to the proper terminals, but he will verify that the system is grounded properly and that the system has been wired according to recognized electrical practices.

The utility should be responsible for all connections to its power lines. Never attempt to make any connections to a utility system. Notify the utility, and they will have a line electrician available to make the intertie.

The following are some very basic NEC considerations that should be included in all microhydropower installations:

- Ground all systems. This will require voltage selections that will contain a neutral conductor, such as 120/240 volt, single phase, three-wire; 120/208 volt, three-phase wye four wire, or 277/480 volt, three-phase, four wire.

- Install properly sized and rated equipment and wire on all systems. Do not skimp.

- Install overcurrent and short circuit protection on all circuits, including the generator, the distribution system, and the branch circuits connected to the electrical system. Do not bypass this equipment. It is installed for the purpose of protection. Use that protection. The cost is minimal when compared to the cost of replacing burned out equipment.

The Category 2 developer who ties into a utility will require equipment that is rated for the voltage of that utility. This will generally be a level of 7200 to 12470 volts, but could be higher. All transformers and protective equipment must be rated for the voltage level used by the utility.

Equipment ratings and wire sizes are basically dependent on the number of amperes that the equipment has to carry. These ratings should always be watched to verify that the equipment is matched to the system. For example, if a generator circuit breaker is too small, it will trip when it is not supposed to; however, if it has too high a rating, the equipment may burn up before the breaker trips. Therefore, always install properly rated equipment.

4.8.2 Generator Selection

There are many different types of generators that can produce power. These include synchronous generators, induction motors used as generators, direct current (dc) generators, and many hybrid generator systems. The standard generators in use on microhydropower projects are the synchronous generator and the induction motor used as a generator.

The synchronous generator is primarily used on stand-alone installations such as those for the Category 1 developer. This generator supplies its own excitation current through either a rectifier system or an external dc generator or battery system. The generator can also be used with utility system interties. This requires synchronizing equipment to determine when the unit can be safely connected to the power line. The equipment is generally a system of lights or an indicating dial to indicate when the generator voltage is in phase with the voltage of the utility.

The induction generator is actually an induction motor used as a generator. It is capable of operating as a generator only when connected to an outside electrical power system. The generator output voltage does not appear at the output terminals until after the generator is connected to the outside power system. Thus, there is no way to synchronize an induction generator with an outside power system as is done with a synchronous generator. To function as a generator, an induction motor must be driven about 1 to 5% faster than synchronous speed, or 2 to 6% faster than the speed it would have when functioning as a motor. The amount of output power that is generated by an induction generator is approximately proportional to the excess speed above synchronous speed. This excess speed is called slippage.

There are two ways to place an induction generator in operation. One method is to bring the machine up to speed by starting it as a motor, then overdrive the unit with the turbine to generate electricity. A second method is to bring the induction machine up to speed with the turbine and then close the main breaker to interconnect the generator with the line. The second method of starting an induction generator has been found to reduce the transients that are noted on a power line when an induction machine is connected to the line. The generator must be connected to the powerline before the turbine overspeeds the unit; otherwise damage to the machinery may occur.

An induction generator requires from the powerline a magnetization current that is out of phase with the normal power. This need for magnetization current is a requirement of the unit operating either as a motor or as a generator. This characteristic of induction motors and generator places an abnormal demand on the power supply line that may be objectionable to the power company. Power companies sometimes require the installation of power factor correcting equipment to compensate for the magnetization current. The magnitude of this problem depends on the capacity of the connecting power line and the size of the induction generator. If the induction generator is started as a motor, the surge of magnetization power at the initial starting instant is approximately five times normal. This may impose a limitation on the method used for startup.

This problem is similar to that encountered in starting any large motor, with the key factor being the size and capacity of the supply line. All power companies are very familiar with the problem and can best judge and predict the extent and solution to the problem.

Another cost for an induction generator is for equipment to correct the power factor. The sum of the additional cost is comparable to the cost of synchronizing equipment and should be considered as tradeoff items when evaluating the use synchronous versus induction machines in the selection of a generator.

A Category 1 developer will probably install a synchronous generator. If the developer buys new equipment, he will want to specify a self-exciting, self-regulated generator. Other forms of excitation are available; however, the self-exciting, self-regulated machine has performed well in "stand alone" microhydropower installations.

The Category 2 developer will have to consider various items before determining which generator to use:

- Technical ability of personnel operating the plant and whether they can start and parallel a synchronous generator with a utility line.

- The length of power line to the first distribution substation. Will the power line be capable of providing the magnetizing current for an induction generator?

- The cost of power factor corrective capacitors versus synchronizing equipment. This should include capital costs and maintenance costs.

4.8.3 Sizing the Generator and Electrical Distribution System

You will have to determine the voltage, phasing, and power output of the generator. The Category 1 developer will probably desire a generator connected to supply 120/240 volts, three-wire, single phase.

The power output of this generator will have to be totally consumed by the equipment located at the site. Therefore, the developer should closely consider the equipment that is connected to the generator and how it can be connected to use the power generated. This can be done with a load control system that controls the loads connected at any time and provides a load sink for any excess load.

The Category 1 developer will have to determine whether to size the generator to handle just the loads connected at the present time, or to provide some excess capacity and a load sink. The developer will then have to make sure that the water source can supply the power required.

The reason for consuming all of the power is that the generator must maintain a constant speed or rpm to maintain a constant frequency. If the load is allowed to vary at random, the speed of the generator will vary, and the frequency will fluctuate. Fluctuating frequency will destroy small motors and solid state equipment.

A single-phase generator can be a generator that is single phase, or a multiphase generator connected as single phase. You can also use one phase of a three-phase generator. This would only produce about 1/3 the power capability of the generator; however, this can be done without seriously harming the generator.

The Category 2 developer will want to investigate the utility's power line and the type of generator and electrical system needed to connect to that line. If the power line is single-phase and you want to use some of the generator output, you will probably generate power at 120/240 volts single-phase. If the power line is three-phase and you desire to use some of the output, you will probably want to generate power at 120/208 volts three-phase, four wire. You can then connect to the generator and "dump" the excess power to the utility. If the power line is three-phase and you desire to sell all of the power developed to the utility, you will probably want to generate power at 277/480 volts, three-phase, four wire.

The Category 2 developer will have to supply step-up transformers and protection equipment to connect to the utility's power lines. Since the Category 2 developer desires to receive maximum return on his investment, the generator power output will be sized for the maximum economical power that the water source can provide.

With the voltage selection, number of phases, and kilowatts of power production known, you can determine the size and ratings of the electrical equipment to be used in the system.

You will also want to consider the following items in generator selection:

- Bearings. Generators usually have a single bearing for a horizontally mounted unit and a two-bearing system for a vertically mounted machine. If the system is a packaged turbine-generator, the supplier will provide the proper bearing to match his system.

- Generator insulation. The generator insulation level should be rated for continuous loading. An insulation level of 105°C will generally be acceptable.

- Generator enclosure. The generator enclosure needs to be determined. A drip-proof enclosure will generally be acceptable.

- Special features. Special features desired on the generator will have to be determined. These items could include a generator winding heater to keep moisture out of the generator during times when generator is not operating, and a generator rating that can handle motor starting overloads or special power factor ratings on efficiency voltage, etc.

If you are building your own turbine, you may desire to purchase the generator only. This generator could be new or used. A new generator would be purchased in a fashion similar to that of the packaged turbine-generator. Therefore, the equipment supplier would need some of the information supplied in the information request form contained in Subsection 4.2, as well as the desired operating speed.

If you plan to purchase a used generator, you should have it inspected and tested by a competent motor repair shop.

Some items to look at in used machines are:

- Inspect the motor to see if there are points of heavy wear or overheating in the commutator and brushes, the windings (as far as can be seen), and the bearings. Check the cleanliness of the motor to determine its previous maintenance. See Figures A6-15, -17, and -19 in Appendix A-6 for location of these items.

- Check the ratings of the used generator and compare them to the following electrical characteristics needed for the system:

  - Kilowatt or horsepower. A horsepower motor needs 1 kilowatt of power, but will only generate less than 0.7 kilowatt.

  - Voltage

  - Phase

  - Amperage ratings at various operating voltages

  - Frequency

  - Service factor

If the generator is old, it should be rated for continuous or motor duty. A generator rated for standby duty may not hold up under continuous operation at full load.

When you have found a generator or induction motor that is properly priced and appears to be suitable for your application, you should have a motor repair shop or other qualified personnel test the machine. This inspection should include:

- Test the insulation of the generator wiring with a megohmmeter.
- Check the pressure and position of generator brushes; clean and replace as required.
- Clean the machine thoroughly, blowing out dirt from windings; wipe the commutator and brushes.
- Check the shaft for end play.
- Check the air gap.
- Examine the connections of the commutator and armature coils.
- Check rectifiers on self-excited synchronous generators to see that they are not burned out.

If the used generator requires reworking, you should get a price quote on the amount of work. Compare this price and the cost of the used generator against a new machine.

There are some units for sale that have been installed and operated for many years. If you find an old turbine and generator suited for your flow and head requirements, you may consider purchase of that system. The unit may not be as efficient as a modern unit, but the cost may be acceptable. You should have the generator checked out as described above. In addition, you will have to examine the turbine, or have it checked, as follows:

- Check all movable bearing surfaces for wear and pitting.

- Check all turbine runners for pitting, rust, and wear to make sure that the turbine is in good shape or can be rebuilt.

- Check the shaft for wear. Can it be rebuilt?

Again check all associated costs and verify that they are reasonable in comparison with the cost of a new unit.

4.8.4 Metering

The generator system should have three metering devices to determine ac voltage output, ac amperes output, and output frequency for a synchronous generator or rpm for an induction generator. A kWh meter may also be required.

The voltage can be measured directly at the generator output terminals. Select a voltmeter with the proper range for the voltage of the system. An ammeter will measure the current flow. However, because ammeters have a maximum current rating of 5 amps, a current transformer is used with the ammeter connected to the secondary of the transformer.

CAUTION: The current transformer should never be removed from the system without a shorting wire or bar installed between the terminals of the transformer.

In stand-alone systems, a frequency meter will be required to verify that the frequency is within the parameters required by the system. For installation of induction generators, an indication of rpm is needed to determine slip.

The Category 1 developer does not require a kWh meter. However, you may want a meter to determine energy use in your system. The Category 2 developer will require at least a kWh meter to determine how much power is sold to the utility. Other metering requirements may be set by the utility. These are discussed in Subsection 4.8.13.

4.8.5 Generator Speed Selection

The synchronous speed of a generator is determined from Equation (A6-14)

$$rpm = \frac{f \times 120}{p} \qquad (A6\text{-}14)$$

where

rpm = synchronous speed

f = frequency in Hertz (cycles per second)

p = number of stator poles.

As can be seen from the equation, the frequency and poles interact to determine the speed of a generator.

Standard speeds of regularly manufactured generators are 3600, 1800, 1200, and 600 rpm. However, because of overspeed considerations, most generators for microhydropower applications are specified in the 900 to 1800 rpm range.

The overspeed of a generator is the speed that the generator will attain when it becomes unloaded and the turbine still has full flow and head available. Turbines and generators can reach speeds two to three times greater than normal operating speeds. This is especially critical in a high-head installation.

Therefore, most generators should be selected in the lower speed of range of 1800, 1200, or 900 rpm so that the machine can withstand a speed of two or three times normal speed for short periods. The control system should always contain some method of shutting down the turbine and generator in response to overspeed.

Subsection 4.5 describes methods of shutting down the water flow under overspeed conditions. It describes ways to minimize the impact of small overspeeds due to varying loads on a generator by the use of governors and load controllers.

4.8.6 Cost of Generators

The costs of both synchronous and induction generators are related to the size of the equipment. The costs of both generators are based on standard production models of the equipment. For this reason, the "standard" synchronous generator is an 1800-rpm generator that is manufactured for the gas- or diesel-fueled emergency or standby generator market.

Figure 4.8-1 is a graph showing the limits of cost versus kilowatt for 1800-rpm synchronous generators, and Figure 4.8-2 is a graph of cost versus kilowatt for induction generators. These costs are in 1982 dollars.

4.8.7 Electrical Equipment Sizing

The Category 1 developer will want to analyze all electrical loads to determine which ones will be used at what times. You should tabulate the electrical loads on the basis of use not only during the day but also at night.

The standard household has many electrical appliances that are used during the day. However, these loads are not all used at the same time. Table 3.1 in Subsection 3.1 gives standard loads used in a residence and gives kWh of use per month for each piece of equipment.

It is evident from a study of this table that heating loads have the highest power use. Careful study of the table will indicate methods for programming a daily use pattern to keep the generators fully loaded.

The electrical loading required for the Category 1 developer example (Appendix B) has been developed to show how a power system will have to be

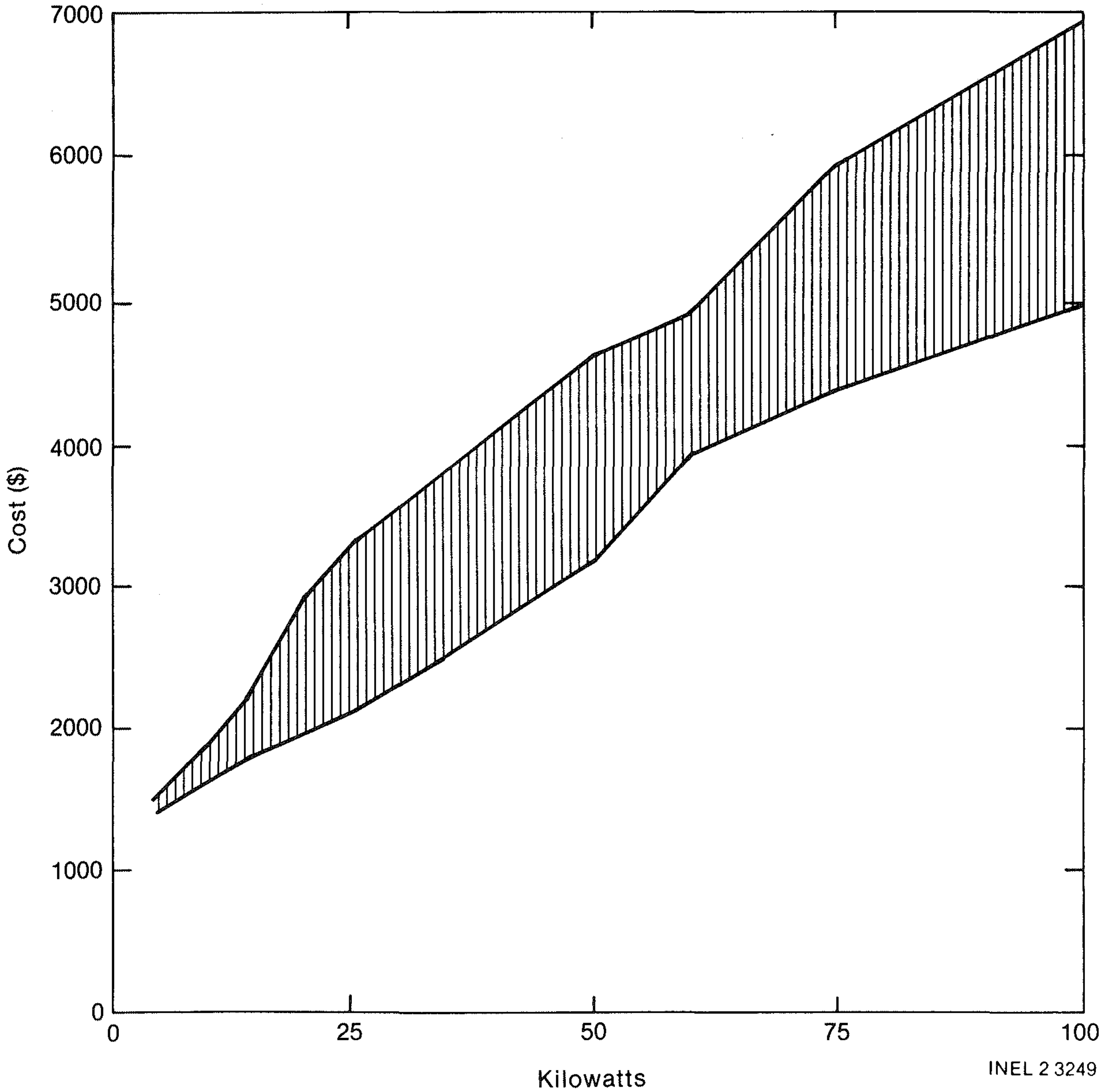

Figure 4.8-1. Limits of cost vs kW for 1800-rpm synchronous generators.

analyzed. The example loading is developed in detail to show how electrical loads relate to a site potential and the equipment that will be selected.

The analysis for a Category 2 developer is very simple. You determine what you can generate, what you can use, and "dump" the remaining power to the utility. If your power consumption exceeds the power available from the generator, then you can supplement by drawing power from the utility.

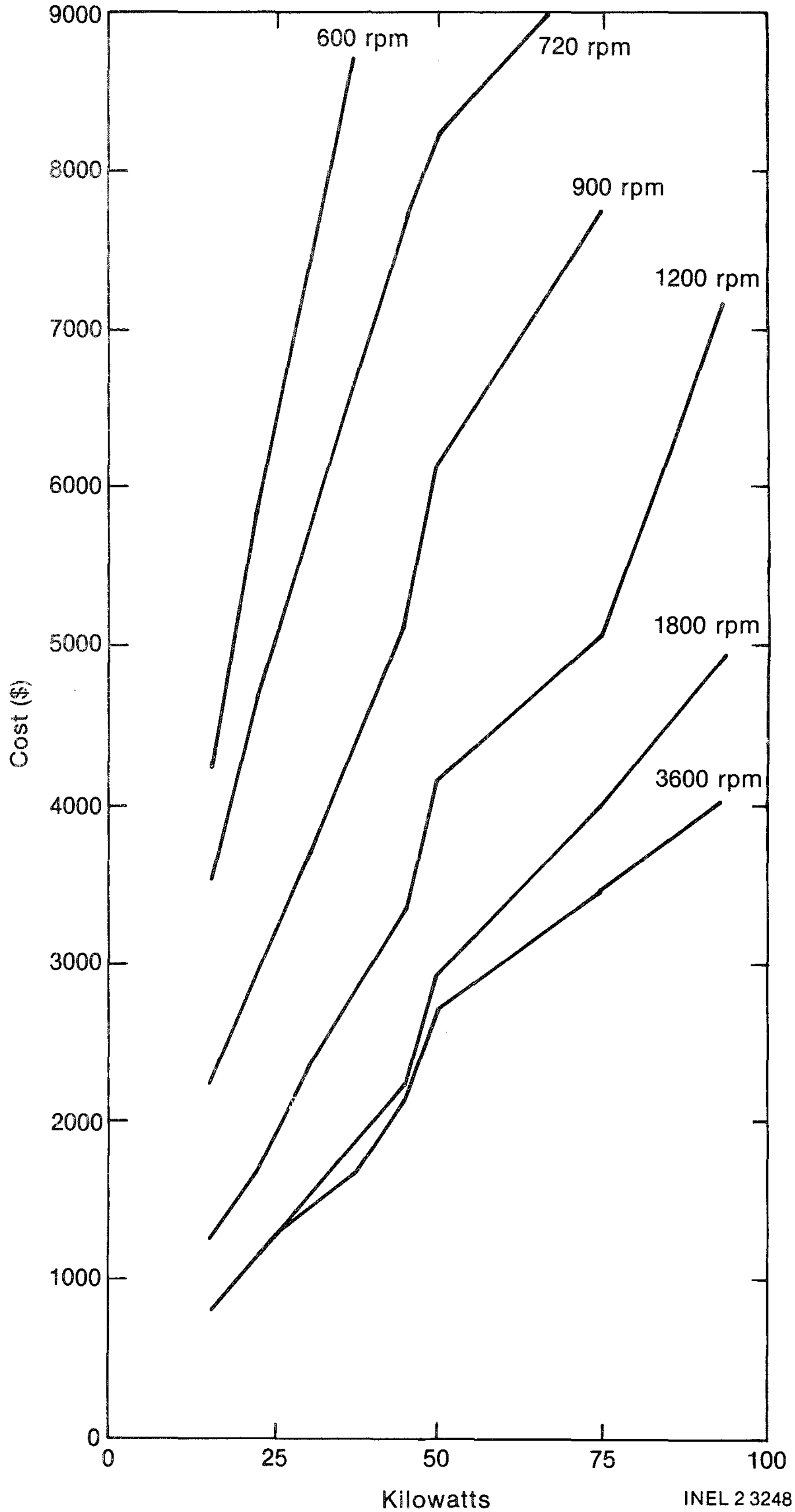

Figure 4.8-2. Cost vs kW for induction generators.

The load analysis for a third situation is even simpler. This is where a Category 2 developer desires to sell all of the power produced to a utility. This system requires little load analysis. The generator will be sized to produce maximum power on the basis of flow, head, and investment capital.

4.8.8 Sizing the Electrical Distribution System

After you have selected a generator and the ratings of that generator, you are ready to design the transmission and distribution system for the electrical energy produced. This is the wiring system that distributes the electrical energy from the generator location to the point of use. It will consist of wiring, overcurrent protective devices, such as circuit breakers or fuses, panelboards, load control systems, and in the case of the Category 2 developer, transformers and high-voltage protection devices.

Figure 4.8-3 is a one-line diagram showing the various components of a typical power system for a Category 1 developer. The generator will have a set of wires from its load terminals to the generator overcurrent device (see Subsection 4.8.9).

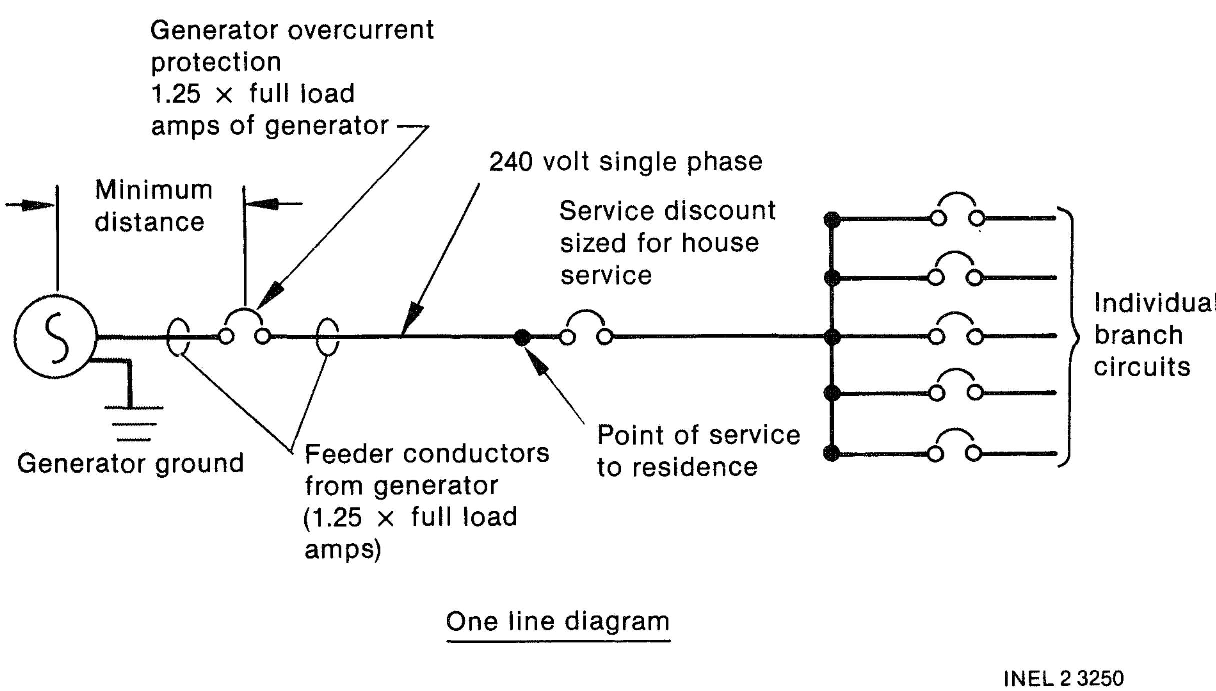

Figure 4.8-3. One-line diagram of typical power system for a Category 1 developer.

The main panel can be located at the house. The electrical wiring from the generator overcurrent device to the house can be installed overhead or it can be directly buried in earth or pulled in buried conduit. The length of this feeder wire has a bearing on the wire size of the wire required for this feeder. The effect of the feeder length is known as the voltage drop of the feeder.

The size of the residence's electrical service equipment is set by the NEC. The residence's service entrance wiring and panels must be sized according to its connected load and then derated as allowed by the NEC. There could be a circumstance where the house service wiring and service disconnect may be considerably larger than the feeder that supplies the house from the generator. A load control system will control this maximum load, but the service will still require the minimum size dictated by the NEC. All electrical overcurrent protective equipment and wire is sized on the current carrying capacity of the equipment. The equipment and wire also have a voltage rating that states that the equipment will safely operate at a given voltage.

Wire ampacity is sized for a single-phase unit from the equation

$$I = \frac{1000 \times P}{E} \qquad (4.8\text{-}1)$$

where

I	=	amperes
P	=	power in kW
E	=	voltage
1000	=	kW to watts conversion function.

Using the example of the 15.5-kW, 120/240-volt, single-phase generator for the rural site, we find the minimum ampacity of the conductor to be

$$I = \frac{1000 \times 15.5}{240}, \text{ or}$$

$$I = 64.6 \text{ amperes.}$$

The NEC requires that the conductor be rated for 125% of its continuous full-load current. Since the generator must operate fully loaded to maintain frequency and speed requirements, the wiring and overcurrent devices can be considered to carry continuous loads. Therefore:

$$I_m = 1.25 \times I \qquad (4.8\text{-}2)$$

where

I_m = minimum wire ampacity

1.25 = 125%

I = amperes, from Equation (4.8-1)

Thus, for the example

$$I_m = 1.25 \times 64.6$$

$$I_m = 80.7 \text{ amps minimum wire ampacity}$$

This is the minimum ampacity of the wire. You should use wire with a higher ampacity than minimum for your installation. Table 3.10-16 in the NEC Handbook can be used to select the proper size wire with insulation that is heat and water resistant (Type THW).

CAUTION: All conductors must have mechanical protection such as conduit or direct burial cables, or be suspended at least 18 feet above ground.

Voltage drop is also a consideration if the load is located a long distance from the generator location. Voltage drop can be calculated as follows:

$$E_D = \frac{I \times R \times l}{1000} \qquad (4.8\text{-}3)$$

where

E_D = voltage drop

I = amperes

R = resistance of wire in ohms per 1000 feet (see NEC Handbook, Table 8)

l = length of wire in feet

Voltage drop should be limited to a maximum of 5% of the voltage. To figure the percentage of voltage drop, take the calculated voltage drop [E_D from Equation (4.8-3)] and divide by the line voltage (E).

$$\%\ \text{drop} = \frac{E_D}{E} \times 100 \qquad (4.8\text{-}4)$$

where

% drop = percentage of voltage drop

E_D = calculated voltage drop in volts

E = line voltage (e.g. 120, 208, 240, 480)

If I (amperes) is constant and the length of the line is fixed, then the only other variable is R (the resistance of the power line). The resistance decreases as wire size increases. Voltage drop will not be problem in most microhydropower installations, because the current is limited to the current produced by a 100-kW generator. The distance to the load or point of power consumption will be short, generally less than 500 feet.

4.8.9 Overcurrent Protection

The amperage rating of overcurrent protection devices can be selected in the same fashion as the minimum ampacity for wire. From Equation (4.8-2):

$$I_m = 1.25 \times I$$

The ampacity of overcurrent protective devices has to be selected from standard ratings. The NEC will allow the use of the next higher rated device. (For the example of 80.7 amps, a 90-amp breaker can be used.)

The overcurrent device for the generator should be located as close to the terminals of the generator as practical. This device can be mounted right on the generator and can be specified to be supplied with the generator by the manufacturer.

4.8.10 Step-Up Transformer

When connecting to the utility, the Category 2 developer will need a step-up transformer that will interface between the generator voltage and the distribution voltage of the utility. This transformer will have to have a kilovoltampere (kVA) rating that is equal to or greater than the kVA rating of the generator. This transformer should have a low-voltage overcurrent device located near the transformer and must have a high-voltage fuse and lightning arrester located on the high-voltage side of the transformer. Again, the high- and low-voltage overcurrent protective devices should be rated at 125% of the full-load, high-side, and low-side currents of the transformer.

CAUTION: The utility's high voltage is dangerous. The utility will make the final connections.

The utility may require additional protective relays. These are discussed in Subsection 4.8.13. The sizing of these devices is critical to the operation of the system. That equipment can be determined cooperatively by the developer, the utility, the electrician, and the supplier when the equipment is needed.

4.8.11 Grounding

Grounding of the power system is very important. If you plan to produce power at 120/240 volts, single-phase; 120/208 volts, three-phase, four wire wye; or 277/480 volts, three-phase, four wire wye; then a very definite ground reference point for the electrical system neutral needs to be established.

If you wish to establish voltage at 240 volts, three-wire, three-phase, delta; or 480 volts, three-wire, three-phase, delta; then an additional ground needs to be established for equipment grounding. Delta generation systems are not recommended for personnel safety and equipment protection reasons.

The NEC requires that a buried metal water pipe with direct contact in earth for a length of 10 feet or more be used as the main grounding electrode. This ground point has to be supplemented with one or more additional ground points. It would be desirable to plan at least 15 feet of buried metal water pipe at the generator location. Other methods of establishing a system ground are discussed in Article 250 of the NEC Handbook.

It has been found to be good practice to weld all of the rebar in the equipment pad as part of the ground system. This rebar should be at least 20 feet in total length and at least 1/2 inch (No. 4) in size. If these requirements are met, the rebar can be connected to the generator as the ground system.

Additional ground points that have to be bonded to the metal water pipe are the metal frame of a building, if available, and a ground ring encircling the building consisting of at least 20 feet of bare copper wire, not smaller than No. 2 AWG.

Additional ground points to supplement the generator grounding electrodes are other metal underground structures and pipes, rod and pipe electrodes, and plate electrodes 2 feet square.

To summarize, the generator ground should consist of the following:

1. All grounds bonded or connected together at one point, preferably in the overcurrent device enclosure.

2. At least 10 feet of buried water pipe, such as metal penstock, waterline, etc.

3. A ground connection extending from the rebar of the equipment pad. All the rebar in the pad should be welded together.

4. A No. 2 AWG copper ground wire encircling the generator building. This ground wire can be put in the ground when the footings are dug.

5. A ground wire to the metal frame of the building if the building is metal.

6. Additional buried structures or pipes, rods, etc.

Ground Systems 1 through 5 are required, if available at the generator site. Ground System 6 can be used if available.

You should install the best ground system that you can implement to maximize the safety of the system.

4.8.12 Governors and Load Control Systems

In order to maintain the generator at a constant 60 hertz (Hz) frequency, it is necessary to maintain the generator shaft at a constant rotational speed. In a stand-alone system, the rotational speed of the microhydropower generator can vary as loads are added to or subtracted from the electrical system. When Equation (A6-14) is rewritten to solve for frequency (f), it can be seen that frequency varies directly with rpm since the number of poles are fixed in any secific generator.

$$f = \frac{120 \times rpm}{p} \qquad \text{(A6-14)}$$

where

f = frequency in Hz

rpm = revolutions per minute

p = number of poles.

