CIVIL FEATURES

VOLUME VI

CONTENTS

FIGURES

TABLES

SECTION 1
INTRODUCTION AND OVERVIEW

Scope of Civil Features Volume

The objective of the Civil Features volume is to provide guidance in the preliminary civil facilities layout and to establish cost guidelines for the civil work required to add small hydroelectric powerplants to existing impoundments. The basic civil work includes:

1. Site preparation
2. Hydraulic conveyance facilities
3. Powerhouse and appurtenant facilities

Site preparation includes grading, foundation excavation, drainage and erosion control, access roads and parking facilities, and construction noise abatement and dust control.

Hydraulic conveyance facilities include penstocks, tunnels, canals, valves and gates, outlet works, and tailraces.

Powerhouse and appurtenant facilities include all structures for the powerhouse and equipment handling facilities, foundations for both the powerhouse and switchyard, and fencing around the project area.

Construction costs in this volume are for July, 1978. Unless otherwise noted, the construction costs used are from the engineering files of Tudor Engineering Company. These costs were developed from numerous small hydroelectric project feasibility cost studies. The historical record of cost increases in construction is presented in Section 6 for use in updating the costs beyond July 1978.

Small hydroelectric power projects, as defined in this volume, have operating heads of 100 feet or less and plant capacities of 15,000 kW or less. The lower limits on hydroelectric development are a function of the available equipment and the economics of developing power at the site.

Civil Features; Proportion of Project Costs

To determine the typical range of civil costs to total project costs for small hydroelectric installations, three main cost categories were compared; civil, electrical/mechanical and development or indirect costs.

Only the costs associated with the on-site features were included in the comparison. Transmission line costs from the plant switchyard to the power grid were not included. Neither were any right-of-way costs included, because these costs are unique to every project and do not have a common or predictable value.

The civil costs are described in this volume. The electromechanical costs are presented in Volume V. These costs were further categorized as turbine/generator, accessory electric equipment and miscellaneous power plant equipment costs for the purpose of this comparison. The indirect costs include the costs associated with engineering, administration, construction management, and legal and financial consulting. Interest during construction is included in the indirect costs. A contingency percentage is not shown as it would be applied to all cost categories to cover any unexpected increases in costs.

Figure 1-1 illustrates the range of proportional costs possible for small hydroelectric development. The top graph shows the case where the civil costs are minimum. The bottom graph shows where the civil costs are maximum. The proportion of the indirect cost for both cases is the same, at approximately thirty percent. The upper graph of Figure 1-1 includes those projects which usually have an existing outlet work which permits the power house to be designed with minimal penstock and other water way passage costs. The lower graph of Figure 1-1 includes the projects that require long penstocks and either major alteration of the existing outlet work or bypassing it by constructing new civil facilities.

Types of Sites Suitable For Hydroelectric Development

Hydroelectric power may be developed at any site where there is a flow of water between two bodies of water at different elevations. Besides sites at impoundment facilities, there may be possible hydroelectric sites at analagous sites such as a drop structure between two reaches of a canal. (Figure 1-2 shows a vertical drop of an irrigation canal.) Another example is a water aqueduct facility where an outlet, either to a lower pressure feeder main or to a storage facility, discharges water under pressure.

Basic Civil Feature Differences Between Small and Major Hydroelectric Installations

Differences between small and major hydroelectric installations are primarily related to the plant size and the importance of the installation to the power grid. The small hydroelectric plant usually has major equipment of a physical size that can be readily handled with portable lifting devices. Large, permanently installed cranes are required only for major installations. Similarly, small hydroelectric installations, not being critical to the power grid requirements, can have longer overhaul periods than would be appropriate for larger installations. This minimizes the area and facilities that are required for maintenance operations. Often, centralized shop facilities can be used, as the equipment items may be of a size that are easily transportable.