Therefore, it is desirable to either control the speed of a hydropower generator by throttling the water to the turbine, or control the load of the power system so that the load always remains constant. Speed control is achieved with an electromechanical governor that controls the flow of water entering the turbine. A load control system maintains a constant load on a generator by using electric relays, or electronic switches, or a combination of both to continuously correct the load to the required level.

4.8.12.1 Governors. There are many small plants that use governors for speed control. The governor usually consists of a vertical shaft that has counter opposed flyweights suspended from the top of the vertical shaft. As the speed of the shaft increases or decreases, the flyweights move up or down the shaft, respectively. This movement is amplified, usually hydraulically, so that small variations in speed can be sensed and a proper control signal transmitted to the valves or deflectors that control the water pressure.

The industry standard governor is a Woodward Type UG, hydraulic turbine control. The same governor that is used on large hydroelectric plants is the one that is used on microhydropower plants. This governor is capable of an output of 8 foot pounds of torque. This output is adequate to power some methods of speed control such as operation of deflectors to deflect the water emitted from the nozzles of a small Pelton wheel. If a means of conserving water is desired for a plant operating from reservoir storage, the governor signal must be amplified again to be able to close a valve to adjust flow. The second stage of amplification is usually accomplished by a larger hydraulic pump that actuates a ram to move the valve actuator. This actuator must respond quickly enough to maintain adequate frequency control, but the flow of water cannot be changed so rapidly that damage to the penstock occurs. Governors are able to provide speed control for a microhydropower installation in the range of 85% of full load speed to 110% full load speed.

4.8.12.2 Load Controllers. Many small hydro plants are using electrical and electronic control schemes. Frequency can be measured electronically and compared against a set point. If the frequency measured is low, i.e., the system is overloaded, then a low-priority load can be deenergized. This method is referred to as Electrical Relaying. Loads can be added or dropped in discrete units. Obviously, the type of load that can be started and stopped often must be one that will not create a hazard, an inconvenience, or a premature equipment failure by being automatically switched in and out. The best loads for intermittent switching are electric heating loads. Motors will overheat and can fail if started and stopped too often.

The development of solid-state electronics has provided many devices that switch much faster and are as reliable as the older electromechanical relays. Some of the solid-state switching devices are used only for electronic logic and signalling, while others are able to handle power loads directly. The silicon controlled rectifier (SCR) or triac is commonly used to switch power loads.

Electronic switches or triacs are capable of controlling the electrical waveform to produce a frequency of 60 hertz but with a diminished amount of power. A load can, therefore, be varied continuously over the range from zero voltage to full load voltage.

An electronic load control system can sense changes in the generator output and can adjust the load by switching electric relays and by controlling electronic switches that can continuously vary their connected load to match the generator output.

Consider the load system that was plotted in the run-of-the-stream example problem (Appendix B).

The system has loadings that must be capable of continual operation and cannot be controlled, such as:

- Refrigerator
- Freezer
- Well pump
- Kitchen equipment
- Kitchen range
- Lighting
- TV and stereo
- Shop equipment.

The loads that can be controlled by the load control system are:

- Water heaters
- Electric dryers
- Electric heat during the winter
- Electric heat loads in other areas, which can be added to keep the generator fully loaded.

With the operation scenario given in the example in Appendix B, the power system will have a base load that varies between 2.2 and 13.6 kW. This leaves the remainder of the generator output for other controlled loads. Electrical water heaters can be installed and set up to be used to control load, operating whenever the generator loading allows.

In addition, the owner of this system needs a heat load operated through an electronic switch that will allow the load to be continuously varied as the other loads vary. For example, 6 kW of baseboard heater could be installed in the greenhouse to provide this load. The other loads, such as the water heaters or house baseboard heaters, can be switched on a priority basis by relays as the loading of the generator allows.

> EXAMPLE: At 4 p.m. one day, the generator has a base load of 7.4 kW that is a combination of kitchen loads, shop loads, lighting loads, and the well pump. Since the generator is operating at full capacity, this leaves 6.6 kW of loads to be controlled. A frequency monitor notes the need for additional loads and sends a signal to the load control panel to start controlling the loads.
>
> The first priority load is switched on--6 kW of greenhouse heat. There are still 0.6 kW of generated power that need to be consumed. The second priority load, a water heater, comes on. This load is 4.5 kW. Therefore, the first priority load is reduced by use of the triac switch to 2.1 kW. Thus, there are 2.1 kW of load in the greenhouse heaters that are now being controlled by the triac. As the base load increases, this varied load will be reduced to zero. Then the loads on priority control will be switched off.

By controlling the loads in this fashion, the system controls the load on the generator and keeps the frequency constant. The load control system is suited for stand-alone power system because it allows the generation system to operate at peak efficiency.

4.8.13 Utility Tie-Ins

There are several reasons for connecting to a utility grid.

- Generation of revenue. If the generation of revenue is a primary concern, the developer will want to tie into a utility to maximize the return on investment.

- Load sink. For Category 1 developers able to consume the majority of the power generated by the site, the utility may provide a load sink by taking the excess energy and keeping the system fully loaded.

- Power Backup. The utility can act as a backup power source for the Category 1 developer whose system is down for repairs, or when the water source is too low for power production.

- Reduction in equipment costs. Connection to an outside system alleviates the need for expensive speed-regulating equipment.

Utilities have many different requirements for connection to their power lines. These can range from as little as a lockable disconnect switch at the point of tie-in to the utility system, to a total control system that involves power metering, telemetering, and protective relaying.

The utility will require that protective equipment be installed for the following reasons:

- Safety. There are times when the power line will be down for maintenance or repairs, or due to accidents, and the generator will have to be taken off the power line. This will require both automatic and manual disconnects.

- Protection of the generation equipment. There are instances where the generator should be taken off the power line to minimize the potential for damage.

- Utility safety. The utility will also require protection for their system and equipment.

The protection equipment that must be installed on a microhydropower site for utility intertie depends on the requirements of the utility. You will have to provide overcurrent and short-circuit protection for the output of the generator. Some utilities may require little more than a lockable disconnect switch on the line side of the generator overcurrent protective equipment. Another protective system may be a high-voltage oil switch controlled by an undervoltage relay. This equipment would be owned by the developer. There are many other inexpensive potential protective schemes.

The most sophisticated and expensive protective system currently being proposed by utilities requires over- and undercurrent protection, over- and undervoltage protection, differential phase protection, and reverse power protection. If the generator is a synchronous machine, the utility will also require a synchronizing device to connect the generator to the system.

The protective equipment listed above will probably have to be industrial grade. This equipment and the associated voltmeters, ammeters, kilowatt meters, switches, and protective equipment become expensive when mounted in a cabinet and installed at the site.

Some utilities may require notification each time the generator is connected online. Notification can be made either by a telephone call or by telemetering equipment installed to monitor the generator's activity. This notification is for the safety of personnel working on the line.

CAUTION: The protection and disconnect system may appear expensive to the developer. However, the intent of this protection is to protect life and property. Work with the utility for this goal.

The utility will require you to install, maintain, test, and calibrate metering equipment to measure the flow of power into the utility's grid. This metering will be by a kWh meter that measures power "out" from the generator. The utility may also require a power "in" meter to measure both demand and kWh used by the microhydropower system.

The utility may also require that you install metering to measure reactive power, or kilovar hours. This would normally be when you are using a large induction motor as a generator.

You will also have other equipment on the system that will have to intertie with a utility. This will include step-up transformers, protective equipment, and a high-voltage power line. Most utilities will quote you a price for installing this equipment; others will insist on installing the equipment so that it is installed according to their standard practices.

You will have to maintain the high-voltage line and step-up transformer. A utility may do this for you but they will charge a maintenance fee.

CAUTION: Make sure that the people working on the high-voltage line are qualified and capable of performing this work.

You may elect to have the power company install and maintain the protective equipment, step up transformer, and power line. The power company would be paid for all of their installation work at the time the equipment is installed. A separate maintenance contract would then be written between you and the utility specifying that you pay the utility a monthly percentage of the construction cost for maintenance.

Another arrangement could be for you to contract with private firms for all equipment installation and then set up a maintenance agreement with the utility specifying a flat rate for maintenance and repairs.

There are many other requirements that a power utility may impose upon the microhydropower developer. These requirements may cost money and would have to be included in all financial analyses of the system.

Following are additional requirements that you need to consider carefully for their legal implications.

- Power factor correction. Power factor corrective capacitors may be required to correct the line power factor to 85% or even 95% when an induction motor is used as the generator. These capacitors could be mounted at the generator site or could be furnished to the utility to be mounted on another segment of the power line remote from the generator location.

  CAUTION: When capacitors are used with induction motors, the motor may continue to generate power even when the utility power is interrupted. This could be a potential hazard to utility personnel and should be discussed with them if they require the use of a capacitor.

- Liability insurance. This insurance could be required to indemnify the utility or developer from loss, damage, expense, and liability to persons who could be injured by the developer's or utility's construction, ownership, operation, or maintenance or by failure of any owner to maintain the system. Insurance limits of $1,000,000 or more could be required.

- Easements. The developer will require easements and right-of-ways to the utility for any interconnection equipment and will therefore need a surveyor to write up the easement.

- Shutdown impacts. The contract may also address what happens when the utility or developer has problems that cause the loss of power generation capabilities by the developer or the utility. This item needs to be addressed to minimize the impact of the shutdown.

The microhydropower developer should remember that the utility is in business to distribute and sell power. The utility desires to generate its own power or to buy power in bulk. The role of the microhydropower developer as power producer is somewhat minimal to a utility. Therefore, the microhydropower developer will need to maintain a good rapport with the utility and should be willing to work with their requirements.

4.9 Drive Systems and Speed Increasers

The drive system is used to mechanically connect the turbine shaft to the generator shaft. This connection may take one of several forms depending on turbine speed and preference of the designer. Where the turbine speed matches that of the generator, the shafts of each are directly connected using a coupling. When the turbine rotates either slower or faster than the generator, a speed increaser or reducer must be installed in the system. This may take the form of a gear drive, belt drive, or chain drive.

Most generators will be selected in the 900 to 1800 rpm range for microhydropower applications. Once the turbine has been selected and its rotational speed determined, the ratio of generator speed to turbine speed can be calculated.

$$R = \frac{G_{rpm}}{T_{rpm}} \qquad (4.9\text{-}1)$$

where

R = Speed Ratio

G_{rpm} = Generator speed in rpm

T_{rpm} = Turbine speed in rpm.

EXAMPLE: Assume that the turbine operates at 600 rpm and an 1800-rpm generator is being used; find the ratio.

$$R = \frac{1800}{600}$$

$$R = 3 \quad .$$

Therefore, the drive system selected must be capable of converting every revolution of the turbine into three revolutions of the generator.

The power that a drive must transmit is an important consideration when selecting and designing a drive system. In Subsection 2.5, the basic power equation was given. An efficiency of 60% was recommended for use in calculating your system's power. This power should not be used to size your drive system, since some of the losses included in the 60% will not be present between the turbine and the drive. The most accurate method of determining the power developed by the turbine is to use the basic power equation but to substitute the turbine efficiency provided by the manufacturer for "e" and the site's net effective head (see Subsection 2.2) for "h". If neither of these values are known, an assumed efficiency of 100% and the pool-to-pool head can be used. This will be conservative and oversize your drive but can be used in preliminary calculations.

4.9.1 Direct Connection Drives

When the turbine speed matches the generator speed, direct connection offers advantages over speed increasing or reducing devices. Direct connection avoids the efficiency losses associated with speed changing devices, maintenance is minimal, and the system is more compact. The major disadvantage of a direct drive is the possible damage that could occur should either the generator or turbine suddenly "lock up" from a lightning strike or debris entering the turbine. The damage to the still rotating component and shafts could be extensive in this case. Even with this disadvantage, however, direct drive is a highly desirable feature.

The connection of the generator shaft to the turbine shaft can be done with either rigid or flexible couplings. Rigid couplings provide a fixed union between the shafts, requiring that the shafts have good initial alignment and stable support bearings. Misalignment can cause worn or failed bearings, fatigued shafts, broken coupling bolts, or worn bores in the coupling flanges. The three principal types of rigid couplings are compression, ribbed, and flange-face. These are illustrated in Figure 4.9-1.

Compression couplings attach to the shafts by the compressive force generated when tapered sleeves are wedged inward as the two halves of the coupling are drawn together by tightening bolts. This coupling is suitable for light to moderate torque loads. A ribbed coupling employs a long key set in keyways in both shafts and the coupling housing to lock the shafts together. A flange-face coupling uses keys to lock the individual flanges to each shaft and the flanges are then bolted together. Both of the latter two couplings are capable of sustaining high torque loads. These couplings are not particulatily suitable for axial loads (loads along the shaft axis). Such loads result from hydraulic thrust of the turbine or from the weight of the rotating components on vertical turbines. If such loads exist, a flange that is an integral part of the shaft should be used.

In cases where misalignment between the shafts can be expected, a flexible coupling should be employed. These couplings are common and are referred to as chain, slider, gear, and flexible member couplings. These couplings may be particularily unsuitable for axial loads. When using these couplings, contact the coupling manufacturer for specific data on load (torque and thrust), deflection, and speed capabilities.

4.9.2 Speed Changing Drives

For the majority of microhydropower sites, some sort of speed increaser drive will be required because of insufficient head or flow to operate the turbine at generator speed. These drives will increase the cost of the installation but are necessary in order to provide synchronous speed for ac generator operation. It is possible that the turbine could rotate faster than the generator in special cases. A speed reducer type of drive would be needed in this case, and the same information is applicable as with speed increasers.

4.9.2.1 Chain Drives. Chain drives have many applications and have the advantage of high efficiency, no slippage, and relatively high load capacity and life. Like couplings, they lock the generator and turbine shafts together, which can cause damage if one component stops suddenly, as

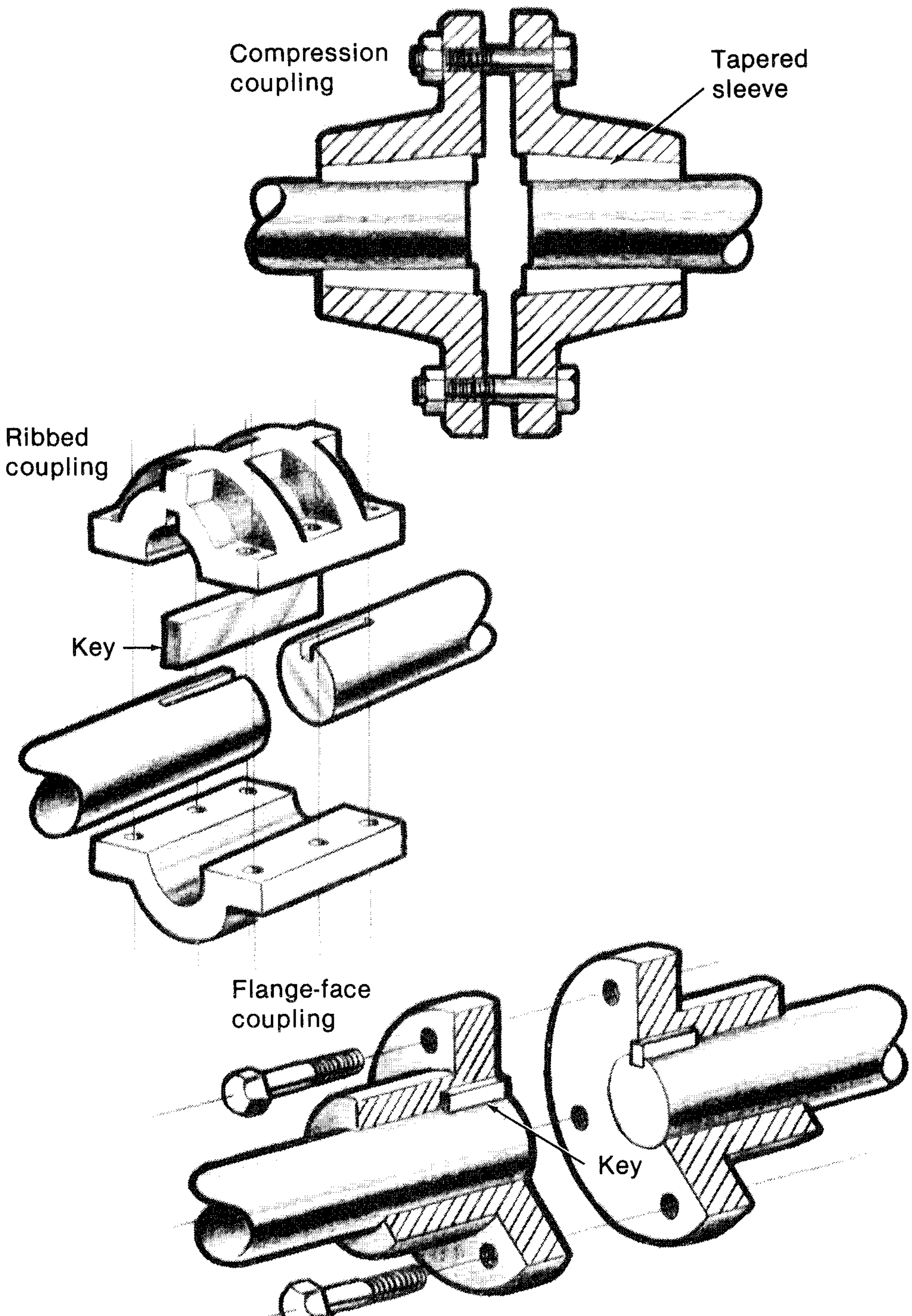

Figure 4.9-1. Types of rigid coupling.

previously discussed. Manufacturers catalogs are the best source of information on procedures for selecting and specifying chain drives. Input information required includes: transmitted power, speeds of driving and driven shafts, space limitations, center distances, and operating conditions. If you determine that a chain drive is the type of system you wish to install, you should contact a manufacturer for further information. Normally, belts are preferred to chains for microhydropower applications because they are less costly to install and maintenance is minimal.

4.9.2.2 Belt Drives. Belt drives provide the lowest cost means of transmitting power from one shaft to another. They operate smoothly and quietly and can absorb appreciable shock. Slippage of the belt and its sheave can occur if the shaft of either the generator or turbine locks up, providing an added measure of protection to the equipment. The basic power transmission belt is the V-belt. It provides the best combination of tractive force, operating speed, and service life. Flat belts were the first belt used for industrial power transmission and still find applications today. To prevent slippage of flat belts during operation, however, the belt must operate under high tension. Such high tensile loads require heavier shafts and bearings, as well as a heavier mounting framework for the drive. Synchronous belts have evenly spaced teeth on the bottom surface that mesh with grooves on the pulley to produce a positive, no-slip driving effect similar to a chain drive. While these belts can be used for microhydropower applications, there does not appear to be any advantage over using a V-belt, and they are more expensive. V-belts are considered the best selection for belt drive arrangements.

To facilitate interchangeability and insure uniformity, V-belt manufacturers have developed industry standards for various types of V-belt drives. Three major areas of application--industrial, agricultural, and automotive--are covered by the standards. Only the industrial type of belts are of concern for microhydropower use.

Industrial V-belts are made in standard cross-sections and are referred to as conventional, narrow, and light duty. Conventional belts are available in A, B, C, D, and E cross-sections; narrow belts are made in 3V, 5V, and 8V cross-sections; and light duty belts come in 2L, 3L, 4L, and 5L cross-sections. Belts are designated by a symbol for the cross-section accompanied by the length designation. The length designation is in inches except for narrow belts where it is in tenths of an inch. For conventional belts, a B90 belt has a B cross-section and is 90 inches long. For a narrow belt, 5V1400 indicates a 5V cross-section and a 140-inch length. Belts carrying the same designation and power rating are interchangeable.

The selection of belts should be done with the help of a manufacturer or his catalog. There are several terms that the developer must be familiar with in order to properly design a belt drive. The wheel on which the belt operates is referred to as the sheave or pulley. As the belt bends around the sheave, the outer belt surface is stretched while the inner surface is compressed. In the middle of the belt is a neutral axis that does not change circumferential length. This line that does not change length is called the pitch line, and it forms a pitch circle with a pitch diameter on the sheave. The sheaves are selected and sized by their pitch diameter in the catalogs. The distance between sheaves is called the center distance. Figure 4.9-2 illustrates belt drive terms.

The sheave diameter and belt cross-section are selected in a preliminary manner from charts and tables in a manufacturers catalog. Selection is always based on the smaller diameter sheave, which revolves at the highest rate. The chart shown in Figure 4.9-3 is for the preliminary selection of conventional cross-section belts. Similar charts exist for narrow and light-duty belts.

Once the type of belt has been selected, the smaller sheave diameter can be selected from a table. Table 4.9-1 is typical of the tables found in catalogs. It gives minimum recommended pitch diameter for the smallest sheave. To use a smaller sheave than recommended would fatigue the belt, reducing its operating life. The pitch diameter of the larger sheave is found by multiplying the speed ratio and smaller diameter sheave together. This large sheave diameter is compared to standard sheaves available in catalogs, and the sheave with the nearest diameter is selected.

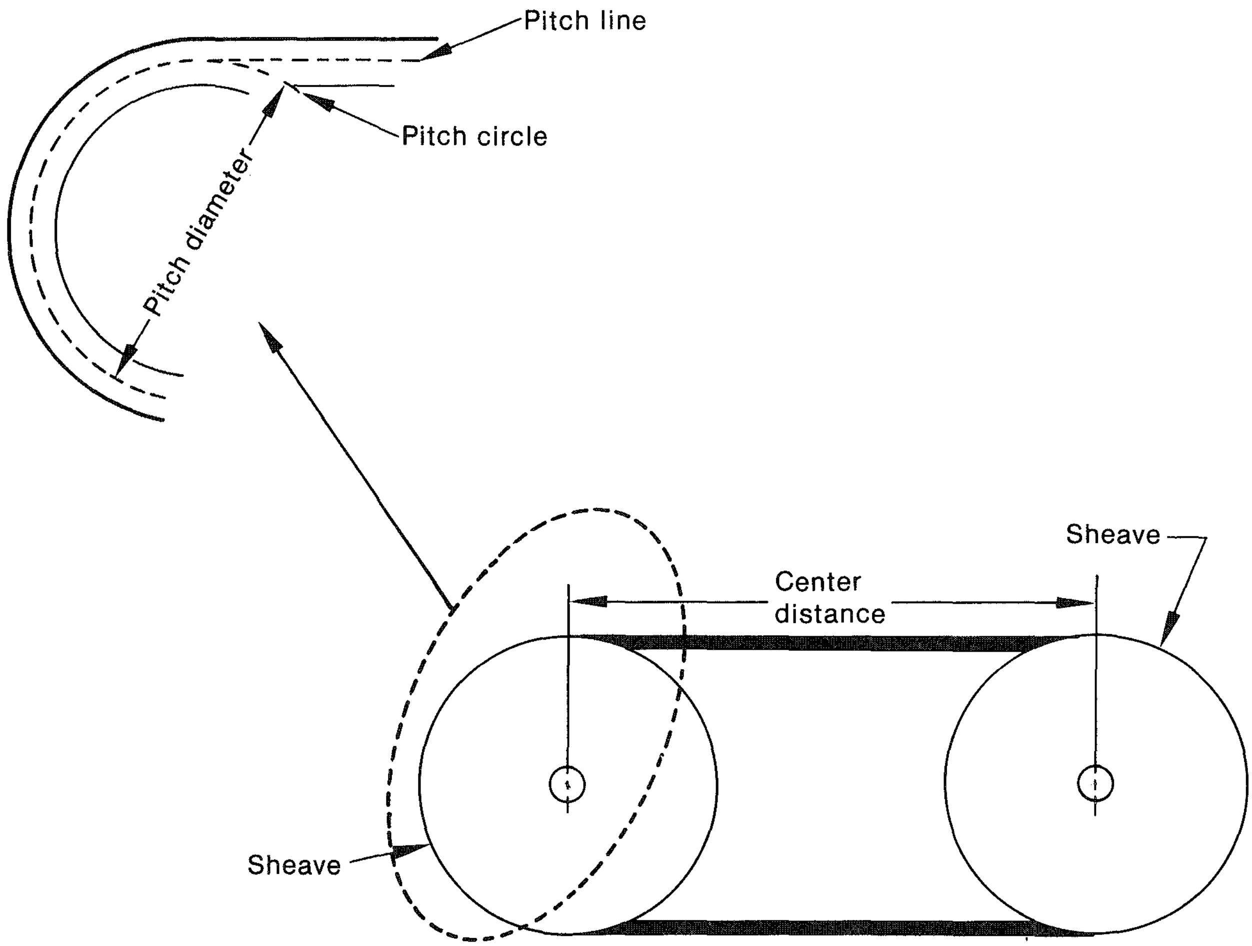

Figure 4.9-2. Belt drive terms illustrated.

TABLE 4.9-1. SHEAVE DIMENSIONS

Belt Section	Belt Size (in.)	Minimum Recommended Pitch Diameter (in.)
A	1/2 x 11/32	3.0
B	21/32 x 7/16	5.4
C	7/8 x 17/32	9.0
D	1-1/4 x 3/4	13.0
E	1-1/2 x 1	21.6

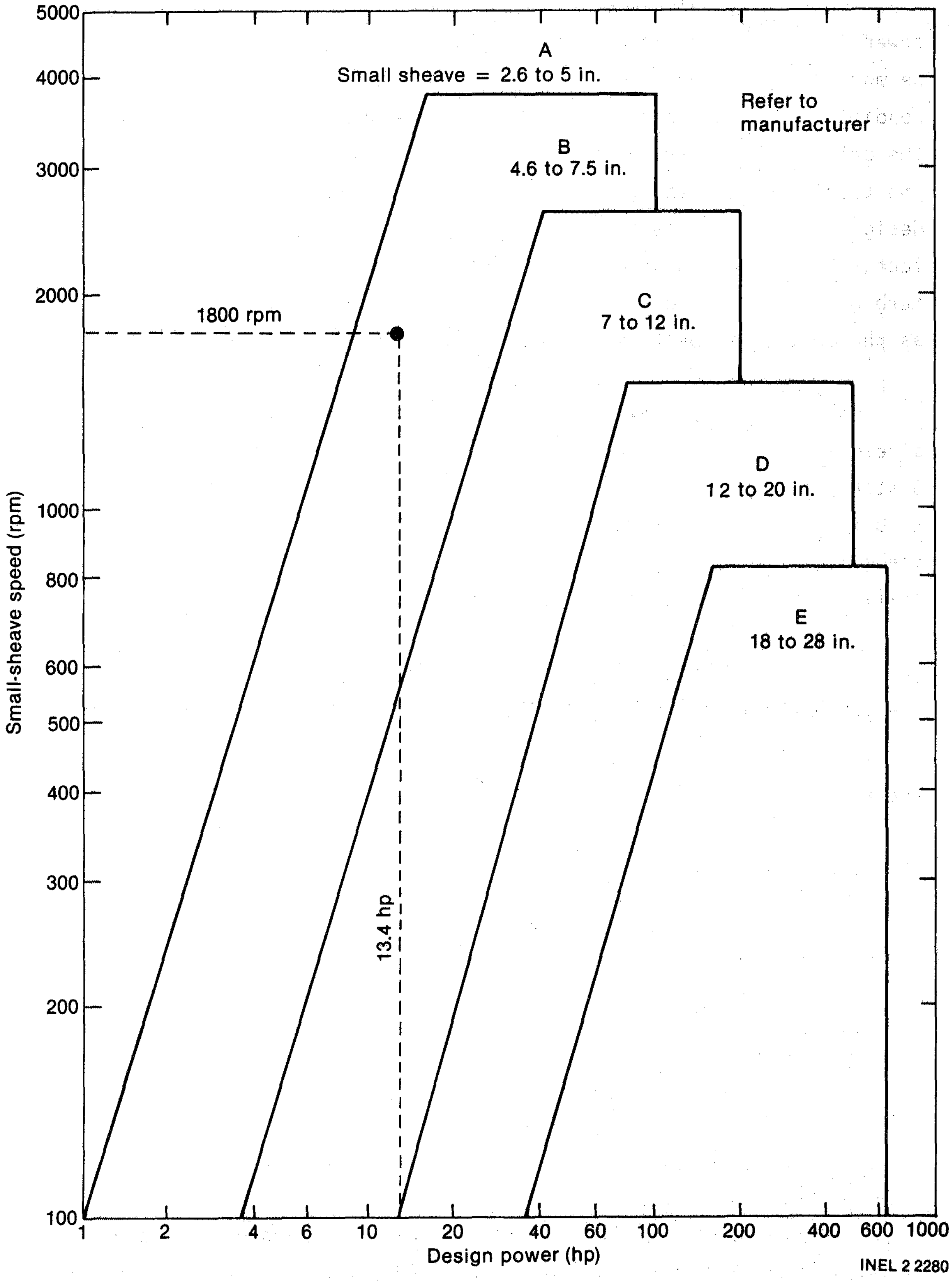

Figure 4.9-3. Conventional belt selection chart.

You can now calculate the power that the belts must transmit. The power of the turbine is used as the starting point. This power rating must be modified to account for starting loads, peak loads, intermittent service conditions, and any other operating factors that may affect the rating of the drive. These various conditions are incorporated in a service factor. The turbine power rating is multiplied by this service factor to give the design power of the belt drive. For hydroelectric turbines, a service factor of 1.4 or 1.5 should be adequate. Therefore, if your hydroelectric turbine is calculated to produce 10 kW and a belt system is to be selected as the drive, the belts should be designed for 14 to 15 kW.

Calculate an approximate center distance unless the distance is already fixed by the system design. A rule of thumb is that the center distance should be 1 to 1-1/2 times the larger sheave diameter. Centers should not exceed 2-1/2 to 3 times the sum of both sheave diameters. Once the approximate center distance is calculated, you can calculate the initial belt length with the following equation:

$$L = 2C + 1.57\,(D + d) + \frac{(D - d)^2}{4C} \qquad (4.9\text{-}2)$$

where

C = center distance in inches

D = pitch diameter of the large sheave in inches

d = pitch diameter of the small sheave in inches

L = pitch length of the belt in inches.

Compare the belt length to the manufacturer's standard belt lengths, and select a belt closest to the calculated belt length. Then recalculate the true center distance using the following equations:

$$K = \frac{L - 1.57\ (D + d)}{2} \qquad (4.9\text{-}3)$$

$$C = K - \frac{(D - d)^2}{8K} \qquad (4.9\text{-}4)$$

where

C = center distance in inches

L = pitch length of the belt in inches

D = pitch diameter of the large sheave, in inches

d = pitch diameter of the small sheave, in inches

K = a factor.

The remaining calculation is called the arc-length correction factor. Horsepower ratings given in catalogs are for belts having a 180-degree arc of contact. For drives other than these, a correction factor must be applied. This factor can be found in catalog tables once you have calculated the arc of contact. Use the following equation to calculate the arc of contact:

$$\alpha = \frac{(D - d) \times 57}{C} \qquad (4.9\text{-}5)$$

where

α = arc of contact in degrees

D = pitch diameter of the large sheave in inches

d = pitch diameter of the small sheave in inches

C = center distance in inches.

Typical correction factors are shown in Table 4.9-2, and an illustration of the arc of contact is presented in Figure 4.9-4. This correction factor is multiplied by the basic power rating of the V-belt to obtain the true belt power rating.

TABLE 4.9-2. CORRECTION FACTORS FOR LOSS IN ARC OF CONTACT IN DEGREES

Loss in Arc of Contract (degrees)	Correction Factor	Loss in Arc of Contact (degrees)	Correction Factor
0	1.00	50	0.86
5	0.99	55	0.84
10	0.98	60	0.83
15	0.96	65	0.81
20	0.95	70	0.79
25	0.93	75	0.76
30	0.92	80	0.74
35	0.90	85	0.71
40	0.89	90	0.69
45	0.87		

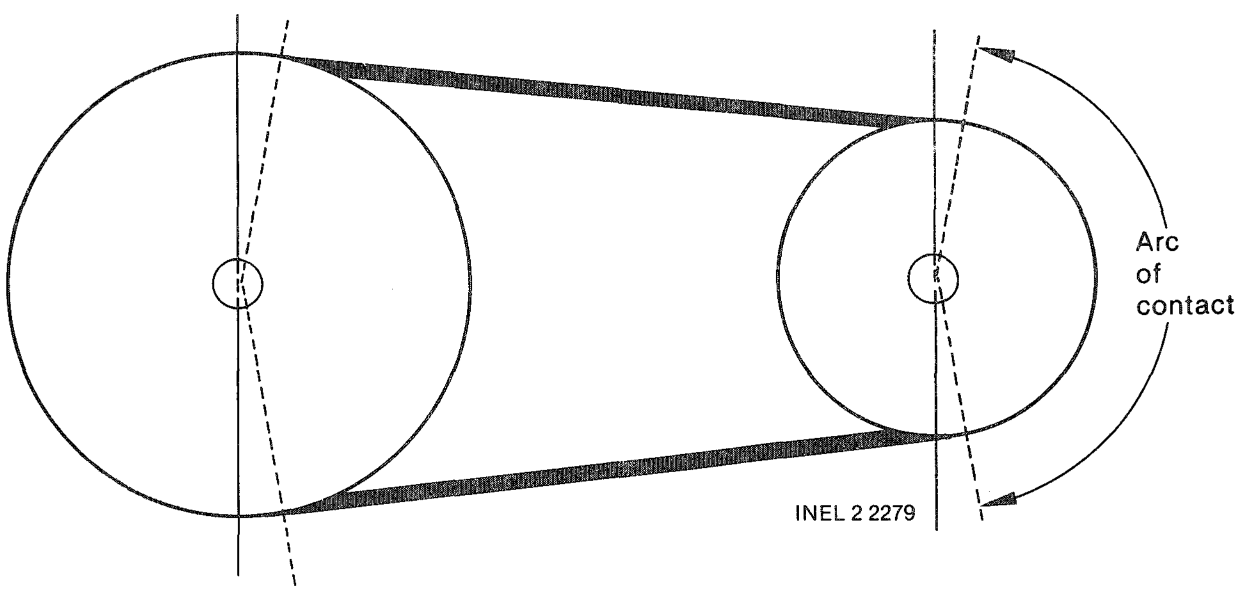

Figure 4.9-4. Arc of contact.

Other correction factors are also used by manufacturers and will be found in their catalogs. Corrections are used for long belt lengths and for high speed ratios. Once you have determined the true belt power rating, find the number of belts needed by dividing the calculated power rating of the drive system by the power rating of the belts:

$$B = \frac{R_D}{R_B} \tag{4.9-6}$$

where

B = number of belts

R_D = power rating of drive system (turbine power x service factor)

R_B = true belt power rating.

EXAMPLE: Assume that the turbine operates at 600 rpm and the generator at 1800 rpm. The turbine power has been calculated at 10 kW or 13.4 horsepower (10 kW x 1.34 hp/kW). Select the belts using the following steps:

Step 1. Select Belt Type

From Figure 4.9-3 at 13.4 hp and 1800 rpm, the belt type is "B".

Step 2. Power Rating of the Drive System

1.5 is the selected service factor. Therefore,
13.4 hp x 1.5 = 20.1 hp

Step 3. Select Sheave Diameters

From Table 4.9-1, the minimum pitch diameter (d) of the small sheave is 5.4 inches. Calculate the larger sheave pitch diameter (D) by multiplying the speed ratio (R) by the small sheave diameter.

$$D = R \times d \qquad (4.9\text{-}7)$$

where

D = pitch diamter of large sheave in inches

R = speed ratio, from Equation 4.9-1

d = pitch diameter of small sheave in inches.

R was found to be 3 in a previous example. Therefore:

$$D = 3 \times 5.4$$

$$D = 16.2 \text{ inches}$$

Check this diameter against manufacturers standard sheave diameters from catalogs; assume that the nearest sheave diameter is found to be 16.0 inches.

Step 4. Determine Belt Length and Actual Center Distance

Using the rule of thumb that the center distance (C) should be 1-1/2 the large sheave diameter (D):

$$C = 1.5 \times 16.0$$

$$C = 24 \text{ inches}$$

The belt length is calculated using Equation 4.9-2:

$$L = (2 \times 24.0) + [1.57 \times (16.0 + 5.4)] + \frac{(16.0 - 5.4)^2}{4 \times (24.0)}$$

$$L = 48 + 33.6 + 1.17$$

$$L = 82.77 \text{ inches}$$

Checking a manufacturer's catalog reveals that a B81 belt has a pitch length of 82.8 inches. This is so close to the calculated length that the center distance will not change significantly. It is recalculated here as an example using Equations 4.9-3 and 4.9-4:

$$K = \frac{82.8 - [1.57 \times (16 + 5.4)]}{2} = 24.6$$

$$K = 24.6$$

$$C = 24.6 - \frac{(16 - 5.4)^2}{8 \times (24.6)}$$

$$C = 24.03$$

Step 5. Find the Horsepower Rating per Belt

The horsepower rating per belt is found in each manufacturers catalog for his specific belts. Assume that the manufacturers catalog allows 6.3 hp per belt after considering correction factors for a speed ratio of 3 and a long belt. Find the arc length correction factor, using Equation 4.9-5:

$$\alpha = \frac{(16 - 5.4) \times 57}{24}$$

$\alpha = 25.18$ degrees

From Table 4.9-2, the factor is 0.93 for 25 degrees

hp = 6.3 x 0.93

hp = 5.86 per belt

Step 6. Determine Number of Belts

From Equation 4.9-6:

$$\frac{\text{20.1 hp (power rating from Step 2)}}{\text{5.86 hp (per belt hp from Step 5)}} = 3.43 \text{ belts}$$

Use 4 belts.

The drive selected then has the following specifications:

4 belts, Size B81
Turbine sheave--4 grooves, 16-inch pitch diameter
Generator sheave--4 grooves, 5.4-inch pitch diameter

It is important to select your belt drive system in accordance with recommended practices. Belt drives optimized for compactness using the latest technology usually have the longest service life. Both overbelting and underbelting produce sizable energy losses. For example, the loss in energy approximately doubles from 3% to 6% when a belt drive is operated at only one-half the rated load capacity. In general, the energy loss due to factors such as belt flexure remain constant even though the belt operating load is decreased by half the rated capacity. Energy losses increase when belt loads exceed their capacity due to belt creep and distortion. This occurs when the belts are underdesigned.

Poor belt maintenance can be another cause of significant energy losses. Low belt tension can cause losses of as much as 10%, and misalignment, worn sheaves, and debris in the grooves all contribute to efficiency loss and reduced belt life. Belt tensioning is an important consideration, and the manufacturer's catalog should be reviewed or the representative contacted to obtain data on correct tensioning of belts. Belt drives should always be designed with center distance adjustment since belts will stretch during use and require periodic adjustments.

4.9.2.3 Gear Drives. Gear drives provide the strongest and longest service of the mechanical drive trains considered when speed increasing or decreasing is required. They are also the most expensive drive systems. If you feel that a gear drive is needed to couple the turbine and generator, you should contact a manufacturer of such drives to assure proper installation.

The most common gears used for the transmission of power between parallel shafts are spur gears, helical gears, and herring bone gears. Spur gear teeth are straight and parallel to the shaft axis. They have no end thrust loads, and are economical to manufacture and easy to maintain. Helical gears have teeth that form a helix. They have greater load carrying capacity, and operate more smoothly and quietly than spur gears of equivalent size. Helical gears are more expensive to manufacture and, because of their design, they produce end-thrust that in turn requires end-thrust bearings. Herring bone gears are double-helical gears that eliminate the end thrust loads of single helical gears. These gears are primarily used for the transmission of heavier loads, which would not be present in microhydropower units. Their expense is probably not warranted for small microhydropower installations.

If the turbine and generator must be mounted at right angles to one another, several gear combinations can be used. The simplest and most inexpensive are bevel gears, which have straight teeth and would perform satisfactorily for microhydropower installations. More expensive gears, which are quieter and can sustain higher loads, are spiral bevel gears and crossed helical gears. Gear drives are also available for situations where shafts are not parallel or perpendicular but are skewed at an angle between zero and 90 degrees.

The design of gear drives is a complicated procedure and best left to the manufacturers of those drives. The calculations for gear tooth, bearing, and shaft loadings, as well as the selection of seals and lubrication are major tasks beyond the scope of this book. When discussing a gear drive with the manufacturer, be sure to have available the power to be transmitted, speed ratio, space limitations if any, the arrangement of the turbine and generator, and any thrust loads that the turbine may introduce into the drive.

5. DESIGN PACKAGE, CONSTRUCTION, AND INSTALLATION

In this section you will assemble the design package (including the final cost estimate and a construction schedule), order equipment and material, and construct and assemble the system.

5.1 Design Package

At this point in the project, you should have a clear idea of how the project will look and what it will do. Events 1 through 22 in the event schedule given in Section 1 should be completed or in progress. All design information should now be put into a single design package so that you can readily refer to any design aspect of the job or track costs and progress during construction. This design package will also help identify problems during initial system startup and during later operation and maintenance of the project. As you obtain equipment manuals and other information during construction, add these to the design package.

The design package should consist of final construction drawings, specifications or data sheets for major components, material takeoff sheets, bid packages, cost estimate, and final schedule. Depending on your particular site, you may not need some of these items in the design package. The purpose of the design package is to ensure the following:

- All site considerations and constraints have been identified
- All equipment has been identified and selected
- The size and operating specifications for the equipment and material are compatible
- All construction material has been identified
- All outside labor has been identified
- All known problem areas have been identified and solved

- The budget and schedule are reasonable and realistic.

5.1.1 Final Drawings

Collect and review all sketches drawn in Section 4. Correct any deficiencies in the design. Provide clear sketches to identify the work to be done by a contractor or someone else. The drawings need not be professionally done, but they should be drawn to scale and show enough detail so that contractors and inspection officials will clearly understand the project. Copies of the drawings will be needed, and therefore the drawing size and material should be compatible with the copying method. Drawings on letter size graph paper can be photocopied, but larger drawings can only be reproduced using a blueprint or similar process.

The recommended drawings include one sketch showing the entire system and several smaller ones showing details of specific components. An elevation cross section should be drawn that includes the elevation of the intake, powerhouse, and tailrace; it should also include the gradient or slope of the penstock. The final drawings should contain enough detail so that an accurate materials list can be generated. Forgotten or insufficient materials can cause serious delays during construction.

The agencies responsible for issuing the permits you must obtain will be more receptive when you present complete plans and working drawings. Furthermore, you will save time during the permit process by having good drawings so that specific questions can be answered quickly.

5.1.2 Data Sheets, Specifications, and Bid Packages

The major data sheets you should have at this point are the Turbine-Generator Information Request in Subsection 4.2 and the Design Specification in Subsection 4.3. If data have changed since the basic concept was presented to the manufacturers, resubmit the new data--for example, new site characteristics--to ensure that the turbine-generator will function properly at your site. The data sheet submitted by the turbine manufacturer should also be in the design package.

For large turbines and other large equipment, you may want to write a formal bid specification. This can be a performance specificaton or a procurement specification. The former specifies performance characteristics; the latter specifies equipment. In most microhydropower applications, formal specifications will not be necessary, but you should still prepare data sheets that describe the performance requirements of major equipment to be purchased. This allows you and the manufacturer to agree on equipment performance and costs.

For items such as pipe, valves, wiring, and concrete, you can call or visit several suppliers to obtain quotes for the items without bothering to use data sheets. This is an acceptable method, but a written quote with a description of any ordered items prevents unwelcome surprises when the items are delivered. Although this paperwork may seem unnecessary, it takes little time and provides a record of the purchase agreement.

Poor timing in the ordering and delivery of material and equipment can delay construction. For example, it may take from 6 months to a year to obtain a turbine-generator, and therefore delivery times should be known and ordering complete before constructin is begin. Always request that suppliers state delivery times when discussing material procurement.

5.1.3 Material Takeoff Sheets

To estimate cost and order material accurately, a material list must be prepared. Carefully review each drawing and sketch to determine exactly what material must be procured. (This further points to the need for accurate drawings and sketches.) List each item to be procured on a "material takeoff sheet." This sheet should contain a description of the item, the quantity, and the name of the supplier, if known. An inaccurate list can waste time and money: the cost and time to deliver a couple of forgotten lengths of pipe or an additional 4 cubic yards of concrete to a project in a remote area can be substantial. You should therefore recheck the material takeoff list to ensure that all needed items are ordered. Order spares if an accurate count cannot be made, or if some items could be lost or damaged. Most suppliers will allow you to return undamaged extras that are not needed.

While estimating the material needed for the project, include construction material such as concrete forms, scaffolding, and earth moving equipment; include these on your material takeoff sheets.

5.1.4 Detailed Cost Estimate

A detailed cost estimate includes the material cost, the estimated labor cost to install or construct an item, and any equipment rental required. The material takeoff sheets should be used as starting points for preparation of the cost estimate.

The three most common materials on the sheets will be concrete, wood for concrete forms and for the powerhouse, and pipe for the penstock. The length of penstock should be known by this time. If concrete is purchased commercially, keep in mind that it is sold by the cubic yard and that 1 cubic yard equals 27 cubic feet. From the working drawings, determine the volume of concrete in cubic yards for the entire project. For example, a forebay wall that is 5 feet tall, 8 feet long, and 6 inches thick would have a total volume of 16 cubic feet (4 x 8 x 0.5 = 16), or about 0.60 cubic yards (16 ÷ 27 = 0.60).

Figure 5-1 is a suggested form to help determine the project cost. For a given item, the form lists the description, material quantity and units, material cost per unit, unit labor hours to install material, total labor hours, labor rate, labor cost, material cost, and total cost. All material, labor, rentals, and equipment should be included in the cost estimate. Copies of the form can be found in Appendix I.

For the total estimated cost, sum the above estimated costs, add 10% for administration (permits, etc.), and then 15% of that sum for contingency.

EXAMPLE: Assume that the summed estimated cost is $10,630; find the total estimated cost.

For administration cost, $10,630 x 0.10 (10%) = $1,063.
The sum is then $10,630 + $1,063 = $11,693.

Microhydropower

Detailed Cost Estimate

Date ____________

Page ______ of ______

Prep. By ____________

Description	Material Quantity & Units	Mat'l Unit Cost	Unit Labor Hours	Total Labor Hours	Labor Rate	Labor Cost	Material Cost	Other Cost	Total Cost

INEL 2 2412

Figure 5-1. Cost estimate form for Microhydropower project.

For contingency, $11,693 x 0.15 (15%) = $1,754.

Thus, the total estimated cost is $11,693 + $1,754 = $13,447.

Now, make the final go/no-go decision. Like the previous decisions, this one should be based on economics. Category 1 developers can compare the total project cost to the benefit gained from the project. Category 2 developers should do a more detailed analysis using the procedure outlined in Subsection 4.3.1. If the decision is to proceed, refer back to Section 1.5 to make sure that Events 27 through 32 are completed before starting construction.

5.1.5 Construction Schedule

Prepare a construction schedule to determine when work on the project must be done, or when it can be done. In developing the schedule, be sure to consider the following:

- Weather--In cold climates, winter can present a serious obstacle. Snow and cold can make the job unpleasant and may affect the quality of the work. Concrete in particular is difficult to work with in freezing temperatures, and concrete work should be scheduled for the best weather possible.

- Streamflow--Work on streams is easier if done in the dry season, which, for most of North America, is in late summer and early fall. Check the stream flow data to determine the dry time.

- Use of Machinery--If you rent small construction equipment such as a backhoe or grader, identify and schedule the tasks for which it will be used before the unit arrives so that you can get maximum output for least cost.

- Availability of Contractors--As the schedule is developed, make sure that the contractors will be available at the time allocated for the task. Make sure that the contractors understand clearly what is expected of them. Use the working drawings to help in this process.

- Availability of Material--To meet a construction schedule, it is important that the material be on the site when needed. Although more common items can usually be obtained as stock items from local building material suppliers, specialty items such as penstocks, valves, and turbine-generator sets must be ordered; delivery times can be critical.

Several people can work on different parts of the system at the same time. For example, one may be digging the penstock trench while another is stringing the transmission line. If only one person is building the system, construction time will obviously be correspondingly longer. Keep in mind that projects of this kind will almost always take longer than anticipated, especially the first time. When scheduling work, take care that unexpected delays don't push critical parts of the project into the winter months. Concrete work should be done when above-freezing temperatures are assured for one week following the pour. Otherwise, the fresh concrete will have to be protected.

A construction schedule is a working document. Even the effort to generate one will be helpful. Most of the needed information is developed for the drawings and cost estimates. To develop the schedule, you will need a list of tasks, their sequence and duration, and who will do them (if more than one person is on the project). A time line summarizing this information can then be generated.

5.2 Construction and Installation

5.2.1 General

Preparations for the construction of the microhydropower project should be carefully planned to assure that construction delays are minimized. The material takeoff sheets and schedule (see Subsection 5.1) should ensure that the construction materials and equipment will be available when needed. There are other problems that can delay or stop construction if you do not consider them. Review any special requirements of your site. The following items should be considered for all sites:

- Heavy Items--Plan to have appropriate lifting equipment available to offload heavy items (e.g., turbine-generator, transformer) and set them in place.

- Access--Provide sufficient access to bring construction equipment onto the site. This may require improving existing roads or building new ones.

- Utilities--The utilities needed for construction (e.g., power, water, compressed air) should be identified early so that you can arrange to have them available when construction starts.

For somewhat remote development sites, the most versatile piece of equipment for lifting and excavating is probably a backhoe. A backhoe can usually be rented locally, or the backhoe work can be contracted for at reasonable hourly rates.

Although ready-mix concrete is usually less costly, limited site accessibility may require that concrete be mixed at the site. For example, if loaded concrete trucks cannot pass over light-duty bridges or culverts, a small, gas-powered concrete mixer can be rented for onsite mixing.

If an overhead powerline is required, it must be installed by an experienced powerline contractor. The equipment and experience required for setting the poles and for installing wire, crossarms, insulators, and pole-mounted transformers are not normally available except through such a contractor. Direct burial of cable for an underground powerline is a different matter; only rented trenching equipment is needed.

Temporary diversion structures required to divert water flow away from construction sites can cause temporary impoundment problems or soil erosion. If a temporary coffer dam of some size is required and water flows are significant, the help of a consulting engineer will ensure a sound structure; worker safety and the integrity of the construction in progress is of primary concern.

5.2.2 Civil Works

The civil works include excavation, placement of the penstock, construction of the powerhouse, laying of concrete, and the building of canals and diversion structures. Depending on your experience and available time, you may want to do some of this work yourself. If you are not experienced in this area, you should hire a contractor to do the work. Failure of civil works through inexperience can be catastrophic to the project. For instance, if insufficient compaction of soil in the trench allowed the penstock to sag and rupture, the resulting flooding could damage the powerhouse.

It is not the intent of this section to enable an inexperienced person to do the work himself; the intent is to provide guidelines and terminology so that you can understand what a contractor is doing and why. References are included so that you can study particular aspects of the job and perhaps do portions of the work yourself.

5.2.2.1 Excavation and Backfill. The burial of the penstock, construction of the powerhouse, and placement of footings require experience with soil and rock excavation and backfill. The excavation and backfill provide a solid base for support of the structure under consideration.

Soil can be excavated by hand or with specialized machinery. For safety, trenches or other excavations more than 5 feet deep should have sides backsloped at approximately 45 degrees to prevent cave-ins on workers. Explosives are used to excavate rock: the rock is drilled, the charges placed, the explosive fired, and the debris cleared away. An experienced contractor should do this work.

The contractor may wish to sample the soil or test the area to be excavated. Although specific soil tests can provide valuable information and save money, you can avoid unnecessary costs by verifying what data and tests are needed. For example, most microhydropower structures will be small; heavy soil loading is not anticipated. The contractor may only need tests to determine the amount of rock in the excavation area or the suitability of the soil as backfill material. Question any aspect of the construction job that you are not familiar with. Most contractors will gladly explain the benefits of testing or of a specific method of working.

Consolidation of soil is a principal cause of structure settlement. Consolidation results when a load on the soil causes the ground water to flow out of the soil. In saturated sands and gravel, which are very porous, consolidation occurs quickly because the water can move freely through the voids. In fine-grained cohesive soil such as clay, the capillary size of the pore spaces between the soil grains prevents water from flowing freely and slows consolidation. Under a load, however, the water will gradually be forced out, allowing the soil particles to crowd together. This reduces the volume of the bed, allowing the structure resting on the soil to settle.

The contractor's experience should help prevent excessive or uneven settlement that can damage the structure. He may suggest increasing the bearing area of a structure's footings, placing a more porous bed of material under the structure to drain the water and spread the bearing load, installing pile foundations, or providing a drainage system to remove the water and keep the soil dry. Soil tests can determine if a settlement problem will exist. Keep in mind that the microhydropower structures should not produce large loads and that proper design of footings will spread the load over a large area and minimize settlement.

Backfill of trenches and areas around structures is important. Proper backfilling supports underground structures and the penstock. When backfill is placed, it should be tamped at regular intervals to ensure that it is compacted. The backfill material should be low in organic content (leaves, branches, etc.) and should not contain large quantities of rocks.

The moisture content of the backfill should also be controlled. Too much or too little moisture can cause the fill material to settle. If settling produces a depression along the penstock or a footing, runoff could erode the remainder of the soil and leave the structure unsupported. Moisture content of the backfill material should be controlled near its optimum level, at which a given soil can be compacted to its maximum density by means of standard compaction methods. This optimum level can be determined by soil analysis or can be judged by experience.

Excavation for footings should be deep enough so that the footing base is below the frost line. If soil freezes, ice crystal formation causes swelling and upheaval of the soil mass. Settlement from thawing can then damage concrete structures extensively.

The detailed informaton in References a through d will help you if you plan to lay underground pipe or compact soil yourself.

5.2.2.2 Concrete. Concrete is a mixture of sand, gravel, crushed rock, or other aggregate held together by a hardened paste of cement and water. When properly proportioned and mixed, the raw mixture can be cast into a predetermined size and shape. The proportioning and mixing can significantly impact the workability and texture of the concrete. Excessive aggregate and minimum sand give a textured rather than a smooth surface. Oversanding the mixture gives a putty-like appearance. Neither mixture produces good concrete.

Workability can be visualized as a composite of texture and slump. The term slump is used in concrete specifications. Slump is determined by filling a frustum of a cone with a concrete mixture, removing the cone, and measuring the subsidence of the mass below its original height. The amount of subsidence is the slump value. Concrete mixes that have low slump values

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a. Handbook of Culvert and Drainage Practice, Armco Drainage and Metal Products, Middleton, Ohio.

b. Handbook of Steel Drainage and Highway Construction Products, American Iron and Steel Institute, New York, NY.

c. Handbook of Soil Compactionology, Bros/Tema Division, American Hoist & Derrick Co., St. Paul, MN.

d. Soil Compaction and Equipment for Confined Spaces, Wacker Corp., Milwaukee WI.

are stiff and hard to work into tight spaces. For thin walls or areas congested with reinforcing steel, a concrete with a high slump is desirable since it will flow into all areas with minimum tamping or vibration. The wetter the concrete mix, the higher its slump value and the lower its ultimate strength.

You should determine what application the concrete is intended for and then decide on whether you need it wet, dry, or medium. For most microhydropower work, a minimum slump of 3 inches and maximum of 6 inches should be adequate. This is a medium mixture and should cure in 28 days with a compressive strength of 3000 pounds or more per square inch. Figure 5-2 illustrates the use of slump to achieve correct consistency in deep, narrow forms.

Water used for mixing cement should be clean and free of organics and excessive minerals. Generally, any potable water is suitable for use. Sewage, industrial waste, and corrosive salt waters should be avoided.

Detailed information on the use of concrete can be found in References a, b, and c.

5.2.2.2.1 Placement--Concrete is placed in structures using either chutes or wheelbarrows. Chutes should have a slope of one vertical to two horizontal so that the concrete mixture flows freely. Flatter slopes encourage the use of additional water, leading to segregation in the mixture

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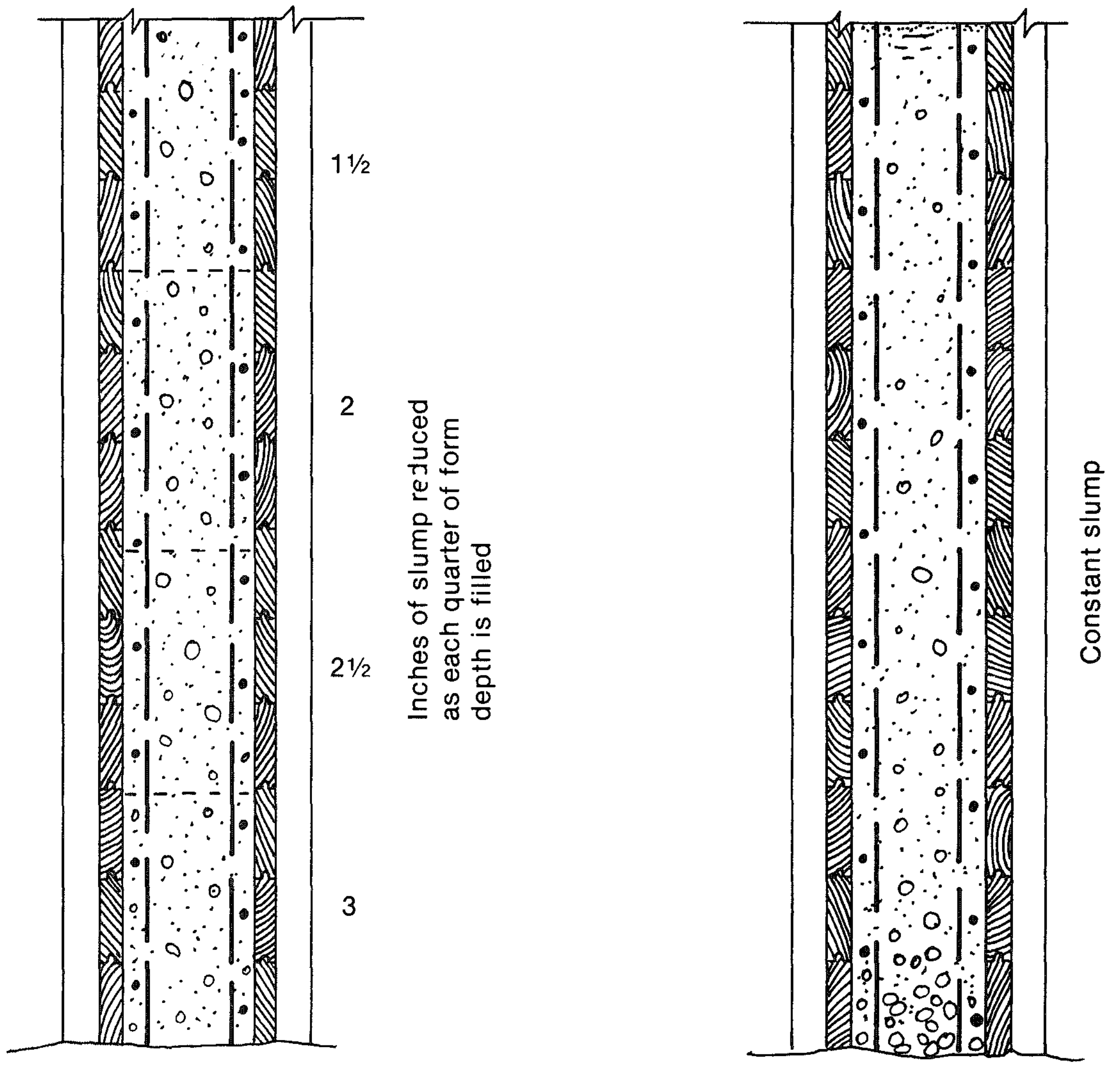
a. Joseph J. Waddell, Concrete Construction Handbook, McGraw-Hill, New York, NY.

b. Concrete Manual, U.S. Department of Interior, Bureau of Reclamation, Washington, D.C.

c. Design and Control of Concrete Mixtures, Portland Cement Association, Skokie, ILL.



Correct

To use wetter concrete at bottom of deep narrow form. Use drier concrete as more accessible lifts near top are reached. Water gain tends to equalize quality of concrete. Settlement and shrinkage are minimum.

Incorrect

To use same slump at top as required at bottom. High slump at top results in excessive water gain with resultant discoloration and loss of quality and durability in the upper layer.

INEL 2 2667

Figure 5-2. Consistency of concrete in dry, narrow forms.

and low strength. The method of placement is also important in preventing segregation. Figures 5-3 through 5-6 provide some examples of placement methods. These examples were taken from Reference a.

NOTE: If you are pouring the equipment pad during construction of the powerhouse, time spent to ensure a level and smooth surface will simplify the installation of equipment.

5.2.2.2.2 Compaction--Concrete is compacted by manual spading, walking in, tamping, or vibrating. Vibrators can be applied to the concrete or to the outside of the form. When placing concrete on a previous pour that is not yet rigid, compaction is important to ensure mixing and bonding at the interface. Compaction works the concrete into the corners of the forms and into areas of dense reinforcing bar placement. Figure 5-7 shows the use of vibrators to compact concrete. The figure also shows removal of a rock pocket to allow better compaction and ensure consolidation of the pour.

5.2.2.2.3 Curing--Curing of concrete ensures proper hydration so that it develops the needed strength and hardness. Concrete should be kept moist for a period of at least 7 to 14 days. Sprayed-on membrane curing compounds can be used to retain moisture, or canvas, straw, earth, or burlap can be placed over the concrete and dampened periodically.

5.2.2.2.4 Watertightness--Concrete can be made practically impervious to water by proper proportioning, mixing, and placing. Patented compounds are on the market for producing watertight concrete, but good results can be obtained by increasing the percentage of cement in the mix. The mixture should contain more fine material and an additional portion of cement. Six bags of cement per cubic yard of concrete will give an acceptable mixture.

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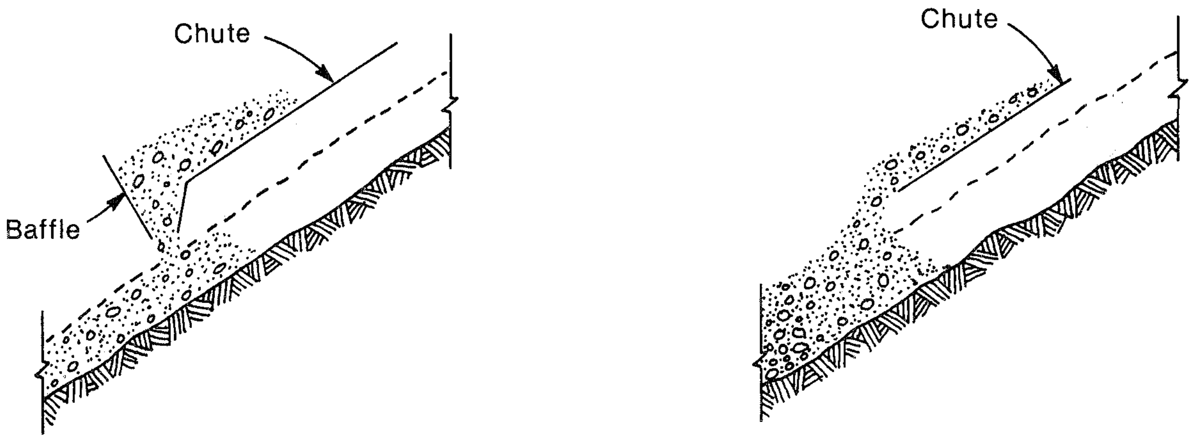
a. Concrete Manual, U.S. Department of Interior, Bureau of Reclamation, Washington, D.C.