Typically, small hydroelectric installations are unattended and remotely operated. This reduces the require-

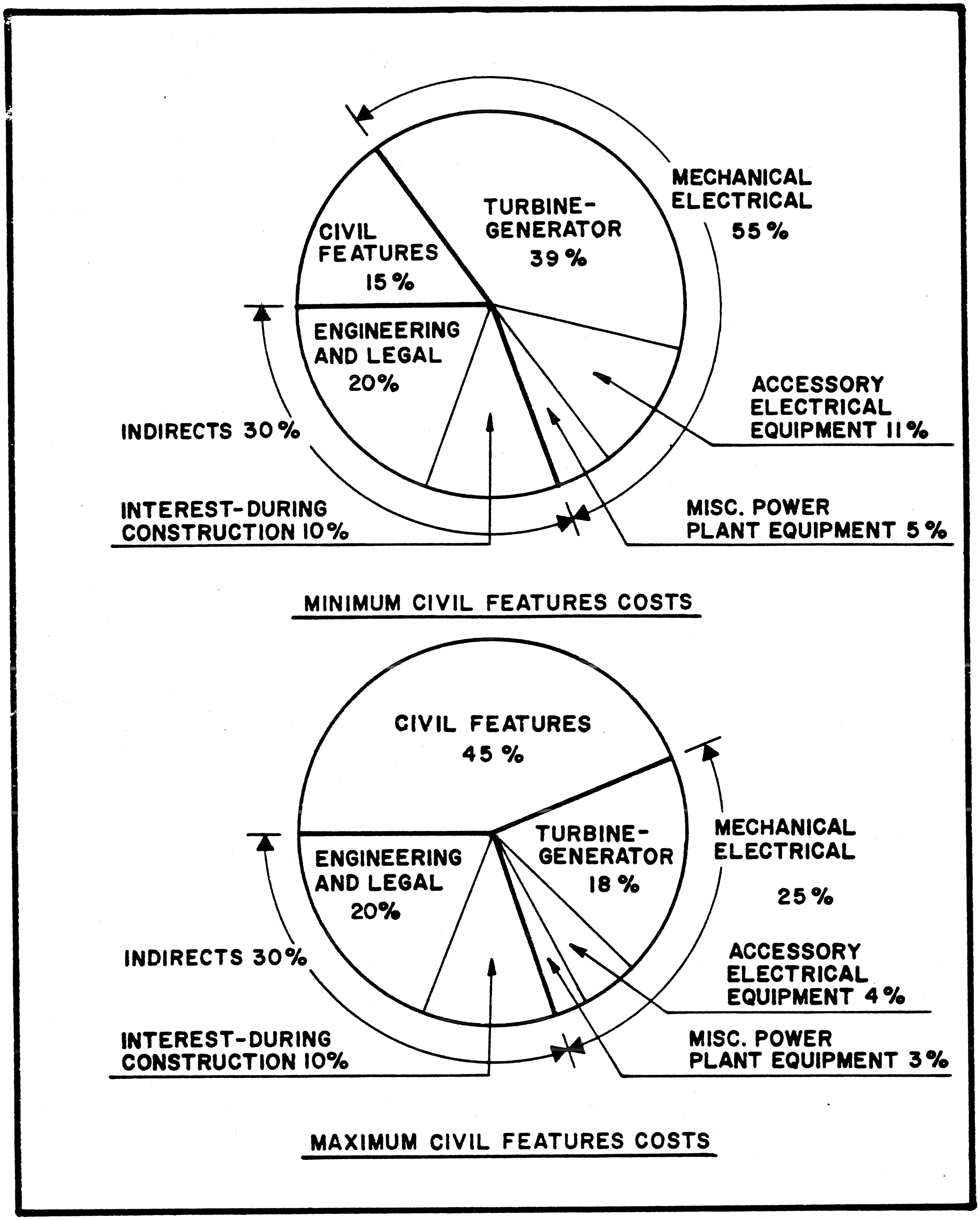


Figure 1-1. Range of Civil Features Costs

ments for working space, storage area, and personnel comfort items such as air conditioning, lockers, potable water and showers, from that which would be required for larger installations. Fire protection systems can also be kept to a minimum, and oil handling, filtering and storage can be portable, with permanent facilities being eliminated.

Methodology for Feasibility Determination

Detail Needed for Feasibility Assessment. This volume presents approximate construction and administrative costs that are adequate for a reconnaissance study. Project costs need only to be estimated to within plus-or-minus twenty percent to be considered satisfactory for an assessment of this type and effort should not be expended with the data to obtain a more precise estimate. The costs of civil features which are site specific and require engineering judgement and experience for their evaluation have not been included in this volume. However these areas are noted and with the addition of these costs the costs thus determined will be satisfactory for a feasibility assessment.