Placing concrete on a sloping surface



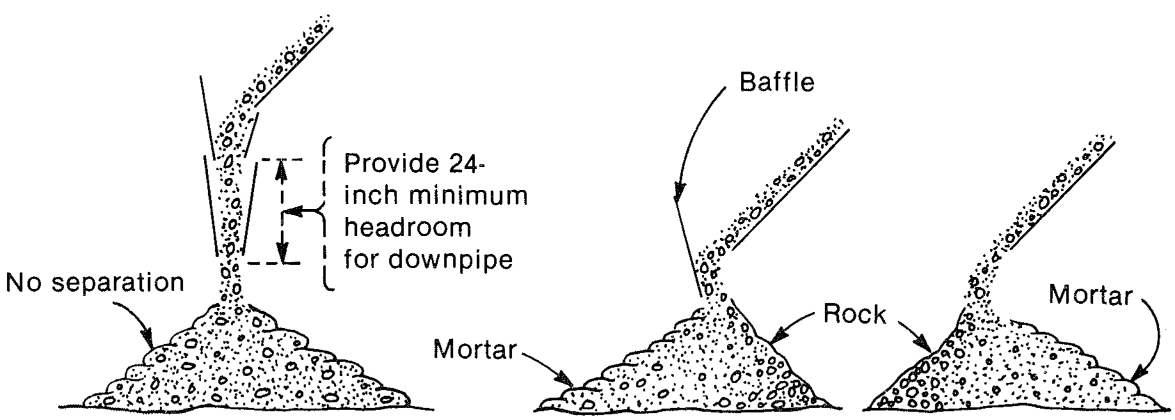
Correct

Place baffle and drop at end of chute so that separation is avoided and concrete remains on slope.

Incorrect

To discharge concrete from a free end chute on a slope to be paved. Rock is separated and goes to bottom of slope. Velocity tends to carry concrete down slope.

Control of separation at the end of concrete chutes



Correct

The above arrangement prevents separation, no matter how short the chute, whether concrete is being discharged into hoppers, buckets, cars, trucks, or forms.

Incorrect

Improper control or lack of control at end of any concrete chute, no matter how short. Usually, a baffle merely changes direction of separation.

INEL 2 2673

Figure 5-3. Placing concrete on slope, and control of separation.

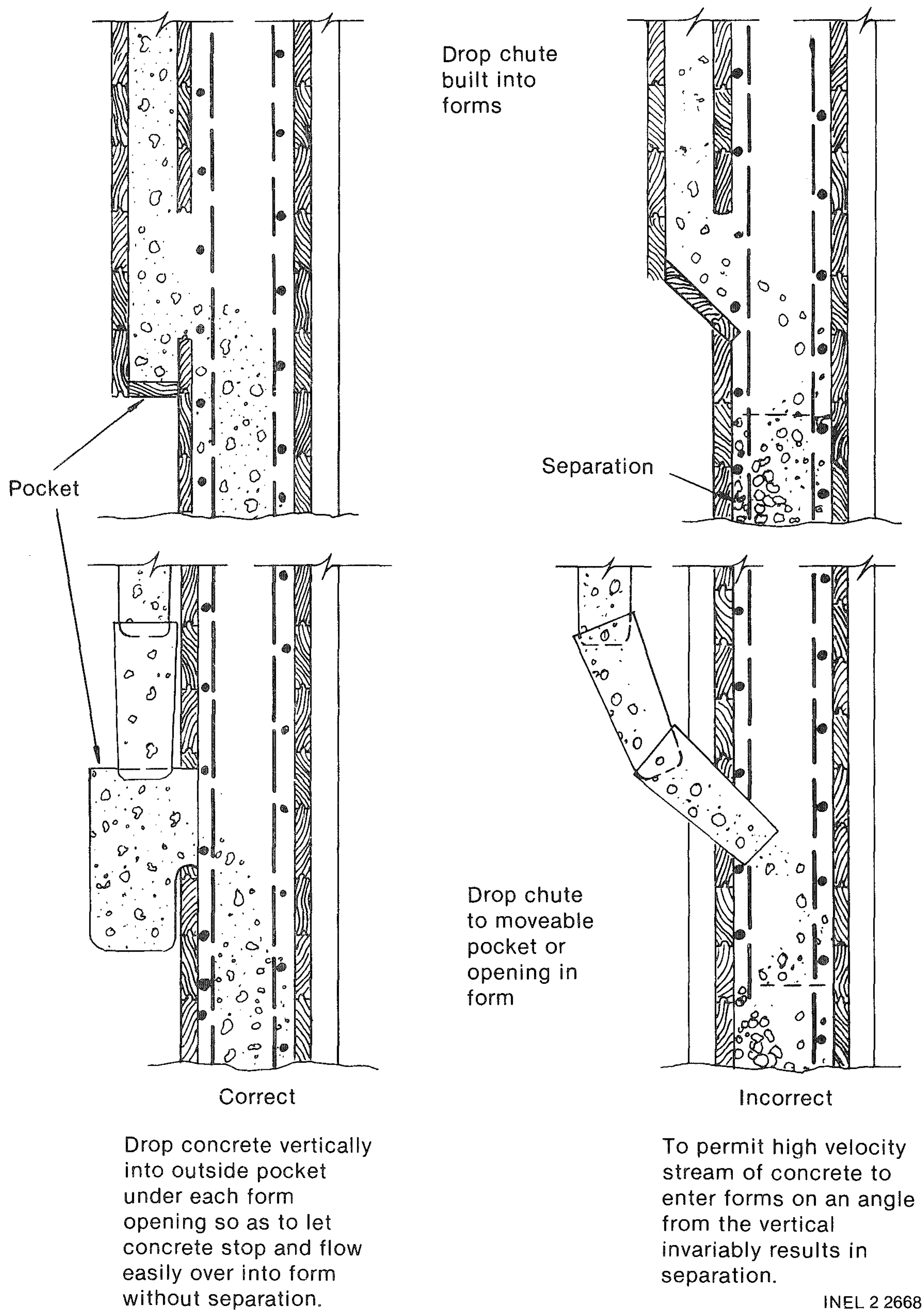
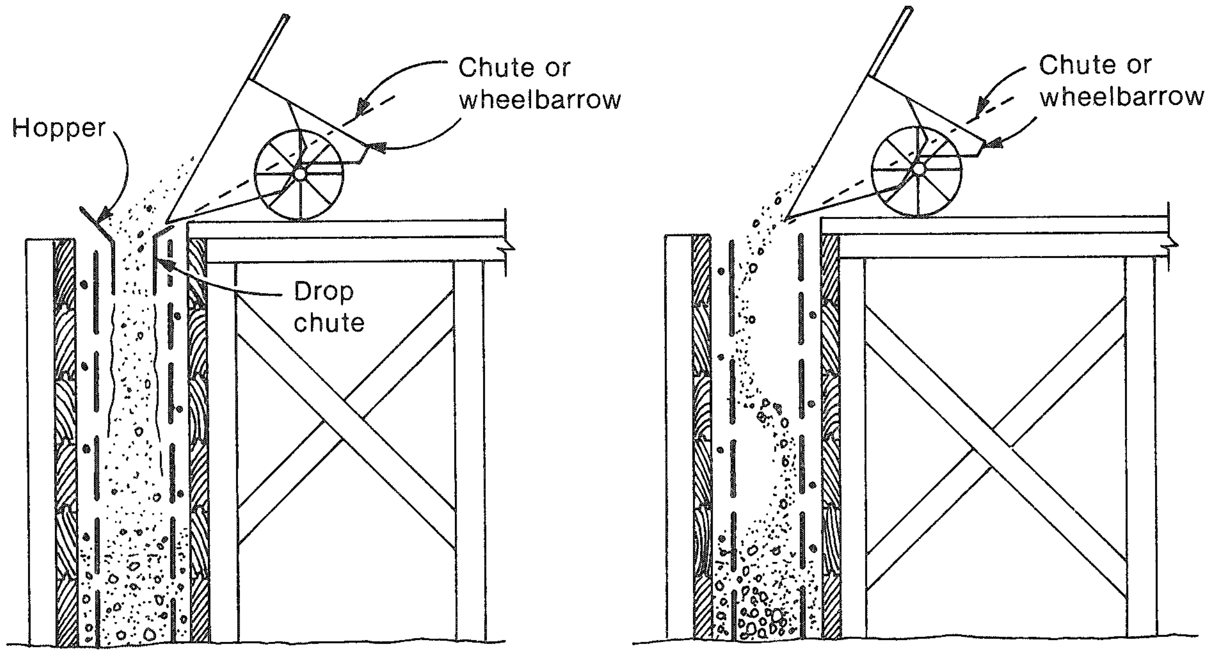


Figure 5-4. Placing concrete in forms.

Placing concrete in top of narrow form



Correct

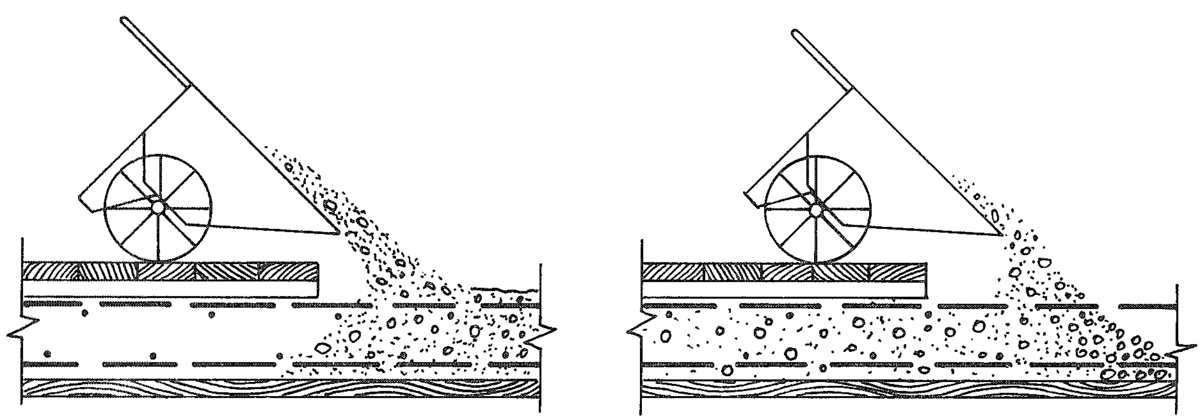
Discharge concrete into light hopper feeding into light flexible drop chute. Separation is avoided. Forms and steel are clean until concrete covers them.

Incorrect

To permit concrete to strike against form and ricochet on bars and form faces causing separation and honeycomb at the bottom.

INEL 2 2671

Figure 5-5. Placing concrete in top of narrow form.



Correct

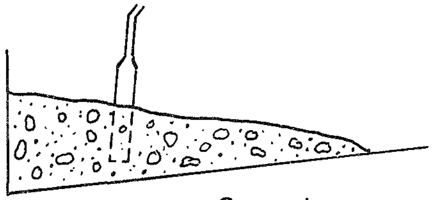
To dump concrete into face of concrete in place.

Incorrect

To dump concrete away from concrete in place.

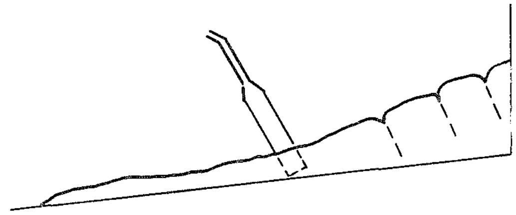
INEL 2 2670

Figure 5-6. Placing slab concrete.



Correct

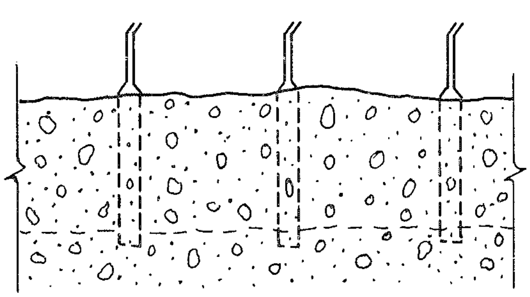
Start placing at bottom of slope so that compaction is increased by weight of newly added concrete as vibration consolidates.



Incorrect

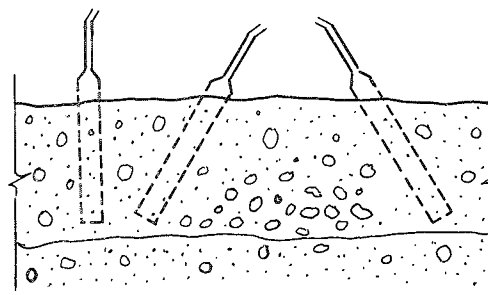
To begin placing at top of slope. Upper concrete tends to pull apart, especially when vibrated below.

When concrete must be placed in a sloping lift



Correct

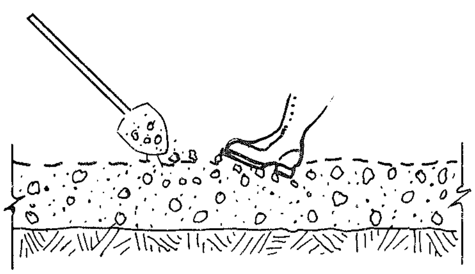
Vertical penetration of vibrator a few inches into previous lift (which should not yet be rigid) at systematic regular intervals.



Incorrect

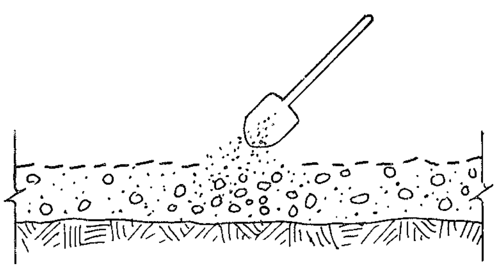
Random penetration of the vibrator at all angles and spacings without sufficient depth to assure monolithic combination of the two layers.

Systematic vibration of each new lift



Correct

Shovel rocks from rock pocket onto a softer, amply sanded area and tramp or vibrate.



Incorrect

Attempting to correct rock pocket by shoveling mortar and soft concrete on it.

Treatment of rock pocket when placing concrete

INEL 2 2669

Figure 5-7. Compaction with vibrators, and treatment of rock pocket.

New concrete can be bonded to old by wetting the old surface, plastering it with neat cement (a mixture of cement and water), and pouring the new concrete before the neat cement has set. Where two surfaces adjoin and one will be poured and allowed to harden before pouring the second, rubber water stops designed to waterproof joints should be installed in the first pour.

5.2.2.2.5 Air Entrainment--The entrainment of air using resins or other air-bubble-forming compounds gives the concrete somewhat greater plasticity and freedom from segregation, and increases its durability against freezing and thawing. Although the added resins and the resulting air voids reduce the strength of the material, the greater workability of the air-entrained mixture allows a reduction of water content and a higher ratio of course aggregate to fine, thus compensating for any loss in strength.

5.2.2.3 Concrete Forms. Concrete to be placed for slabs, walls, or columns must be supported in forms. The purpose of the forms is to contain the concrete until it has the strength to stand by itself and to prevent leakage that will cause the concrete to honeycomb. It is important that the forms have sufficient strength and rigidity to prevent bulging or sagging, which will permanently damage the structure. The pressure on the forms is equivalent to that of a liquid with the same density as concrete. The forms should be left in place 7 days for vertical walls and 28 days for a support structure.

The forms should be checked for line and grade when they are placed. The interior surface of the forms must be smooth and tight at joints to give a clean finish to the concrete. All dirt, shavings, and other debris should be removed from the forms. Wood forms should be drenched for 1/2 hour or more before placement of concrete, since swelling of dry forms in contact with wet concrete may distort the form. Forms that are reused should be thoroughly cleaned and oiled. A light oil should be used, and any excess should be wiped off to prevent staining the concrete surface.

Stability is an important consideration in construction of forms. If there is any movement of the forms as the concrete is poured, all work should be stopped and the problem corrected. Some common deficiencies resulting in form failure are:

- Inadequate cross-bracing of the shores
- Inadequate horizontal bracing and poor splicing
- Failure to regulate the rate of concrete placement
- Poor regulation of the horizontal balance of form filling
- Unstable soil under the mud sills
- No provision for lateral pressure
- Inadequate bracing for wind pressure
- Vibration from adjacent moving loads
- Nearby embankment slippage.

If vibrators are to be applied to the outside of the form, it is essential that the forms be sturdy enough to prevent misalignment or other damage from this added stress.

5.2.2.4 Concrete Reinforcing Steel. Reinforced concrete is a combination of steel and concrete fabricated into a structural member. Concrete is weak in tension, and steel bars embedded within the concrete provide the needed tensile strength. The concrete protects the steel against corrosion and fire damage. The concrete adheres to the surface of the bars, and lugs on the bars also anchor them in the concrete. This gripping action, referred to as a bond, keeps the bars from slipping through the concrete so that the concrete and bars act as a single unit.

Reinforcing steel is available as single bar lengths or wire mesh. In light gages, wire mesh is available in rolls and is common for building construction. Large sheets of heavier gages are used for highly loaded slabs. The wire mesh is furnished in square or rectangular patterns welded at each intersection. A 4-inch-square mesh will greatly enhance a slab's durability and resistance to cracking. If lighter gages are used, the concrete will tend to push the wire to the bottom of the form. A hook tool should then be used to pull it back up into the concrete after the concrete has been tamped and before troweling the surface. The wire should be pulled up about 1 inch from the bottom of the form.

Single bar reinforcing steel is used for walls, columns, and the equipment pad. Reinforcing bars come in many sizes and several grades. Table 5-1 gives the available sizes of bars, and Figure 5-8 shows the various grades with identification marks. The grades refer to the different strength properties of the materials from which they are fabricated. For microhydropower applications, any of the grades should be acceptable.

TABLE 5-1. ASTM STANDARD REINFORCING BARS

Designation	(in^2)	(lb/ft)	Diameter
#3	0.11	0.376	0.375
#4	0.20	0.668	0.500
#5	0.31	1.043	0.625
#6	0.44	1.502	0.750
#7	0.60	2.044	0.875
#8	0.79	2.670	1.000
#9	1.00	3.400	1.128
#10	1.27	4.303	1.270
#11	1.56	5.313	1.410
#14	2.25	7.650	1.693
#18	4.00	13.600	2.257

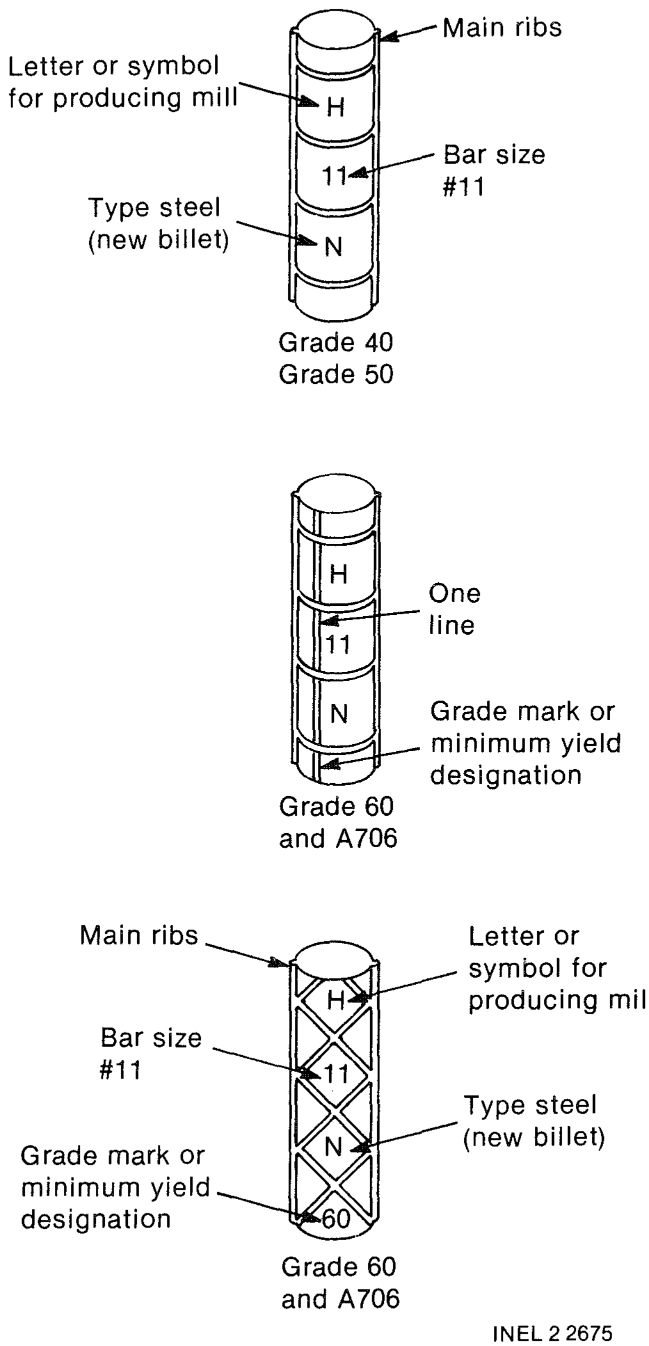


Figure 5-8. Reinforcing bar grades.

The proper embedment of the bars in the concrete is important to the strength of a reinforced concrete member. The minimum standards shown in Figure 5-9 can be used when the embedment has not been specified on a drawing. The exact positioning of the bars in relation to one another is generally not as critical as the embedment as long as the number of bars called for used. The amount of steel bar used should be determined by a technical person if the structure is to be heavily loaded and unsupported over a long distance. If you are not familiar with the placing of reinforcing bar in concrete, seek help in determining the bar size and placement. If the equipment pad is to be placed on the ground, No. 4 rebar on 1-foot centers should provide an adequate mounting pad.

Once the bars have been placed, they should be securely held in position by wiring or welding the bar intersections to avoid displacement during pouring. This wiring or welding of the bars only provides stability; it adds nothing to the strength of the structure. The number of intersections that must be tied or welded is a matter of judgement, but it should be sufficient to secure every intersection around the periphery and every third or fourth intersection in the interior. Methods for tieing bar intersections are shown in Figure 5-10. If the bars are welded at the intersections rather than tied, the slab and bar can serve as an electrical ground through a lead from the bar to the generator ground system.

Additional information on the placement of reinforcing bar can be found in Reference a.

5.2.2.5 Anchor Bolts. Anchor bolts to mount major equipment should be positioned before pouring the concrete for the equipment pad or powerhouse floor. If anchor bolts have not been set into the concrete, you may have to chip out the concrete to install and grout the bolts in place. For mounting small equipment, the concrete can be drilled to install concrete anchors.

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a. Manual of Standard Practice for Placing Reinforcing Bars, Concrete Reinforcing Steel Institute, Chicago, IL.

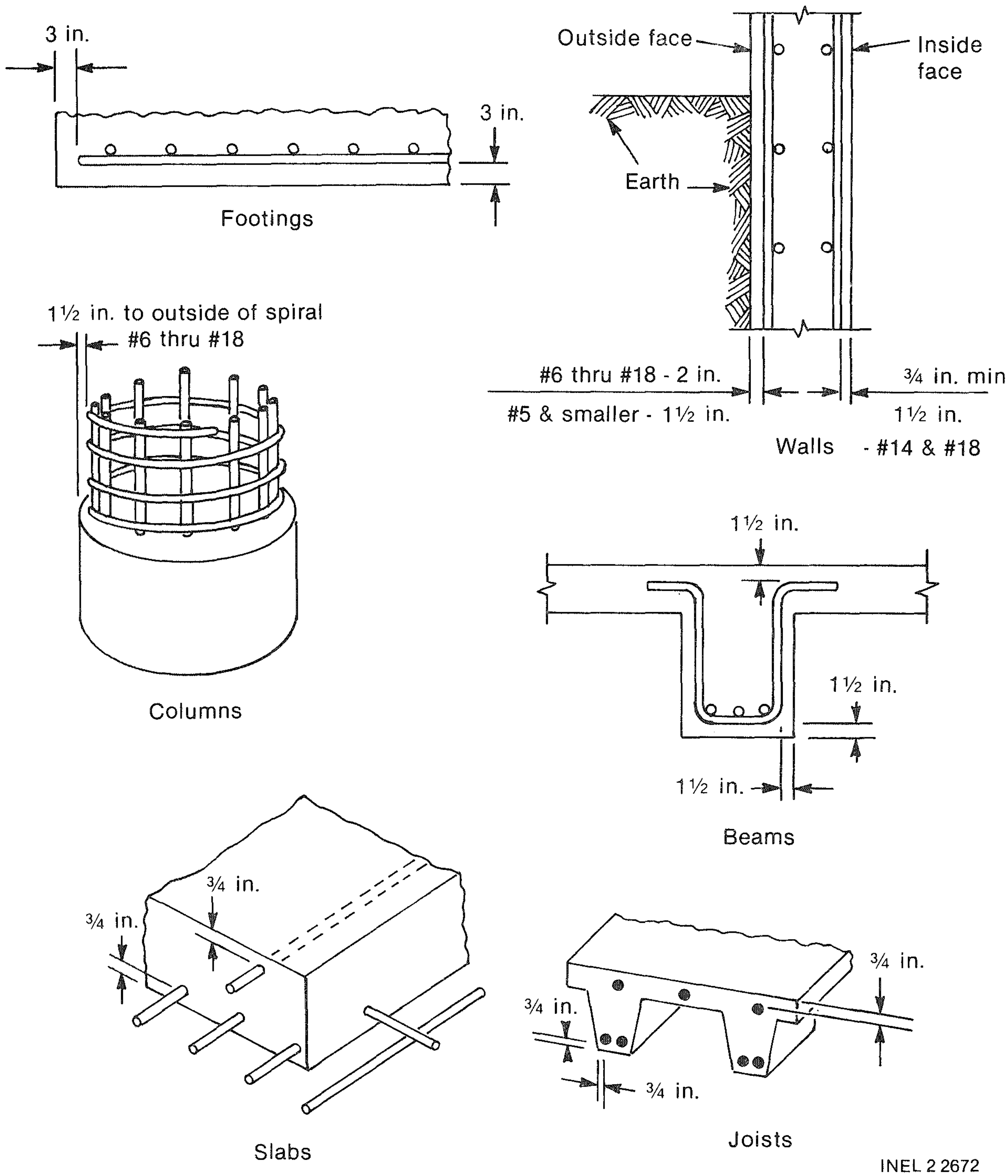

Figure 5-9. Reinforcing bar embedment standards.

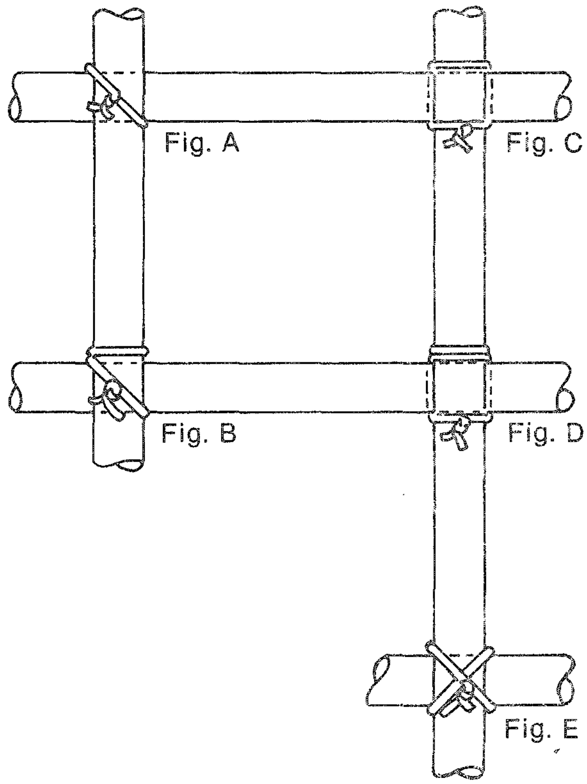

Figure 5-10. Methods for tieing reinforcing bar intersections.

The anchor-bolt size should be recommended by the equipment manufacturer. If the equipment must be leveled, leave an additional 1/2- to 1-inch length of bolt above the floor over the length needed for the equipment base, nut, and washer to allow for shimming and grouting (see Subsection 5.3).

A solid connection of the turbine-generator to the equipment pad is essential. The mounting bolts poured into the pad must line up precisely with the corresponding holes in the turbine frame. To ensure this alignment and proper bolt depth, some turbine manufacturers supply a steel template and mounting bolts. (A steel template can also be fabricated, if necessary, once the exact spacing, depth, and bolt size is known.) Each bolt is inserted in the corresponding hole in the template and held securely with a nut. The steel template assembly is then cast into the equipment pad.

A less costly plywood template can also be used. A plywood template is usually not cast into the slab, but used only to aid in placing the mounting bolts. For plywood templates, two nuts, one above and one below the template, are adjusted to hold the bolt at the proper depth.

If anchor bolts are poured into the concrete and protrude from the floor, you will have to lift the equipment and place it on the bolts. Therefore, heavy lifting equipment or other lifting provisions, should be available in your powerhouse. If concrete anchors are used, the equipment can be rolled or skidded into place and the bolts then installed and tightened.

5.2.2.6 Penstock. To ensure tight joints, penstocks are typically laid from the lowest elevation up. The pipe should be well supported even in the bottom of the trench. Rocks should not be in contact with the pipe; where rocks are a problem, the trench should be lined with sand or fine dirt before placing the pipe. Straw can also be used to provide a bedding for PVC or other plastic pipe. If steel pipe is used, a protective coating to prevent corrosion should be specified, and the pipe should not be bedded in cinders.

The route of the pipe, whether it is above or below ground, should be graded so that a channel for surface runoff is not formed. If the installation is aboveground, remove nearby trees that could fall and large rocks that could roll on the pipe. Do not backfill the penstock until it is pressure checked for leaks (see Subsection 5.3). When all leaks have been corrected, 6- to 7-inch layers of loose material should be placed and lightly tamped until the pipe is covered by at least 6 inches of fill material. The remainder of the trench can then be filled all at once and the site graded.

5.2.3 Mechanical Equipment

Most mechanical equipment will be installed and checked out after the civil work is completed. The mechanical equipment work includes setting, leveling, and aligning major equipment such as the turbine-generator;

flushing and cleaning water passages; adjusting equipment for operation; and lubricating newly installed equipment. In addition to the usual wrenches, screwdrivers, and pliers needed for working on mechanical equipment, a hand-held tachometer, pressure gage, carpenter's level, square, hydraulic jacks, come-alongs, chain hoists, dial indicator, caliper, feeler gages, straight edge, and torque wrench could be required. Plan to have needed tools available.

5.2.3.1 Equipment Installation.

5.2.3.1.1 Positioning and Setting Equipment--The major equipment to be installed in the powerhouse is the turbine-generator set. In many cases, this will be furnished assembled on a frame; lifting and positioning of this item over the equipment pad can become a major obstacle if not carefully planned. If the powerhouse has been designed with sufficiently large doors, the entire unit can be lifted by a forklift and set into position. If this is not feasible, and the powerhouse overhead does not have a beam capable of supporting the weight of the unit, a steel "A" frame can be constructed over the pad for lifting and positioning. If anchor bolts are not protruding from the floor, the equipment can be pushed into position on rollers made of pipe (3/4- to 1-1/2-inch diameter). Hydraulic jacks can then be used to remove the rollers and lower the equipment into position.

If the turbine-generator set is furnished assembled on a frame, the entire assembly must be leveled after it is positioned on the pad. If you have poured the pad during construction of the powerhouse, the extra time spent to ensure a level and smooth equipment pad will be time well spent, and the frame need only be set on the pad and bolted down. However, if the pad is not level, perhaps because an existing building is being used, the unit may have to be leveled and grouted in place. The frame should be leveled with hydraulic jacks and metal shims placed between the floor and frame for support. A nonshrinking grout cement, mixed according to the manufacturer's directions, should then be forced under the frame to fill the area on which the frame will rest. After the grout has dried, the nuts can be placed on the anchor bolts and tightened to hold the unit in place.

5.2.3.1.2 Aligning and Adjusting Equipment--If the turbine, generator, and drive system are purchased as separate units, you must attach them to a frame. Separate components are lighter to handle during installation, but some times a shaft alignment is needed. If a belt drive system is used, the shafts of the turbine and generator will be parallel, and the alignment is not as critical as with direct drive or gear drive systems. For a belt-drive system, check the shaft alignment before bolting the generator and turbine to the frame. Accurately measure the distance between the shafts at the motor end; adjust to the same shaft distance at the outer end by moving one of the components. A large caliper can also be used to measure the distance. To check vertical alignment, place a level along each shaft, and shim the front or back of the components to raise or lower the ends of the shafts as required. Securely tighten the component that will not be moved to prepare for tensioning the belt.

The sheaves should then be placed on the shafts. Check the shafts and keyways first to ensure that they are smooth and free of burrs. Wipe the shaft, key, and sheave bore with light oil. Do not drive the sheaves on the shaft; they should slip on freely. If the sheaves or keys do not slip on freely, remove and check the size or correct the problem. Once both sheaves are in place, tighten one and then place a straight edge across its face, above the shaft. Slide the other pulley on its shaft until the sides of its face evenly touch the straight edge; tighten it in this position. The sheaves should now be aligned.

A properly designed belt system can be tightened by moving one of its components, which will have elongated mounting bolt holes. When mounting the belt(s) do not force it (them) over the sheaves; adjust the component position to allow the belt(s) to slip on easily. Then tension the belts to the manufacturer's recommendations and tighten the component mounting bolts, making sure to maintain alignment as described above.

If the motor and generator are directly connected to one another or to a gear box through couplings, the shafts of the components must be accurately aligned within the manufacturer's tolerances to prevent excessive wear on the shafts and bearings. If the couplings are flanges that are an integral part of the shafts, the components can be brought together so that their flange faces touch and then a feeler gage inserted between the flanges at their periphery. Move each component and shim as necessary until the flanges are flush with each other. Rotate the flanges several times and check separation to ensure that the shafts are not at an angle to one another. To determine if the shafts are in line with one another, a dial indicator can be attached firmly to the outer diameter (rim) of one flange with hose clamps (a bracket bolted to one flange with the dial indicator attached is the most accurate method), and the pointer of the indicator set on the outside diameter of the other flange. Rotate both flanges together through 360 degrees to locate the point of minimum reading. Move or shim one unit to bring this point to zero on the dial indicator. Repeat this operation until the shafts are in alignment, then tighten all mounting bolts and insert and tighten the coupling bolts.

If the coupling is not integral with the shaft but slides on the shaft (such as the flange face coupling shown in Figure 4.9-1), the angular alignment can be done more accurately with a dial indicator than with a feeler gage. Separate the couplings enough so that the pointer of the dial indicator, attached as discussed above, can touch the face of the coupling flange. One coupling is rotated through 360 degrees to locate the minimum reading position. The units are moved to bring this reading to zero, and the measurement is repeated. This procedure can be used with any of the couplings where some separation between flanges is possible.

A reverse indicator method of alignment can be used when the couplings are ribbed or otherwise unsuitable for the above alignment methods. Attach a dial indicator firmly to the outside diameter of one shaft with hose clamps, and place the pointer on the outside diameter of the other shaft. Rotate the shafts in unison and determine the minimum reading. Move the units to bring this reading to zero, and then repeat the procedure. Once the first shaft is aligned in this way, remove the dial indicator, attach it to the opposite shaft, and repeat the procedure to align both shafts. Recheck the alignment by repeating the entire procedure.

5.2.3.1.3 Bolting--All bolts should be torqued to their required loads. This procedure is important not only for bolts used for mountings and couplings, but for those used for valves and flanges that prevent leakage of water to the turbine. Bolts in circular patterns should be tightened alternately from one side of the pattern to the other. Bolts in a straight line pattern should be tightened from the center of the line outward, alternating from one side of the center to the other. First, tighten all bolts to 75% of the recommended torque; then repeat the procedure, using the alternating technique to bring all bolts to 100% of the recommended torque.

Torques for equipment bolts are normally supplied by the manufacturer. If torque values are not provided for low-strength bolts, use the values given in Table 5-2; for high strength bolts such as ASTM-A-325, ASTM-A-193 B7, or ASTM-A-409, increase these values by a factor of 2 to 3.

5.2.3.2 Flushing and Testing Water Passages. Before turning water into the system and before the penstock trench is backfilled, it is imperative that the entire system from intake to tailrace be checked. This includes checking the gates and valves to ensure that they operate smoothly

TABLE 5-2. TORQUE VALUES FOR LOW-STRENGTH BOLTS

Bolt Diameter (in.)	Torque (ft-lb)
1/4	2
3/8	10
7/16	18
1/2	28
9/16	40
5/8	55
3/4	100
7/8	160
1	250
1 1/8	340
1 1/4	490
1 1/2	850

without binding. Walk the canal and intake structure and remove all debris. If everything is in order physically, the next step is to flush the canals and intake structure.

Flushing clears the system of all loose material that could be washed into the penstock and then into the turbine. This flushing will loosen and remove the small particles and leave the larger, more stable rock. This process is known as "armoring" and is an important preoperational step.

To flush the intake canal, close the slide gate or valve so that loose material cannot enter the penstock. Flush the water and loose material through the intake structure cleanout pipe. Be sure that the water path below the outlet is riprapped to prevent erosion of the soil. Flush the system for several hours, or as long as necessary to get it clean. This flushing operation also provides a good opportunity to check that your stop log frame or canal intake gates can regulate flow properly and stop flow quickly.

When the intake is clean, flush the penstock. Open the penstock purge valve and close the turbine isolation valve. Slowly open the inlet slide gate or valve to the penstock intake. Water should flow into the penstock and bypass the turbine. Whatever is in the pipe should go out the purge valve. After flushing for several hours, slowly close the purge valve. After the valve is closed, check the penstock for leaks. If no leaks are present, drain the penstock and backfill where needed. After backfilling, open the purge valve and then the headgate. Slowly close and open the purge valve and check for signs of movement in the penstock. Increase the anchorage and support of any section that is questionable.

5.2.3.3 Lubrication. Before operation, the turbine-generator and other equipment should be lubricated according to the manufacturer's requirements supplied with the units. Gear boxes should be filled with oil; bearings and shafts should be greased to ensure smooth operation.

5.2.3.4 Equipment Checkout. The turbine-generator must be checked out before it is energized. Auxiliary turbine-generator systems, such as cooling or lubrication systems, should be checked out first to ensure that they function in accordance with the manufacturer's instructions.

The turbine-generator can now be checked for rotation and vibration. With the penstock purge valve open and the valve to the turbine closed, the penstock headgate can be opened slowly. Allow water to fill the penstock until it flows freely through the penstock purge valve, and then slowly shut the purge valve. Check to be sure that the generator is not connected electrically to the system, and then partially open the turbine inlet valve. Because the generator is unloaded, the inlet valve should not be fully opened under any circumstances or the turbine will quickly reach runaway speed.

Once the equipment is rotating near design speed, a check for vibration and shaft speeds can be made. A hand-held tachometer is useful to determine speed. Accessable shafts and bearings should be checked for quietness of operation. A screwdriver or metal rod firmly pressed against the bearing housing will indicate rumbling or uneven operation that may be due to dirt. A whistling sound is attributable to improper lubrication or insufficient internal clearance. Unusual noises should be investigated immediately.

The temperature rise caused by bearing operation may make the bearing housing too hot to touch. Bearings can operate to temperatures of 200°F and greater without failure. If you suspect that the temperature is too hot, consult the bearing manufacturer. Operating temperatures can be predicted from the operating parameters of your site.

Make a manual check of the emergency shutdown system at this time to ensure that it operates reliably.

Once all checks have been made, the system can be shut down: slowly shut the turbine inlet valve, and then slowly open the penstock purge valve and close the intake headgate.

5.2.4 Electrical

CAUTION: Electricity is Hazardous. As stated in Subsection 4.8.1, a qualified electrician should help install the electrical system.

Before the electrical system is energized for the first time, it should be inspected by an electrical inspector. In many localities, this inspection will be a state or county requirement.

The electrical system can be constructed concurrently with other portions of the microhydropower system. The final connections to the generator, however, cannot be made until the generator is permanently installed.

Some rules for the electrical installations are:

- All conductors must be mechanically protected, or else routed at such a height that they are not a hazard. Mechanical protection can be conduit, metal raceway, or burial in the earth. Minimum heights for overhead lines should be as specified by the National Electric Code (NEC).

- All conduits, boxes, equipment enclosures, and other electrical equipment must be securely supported and anchored. Standard installation procedures are to support all boxes and enclosures independently. Conduits should be anchored every 8 feet on center and within 3 feet of every bend or enclosure and as specified by NEC.

- All wire splices must be properly made and properly insulated as defined by NEC.

- All wiring connections to equipment must be made up tight.

  CAUTION: Do not energize the system until all protective equipment for that specified portion is installed.

- The electrical installation consists of connecting the generator to the load through the overcurrent protective devices. These pieces of equipment will be interconnected by the system wiring and made ready for service.

- If the power system has a load control system, this system must be set up, connected, and made ready for operation.

- If the power system interconnects to a utility system, the step-up transformer and its protection equipment must be installed and made ready for service. This work will usually be done by the utility company and the cost billed to the developer. Even if the utility does not perform this installation, close coordination with them is required.

  CAUTION: Do not connect to the utility's power line.

- When the generator has been permanently set and aligned, the electrical system can be connected to the generator. The coils of the generator will have to be interconnected to provide the required voltage in accordance with the supplier's recommendations. After the generator has been connected to provide the voltage desired, it can then be interconnected to the rest of the system.

- All system connections must be verified before the system is energized for the first time. This should be done on a point-to-point basis. Any wiring diagrams that have been produced will be helpful in this final checkout.

- Final connection to a utility line must be made by the utility. The utility should be contacted and asked to proceed with any work they have to perform. All disconnects must be left open at this time.

6. STARTUP, OPERATION, AND MAINTENANCE

Once the completed microhydropower system has been checked out, startup, equipment calibration, and steady-state operation are the next items of concern. After the system has been placed in steady-state operation, a good maintenance system must be implemented to ensure that the equipment will give trouble-free operation.

6.1 Initial System Startup

Starting up the completed system for calibration and then steady-state operation requires the following test instruments:

- Fuse tester
- Hand-held tachometer
- Volt-ohm-ammeter
- Clamp-on ammeter
- Pressure gage with an air purge valve.

6.1.1 Synchronous Generator Startup

If the no-load test run of Section 5 checks out as expected, then startup and operation of the generator with a small amount of connected electrical load can begin. The generator should not initially be started fully loaded; it should be started with about 10% load and then incremental loads added if smooth operation continues. Resistance loads that produce heat will work best because they are steady and can be easily controlled in small increments. If a load controller is being used in the system, you should analyze it to determine what resistance can be used. If motor loads exist, they should be disconnected during the low output testing of the generator since sufficient power may not exist to operate them at their design condition. This can be done by throwing the breaker in the panel. If you are using a governor, review the manufacturer's data to determine at what minimum load it will operate, and start there.

Slowly open the turbine isolation valve a small amount to generate the 10% load. The generator is loaded, and the system should run at its design speed. The amperage meter should reflect the power being generated, and both frequency and voltage should be right on specification.

Two or three frequency cycles either side of 60 Hz is acceptable, but any more than that will require adjustment of the governor. A 10% system load will depend on the size of the system. For a 10-kW plant, 10% will be 1 kW, or 1000 watts (about the load rating of one small baseboard heating unit or a hand-held hair dryer). Larger plants will require correspondingly greater converted loads to get to the 10% load level. Many homes powered by microhydropower plants use electric heat, and these systems can be operated so that the loads are connected in increments for testing purposes.

Once the system is operating well at the 10% load level, the load can be increased. The power output will increase, but the frequency should stay right at 60 Hz. There may be a momentary blip in frequency when the additional load comes on, but that should last only a second or two until the governor system compensates.

The frequency is a function of generator speed, and the governor or electronic load controller will control either the power supplied by the turbine or the electrical load on the generator so that generator speed and frequency are maintained. Both hydraulic and electronic systems may require some adjustment before they operate properly.

Specific operating instructions for governors should come from the operation manuals for those units. Each has its own sequence for making adjustments and fine tuning the system. Once the right set points are found, mark the panel faces so they can be reset if moved.

Let the unit run at part load for 1/2 hour or more. Monitor temperatures of the generator and bearings for abnormal heat buildup. Listen for any vibration that is more than a common type hum, and be aware of any abnormal smells that could indicate excessive heat buildup or electrical insulation problems.

Increase the electrical load on the generator gradually. The frequency meter should remain at 60 ± 1 Hz, indicating that the governor is operating properly. Heat and vibration levels should not change. As the load on the generator changes, the speed of the turbine and generator should remain the same. You can check this function by varying the load. The frequency meter will show any problems by varying more than 1 Hz from the 60-Hz reading.

When you have the system operating at full output, note the way it sounds and feels. Later, any change in those characteristics may indicate that something is wrong. An intuitive sense of when it is running well will be very helpful. It may be helpful in developing that sense to sit and watch the unit run for several hours.

When one or more of the various protective devices such as governors or load controllers (see Subsection 4.8.12) are included, they should be activated to be certain that they work properly. Be certain that all operators understand the operation of these devices and know how to reset them if necessary.

The tachometer can be used to verify generator or turbine speed if problems are encountered with speed control and frequency output. The electrical instruments should be used to help adjust over current relays, emergency shut down relays and circuit protective devices included in the electrical control system.

6.1.2 Connecting Synchronous Generators to Utility Powerlines.

The utility's representatives should be present during initial startup and synchronization of the generator to the powerline. Syncronous generators are connected to active utility powerlines only after the generator has been brought up to the frequency and voltage of the powerline.

Making a smooth connection to the powerline requires that certain prerequisite conditions be met. The output voltage of the generator must be the same as the powerline, the speed of the generator must correspond to the frequency of the powerline, and the generator voltage must be in phase with the powerline. In actual practice, there is some tolerance in these conditions. A slightly higher generator voltage when connecting to the powerline does not cause any serious problem. At the instant the connection is made, the two voltages are forced to be the same. Minor differences in voltage are neutralized by the internal impedance of the generator, which will seek a phase angle with respect to the powerline that brings the voltages together.

Some minor difference in generator speed with respect to the powerline is tolerable at the instant the connection is made, but immediately following closure, the generator speed becomes locked to that of the powerline. Any appreciable difference in speed at the instant of closure will result in a corresponding mechanical and electrical jolt to the system.

When the individual cycles of the powerline are exactly in step with those of the generator, then the generator and the powerline are said to be "in phase." It is only when the generator and powerline are in phase that the generator can be smoothly connected to the powerline. This is roughly equivalent to engaging two rotating mechanical gears. It is not sufficient that the gears be rotating at the same speed to make a smooth engagement. It is also necessary that the gear teeth be properly aligned at the instant of engagement. If the generator and powerline are out of phase, the generator is operated either faster or slower than the powerline until the two systems are in phase. In actual practice, the speed of the generator is adjusted until it is as near the frequency of the powerline as possible. The speed of the generator, however, rarely remains precisely the same as the powerline for more than a few seconds at one time. With this slight difference in speed, the two systems will slowly wander into and out of phase. It is necessary to observe the phase relationship and close the connection to the powerline only at the instant when the two systems are in phase.

The typical power plant has voltmeters to compare voltages of the two systems and a synchroscope to determine the relative speed of the two systems. A synchroscope is a round dial with a single pointer. The pointer rotates at a speed which is the difference between the frequency of the powerline and the generator. The pointer comes to a halt when the generator is operating at the speed of the powerline; and the pointer points up when the systems are in phase. In a typical plant, the pointer on the synchroscope will not come to a complete halt until the generator is connected to the powerline. After the connection is closed, the pointer will remain fixed pointing upward. Counterclockwise rotation of the pointer indicates that the generator is rotating more slowly than the powerline frequency, and clockwise rotation indicates that the generator is rotating faster than the powerline frequency. It is generally accepted that closure to the powerline is best made with the pointer moving slowly clockwise and with the needle slightly past the straight up position. This, however, is somewhat dependent on the characteristics of the plant.

If the voltage, speed, and phase are correct, the generator is said to be synchronized with the powerline, and connection to the powerline can be made with no noticeable mechanical or electrical reaction. A mismatch of voltage, speed, or phase when connection to the powerline is made will cause a mechanical reaction and an electrical surge in the connecting lines. The severity of the reaction will depend on the degree of mismatch. Closure of the connection when the generator is 180 degrees out of phase is the worst case situation. Such an event may result in an electrical surge that is worse than short circuit and could do considerable damage to the generator. A properly designed system will have protective equipment that should prevent damage from such an event by disconnecting the generator from the line.

Use of a synchroscope is one of several ways that can be used to synchronize the generator with the powerline. There is a very unsophisticated method that uses lamps connected between the powerline and generator to indicate phase and frequency and in a crude way voltage also. The lamps blink on and off at a rate that corresponds to the difference between the speed of the generator and the frequency of the powerline. When the lamps stop blinking, the generator speed is matched to the powerline. Depending on the connection, the lamps will be full bright or totally dark when phase and voltage are correct. Similarly, voltmeters can be connected so as to react with the same pattern as the lamps. Combinations of lamps and voltmeters can also be used. A problem with this method is that both lamps and voltmeters have reaction patterns that lag behind the true voltage being indicated. However, such systems have been used very successfully.

Some equipment suppliers are supplying microhydropower developers with solid-state equipment that senses when conditions are correct for closing the connection to the powerline and automatically closes the switch. In these installations, the operator adjusts speed and voltage. When conditions are correct, the system automatically makes the connection without the need for a synchroscope.

With the generator connected to the powerline, load can be added by increasing water flow to the turbine. As load is increased, it may be necessary to add excitation current if the generator has an external exciter, but most small plants begin operation with an excess of exciter current, which permits a wide range in generator load without need for adjusting the exciter current. Self-excited generators are usually self adjusting. If the exciter current is run too low, the power factor of the generator will be low and the generator may pull out of synchronism.

For this type of installation there is little need for automatic speed regulating equipment unless there are periods when the plant is to run stand-alone.

Before three-phase generators are connected to a powerline, it is customary to check the phase rotation of the generator. It is possible to make an error in the wire connections so that phase rotation is opposite that of the powerline. Checking the phase rotation is usually done with a special meter with leads that clip onto the three output leads of the generator. The generator should come with sufficient wiring information to be able to make the connections without error. However, it is a good idea to check the phase rotation from the actual output voltages of the generator because an error could cause damage to the generator. If a synchroscope is used on the plant, incorrect phase rotation would be shown by the fact that it would not function.

6.1.3 Induction Generator Startup

The startup of an induction generator differs somewhat from a synchronous generator. An induction generator is always connected to a utility powerline, and so a utility representative should be present for initial startup. The induction generator should be energized momentarily to check for correct rotation acting as a motor. Any reverse current relays will have to be switched out of the control circuitry. If rotation is incorrect, then a reconnection of the wires at the generator will correct the problem. Once the generator has been wired to rotate correctly acting as a motor, then it can be energized again to run as a motor.

While the generator is running as a motor, make calibration checks to determine what the incoming power characterisitcs are on all phases. Look for an imbalance in voltage between phases. A difference of ±5 to ±8% is probably not abnormal, but more than 10% could indicate a problem on the utility line.

Check the shutdown circuitry to ensure that it functions properly for over- and undervoltage tripout, over- and underfrequency shutdown, reverse current trip, etc.

After the shutdown circuitry has been checked and the relays have been properly adjusted, the generator can then be energized again as a motor. Once the unit is running smoothly, open the turbine inlet valve slowly while monitoring the system ammeter. Remember, reverse current relays will be switched out of the control circuit at this time. As additional water is allowed to flow through the turbine, the ammeter will slowly decrease until the synchronous speed of the generator is reached (no motor slip exists). Once the synchronous speed is exceeded, the generator begins to function not as a motor but as a generator, and the ammeter now reads output instead of input. The turbine inlet valve can be set for maximum generator output, and the reverse current relays can be switched back into the control circuit. The generator is now on-line, and the synchronization of the power output from the generator is being controlled by the utility's system. With the water running, check the shutdown controls again to ensure their proper function.

6.1.4 System Troubleshooting

If your plant is not producing the power output for which you have designed it, there are a few checks you can make before contacting the turbine manufacturer. These data may help in understanding the problem. pressure gage can be placed on a tap immediately upstream from the turbine. This device can give the pressure at the turbine from which you can determine your head. Check the pressure with the turbine isolation valve both closed and full open while the turbine is fully loaded.

Use one of the methods discussed in Section 3 to check the flow in your system while the turbine is running fully loaded. This can be done in the intake structure or canal. The stop log structure could be used to fabricate a weir. With head and flow information available, you can discuss the turbine problems with the manufacturer. The manufacturer will also need to know the size of your penstock where the pressure measurement was taken in order to calculate the velocity head at this point. If you are using a reaction turbine with draft tube, the elevation from the pressure tap to the tailwater level must be measured.

If the flow in you system is lower than predicted, check the trashrack, intake structure, and waterways for obstructions. Review all of your calculations to ensure that you have not made a mistake. Observe your system in operation. Ensure that the draft tube, if used, is always submerged to prevent air from entering.

Compare the output of the generator with the calculated power from the head and flow. Dividing the generator output by the calculated power will give the efficiency of your system. Compare this with the predicted efficiency. If it is low, check the drive to ensure that it is functioning properly, i.e. that the belts are not slipping. If all appears to be working, have an electrician check the generator operation.

6.2 Startup

Normal operation of the system should be relatively trouble free. Things that can cause shutdown include an interruption of water flow, overheating of bearings, unloading the generator, overloading the generator, a power surge due to lightning, and--if your system is connected to a utility--a power outage on their line or utility power being out of specification for individual relay settings.

Startup procedures in a step-by-step sequence should be written down and posted at the generator. If a shutdown has been caused by a loss of water, or by bearing or drive problems, the startup procedure after the water flow has been restored and problems corrected should be the same as for initial startup. If an electrical problem has caused a shutdown, then after investigation to determine the cause and corrective action as required, the startup procedure should include bringing the generator up to speed and resetting appropriate tripout relays.

Continue to monitor the equipment for excessive temperatures or vibrations. The powerhouse should be kept clean, and clear access around equipment and controls should be maintained. Electrical hazard warning signs should be posted where appropriate, and electrical control boxes should be kept locked or interlocks provided for foolproof tampering. The powerhouse should be kept locked and a security fence provided.

An operational log is another useful tool to keep records on power outputs, water flows, etc. This information can be useful in future planning for plant upgrade, future power sales, and in plotting the cost of operating the overall plant.

If your system uses an induction generator, there are two methods for starting it. The first is the method discussed in the checkout procedure where the generator is operated as a motor until it reaches synchronous speed and then is overdriven by the turbine to generate power. This method will cost money for the power to operate the generator as a motor.

The other method is to bring the generator up to synchronous speed with the turbine. The generator is connected to the utility line and overdriven by the turbine to start generating electric power. The speed of the generator should be not greater than but very near to synchronous speed when connected to the powerline. Since it is being started in the no-load condition, you must be cautious in opening the turbine inlet valve to prevent the unit from reaching runaway speed.

If your microhydropower installation is remote from your residence, you should have instruments to remotely monitor the status of the plant. These instruments may take the form of a single alarm that tells when the plant has tripped off line. This is particularly true if it is tied into a utility powerline so that loss of power would not be noticed at your residence. The alarm would tell you when the system needs attention. Other more detailed instrumentation could be installed to allow you to monitor specific operating characteristics of the plant, such as volts, amperes, power, head, etc. Cables can be buried or attached to the power poles to transmit this information to your residence.

6.3 Maintenance

Maintenance of a microhydropower plant is not complicated, but a constant effort should be maintained to ensure a trouble free plant. With periodic maintenance, properly built systems should run for years without major overhaul. Problems that arise because of mechanical failure, such as burned out bearings or runner damage, should be repaired promptly to avoid more serious damage. Hydropower plants are installed in areas where conditions are not ideal. Dust, dirt, and moisture are abundant, making good housekeeping and regular maintenance a necessity.

A maintenance log is a good way to spot continuing problems that may necessitate some system redesign, or to verify maintenance on items covered by warranty. You should maintain such a log for your own information and as a notice of when maintenance is due.

6.3.1 Manuals

Maintenance manuals should be obtained for all major equipment purchased. If you have bought used equipment, write the manufacturer for a manual. Follow all directions in the manuals in servicing the equipment. If manuals are not available, the general information given in the following sections provides guidance for maintaining equipment.

6.3.2 Waterways

Inspect the canals, penstocks, settling basins, intake structure, and tailrace at least four times a year for signs of erosion, movement, or leakage. Drain and inspect the underwater portions of the system at least once a year. Concrete repairs can be made with an epoxy cement to cover exposed reinforcing bar and seal damaged areas. Inspect the trashrack, gates, and stop logs for damage, and repair if necessary. Clean debris from the waterways and repair erosion of the earthen portions of the structures, or add riprap.

Depending on your particular site, flush the settling basins and forebay as appropriate. Observe the quantity of settlement in these structures to determine how often this must be done. If there are large quantities of settlement, you may want to crack open the valve(s) on the system's flush line(s) to allow a slow continous purge of these structures.

Another maintenance task that depends on the characteristics of the stream on which your site is located is trashrack cleaning. This may be a daily chore in spring when the stream is high and carrying a lot of debris, in summer when moss is floating on the water, in fall when leaves from trees fill the stream, or in the winter when ice builds up on the trashrack. The cleaning of the trashrack is an area that must be attended to as often as necessary to prevent loss of power generation. A trash rake should be kept in the powerhouse to clean the rack.

6.3.3 Mechanical

Inspect your turbine once a year when you drain the system to inspect the waterways, or follow the maintenance schedule in your manual. Inspect the metal blades or buckets for signs of erosion. If the erosion is heavy on these items, you may want to remove and repair them by welding. If erosion appears heavy every year, it could be a sign of problems in the design of your system such as improper turbine setting. This is an area where help should be requested from the turbine manufacture. Check the surfaces of the spiral case, needle valve, draft tube, and wicket gates for damage, and repair as necessary.

If the turbine has unusual vibration, check the bearing and shaft clearances, the turbine blades or buckets, and the water passages. Turbine vibration is an indication of serious problems and should be corrected immediately.

Lubricate shafts and bearings at regular intervals. Manufacturers will specify a lubrication period generally based on hours and type of service. If there are no guidelines for greasing of equipment, you should probably lubricate the bearings every 1200 to 2000 hours of operation. Wipe off any grease that has leaked from around the seals onto the outer bearing surfaces. Dirt will collect in these areas if this is not done.

Gear boxes, hydraulic governors, and other equipment containing a reservoir of lubrication or working fluid should be checked every 3 months and refilled if necessary. Use only the fluids recommended by the manufacturer. Remove and clean filters for these systems yearly unless otherwise directed.

Check valve packings and flange joints for leakage. If leakage noticed is not critical, replace the packing or gasket during your annual shutdown of the water system. If leakage is excessive, shut the system down right away and replace the packing or gasket. Test all manual and motor-operated valves monthly to ensure proper operation.

Inspect the belt drive system every 6 months or when the unit is shut down. Check the tension in the belts to ensure that they meet manufacturers' recommendations. Belts tend to loosen with operation and should be tightened periodically. Loosen the unit that is designed to take up the slack and tighten the belts, making sure to maintain alignment. If you are in doubt about the alignment, refer to Section 5 for aligning procedures.

Check the belts for cracks, tears, or worn areas. If you decide to replace a belt because of a problem, replace all the belts on the drive at the same time. Loosen the drive to remove and replace the belts. Do not force the belts over the sheaves. Again, ensure that alignment is maintained.

Clean the sheaves and belts periodically of dust, oil, and rust, which reduce belt life and efficiency.

Review and check other mechanical equipment such as ventilation fans, doors, or hoists, and oil and service as needed. Check and tighten bolts and nuts on moving parts such as the sheaves on the belt drive, couplings, shafts, etc. Anchor and mounting bolts and nuts should also be checked periodically.

6.3.4 Electrical

A systematic and periodic inspection of the generator is also necessary. Most generators are located in areas where dirt can accumulate and lower the insulation resistance. Some type of dust are highly abrasive and can damage seals and bearings. Hence, it is desirable to clean generators periodically. For severe conditions, weekly inspection and partial cleaning may be needed. Most machines require a complete cleaning about once a year.

At the annual inspection and cleaning, air-clean the generator using moderate-pressure, compressed air (about 25 to 30 psi). On most ac generators, this requires removing some of the protective covers.

On large machines, take generator insulation resistance readings periodically with a megohmeter. As long as the readings are consistent, the condition of the insulation can be considered good. Low readings indicate increased current leakage to ground or to other conductors, perhaps caused by deteriorated insulation, moisture, dirty or corroded terminals, etc.

Inspection and servicing should be systematic. Frequency of inspection and degree of thoroughness may vary and must be determined by the owner. This will be governed by the importance of the produced power, the nature of the service, and the environment. An inspection schedule must therefore be elastic and adapted to the needs of each system. The following checklist, covering both synchronous and induction generators, is based on average conditions insofar as dust and dirt are concerned. If your generator manufacturer has not provided such a checklist, use this one as a guide.

POWER PLANT EQUIPMENT MAINTENANCE CHECK LIST

Daily

- Check air inlets and exhaust screens for blockage or accumulated dust.
- Check the voltmeter to see that the generator is running at a steady voltage.
- Check the frequency meter to see that the frequency is correct and stable.
- Check for any unusual noise, vibrations, or temperature changes in the bearings or casings on the turbine, generator, and any gear boxes.

Weekly

- Check oil level in bearings and gear boxes as appropriate.
- Examine switches, fuses, and other controls.

Monthly

- Lubricate ball and roller bearings as recommended by the manufacturer.

- Check for any leaking seals on all bearing housings.

Biannually

- Clean the generator thoroughly, blowing out dirt from windings, and wipe commutator and brushes as appropriate.

- Check the brushes (if used), and renew any that are more than half worn.

- Drain, wash out, and replace oil in the sleeve bearings (or service as recommended by the manufacturer).

- Inspect and tighten any loose electrical connections on the generator and control section components.

- Examine the drive system critically for smoothness of running, absence of vibration, and worn gears, couplings, or belts.

- Check anchor bolts, end-shield bolts, pulleys, couplings, gear and journal setscrews, and keys for tightness.

- Observe that all covers, belts, and gear guards are in good order, in place, and securely fastened.

Annually

- Clean out and replace the grease in ball- or roller-bearing housings (or service as recommended by the manufacturer).

- Test generator insulation with a megohmmeter.

- Check clearance between the shaft and journal boxes of sleeve-bearing units to prevent operation with worn bearings.

- Clean out undercut slots in the generator commutator if required.

- Examine connections of the commutator and armature coils.

- Inspect the armature bands.

6.4 Safety

Post warning signs to explain the correct operation of valves, electrical switches, and test eqipment. Provide a fuse puller for replacing fuses, electrical interlocks, and keyed safety bypasses. Keep the equipment pad clean and free of water. Protect electrical equipment from water. Keep a fire extinguisher rated for electrical fires in the powerhouse. Provide guards on all moving equipment such as belts and shafts. Provide guard rails around the intake and cleanout areas if falling into them would be hazardous.

Provide security fences around the powerhouse and transformer pad as well as the intake structure. Locks to prevent unauthorized operation of bypass valves and the headgate are also good safety precautions.

Provide an emergency shutdown switch at the generator to shut the turbine and electrical system down. This switch should be used only in emergency situations and should be labeled as such.

6.5 Spare Parts

The powerhouse should be stocked with spare parts for the power plant. Many sites will be located in remote areas where the availability of parts is limited. Review the manufacturers literature to determine what spare parts are recommended. Additional item that should be kept are:

- Fuses
- One set of belts
- Valve packing
- Gasket material
- Bearings
- Lubricants
- Valve trim (seats, plug, disk, etc.)
- One section of trashrack
- Generator brushes.

7. ECONOMIC AND FINANCIAL CONSIDERATIONS

Economic and financial considerations are an important aspect of evaluating the potential use of microhydropower. Accordingly, the following section details some economic and financial concerns. The section is divided by developer categories. The Category 1 developer is discussed first, and the Category 2 developer is discussed second. For a detailed discussion on how to prepare an economic analysis, see Appendix A-5.

7.1 Category 1 Developer

Category 1 developers are unique because their primary motive for operation is to supply energy for their own needs. The market for this energy is identified and quantified. This situation may occur in remote areas not presently served by electrical utilities or where present electrical needs are served with small fossil-fueled generators.

To perform an economic analysis, you must first estimate your current power consumption and identify its cost. Assume, for example, that you have identified your needs at about 64,000 kWh per year, i.e. you need a 15 kW unit. You have three options: purchase the required electricity from a utility, generate your own power with a gasoline-fired generator, or install your own microhydropower unit.

Electricity purchased from the utility currently costs $3200 per year at 50 mills per kWh, or 5¢ per kWh. This dollar amount assumes extra charges for peaking, transmission hook-up, etc. This cost is highly geographically dependent.

The gasoline-fired generator has a capital installed cost of $5000 and will require $4,670 per year to purchase gasoline for operation. One gallon of gasoline will generate 13.7 kWh. Therefore, 64,000 divided by 13.7 equals 4670 gallons per year; at $1.00 per gallon, the cost is $4,670.

The microhydropower unit (15 kW) will cost $22,500 if $1,500 per kW is used as an estimate. Operating costs can be estimated at 1% per year of capital costs, or $225.

Annualizing the costs of the installed equipment over a 15-year life cycle results in $1500 per year for the microhydropower unit and $333 per year for the gasoline-fired generator. The following table shows these costs for Year 1.

TABLE 7-1. COSTS FOR YEAR ONE

	Utility	Gasoline-Fired Generator	Microhydropower
Annualized Cost	-0-	333	1500
Operating Costs in Year 1	3200	4670	225
Total Costs	3200	5003	1725

Clearly, the microhydropower unit holds an economic advantage. Because gasoline prices and electricity prices fluctuate with inflation, the cost per year will not remain constant over the 15-year life cycle. Hence, an escalation factor must be used to determine the annual costs at the end of the 15 years. Using 6% per year escalation on all costs subject to inflation, i.e., operating costs, the following cost table can be prepared with the escalation formula:

$$F_V = P_V (1 + r)^n$$

Where

F_V = Future value

P_V = Present value

that your project presents an acceptable risk. The more risk that you can remove from the lending institution, the lower the interest rate you will pay.

The greatest risk for a microhydropower development is the sale of the power. That is why it is essential to work out a contractual agreement with the utility company. Another risk is that the project may not operate at its designed capacity. Professional engineering services will lower this risk. Another risk is that the expected revenue will be less than anticipated. This could happen for several reasons. The water flow could be below normal, the equipment may require more shutdown time than anticipated, or the rate paid by the power purchaser may fall below forecast. The contractual agreement with the power company will lessen this risk.

The risk level assigned to your microhydropower development by a lending institution will be primarily a function of that institution's perception of your capacity to repay the loan. The institution's previous experience with you and collateral other than the hydropower site are important considerations. To obtain a loan, you must present the bank with a sound business plan as well as a sound technical plan. If you prepare these plans without professional assistance, you must be prepared to demonstrate to the bank that you are qualified to prepare them.

The business plan should contain the necessary permits and licenses. All construction costs should be identified. Wherever possible, provide vendor quotations and contracts. This lessens the risk of underestimating the project's total cost. The business plan should also contain realistic projections of the project's revenues and operating costs over a period at least as long as the proposed term of the loan. This projection must show that the project can afford the loan payments. However, as a minimum you should be able to demonstrate that the annual revenues less the annual operating costs exceed the debt service (i.e., interest and principal loan payment) by at least 25% during the entire life of the loan. This is called a 125% debt service coverage.

Bank financing may be available for Category 2 developers. However, previous experience indicates that the key to arranging the financing is the contractual agreement between the utility company and the developer. Commercial banks typically offer construction loans on a short-term basis, with the long-term financing available when the project is complete. Although this appears to be two separate loans, they are generally negotiated at one time, i.e., prior to construction.

Another possible source of financing is the Small Business Administration (SBA). This is usually an excellent source of financing for any small business. And, this source should definitely be pursued if the developer appears financially "thin." This means that the financial statement of the developer does not meet the minimum requirements of the lending institution. This minimum requirement is usually that income, less expenses, allows for 1-1/4 times the payment of principal and interest.

You may want to investigate a limited partnership. Limited partnerships can be formed with the aid of an attorney. They generally are structured as a tax shelter in an effort to pass along tax advantages from the developer to other persons who want the tax savings. The developer becomes the general partner and usually contributes a 10% equity share. The limited partners contribute the other 90% of the equity. This is a fairly complex source of financing and requires legal counsel.

Microhydropower presents some risk in development. It is important before securing financing to understand the risk-return tradeoff.

In general, an institution expects higher returns for accepting greater risks. For example, oil companies risk millions of dollars to drill a well that may never produce. But if they strike oil, their returns are extremely high. Lending institutions such as commercial banks are risk-averse. As risk increases, they charge higher interest rates. At some point the risk becomes so great that they will not even participate in the loan. If you intend to use any debt financing, you must convince the lending institution

These estimates along with a financial statement of the developer will help initiate discussions about financing. The preparation of these estimations is presented in Appendix A-5.

7.2 Category 2 Developer

The critical factor for Category 2 developers is to contact the utility company serving the area and work out a contract for the purchase of the power. This market element is essential to the successful completion of the project. Because of recent legislation, the utility company, either public or private, may be willing to negotiate a contract. The utility may also be helpful in obtaining permits, obtaining financing, and obtaining engineering advice.

In determining the economics of the potential site, a complete analysis of capital equipment costs is a prerequisite. Also, the potential revenues and operating costs must be identified and estimated with the help of the utility district. Alternative methods of securing the power should be evaluated. The mechanics of preparing a cash flow analysis, benefit-cost analysis, simple payback, and a sensitivity analysis are detailed in Appendix A-5.

Financing options may be limited. The utility company will know the potential financing options acceptable in a particular area.

Basically, the two kinds of financing available are debt and equity. Debt financing places a contractual obligation on the developer to repay the loan in accordance with the loan terms. Equity financing is the amount of collateral, cash, or services the developer uses as his down payment. This debt-equity arrangement is similar to a home mortgage where the down payment is the original equity and the debt is the amount borrowed. Because hydropower tends to be capital-intensive, the debt fraction is generally quite high. "Capital-intensive" means that the original cost of equipment and installation are much higher than the operational costs.

r = Escalation percent; 6% = 0.06

n = Number of years.

TABLE 7-2. COSTS IN YEAR FIFTEEN

	Utility	Gasoline-Fired Generator	Microhydropower
Annualized Cost	-0-	$ 333	$ 1500
Operating Costs in Year 15	7,669	11,192	539
Total Costs	7,669	11,525	1,839

Again, the microhydropower unit holds the economic advantage.

Financing alternatives for the Category 1 developer may be limited, but some suggestions are presented. The first and most widely accepted suggestion is the power company. Public or private utilities may find it beneficial to finance 50% or less of the project, depending on how costly it would be to install service to the area. Bank financing should also be pursued. A second mortgage on the property or a loan secured by other collateral may be obtainable through your commercial bank. In some cases, a line-of-credit extended for farm operations could be used to finance the microhydropower development. Another alternative is the equipment manufacturer. They may have some financing arrangements available; however, this may be very costly in interest charges. Finally, the Small Business Administration (SBA) should be contacted if a business is involved. More elaborate financing mechanisms such as limited partnerships set up for tax shelters may be too complicated and costly for the very small developer.

The requirements necessary before going to any lender would be a capital cost estimation, revenue estimation, and operating cost estimation.

The most uncertain projection in the business plan is likely to be the project's annual revenues. As previously mentioned, the marketing arrangement is closely related to the financing alternatives available. You can significantly reduce the bank's risk by presenting a power purchase contract. Most banks will not consider the loan without such a contract. The degree of security a bank assigns to a power purchase contract will depend on the reliability of the purchaser and the terms of the contract. The most secure arrangement for the bank would be a "Hell-or-high-water" contract with a major utility. Under such a contract, the utility would agree to make annual payments to you whether or not your microhydropower site operates as designed. In negotiating this contract, risk is transferred from you and the bank to the utility. In return for accepting this risk, the rate offered by the utility will be lowered. This type of contract represents the greatest security to the bank and the smallest return to you. At the other extreme, you and the utility could negotiate a contract for the utility to purchase power at the negotiated rate. Because this rate can be volatile, such a contract presents a greater risk to the bank. To compensate for increased risk, the bank may lend a lesser amount for a shorter period of time at higher interest rates than if you had negotiated a "Hell-or-high-water" contract.

The revenues projected in a business plan can be lower than the revenues that you actually expect to receive. For example, you may expect your revenues to escalate by 8% per year as the price of energy increases with inflation. You may consider this an acceptable risk and base your expected return on it. However, a lending institution would find such a risk unacceptable if their debt service depended upon it. An acceptable risk to a bank might be on the order of "current rates will not decrease over the term of the loan." When you and the lender have different perceptions about the project's future, the lender's perception will dominate the loan negotiations. It is for this reason that it is best to have a long-term power purchase contract.

8. LEGAL, INSTITUTIONAL, AND ENVIRONMENTAL CONSIDERATIONS

This section focuses on the many local, state, and Federal laws that apply to microhydropower development, the regulations that are involved, and the problems that must be addressed in getting the certifications, permits, and licenses or exemptions necessary to proceed with construction of a microhydropower project. The fact that microhydropower developments are very small and may cause very little impact does not, in most cases, exempt the developer from complying with these laws and regulations. Fortunately, there is an ongoing effort at all levels of government to simplify the licensing procedures for microhydropower developments.

The process of obtaining the necessary permits and licenses or exemptions for any hydropower project should always be started at the beginning of the project. A systematic approach to licensing[a] will greatly reduce the time required and minimize the pitfalls encountered. This systematic approach should begin with the initial agency contacts. The key agencies in the licensing process should be alerted early to the proposed project and asked for information on the prerequisites for their specific permits, certifications, licenses, etc. The developer must deal with three levels of government: local, state, and Federal. Normally, all three levels must be fully satisfied before construction can begin. At the local level, the developer must comply with county, township, or municipal planning and zoning regulations. Especially where urban development has surrounded an existing dam, it is important to make sure that a generating facility is acceptable under applicable codes. A building permit and possibly other local permits are needed to build or refurbish a microhydropower development. Normally, cognizant state agencies and the Federal Energy Regulatory Commission require compliance with local laws before issuing their respective licenses.

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a. As used here, the term "licensing" includes all permits, licenses, certifications, letters, and exemptions necessary for a project.

At the state level, at least a water right permit, a water quality certification, and a general environmental certification are necessary. A variety of other state permits may be required, depending on the specific site.

The Federal Energy Regulatory Commission (FERC) is the agency responsible for licensing at the Federal level. Where a microhydropower project does not involve Federal land, a navigable stream, or an upstream Federal water project, submitting copies of the state permits and certifications along with the appropriate FERC exemption or license form is generally adequate. Where Federal lands, a navigable stream, or an upstream Federal water project are involved, additional permits are needed from the appropriate Federal agencies. In a few cases involving private onsite energy use and a private water source, an FERC license will not be necessary. However, this special case should always be cleared with the FERC to avoid any later problems.

Because requirements vary widely from site to site and from state to state, it is not possible to present a generally applicable step-by-step procedure for obtaining all the necessary certifications, permits, and licenses or exemptions. Therefore, this section discusses considerations that affect the licensing process and the various requirements encountered at the various levels of government, and then presents a general discussion of procedures for licensing the two example sites used in this handbook.

8.1 Environmental Considerations

Environmental considerations affecting microhydropower development and operation are very site specific. The general guidelines outlined in this subsection are intended to acquaint the developer with most of the issues that should be addressed. In most areas, local, state, and Federal agencies can be helpful in identifying potential ecological concerns. Following is a partial list of such agencies:

- Federal Fish and Wildlife Service

- State Fish and Game Department
- Federal Environmental Protection Agency
- State Department of Environmental Resources
- State Health Department
- National Historical Society
- Army Corp of Engineers
- Soil Conservation Service
- County and university extension services.

Generally, a developer can expect better cooperation from the appropriate agencies if initial contact is made early in the planning stages of a project. These early contacts can provide the developer with valuable information on stream characteristics and on previously overlooked adverse environmental impacts that could block the project.

Environmental considerations development are different during the construction and operation phases of a microhydropower project, although some overlapping does occur. Therefore, the two phases are considered separately.

8.1.1 Environmental Considerations During Construction

Environmental concerns during microhydropower project construction fall into five broad categories:

- Water quality
- Diversion of stream flow

- Sediment control and dredging

- Wildlife and migratory fish

- Historical significance and aesthetics.

8.1.1.1 Water Quality. Water quality concerns during microhydropower project construction usually involve turbidity (see Subsection 8.1.1.3) and changes in nutrient loading, temperature, and dissolved oxygen values. Regulations and standards governing these parameters vary considerably depending on the type of watershed and its uses. Contact a local office of the U.S. Environmental Protection Agency (EPA), the state agency concerned with water quality, or an appropriate local agency or county extension service to determine what regulations are applicable to the proposed development.

8.1.1.2 Diversion of Stream Flow. During construction, you may have to divert part or all of the flow in a stream. If such action is necessary, there are usually several options that you can employ (i.e., construction during low flow periods or winter months, temporary dikes, etc.) to minimize any adverse environmental effects. State and local agencies and county extension services can usually help in outlining these options.

8.1.1.3 Sediment Control and Dredging. Dredging operations and sediment control during construction are an important problem that must be addressed. Before starting construction, consider what actions are necessary to control erosion and minimize sediment transport from all disturbed areas (e.g., access roads, equipment site, transmission lines, etc.). The Soil Conservation Service, as well as other agencies, can be very helpful in outlining plans with the developer.

Dredging of existing channels or impoundments can result in increased nutrient loading and decreases in dissolved oxygen in the water. Materials that have settled to the bottom of a stream are often subject to a reducing environment caused by a lack of oxygen. This condition can result in a buildup of toxic elements that may cause adverse environmental effects if the settled material is put back into suspension. If these conditions are present, you may require special permits to dispose of the dredge material.

8.1.1.4 Wildlife and Migratory Fish. During the planning stage of any microhydropower project, contact the appropriate fish and wildlife agencies to ensure that the proposed project will not affect any threatened or endangered species. If migratory fish species occupy the watershed, schedule construction of the project to minimize any conflicts. State and Federal agencies can help in protecting sensitive areas and providing suggestions for restoring areas that have been disturbed.

8.1.1.5 Historical Significance and Aesthetics. During the project planning stage, contact the appropriate state agency and check the National Register of Historic Places to ensure that the proposed project will not affect any protected historical or archeological site. At the same time, bring any adverse impact on the aesthetics of the project area, including proposed transmission lines, to the attention of the appropriate agencies or planning commission.

8.1.2 Environmental Considerations During Operation

Environmental concerns during microhydropower project operation fall into four broad categories:

- Effects of water level fluctuations
- Instream flow requirements
- Water quality changes
- Effects on migratory fish.

Some of the concerns addressed for the construction phase may need to be considered again for the operating phase. Most of the following concerns need to be addressed on a site-specific basis.

8.1.2.1 Effects of Water Level Fluctuations. Effects of water level fluctuations are usually associated with man-made sources (e.g., impoundments) since run-of-the-river operations, by definition, do not normally have significant adverse impacts. Potential impacts include:[a]

- Reduction in riparian habitat, vegetation, wetlands, and avian nests
- Inundation of small tributaries
- Decreased stability of stream banks
- Decrease or loss of quality aquatic habitat and spawning areas
- Altered sedimentation patterns
- Stranding of fish and benthic invertebrates
- Disruption of fish migration
- Alteration of food chains
- Changes in algal communities.

8.1.2.2 Instream Flow Requirements. The instream flow requirement may be the most significant issue associated with microhydropower development. This term refers to the amount of water flow needed in a natural stream or channel to sustain the instream values, or uses of the water in the stream, at an acceptable level.[b] It identifies the flow

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a. S. G. Hildebrand, L. B. Gross, Hydroelectric Operation at the River Basin Level: Research Needs to Include Ecological Issues in Basin-Level Hydropower Planning, EPRI WS-80-155, June 1981.

b. J. M. Loar, M. J. Sale, Analysis of Environmental Issues Related to Small-Scale Hydroelectric Development V. Instream Flow Needs for Fishery Resources, ORNL/TM-7861, October 1981.

regime that will sustain all uses of water within the channel while maintaining aesthetics and water quality. Water uses include support of fish and wildlife populations, recreation, hydropower generation, navigation, and ecosystem maintenance, which in turn includes freshwater inflow to estuaries, riparian vegetation, and floodplain wetlands.[a,b]

You can obtain the minimum flow requirements that must be met for rivers and streams in many areas of the country from the Fish and Wildlife Service and from state Fish and Game agencies. These requirements will differ depending on changes in the flow regime patterns. For the microhydropower developer, localized changes are the major concern, since in many of the projects water will be diverted through a flume or penstock to a generator at a lower elevation before being returned to the original stream channel. Projects on the effluent end of liquid waste disposal operations must maintain sufficient flow to ensure that the waste stream is adequately diluted and that none of the water quality discharge standards for the watershed are exceeded (e.g., dissolved oxygen, temperature, etc.).

Finally, because water used to maintain instream flow is usually not available for power production, the potential energy that can be produced by a microhydropower project may be less than expected. This is a major concern since your microhydropower system may be faced with a mismatch between energy demand and stream flow requirements.

8.1.2.3 Water Quality Changes. Water quality concerns that may be an issue to the microhydropower developer include:

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a. K. Bayha, "Instream Flow Methodologies for Regional and National Assessment," Instream Flow Information Paper No. 7, FWS/OBS-78/61, Cooperative Instream Flow Service Group, U.S. Fish and Wildlife Service, Fort Collins, Colorado; unpublished report, 156 pp, 1978.

b. P. S. Wassenberg, S. Olive, J. L. Demott, C. B. Stalnaker, "Elements in Negotiating Stream Flows Associated with Federal Projects," Instream Flow Information Paper No. 9, FWS/OBS-79/03, Fort Collins, Colorado, 41 pp, 1979.

- Changes in nutrient transport and cycling
- Altered temperature regimes
- Altered dissolved oxygen regimes
- Altered material cycles, including trace elements, heavy metals, and organics.

The most subtle changes to consider are possible secondary impacts on biological components of impoundments and tailwaters.

8.1.2.4 Effects on Migratory Fish. The issue of fish migration is perhaps the most obvious ecological concern in most hydropower developments. An improperly designed microhydropower project can block the downstream migration of juveniles or the upstream migration of returning adults. Contact local fish and game personnel early in the planning stage to determine if migrating fish are a concern and what type of structure should be designed into the project to avoid any adverse impacts.

Fish migrating upstream are generally blocked by obstructions greater than 18 inches in height. The extent of blockage varies with flow and species and size of migratory adult. Bypass systems for adults can be engineered since the swimming abilities of most migratory species are fairly well understood.

The downstream movement of juveniles presents a more significant problem for microhydropower developments. Turbine intakes must be screened and regularly cleaned to minimize adverse impact. Another way of minimizing the mortality of migrating juveniles would be to shut down for the period of downstream migration. Most downstream migrating species leave smaller tributaries during a 2- to 4-week period. Shutdown during this time could eliminate problems with downstream migrating species. If your project is designed to take all or a significant proportion of the flow of a stream in which there are migrating species, you will probably have to consider the shutdown option.

8.2 State and Local Requirements for Development

Because state and local laws vary widely, it is difficult to define the specific state and local requirements that must be met in developing a microhydropower plant. Many states have energy offices to assist in energy development and energy conservation programs. Several have developed useful guidelines and handbooks similar to this one to aid the energy developer. Contact your state energy office or its equivalent to determine if such a document exists. State energy offices are listed in Appendix E-8.

Table 8-1 lists the responses of the various states to a microhydropower survey, showing whether certain requirements are in effect and indicating whether a single agency exists to help the developer meet the many state requirements. Table 8-2 lists the state permits that might be required by a state--in this case, the State of Washington--for a conventional hydropower project development. Figure 8-1 is a flow diagram showing a sample procedure for dealing with state regulations--in this case, the state of New Hampshire. These two examples can serve as guides to microhydropower developers.

The Department of Energy has funded studies of the legal, energy incentive, and institutional problems encountered in many states with small-scale hydropower development. Appendix H lists the titles of publications for states studied for the Department of Energy by the Energy Law Institute of the Franklin Pierce Law Canter, Concord, New Hampshire.

The rest of this subsection briefly discusses the more general requirements of

- Water rights
- Public Utility Commission permits
- Use of state lands

TABLE 8-1. STATE RESPONSES TO MICROHYDROPOWER SURVEY

	Survey Questions							Survey Questions					
Name of State	Q-1	Q-2	Q-3	Q-4	Q-5	Q-6	Name of State	Q-1	Q-2	Q-3	Q-4	Q-5	Q-6
Alabama	QNR	QNR	QNR	QNR	QNR	QNR	Montana		C		C	X	
Alaska	X	A		C	X		Nebraska	X	C				
Arizona	QNR	QNR	QNR	QNR	QNR	QNR	Nevada	X	C	X	C		X
Arkansas		R					New Hampshire	X	R			X	
California		C		X	X		New Jersey		R		Y		X
Colorado		A					New Mexico	A					
Connecticut	X	R		C	X		New York	QNR	QNR	QNR	QNR	QNR	QNR
Delaware	X	R	X	X		X	North Carolina	X	R		C	X	X
Florida		C		C			North Dakota		A				
Georgia	X	C					Ohio		R		C		
Hawaii		A		C			Oklahoma		C				
Idaho		A					Oregon	X	A	X		X	
Illinois	X	R		C			Pennsylvania	X	R				
Indiana	X	R		C	X	X	Rhode Island	X	R		C	X	
Iowa	X	O		C			South Carolina		R		C		
Kansas	X	R		C	X		South Dakota	X	C		C		X
Kentucky	X	R	X				Tennessee		R		C		
Louisiana		O		X			Texas	QNR	QNR	QNR	QNR	QNR	QNR
Maine	X	R			X		Utah	QNR	QNR	QNR	QNR	QNR	QNR
Maryland		C					Vermont	X	R		X	X	X
Massachusetts	X	R	X	X	X		Virginia		R	X	C		
Michigan	X	R		C			Washington	X	A		X	X	
Minnesota	X	R		C			West Virginia	QNR	QNR	QNR	QNR	QNR	QNR
Mississippi		A		C			Wisconsin		R		C		
Missouri		R					Wyoming	QNR	QNR	QNR	QNR	QNR	QNR

Q-1. "X" indicates states with a central clearinghouse to handle applicatins for microhydropower developments.

Q-2. "R" indicates states that follow the riparian doctrine in water rights regulations, "A" indicates states that follow the appropriation doctrine, "C" indicates states that follow combination of the two, and "O" indicates states that follow other water rights doctrines.

Q-3. "X" indicates states having exemptions for microhydropower developments (under 100 kW).

Q-4. "X" indicates states that require an environmental impact statement for small hydropower developments, and "C" indicates states where the need for an environmental impact statement is determined on a case-by-case basis.

Q-5. "X" indicates states that provide tax or marketing incentives other than those imposed by PURPA (P.L. 950619), the Federal legislation that requires utilities to buy power from small hydropower producers.

Q-6. "X" indicates states that have a separate state agency for handling hydropower development permits and state certification.

QNR. "QNR" means Questionnair Not Returned.

TABLE 8-2 POSSIBLE STATE PERMITS REQUIRED FOR DEVELOPMENT OF A HYDROELECTRIC PROJECT

Permit	Agency	Comments	Fees	Approximate Time
State Environmental Policy Act compliance	WDOE and/or lead agency		None	3 weeks 3 years
Permit to appropriate public waters (water right)*	WDOE	Required for any use of water for hyropower generation. An existing right may be changed to hydropower use upon approval by WDOE.	Examination fees: $10 minimum, or for each cfs appropriated: 1-500 - $2/cfs. 500-2000--50¢/cfs. 2000 + -20¢/cfs. Other fees also apply. Contact any WDOE office or see RCW 90.03.470.	2+ months
Reservoir permit & dam safety approval*	WDOE	For any man-made reservoir with a volume of 10 acre-feet or 10 feet in depth.	$10 or cost, whichever is greater	2+ months
Water quality certification*	WDOE	Required before an FERC license is issued.	None	2 months 1 year
Temporary modification of water quality criteria	WDOE	Required for any activity that will result in temporary violation of state water quality standards (Chapter 173-201 WAC).	None	2 months
Flood control zone permit*	WDOE	Required if project is located in designated flood control zone.	None	1 month
NPDES and/or state waste discharge permit*	WDOE	Needed if pollutants will be discharged into surface or ground waters.	None	2 months
Sewage and industrial waste treatment approval*	WDOE	May be required if project includes sewage treatment or disposal system.	none	2 months
Annual power production license fee	WDOE	Assessed at the beginning of every year. Based on theoretical water power. 50 hp exemption.	0-50 hp--exempt 500-1000--10¢/hp 1000-10,000--2¢/hp 10,000+--1¢/hp	----
Hydraulic project approval*	Fisheries and Game	Required for any construction affecting surface waters or stream bed.	None	2 months
Public water supply approval*	Social & Health Services	If public drinking water supply is needed or altered.	None	3 months

TABLE 8-2 (Continued)

Permit	Agency	Comments	Fees	Approximate Time
Archeological approval	OAHP	Contact prior to surveys required by FERC.	No set standards	2 months
Forest practices application/ notification*	DNR	For construction on forested, nonfederal land.	None	5-30 days
Surface mining permit*	DNR	Operations disturbing 2 acres or 10,000 tons or greater of surface material on nonfederal land.	$25	2-3 months
Burning permit*	DNR	To burn wood and debris.	None	1 week
Dumping permit*	DNR	Dumping 750 cubic yards of land-clearing debris on nonfederal land.	None	1 week
Lease of state lands	DNR	Facilities, transmission lines on state lands.	Fair market value	4 months
Right of way or road use	DNR	For easements to cross state lands.		2+ months
Application to purchase valuable material	DNR	Covers excavation and use of any stone, rock, sand, gravel, or silt from state lands.	Fair market value	2+ months
Permit to temporarily remove or destroy survey monument	DNR	Removal or destruction of any section corner or other land boundary mark or monument.	None	2 weeks
Permit to operate overheight vehicles on state highways	DOT	Road conditions are sensitive to damage from overweight vehicles.	None	1 day
New source construction approval*	Local Air Pollution Control Authority	For dust control during use of construction machines such as concrete batch plants and asphalt plants.	Based on amount of pollutants emitted	1-2 months

NOTE: Most projects will not require all of the permits listed. Small projects are likely to require only a few of these permits.

* Included in the Washington Environmental Coordination Protection Act
WDOE- Washington Department of Ecology
DNR - Department of Natural Resources
OAHP- Office of Archeological and Historical Preservation
DOT - Department of Transportation

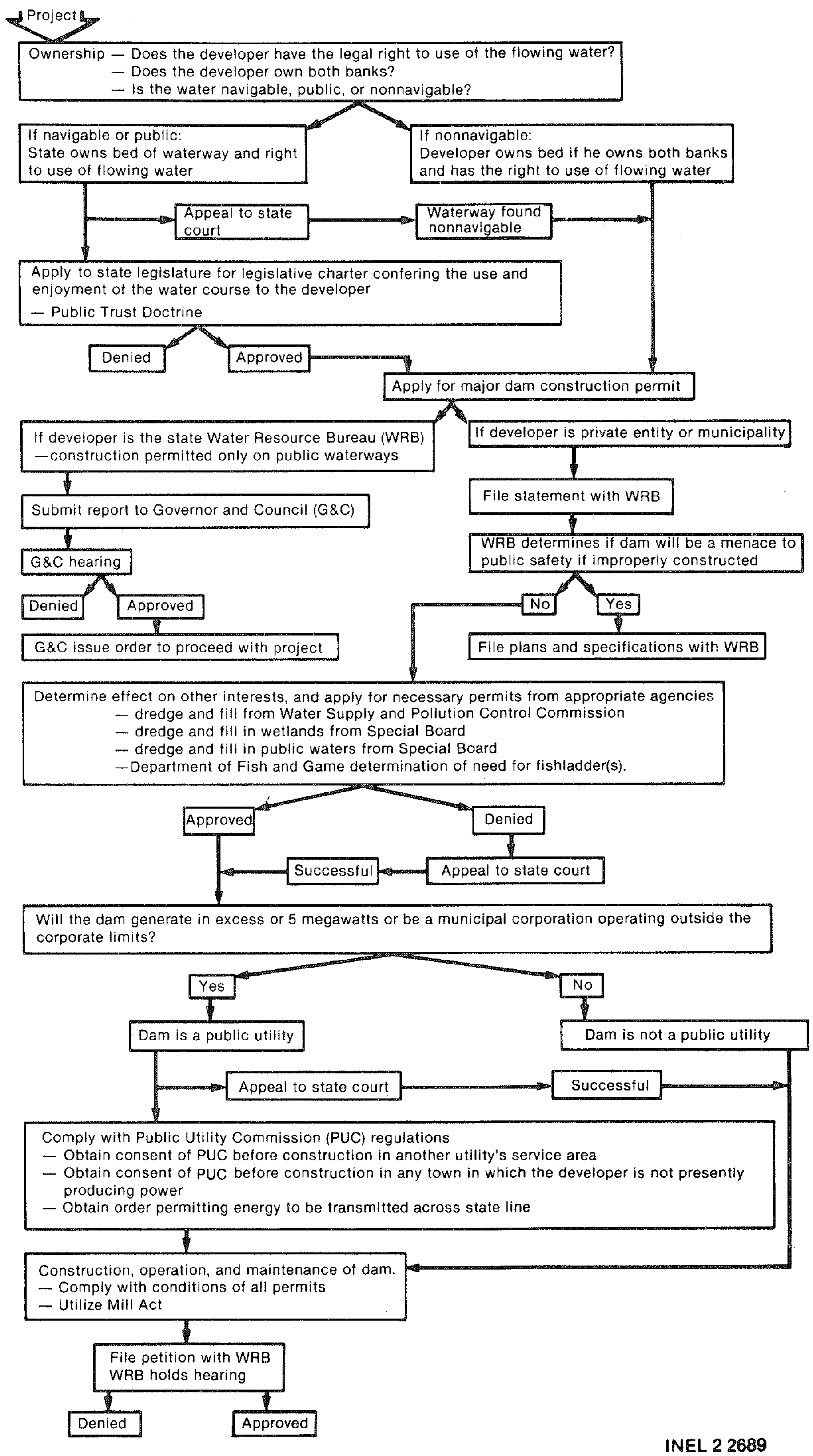

Figure 8-1. Sample flow diagram of procedure for dealing with state regulations (New Hampshire).

- Dam safety and other safety requirements
- State environmental considerations
- Historical and archeological considerations
- Transportation permits
- Local planning, zoning, and building permits.

8.2.1 Water Rights

Securing a water right is one of the most important state requirements to be met in a microhydropower development. Obtaining an appropriate water right is a requirement for FERC licensing. Contact the water agency in your state to determine what the requirements are and to start the process of obtaining the water rights. State water agencies are listed in Appendix E-1. In some states, the water rights agency is separate from the water resource department.

Different doctrines prevail in different states for administering water rights. Basically, all waters are the property of the state, and the user is given permission or acquires a right to use the water for some beneficial use. In the eastern states, the "riparian rights" doctrine prevails, specifying that a land owner adjacent to a stream has a right to use the water in the stream in a reasonable manner as long as that riparian owner does not inflict substantial injury to other riparian landowners upstream or downstream. Thus, if your development is in a state where the riparian rights doctrine prevails, you must have ownership along a stream to qualify for a water right. Generally, you must have title to both banks of the stream. Throughout the country, development of hydropower has traditionally been considered a reasonable use of water, even when a diversion from the natural channel is required. Some states require a formal application for the riparian water right while others do not.

In the western states, a different water rights doctrine, the "prior appropriation" doctrine, prevails. In states where this doctrine applies, a person, company, or government entity may acquire a water right without owning the land. Simply stated, the first person to appropriate water and apply it to a beneficial use has first right to use the water from that source. Subsequent appropriators may take water but only after the first appropriator's use has been satisfied. Usually, this system operates on a permit basis, and the date of application for a water right permit constitutes the priority date. In some states that have not had a mandatory permit system, constitutional provisions have been interpreted to mean that if the beneficial use has been exercised, a water right has been secured. Most states have now converted to a mandatory permit system to administer water use.

Under the prior appropriation doctrine, you should file for a water right permit as soon as possible; if there is competition for the development of a particular site or section of a stream, the earliest water rights application has the prior claim.

Some states have a dual procedure for acquiring water rights in which elements of both the riparian rights doctrine and the prior appropriation doctrine apply.

8.2.2 Public Utility Commission Permits

Two types of permits may be issued by the Public Utility Commission (PUC) or its equivalent in each state. One is a certificate that authorizes construction of an electrical power plant or an electrical transmission line. This certificate verifies the need for the facility, provides for administrative reporting of energy production, and covers possible fees charged for licensing the production of electrical energy in the state. The license authorizing construction of the hydropower facility may also be handled by another state agency.

The second type of permit involves confirming the "qualifying facility" status for avoided cost under the Federal PURPA act, which is discussed in Section 8.4, Marketing.

Contact your State PUC or its equivalent to obtain the necessary permits. State PUCs are listed in Appendix E-2.

8.2.3 Use of State Lands

You may need to acquire or use land administered by the state for your construction site, water conveyance system (penstock or canal), transmission line, or access roads, or as a source of construction materials. The beds of navigable streams in most states are owned by the state. Different states have different policies for leasing or for outright sale of the state lands involved. Customarily, the development site requires full ownership of the land, while rights-of-way for access, transmission lines, water conveyance systems, and material sources such as rock require only leases or use permits. Contact the appropriate state agency to determine what steps you will have to take and to start the process. State agencies responsible for administration of state-owned land and land laws are listed in Appendix E-3.

Most states have land withdrawn or set aside for parks, natural areas, scenic areas, wild or recreational river segments, wildlife refuges, mineral sites, and hydropower sites. You should make certain that your site does not impinge on any of the withdrawn or reserved areas, since development of a microhydropower site in these areas will be difficult or impossible. A variety of state agencies administer portions of the state lands, but a state Department of Lands, or Land Commission, or Department of Natural Resources usually has maps of state lands and the withdrawn areas and sites, as well as personnel familiar with these areas.

8.2.4 Dam Safety and Other Safety Requirements

The responsibility for administering dam safety programs to reduce the risk of dam failure has been delegated to the states by the Federal government. FERC regulations require that a hydropower developer obtain appropriate permits from an authorized agency. Normally, you will need a dam safety permit if your dam or impounding structure is greater than a specified height in feet or if your reservoir capacity is greater than a specified volume in acre feet. The dam height and water volume requirements vary from state to state. Many dams or impoundments used in microhydropower projects are exempt from this permit requirement because of their small size. Contact the state Department of Water Resources or the equivalent agency in your state (listed in Appendix E-1) to find out if you need a permit and to start the permitting process if necessary.

A related safety requirement is that of flood plain protection, which requires that appropriate restraints be made to protect structures in a flood plain. This is mandated by Federal legislation, A Unified National Program for Flood Plain Management, P.L. 90-448. The administration of this program is handled at the Federal level by the Federal Emergency Management Agency. Some states have old mill acts that provide rules and regulations governing the control of flooding that could result from mill impoundments. At present, most states have flood plain zoning and local flood control districts that prescribe the standards of construction that must be met in the flood plain. To obtain advice and get necessary permit information, contact the local planning and zoning commission, the State Department of Water Resources (listed in Appendix E-1), or a district office of the U.S. Army Corps of Engineers (listed in Appendix D-1) or the Federal Emergency Management Agency. Each of these entities will have some jurisdictional concern.

Another often obscure safety requirement that must be met is a permit for the use of explosive materials during construction. This is normally regulated by the Public Safety Division of a State Department of Labor.

8.2.5 State Environmental Considerations

Environmental considerations involve three principal areas of concern:

- Water quality and pollution control
- Fish and wildlife
- General environmental impact.

Some states have enacted environmental coordination legislation that covers all three together. However, Federal legislation has generally separated the water quality aspects. The actual monitoring and administering of the water quality standards on navigable streams has been delegated to the states. In rare cases where a state's programs did not meet the mandates of Federal law, the EPA has administered elements of the water quality and pollution control regulatory program.

Your microhydropower development will require a state certification that water quality standards will be maintained. In most cases, you can obtain a permit to allow a temporary violation of the water quality standards during construction. To start this process, contact the state agency concerned with water quality, which may be a Department of Pollution Control, Department of Ecology, or Department of Health and Welfare. State agencies responsible for water quality and pollution control are listed in Appendix E-4.

Much of the water quality control involves fish and wildlife considerations; a number of states have separately administered Fish and Wildlife Departments that exercise control over the fish and wildlife and the habitat associated with each. Although permits are not normally needed, state laws usually require that developments minimize and mitigate effects on fish and wildlife. In some cases, the Fish and Wildlife Agency has classified streams and designated in general what activities are permitted along streams and in land areas where fish and wildlife can be affected. You can obtain maps of these streams from your State Fish and Wildlife Agency. Appendix E-5 lists the various state Fish and Wildlife agencies.

You should contact the Fish and Wildlife agency in your state to determine if there will be opposition to your microhydropower development. A primary environmental consideration will be the minimum flow required to maintain aquatic life in the stream. Diversions for microhydropower development that reduce stream flow to below this minimum will not be permitted. This problem was discussed briefly in Subsection 8.1, Environmental Considerations.

A third, somewhat overlapping concern is that of general environmental impact. This state requirement arises from individual state environmental protection acts that are much like the National Environmental Policy Act, P.L. 91-190. In a number of states, this act is designated the State Environmental Protection Act, abbreviated SEPA. The environmental concerns mandated extend beyond fish and wildlife to cover the impacts of many types of developments--including microhydropower--on land forms, plant life, and human activity. Normally, microhydropower developments are small enough that general environmental impacts are negligible. State agencies that administer SEPA programs are Departments of Ecology and Departments of Environmental Protection. Appendix E-6 lists the state agencies concerned with environmental protection.

8.2.6 Historical and Archeological Considerations

In most states, historical and archeological sites are protected by law. A state certification of compliance with the law is required under the National Historic Preservation Act, P.L. 89-665, for FERC licensing. Each state has an agency or council that maintains a list of protected sites. Appendix E-7 lists the state agencies concerned with archeological and historic preservation. Contact the appropriate agency in your state to determine if your development impacts such a reserve or dedicated area, and to obtain any necessary letter of compliance.

8.2.7 Transportation Permits

You may need permission to connect an access road from your microhydropower development to an existing highway. Contact the state Highway Department for that purpose.

A minor but important permit you may require during development of your project is one for transporting oversize or overweight equipment over a state highway. In most microhydropower developments, a need for this permit is unlikely.

8.2.8 Local Planning, Zoning, and Building Permits

Local governments require certain permits for any type of construction development with an investment value greater than some specified minimum. Often this requirement is mandated under a state law requiring that a comprehensive plan be developed for communities and counties. Such plans are usually administered at the county or city government level. A planning and zoning commission receives an application and makes a recommendation concerning it to the administrative officials of the community or county, who in turn issue the necessary permit or the required certificate of compliance. Table 8-3, from the State of Colorado Small-Scale Hydro Office, is an example of possible local permit requirements. You should contact local agencies to determine what the requirements are in your area and to start the process of obtaining necessary permits.

8.3 Federal Requirements

8.3.1 Federal Energy Regulatory Commission Regulations

The major Federal agency concerned with hydroelectric development in general and microhydropower development in particular is the Federal Energy Regulatory Commission (FERC). This agency issues preliminary permits, licenses, and license exemptions for hydroelectric developments. The FERC has jurisdiction where non-Federal hydroelectric projects affect navigable waters, occupy Federal lands, use water stored behind government dams, or affect interstate commerce. This includes almost all developable sites.

For microhydropower developments, one of five conditions may apply:

- The FERC may rule that it has no jurisdictional responsibility.
- The FERC may permit a categorical exemption from licensing under FERC Order No. 202.

TABLE 8-3. POSSIBLE LOCAL PERMITS

Action Required	Agency	Reason
Zoning conditional use permit/Special use permit	Planning Department/Zoning Department	Required if hydropower is not a use permitted under present zoning.
Drainage of surface water permit	Department of Public Works	If surface water is to be drained. May be required for other permits.
Building permit	Building Department	For construction of powerhouse and other structures.
Temporary road closure Permit	Department of Roads or Department of Public Works	Needed for any construction that would close a road to traffic.
Other road permits of temporary nature	Department of Roads or Department of Public Works	To operate overweight vehicles, etc.
Utility permits	Department of Public Works	Needed for transmission lines; interconnection.
Plumbing permit	Building Department or Plumbing Department	Approval of any plumbing plans.
Temporary sewage holding tank permit	Sanitation Department or Department of Health	For sewage facilities installed as part of project on permanent basis.
Grading permit	Department of Roads or Department of Public Works	For all excavation or filling activities except as noted in Uniform Building Code.
Floodplain permit	City/County/Planning Department/Zoning Department/Building Department	For any development in a regulated floodplain that would potentially affect flood flows or flood elevations.

Data derived by Colorado Small-Scale Hydro Office in consultation with state agency officials.

- The FERC may permit a "conduit" exemption under FERC Order No. 76.
- The FERC may permit a case-by-case exemption under FERC Order No. 106.
- The FERC may rule that a formal license application is necessary.

You should first review the material in this subsection to determine which of the above conditions applies. If you are still uncertain as to which condition applies after reviewing this information, write a letter requesting an opinion on whether the FERC will assert jurisdiction and which condition will apply. The letter should give the stream location; the type of diversion; the design head, flow, and capacity, including, if available, a flow duration curve for the site; and the land ownership involved. Contact the FERC at:

Federal Energy Regulatory Commission
Office of Electric Power Regulation
825 North Capitol Street, N.E.
Washington, D.C.

Figure 8-2 is a flow diagram showing possible FERC licensing options and a list of the FERC regulations that apply. The paragraphs that follow discuss, in order of increasing effort and time requirement, developer actions necessary to obtain FERC licensing.

8.3.1.1 No Jurisdiction. The area of no FERC jurisdiction is quite rare. All of the following conditions would have to apply:

- The development should be in a water conveyance system such as a pipeline or canal that is privately owned.
- Control of the water should be entirely independent of a free flowing stream or connected lake system.

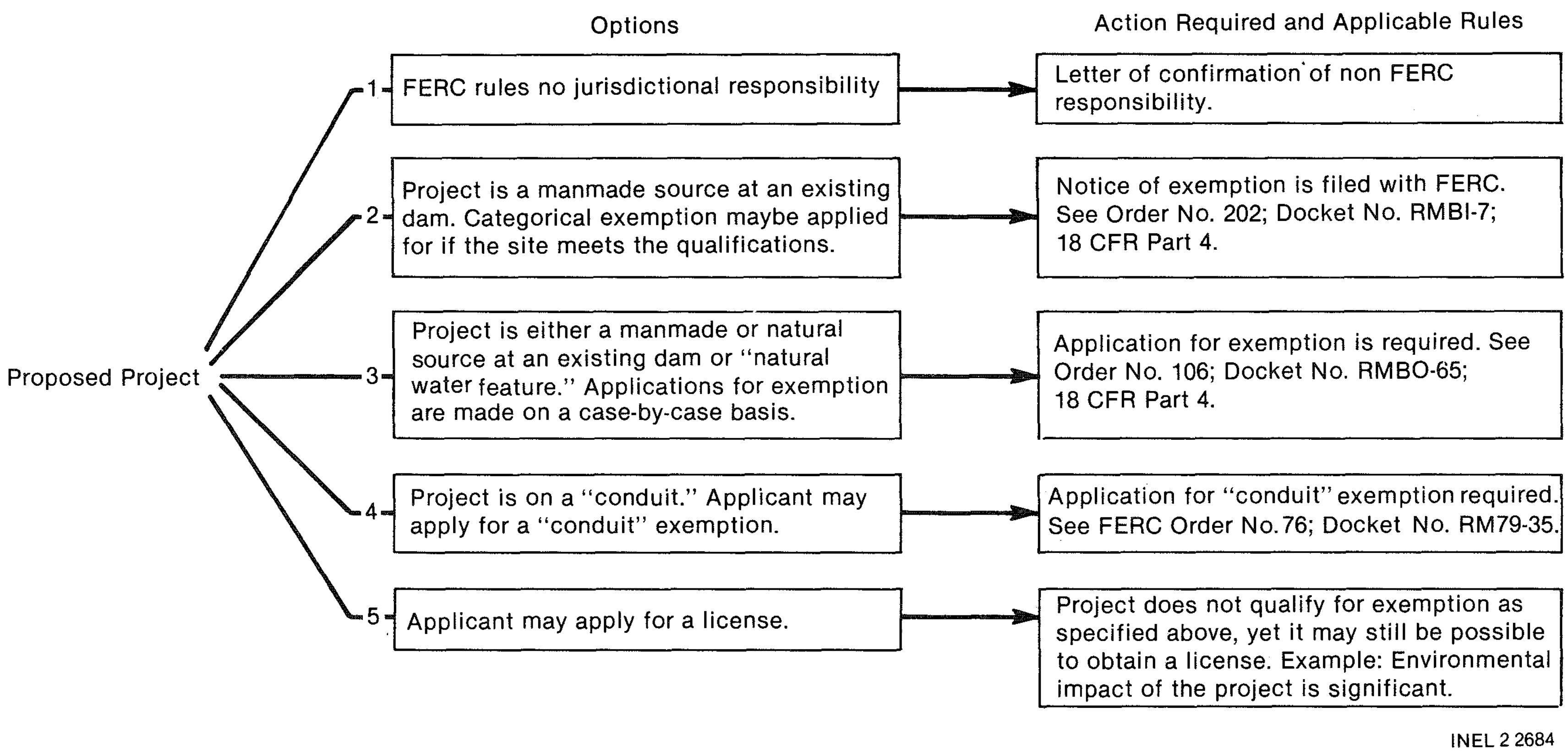

Figure 8-2. Flow diagram of possible options for FERC licensing.

- The power produced should not be connected to a commercial transmission system.

If you believe that your development may qualify, write to the FERC requesting a "no jurisdiction" ruling.

8.3.1.2 Notice of Exemption for Existing Dams. If your microhydropower project involves an existing dam, the simplest action you can take is to obtain FERC approval through a "notice of exemption" from licensing,[a] which only takes 30 days from the time of filing with the FERC. Figure 8-3 is a flow diagram of the application process for the exemption.

The requirements for approval under this categorical exemption are quite stringent. To qualify, your proposed microhydropower development must meet the following conditions:

- The proposed development cannot be larger than 100 kW (it is assumed throughout this handbook that you are planning a microhydropower development of 100 kW or less)

- The project must use the water power potential of a manmade source at an existing dam for generating electrical power.

- Either the existing dam must be at a site where there is no significant existing population of migratory fish, or it must not obstruct the passage of fish upstream or downstream.

- The development must not divert water from the waterway for more than 300 feet from the toe of the dam to the point of discharge back to the waterway.

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a. See FERC Order No. 202, Docket No. RM81-7 dealing with 18 CFR Part 4. This can be found in the Federal Register, Vol. 47, No. 20, January 29, 1982, pp 4232-4246.

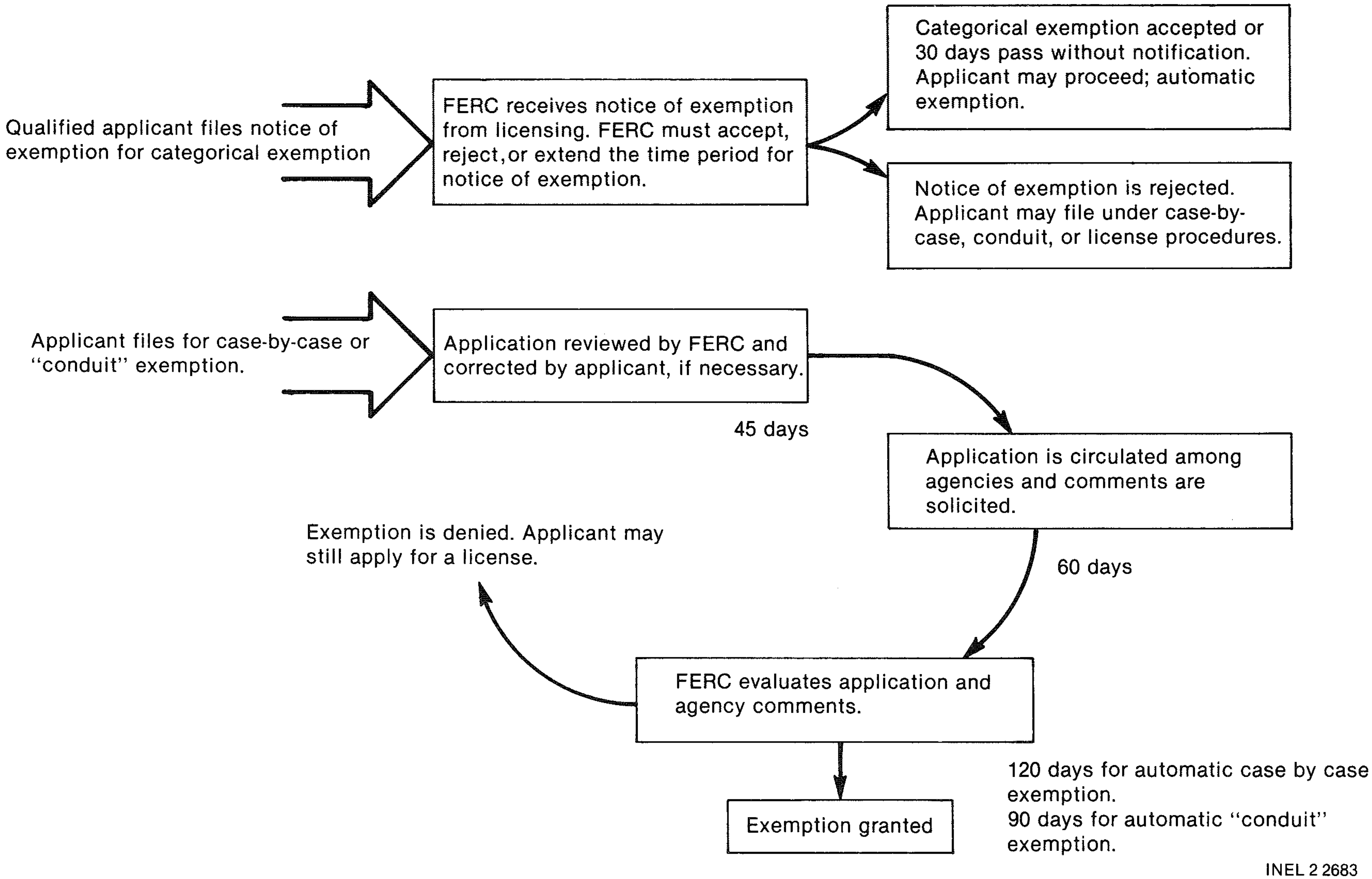

Figure 8-3. Application process for an exemption from licensing requirements.

- Construction or operation of the development must not adversely affect any threatened or endangered species or critical habitat listed in the regulations of the U.S. Fish and Wildlife Service of Department of the Interior and the National Marine Fisheries Service of the Department of Commerce.

If only Federal lands are needed to develop and operate the proposed microhydropower project, any developer may file a notice of exemption from licensing if the site meets the above criteria. If non-Federal lands are required to develop and operate the project, the developer must have all the real property interests in the necessary non-Federal lands in order to file a notice of exemption.

In filing a notice of exemption with the FERC, you should include copies of letters from the U.S. Fish and Wildlife Service or a similar state agency and the state historical agency. The notice of exemption from licensing is automatically approved if no followup from the FERC is received within 30 days of the filing.

Although this action completes the licensing procedure with the FERC, it does not eliminate the need for you to meet all state and local requirements or to obtain approval to use any Federal lands that may be involved.

8.3.1.3 Conduit Exemption. If your microhydropower project does not qualify for the notice of exemption but does use a manmade canal or conduit, then your next option is to request a conduit exemption.[a] The conduit exemption is simpler than a case-by-case exemption (the next category) because of its location on a manmade conveyance system. If your site meets the following qualifying criteria, your application for exemption will be granted within 90 days of filing with the FERC:

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a. The conduit exemption is explained in FERC Order No. 76, Docket No. Rm 79-35, which can be found in the Federal Register, Vol 45, No. 83, April 28, 1980, pp 28,085-28,092.

- The site must be entirely on non-Federal land.

- The principal purpose of the conveyance system must be other than the generation of electrical power, i.e., water supply for irrigation, domestic use, industrial use, etc.

- No dam can be involved that would not have been built even without the hydropower generation.

Your application for exemption will be circulated by the FERC to appropriate Federal agencies for 45 days. If these agencies return no comments within that period, their acceptance of the application is assumed. The FERC then has another 45 days to act on the application. If the FERC takes no action within 90 days of the initial filing, the application for exemption from licensing under Part I of the Federal Power Act is automatically granted. If all necessary local and state requirements have been met, you can now proceed.

8.3.1.4 Case-by-Case Exemption. If your microhydropower project does not qualify for the notice of exemption and is not using a man-made canal or conduit, then your next option is to request a case-by-case exemption.[a] The case-by-case exemption process is similar to that for conduit exemptions, but it is broader in coverage and takes 120 days for automatic approval. The case-by-case exemption covers existing dams and natural water features--that is, elevation features in streams that lend themselves to diversions for water power generation without the need for a dam or impoundment--on all lands.

For this case, if your project uses an existing dam, it must have been built prior to April 20, 1977; furthermore, the impoundment cannot be altered through reconstruction of an unsafe dam. The operation of the project must be acceptable to the U.S. Fish and Wildlife Service, or the

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a. The case-by-case exemption is explained in FERC order No. 106, Docket No. RM80-65, which can be found in the Federal Register, Vol 45, No. 224, November 18, 1980, pp 76,115-76,165.

National Marine Fisheries Service, or a similar state agency where appropriate.

If the project site is totally on Federal land, any developer may apply for an exemption. If non-Federal land is involved, the developer must have all the necessary non-Federal real property interests on order to apply.

As mentioned above, your exemption is automatically granted in 120 days if the FERC has not acted. Once again, this does not exempt you from applicable local, state, and Federal regulations not covered by Part I of the Federal Power Act. However, obtaining this exemption is a major step, and it often satisfies other requirements.

8.3.1.5 License. If your microhydropower project cannot be exempted under one of the above options, then your remaining course is to pursue a license, generally a minor license. Normally, this procedure will be too expensive for Category 1 developers to justify. If this route must be followed, it would be wise for a Category 2 developer to build a project large enough to cover the costs involved in the rather lengthy licensing process. Also, you will probably require the assistance of an architectural engineering firm with experience in hydropower to complete the licensing process.

There are three actions normally taken by the FERC:

- Issuing an exemption from licensing (already discussed in the previous paragraphs)
- Issuing a preliminary permit for a hydropower development
- Renewing or issuing a license for a hydropower development.

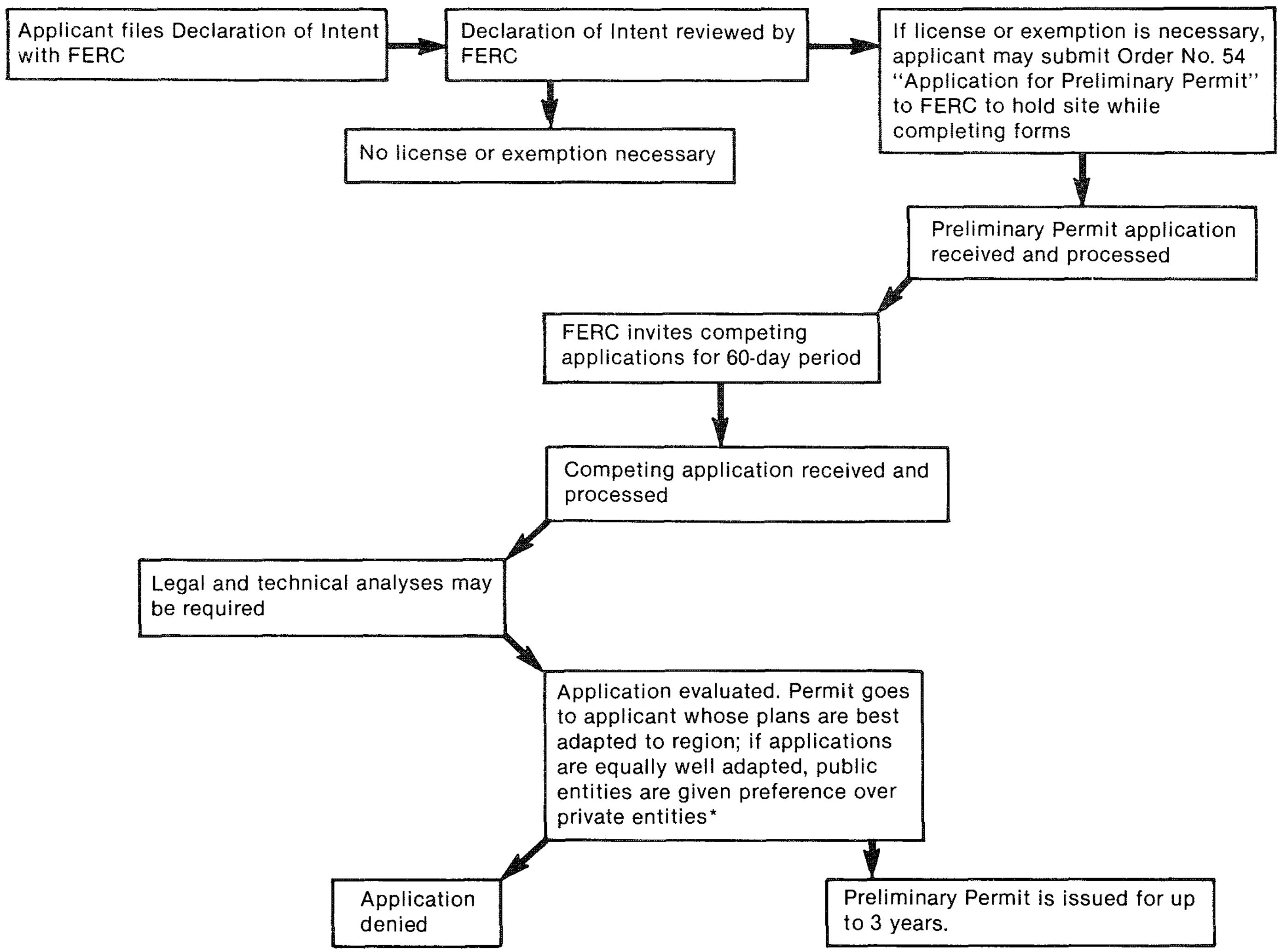
The purpose of obtaining a preliminary permit is to secure priority for your license where there is competition for development of a site. This protects your claim to the site while you collect the necessary data and make feasibility studies in preparation for submitting the formal license application. You do not have to have a preliminary permit, but obtaining one may be a very important step in protecting your claim to a particular site. Figure 8-4 is a flow chart of the FERC preliminary permit process. The contents of an application for a preliminary permit are specified in Section 4.81 of Chapter 1, Federal Energy Regulatory Commission, Title 18, Conservation of Power and Water Resources, Code of Federal Regulations (CFR).

The license application is the final and most complex step in the FERC licensing process. If you cannot obtain an exemption from licensing as described above, you should be able to use the FERC's short-form license application for your microhydropower development. The short-form license applies to minor projects. The requirements for the short-form license application are specified in Section 4.60 of Chapter 1, CFR 18.

FERC licensing regulations give municipalities and quasi-government agencies a preference under competitive licensing action. You should consider the advantage or disadvantage of this preference to a developer when applying for a license. Under the new rule-making orders of the FERC, however, this advantage for municipalities and quasi-governmental developers ceases to exist when exemptions are applied for. Thus, as an individual microhydropower developer, you are better off securing an exemption of one form or other rather than going through the complex licensing process.

8.3.2 Corps of Engineers and EPA Permits

The U.S. Army Corps of Engineers (COE) through three important Federal Acts--Section 10 of the Rivers and Harbor of 1899; Section 404 of P.L. 92-500, the Federal Water Pollution Control Act; and Section 103 of P.L. 92-532--has responsibility for permits authorizing structures and materials movement in navigable streams of the United States. This is often referred to as the navigation servitude requirement through which the Corps of Engineers protects the navigability of the waters of the nation. This authority covers the placement of fill necessary for the construction



*Recent practice seems to indicate that the permit goes to the earliest applicant because limited information on the best adopted plan is not available.

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Figure 8-4. FERC preliminary permit process.

of any structure; the building of any structure or impoundment requiring rock, sand, dirt, or other materials; the building of dams or dikes; fill for structures such as intake and outfall pipes associated with power plants; and any dredging. Figure 8-5 is a flow diagram of the procedure to be followed in securing a COE permit, known as the 404 permit. Contact the COE to determine how your project is affected and to obtain copies of the form (Form 4345) you must use to apply for the 404 permit. COE offices are listed in Appendix D-1.

You may have to provide several inputs under EPA-administered programs. The most important of these, required under Section 402 of P.L. 92-500 (33 U.S.C. 1341), is frequently referred to as the 402 permit or, more specifically, the National Pollution Discharge Elimination System (NPDES) permit. This section of the act covers the discharge of any pollutant into a navigable stream from any point source. It requires that you determine whether your microhydropower development will discharge any pollutants. If your project in any way diminishes the quality of the water by adding sediments, decreasing the oxygen content, or increasing the temperature, it can be considered as discharging pollutants. Another question is whether a microhydropower development constitutes a point source. The courts have tended to rule that a dam does constitute a point source of pollution.

While Federal responsibility for this program lies with the EPA, the actual administration and field checking are generally delegated to an appropriate state agency. To apply for a 402 permit or a waiver showing compliance with the Federal water quality standards, obtain EPA Form 7550-8 from the state agency responsible for assuring compliance with these standards. This form can also be obtained from the nearest regional office of the EPA. The state agencies responsible for water quality and pollution control are listed in Appendix E-4, and EPA offices are listed in Appendix D-2.

The EPA may also require inputs under Section 404 of P.L. 92-500. The 404 and the 402 permitting processes have many overlapping provisions, and the question arises: If a 404 permit is granted, does it exempt a

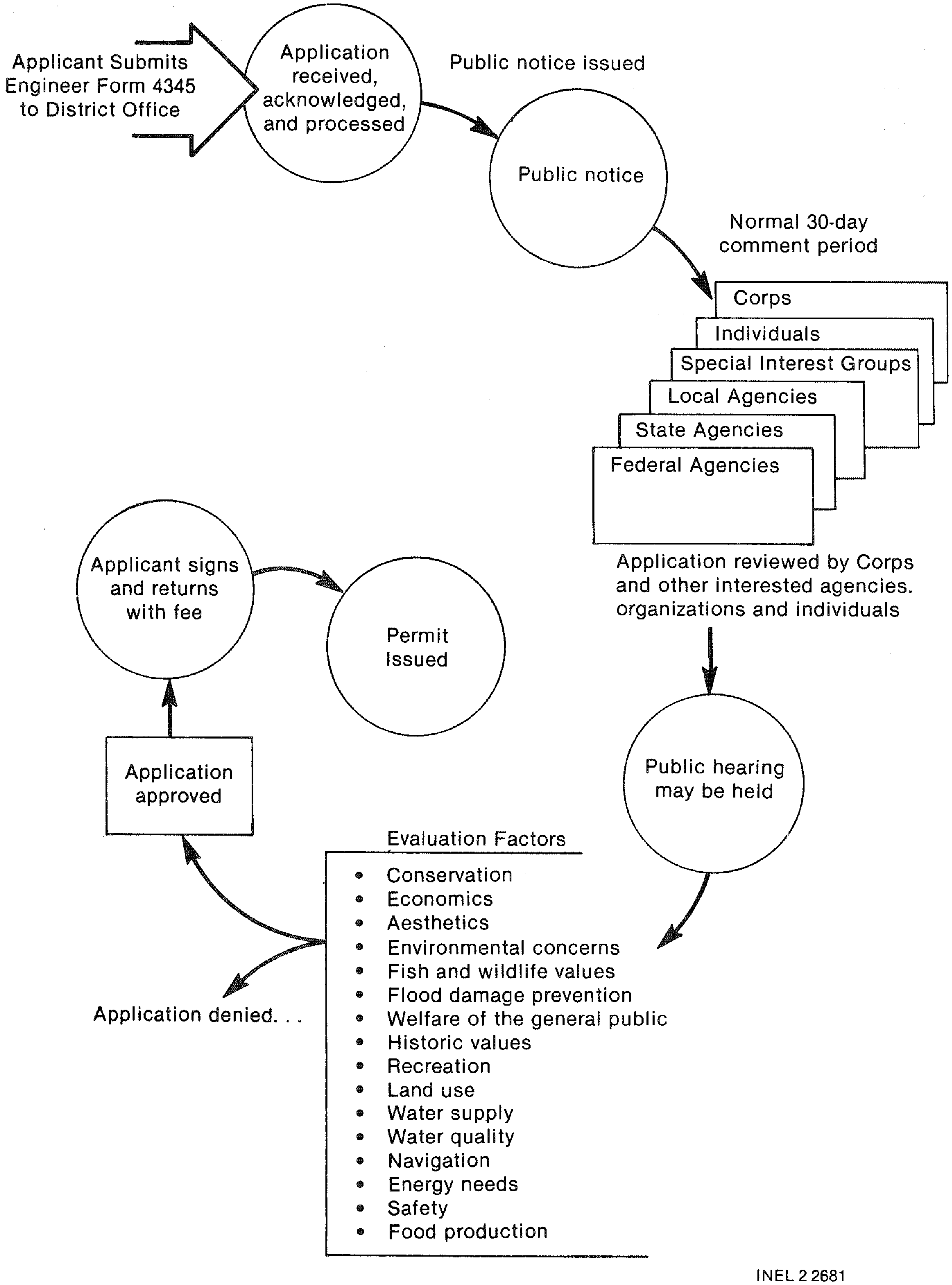

Figure 8-5. Flow diagram of U.S. Army Corps of Engineers permit procedures.

developer from obtaining a 402 permit? There seems to be confusion in the courts on this issue. While two references[a,b] appear to support the contention that obtaining a 404 permit does exempt the developer from obtaining a 402 permit, it would be prudent to check with the EPA.

8.3.3 Other Federal Laws and Federal Land-Use Permits

Even though the permit processes described above cover the most frequently needed Federal permits, there are other Federal laws you may need to consider, depending on specific characteristics of your site. The most important of these laws are listed in Table 8-4, and a brief discussion of their significance to microhydropower development is presented in Appendix C. Also in Appendix C is a discussion of Federal land-use permits such as for the use of Forest Service land. You should determine at an early stage whether any of these are applicable and, if so, take the appropriate steps to obtain any necessary permits, approvals, etc.

TABLE 8-4. LIST OF PERTINENT FEDERAL LAWS

1. National Environment Policy Act (January 1, 1970), 91st Congress
   (P.L. 91-190)
   42 U.S.C. 4321F.

2. Fish and Wildlife Coordination Act (August 12, 1958), 85th Congress
   (P.L. 85-624)
   16 U.S.C. 661-64; 1008

3. Endangered Species Act (December 28, 1973), 93rd Congress
   (P.L. 93-205)
   16 U.S.C. 1531-41F.

4. National Historic Preservation Act (October 15, 1966), 89th Congress
   (P.L. 89-665)
   16 U.S.C. 460a-t

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a. W. H. Rogers, Environmental Law, West Publishing Co., 1977, p. 399.

b. Environmental Law Institute, Air and Water Pollution Control Law, 1980, p. 485.

TABLE 8-4. (continued)

5. Federal Water Pollution Control Act (October 18, 1972), 92nd Congress (P.L. 92-500)
   33 U.S.C. 1251-1265F.

6. Water Quality Improvement Act (April 3, 1970), 91st Congress (P.L. 91-224)
   33 U.S.C 466 + more

7. Clean Water Act Amendments of 1977 (December 27, 1977), 95th Congress (P.L. 95-217)
   33 U.S.C. 1251

8. Wild and Scenic River Act (October 2, 1968), 90th Congress (P.L. 90-542)
   16 U.S.C. 1271-87

9. National Wilderness Preservation Act (September 3, 1964), 88th Congress (P.L. 88-577)

10. Coastal Zone Management Act (October 26, 1972), 92nd Congress (P.L. 92-583)
    16 U.S.C. 1451-1464

11. Federal Land Policy and Management Act of 1976 (October 21, 1976), 94th Congress (P.L. 94-579)
    43 U.S.C 1701, 02F

12. Federal Power Act (June 10, 1920; Aug. 26, 1935; May 28, 1948, etc.). See also Federal Water Power Act

13. Public Utility Regulatory Policy Act of 1978 (November 9, 1978), 95th Congress (P.L. 95-617)
    16 U.S.C 2601-2633F

14. National Trails System Act (October 2, 1968), 90th Congress

15. Pacific Northwest Power Planning and Conservation Act (December 5, 1980), 96th Congress (P.L. 96-501)
    16 U.S.C. 837-839

8.4 Marketing

All Category 2 developers and some Category 1 developers who plan to sell their excess power will be required to enter into a sales contract with a utility. The contract can be negotiated directly with the utility, or the developer may decide to pursue a contract based on the Public

Utility Regulatory Policy Act (PURPA) rates, which may or may not be set by the State PUC. Generally, only Category 2 developers will want to pursue the PURPA rate and then only if they are producing significant power.

The first part of this subsection discusses a general sales contract. The second part explains PURPA and what is required to qualify.

8.4.1 Sales Contract

If you are a microhydropower developer who plans to sell power, you will be required to enter into a written contract for the sale of produced energy to the power distributing utility. This is a negotiated agreement. If you are able to finance the project without other securities as collateral, you will generally need a contract that runs until the conclusion of debt service payments in order to obtain the necessary financing. The following are representative contracts:

- One with constant cash flow, in which the purchasing utility pays a set annual fee independent of the power produced, with an escalation clause, if desired

- One written to recover all the facility costs plus some profit for the developer

- One written to require the purchasing utility to pay a floating price based on its cost of purchasing power elsewhere.

In general, the first case will be less risky for the developer and thus will usually involve a lower price for the electricity produced. The second case puts more risk on the developer since it does not cover the risk of zero output. The third case gives the developer the least protection but would likely result in a higher unit price for the electricity sold. Variations of these forms of contracts will prevail, depending on the desires of the contracting parties. It is customary for these sales contracts to be on file with the State PUC because the information is necessary for the commission to set utility rates.

Normally, you will be required to pay for all costs of interconnection with the purchasing utility's system. You will also be expected to purchase insurance covering liabilities arising from the operation of your microhydropower development and its interconnection with the purchasing utility's system. The contract will normally specify the phase, current frequency, voltage, and delivery location of the delivered energy, and will require appropriate facilities for its connection to the purchasing utility's system. The terms of the agreement will also define the sales price or prices, termination procedures, and provisions for reasonable inspection and for interruption of the electricity. Many purchasing utilities have developed a standard agreement form for units in the microhydropower range of 100 kW or less.

You should contact the individual purchasing utility or utilities early in the planning process to obtain needed information and to develop the necessary harmonious working relations. Where more than one purchasing utility is available, there may be a significant difference in the avoided cost permitted by the PUC. Hence, you should inquire with more than one utility if possible. You should also contact the State PUC for information on the various options that are available in the negotiation of the sales contract.

8.4.2 PURPA

The U.S. Congress in 1978 enacted the Public Utility Regulatory Policy Act (PURPA), P.L. 95-617 (16 U.S.C. 2701), to help preserve nonrenewable energy resources and to give incentives for development of renewable resources that are not being used to their optimum potential. This includes existing dams and remaining stream sites that are readily adaptable to power generation but are presently undeveloped. The construction of small-scale hydropower plants at such stream sites could lessen the nation's dependence on foreign oil and help alleviate inflation by countering the Country's balance of payment deficits. The full text of PURPA can be found in the Federal Register, Volume 45, No. 56, dated March 20, 1980.

Provisions of the act encourage municipalities, electric cooperatives, industrial development agencies, private entities, and nonprofit organizations to undertake small-scale hydropower developments at qualified sites. This is done by requiring electrical utilities to purchase the power produced by these small power plants at the utility's avoided cost (see Subsection 8.4.2.2). The act eliminated several problems for developers: (a) the reluctance of electric utilities to purchase the power produced because of the lack of in-house control and the perceived unreliability of the production, (b) the charging of discriminatory rates for backup power by some electrical utilities, and (c) being considered an electric utility and thus becoming subject to extensive state and Federal regulations.

8.4.2.1 Qualifying Facility. Significant among PURPA requirements is the definition of a "qualifying facility." Your facility can qualify for avoided-cost payments from electrical utilities under PURPA as specified above under the following conditions:

- The power development and all other facilities at the same site that use the same energy source must not exceed a generating capacity of 80 MW. Facilities are considered as located at the same site if they are within one mile of each other and, for hydropower facilities, if they use water from the same impoundment for power generation.

- More than 50% of the facility's total energy input must come from the use of biomass, waste, renewable resources, or a combination of these.

- The small hydropower facility may not be owned by a person or company primarily engaged in the generation or sale of electric power. A cogeneration or small production facility will be considered as owned by a person or company primarily engaged in the generation of electric power if more than 50% of the equity interest in the facility is held by an electric utility or utilities, or by a public utility holding company or companies or any combination thereof.

8.4.2.2 Avoided Cost. The provisions of PURPA, P.L. 95-617, are designed to provide incentives for developing renewable energy resources, including hydropower. A number of states have also passed state public utility regulatory acts to further encourage development of renewable resources, including hydropower. If the purchasing utility can reduce its costs or avoid purchasing energy from another utility by purchasing electric energy from a qualifying facility (as defined above), the rate for the purchase is to be based on those energy costs that the utility can avoid, which are called the avoided costs. This implies that the purchasing facility can defer or delay the construction of a new generating plant, or decrease the purchase of power from another utility because of the power purchased from the small hydropower development.

Factors influencing the price you will receive for power you sell under PURPA include:

- The availability of capacity or energy[a] at a qualifying facility during daily and seasonal peak energy demand periods

- The reliability of the capacity or energy supply

- The duration of the period during which the qualifying facility can contractually guarantee a given capacity or supply of energy to the utility

- Coordination between the scheduled outages of the qualifying facility and of the utility

- The backup capability of the qualifying facility in the event of a utility system emergency

- The lead time associated with the addition of the qualifying facility

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a. The difference between the energy and capacity of a hydropower plant is important in understanding the avoided-cost rate. These terms are defined in the Glossary (Appendix G).

- Costs or savings that can result from differential line losses in transmitting and delivering the energy

- Alternative nonrenewable energy fuel costs.

PURPA also requires that the purchasing utility offer to purchase the total output of energy or capacity or any portion of either that the qualifying facility wishes to offer. The avoided-cost rate that must be paid to a qualifying facility

- Shall be just and reasonable and in the public interest

- Shall not discriminate against the qualifying power producer.

The ultimate responsibility for defining the avoided cost has been assigned to the State PUC or its equivalent in each state. The PUCs in turn have required the purchasing utilities to present their supporting information for defining the avoided costs. The burden of proof falls on the purchasing utility when it establishes an avoided-cost rate for the purchase of power. The rate must be based on accurate data and systematic costing principles.

You must contact both the purchasing utility and the State PUC when making arrangements for an avoided-cost sale contract under PURPA. State PUCs are listed in Appendix E-2. Knowing how to contract with a purchasing utility is important to the early planning of any microhydropower project from which you plan to sell power. A detailed treatment of this topic for the state of Washington is covered in Marketing Manual, Volume II, Developing Hydropower in Washington State, published by the Washington State Energy Office and the Department of Energy.

8.4.2.3 Sales Opportunity. The PURPA act specifies that purchasing utilities must purchase the output from qualifying facilities. To take advantage of this sales opportunity, you must first know that your proposed microhydropower development is a qualifying facility, as discussed in Subsection 8.4.2.1, above. Purchasing utilities can include investor-owned utilities, municipal electrical utilities, electric cooperatives, public utility districts, state agencies, federal agencies, or any person who sells electricity. Federal electric energy marketing entities like the Tennessee Valley Authority and the Bonneville Power Administration can also be purchasing utilities. Federal power marketing entities are listed in Appendix D-7.

A purchasing utility cannot have more than a 50% equity interest in a microhydropower development if the development is to be classified as a qualifying facility and claim the avoided cost price structure mandated by PURPA. This means that no public utility holding company or person owning a portion of the purchasing utility can claim the avoided-cost provisions of PURPA if they also have an equity interest greater than 50% in the qualifying facility.

The state can furnish listings of purchasing utilities. This information is normally available from the State PUC (listed in Appendix E-2) or from the Office of Energy (listed in Appendix E-8) in each state.

Section 292.303 (f) of PURPA indicates that there are situations in which a purchasing utility is not obligated to purchase energy from the qualifying facility of a microhydropower developer:

- A purchasing utility is not obligated to purchase from a qualifying facility during periods when such purchases would result in a net increase in operating expenses for the electric utility

- A purchasing utility can discontinue purchase from a qualifying facility during an emergency if the purchase of energy will contribute to the emergency.

The State PUC or energy regulatory agency has the authority to verify whether these exemptions from purchase can be allowed. As mentioned earlier, State PUCs or the equivalent agencies are listed in Appendix E-2.

8.5 Example Sites

This section presents step-by-step procedures for obtaining the necessary certifications, permits, and licenses or exemptions for the two example sites used in this handbook:

- A run-of-the-stream site in Washington State
- A manmade site in New Hampshire.

8.5.1 Run-of-the-Stream Site

The run-of-the-stream site is located in mountainous terrain in Washington. This site has been described previously in Subsection 2.7. The owner is a Catergory 1 developer whose primary objective is to provide power for two family dwellings that are currently satisfactorily supplied power from a 12-kW diesel generator.

For this example, it is assumed that title to the generating site belongs to the developer. It is also assumed that during the reconnaissance study, the developer contacted

- The Federal Energy Regulatory Commission (the Federal agency responsible for licensing essentially all non-Federal hydropower projects)
- The Washington Department of Ecology (WDOE) (an environmental checklist was obtained, filled out, and returned)
- The Washington Department of Fish
- The Washington Office of Archeological and Historical Preservation
- The Washington State Energy Office (WSEO), and
- The U.S. Forest Service.

to determine whether there are any major hindrances to development. Major hindrances to development would include the presence of a threatened or endangered species in the site area, an anadromous fish run in the stream, a historic site at the diversion dam or power plant site, a scenic designation for the site, or major agency opposition for some reason. Each agency contacted was asked for advice, the prerequisites for its permit(s), and the time involved between application and issuance.

Figure 8-6 shows a flow diagram of the licensing process for microhydropower projects in Washington. The State of Washington has published an excellent guide book for the licensing process, Developing Hydropower in Washington State: A Guide to Permits, Licenses, and Incentives, which can be obtained from either the WDOE or the WSEO. The developer in Washington should obtain this guide book early in the reconnaissance process and follow it throughout.

As soon as the reconnaissance study indicates an environmentally and economically favorable site, the developer should submit to the FERC a notice of intent to file for an exemption or preliminary permit. Although a notice of intent is not necessary, it is generally a good investment, since it secures the site against all competition that might be considering the same site. A notice of intent to file for exemption only requires an acknowledgment, whereas it generally takes about 6 months to obtain a preliminary permit from the FERC. The applicant should specifically ask for any recent additions or changes in the application process. A number of ways to simplify the process for small-scale hydropower developments, especially microhydropower, are currently under study by the FERC.

Every hydropower project must have a water right. Filing for a water right permit should be one of the developer's first steps, in order to establish his claim. Since the WDOE issues Washington water right permits, there should be no technical problems in obtaining the permit if the developer has already established contact with the WDOE as previously suggested.

Initiating Contacts made with:

1. Federal Energy Regulatory Commission
2. Washington Department of Ecology
3. Washington Department of Fish
4. Washington office of Archeological and Historical Preservation
5. Washington Energy Office

Step 1

Send FERC a notice of intent to apply for a case-by-case exemption, or apply for a preliminary permit, to secure the site while completing the "licensing" process.

Step 2

Local Government Permission

Step 3

Application for Water Right and State Environmental Certification

Step 4

Water Quality Certification

Step 5

U.S. Forest Service Land-Use Permit

Step 6

Miscellaneous Permits as Required

Step 7

Federal Energy Regulatory Commission
Case-by-Case Exemption or Minor License

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Figure 8-6. Flow diagram of licensing process for a microhydropower project in the state of Washington.

Insofar as possible, the developer should accomplish the steps described in the following paragraphs simultaneously.

The microhydropower project must comply with local planning and zoning ordinances. In this case, the agency for the developer to work with is probably the county planning and zoning commission or the public works department. The developer may have to obtain a building permit or a letter certifying that the proposed project is in compliance with local ordinances. The building process itself should be discussed with these local officials since a variety of specialty permits may be needed, depending on the actual construction process. Page 13 of the Washington guide book, reproduced here as Table 8-5, lists local permits commonly required in the State of Washington.

The project will also need environmental certification under SEPA, the Washington State Environmental Policy Act. The WDOE is the administrator of this program. This step should be straightforward if the environmental checklist was filled out and turned in to the WDOE during the reconnaissance study. The expected result at this point is a negative declaration, meaning that no significant environmental impact is expected as a result of the project. This expectation is based on the incorporation of suggestions received during initial contact with the agency about minimizing the potential environmental impact of the project. Had a major obstacle arisen during the initial contacts, it would probably have required an environmental impact statement, or at least a hearing, either of which would seriously jeopardize the economics of a microhydropower project.

If the environmental certification does not include historical and archeological considerations, then the developer should contact the appropriate agency and obtain a letter certifying that the site is in compliance with the related state code. In the State of Washington, this is the Office of Archeology and Historic Preservation. FERC Order No. 202 does not require a historical and archeological certification on categorical exemptions for microhydropower projects, but the other exemption and licensing options do.

Water quality certification is also required under Federal law (Federal Water Pollution Control Act, P.L. 92-500; Water Quality

TABLE 8-5. LOCAL PERMITS THAT MIGHT BE NECESSARY IN THE STATE OF WASHINGTON.

LOCAL PERMITS

The local (city and county) permits that are necessary for a hydro project will vary from county to county in number, type, application, location, and cost. The following table shows the most common permits.

Name	From	Reason	Approximate Time
Shoreline substantial development permit	County Planning Department	Required if any part of project is within 200 ft of an applicable shoreline.[a]	4 months
Zoning conditional use permit	County Planning Department	Required if project is not in conformance with zoning for county master plan.	3 months
Surface water drainage plan approval	County Department of Public Works	Drainage plan must be approved before several other permits can be issued.	1 month
Commercial building permit	County Building and Plumbing Department	Applies to construction of powerhouse.	2 weeks
Temporary road closure permit	County Department of Public Works	Needed for any construction that would completely close a road to traffic.	1 week
Utility permits	County Department of Public Works	Needed for transmission lines and utility intertie.	2 weeks
Sewage holding tank variance	County Department of Health	For sewage facilities installed as part of the project on a permanent basis.	2 months
Grading permit	County Department of Public Works	For all excavation or filling activities, except as noted in the Uniform Building Code.	1 month
Plumbing permit	County Building and Plumbing Department	Must approve plumbing plans.	1 day
Interlocal agreement for construction on county roads	County Department of Public Works	Short-term agreement applies to upgrading and performing maintenance work on county roads used by overweight construction equipment	1 month review 3 months agreement
Permit to operate overweight vehicles on city or county roads	City/County Department of Public Works	Required only where road conditions are sensitive to damage by overweight vehicles.	1 day

[a]Shorelines on segments of streams upstream from a point where the mean annual flow is 20 cfs or less and shorelines on lakes less than 20 acres in size are not designated as applicable shorelines.

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Improvement Act, P.L. 91-224; and Clean Water Act Amendments of 1977, P.L. 95-217). The WDOE is the state agency responsible for this certification. For the described project, there should be no significant problems, although the developer may have to install the diversion structure and bury the penstock piping in accordance with agreed specifications. In this particular example, the developer may have to obtain the USFS land use permit described below before the water quality permit can be issued. The key to minimizing problems at this stage lies in clarifying the priority of applications during the initial contacts with the various cognizant agencies.

A U.S. Forest Service permit to use government land for the diversion structure, penstock, and access roads will be necessary. The developer should obtain the necessary forms during the reconnaissance study so that they can be filled out as the required information becomes available.

A variety of other permits could be necessary, depending on the final project plan and on local and state regulations. Insofar as possible, these should be determined in advance during the reconnaissance study. (See pp 13, 17, and 18 of the Washington handbook for other local and state permits which might be necessary).

Since the FERC is required by Federal law to ensure compliance with appropriate local, state, and Federal laws before issuing a license or exemption, The FERC short-form license or exemption is generally the last permit the developer obtains before starting construction. In the case of the categorical exemption for microhydropower under FERC Order No. 202, however, this is not true. The categorical exemption can be granted before other Federal, state, and local requirements are complied with. In any case, the developer should obtain the specific forms required at the time of initial contact during the reconnaissance study. Much of the information required by the FERC is identical to that required by the state. Therefore, certifications or permits from the various state agencies are generally acceptable to the FERC and will greatly expedite obtaining this final license.

Once again, the importance of establishing early and ongoing communication with the permitting agencies to assure orderly compliance with their requirements cannot be emphasized too strongly.

8.5.2 Manmade Site in New Hampshire

The manmade site is located at an existing dam on a small stream in the rolling hills of New Hampshire. The site includes an old, retired gristmill. The electric utility's distribution line passes within 300 yards of the mill. This site has been described previously in Subsection 2.7. The owner is a Category 2 developer whose primary objective is to supply his own electrical needs and sell any excess power to the utility.

As with the previous example, it is assumed that the developer has approached the licensing process systematically by establishing early contact with key local, state, and federal agencies. These include

- The Federal Energy Regulatory Commission
- The New Hampshire Water Resource Board
- The New Hampshire Water Supply and Pollution Control Commission
- The New Hampshire Department of Fish and Game
- The New Hampshire Department of Resources and Economics
- The responsible local government entity.

Figure 8-7 shows a flow diagram of the licensing process for a microhydropower project in New Hampshire. Also see Figure 8-1, which shows a detailed flow diagram of the State of New Hampshire requirements for hydropower projects of all sizes.

Initial Contact with local, state and Federal agencies

1. FERC
2. N.H. Water Resource Board
3. N.H. Water Supply and Pollution Control Commission
4. N.H. Department of Fish and Game
5. N.H. Responsible local government entity

Step 1 ↓

Submit a letter of intent to file a notice of exemption, or file for preliminary permit with intent to file for exemption

Step 2 ↓

Legal title to dam site

NOTE: As many as possible of these steps should be performed simultaneously.

Step 3 ↓

Water right

Step 4 ↓

Dam safety permit

Step 5 ↓

Water quality certification

Step 6 ↓

Dredge permit

Step 7 ↓

Historic site certification

Step 8 ↓

Fish and game certification

Step 9 ↓

Planning and zoning certification or building permit

Step 10 ↓

FERC exemption

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Figure 8-7. Flow diagram of licensing process for a microhydropower project in the state of New Hampshire.

No two water development sites are exactly the same. The exact number of permits, certificates, and licenses or exemptions required will vary with the site characteristics and the mix of private lands, public lands, public waters, and navigable and nonnavigable waters involved. The exact step-by-step sequence for licensing this New Hampshire site cannot be specified without additional site-specific information and the output of interactions with the various local, state, and Federal agencies. The best procedure is for the developer to establish agency contacts early, ask for the necessary licensing forms and any written instructions that might be available, and then systematically complete the paperwork for local, state, and Federal licensing.

When making the initial agency contacts, the developer should take or send a land ownership map of the site, a drawing of the proposed project, and some pictures of the dam, gristmill, pond area, and stream. These will help the agency personnel in outlining requirements for licensing the development.

At the state level, the developer must obtain at least a water right permit, a dam safety permit, and a water quality permit or certification under Section 401 of P.L. 92-500. The state agency responsible for these is the New Hampshire Water Resource Board. The Water Resource Board must also consider effects on scenic and recreational values, fish and wildlife, downstream flows, and public uses where appropriate. The developer should secure all applicable forms at the initial contact.

During the initial contact, the developer should also ask the Water Resources Board about the historical classification of the old gristmill and dam. If the Water Resources Board cannot immediately answer this question, the developer should call or visit the Department of Resources and Economic Development (see Appendix E-9), which is in charge of historic preservation, to determine whether the proposed development is affected in any way.

During initial contact with the Fish and Game Department, the developer should clarify the status of the impacted land area and the stream. Since the stream has a considerable flow, it may be important to anadromous fisheries, or it may be classified as public trust or even as navigable. Any of these could present additional requirements leading to time delays and additional costs. The developer should also ask whether the development might affect any threatened or endangered species in the vicinity of the dam site. The presence of such species could greatly complicate the development of the site.

If the project calls for dredging, the developer will need a permit from the Water Supply and Pollution Control Commission (see Appendix E-4). The correct form should be obtained during initial contact with the agency and filled out in a timely fashion.

Next, assuming that the initial inquiries do not uncover any insurmountable difficulties, the developer should procure a legal determination of ownership of the affected lands and the riparian right to the water. Legal ownership of both sides of the stream at the dam site is critical. The pondage area could be acquired by eminent domain if necessary, provided the developer has legal title to the dam site.

As soon as the site ownership is determined, the developer should submit to the FERC a notice of intent to file for an exemption or preliminary permit. Although a notice of intent is not necessary, it is generally a good investment, since, with one exception, it reserves the site against competitive licensing applications. The developer should have obtained the ncessary forms during the first contact with FERC and should have gathered the required information during the reconnaissance study.

The next step is a study to ascertain as closely as possible the technical, economical, environmental, and institutional feasibility of the project. The larger the project, the more likely it is that a professional engineer or consulting firm should be handling this step. An engineer will need to certify the safety of the dam in this particular project.

Since this project is less than 5 MW, it is exempt from New Hampshire Public Utility Commission regulations, but the PUC avoided-cost rulings could be a major input to the economic analysis and overall project feasibility. Therefore, the developer should seek out the New Hampshire PUC (see Appendix E-2) to get this information.

If the stream is considered navigable, the developer will have to obtain a permit under Section 10 of the Rivers and Harbors Act of 1899 from the COE, which is responsible for protecting navigable streams. If dredging is involved, a permit under Section 404 of P.L. 92-500 will probably be required from the COE as well as from the state. Considerable review is involved in these permits since The U.S. Environmental Protection Agency, the U.S. Fish and Wildlife Service, and various state agencies all comment on them.

At the same time the state and Federal permits are being secured, the developer should be working with local governmental entities to establish compliance with the necessary planning and zoning regulations and obtain a building permit. Land ownership certification and a dam safety permit may be prerequisites for a building permit. The key to minimizing problems at this stage lies in clarifying the priority of applications during the initial contacts with the various cognizant agencies.

All of the necessary forms for licensing should be filled out as part of the feasibility study so that, with a favorable feasibility report, licensing can be completed shortly thereafter. The time from the initial contacts to the licensed project may be more than a year. The larger the project, the longer this process will take.

Since the FERC is required by Federal law to ensure compliance with appropriate local, state, and Federal laws before issuing a license or exemption, The FERC short-form license or exemption is generally the last permit the developer obtains before starting construction. In the case of the categorical exemption for microhydropower under FERC Order No. 202, however, this is not true. The categorical exemption can be granted before other Federal, state, and local requirements are complied with. In any case, the developer should obtain the specific forms required at the time of initial contact during the reconnaissance study. Much of the information required by the FERC is identical to that required by the state. Therefore, certifications or permits from the various state agencies are generally acceptable to the FERC and will greatly expedite obtaining this final license.

Once again, the importance of establishing early and ongoing communication with the permitting agencies to assure orderly compliance with their requirements cannot be emphasized too strongly.

The FERC is currently streamlining its licensing process for microhydropower projects. The developer should seek the latest rulings from the FERC during the initial contact so as to comply with the correct regulations and minimize the paperwork involved. The

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should also be contacted for the latest New Hampshire information on legal requirements and also other information on incentives, sales contracts, marketing, and technical information helps.

Finally, when the project is licensed for construction, the developer must secure annual permits and plan for annual costs. These should also be considered in the reconnaissance and feasibility study stages because of how they influence the overall project economics.

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