Steps for Determining Costs. Figure 1-3 graphically illustrates the steps that should be followed to determine the civil costs for a potential project. It is assumed that some information regarding the plant configuration will have already been determined from the other volumes of this manual. In particular, turbine type and throat diameter, powerhouse type, number of turbine/generator units and their capacity, flow rate, and design head for each unit should be determined prior to the evaluation of the civil costs.

After the above items have been determined, the project area should be analyzed and a tentative plant location selected. From the plant location and other information, the site area, the powerhouse area and the necessary facilities to convey water to the powerhouse and back to the streambed should be determined. Following the steps shown in Figure 1-3, the total civil cost is then determined for either a reconnaissance or feasibility cost assessment dependent upon the input data used.

After the civil cost has been estimated, the plant location selection should be examined to determine if a change in location or orientation could reduce costs. Several alternate locations may be evaluated and the least cost alternative selected.

General Description of Civil Features

Configuration. There is no standard configuration for adding a small hydroelectric installation to an existing

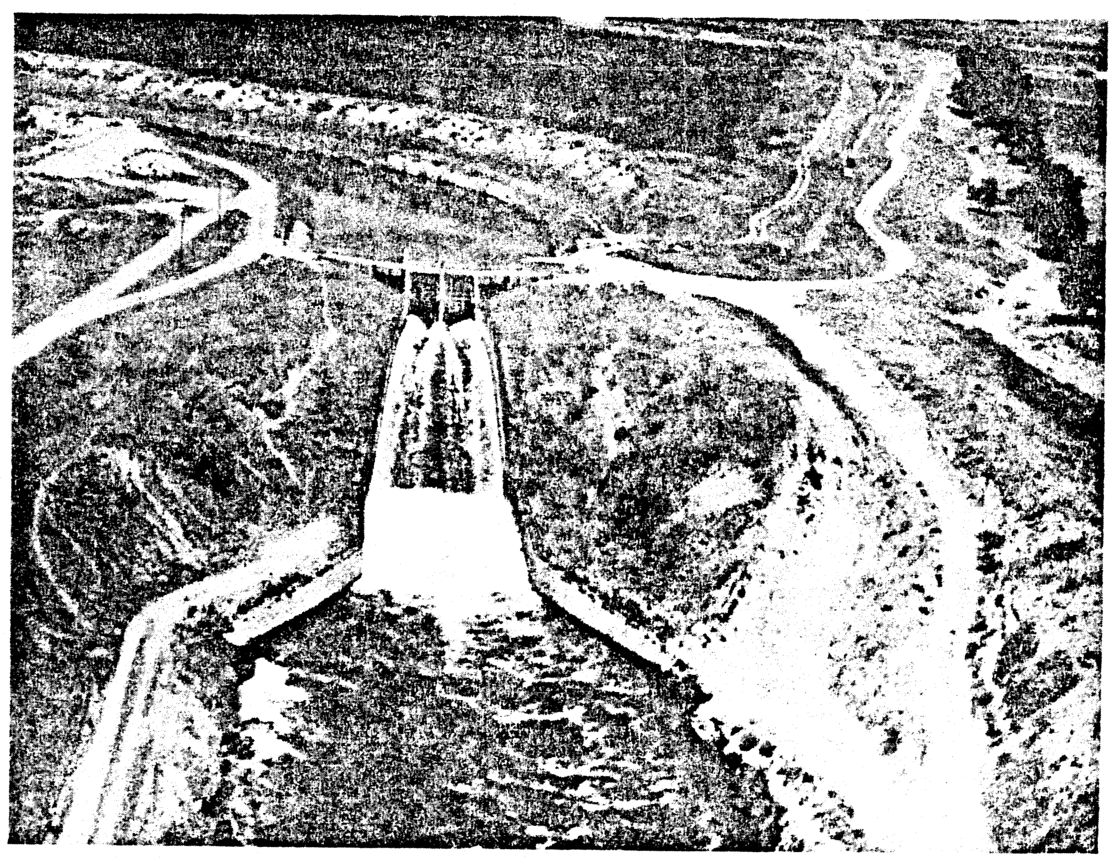


Figure 1-2. Vertical Drop on an Irrigation Canal

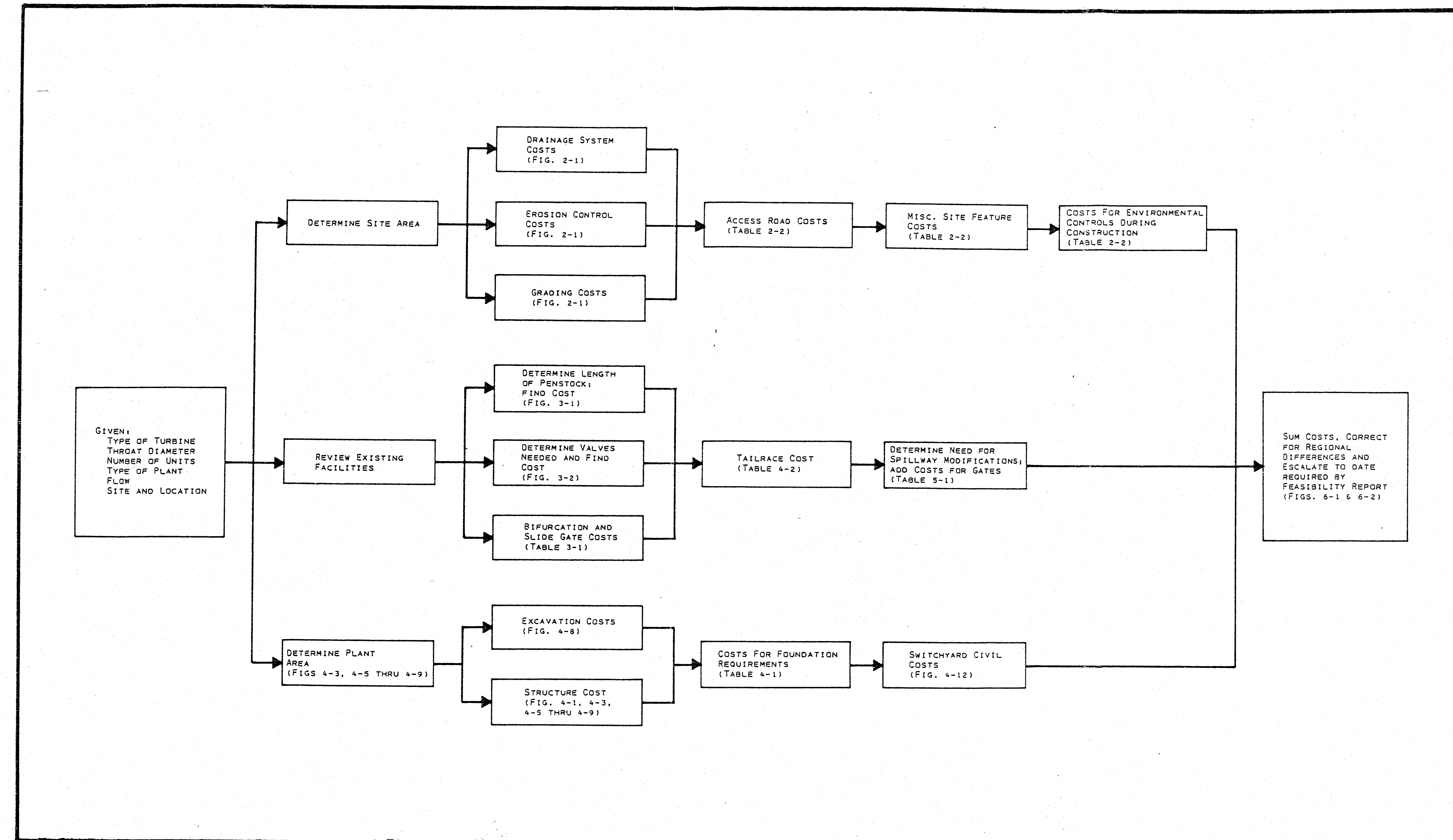


Figure 1-3. Steps for Determining Costs-Flow Chart for

impoundment. Many design decisions have to be made which are a function of the type of dam, location and type of outlet works, use of impoundment water, and location of the nearest electrical power grid. Nonetheless, the typical design configurations used for the basis of evaluating civil costs in this volume are sufficiently general, so that cost estimates prepared from the data presented should be suitable even for sites that require somewhat unusual configurations.

A potential hydroelectric site will have an existing outlet works, and the use of this existing outlet for the new plant should be made whenever possible, and is often necessary to achieve economic feasibility. This is usually done by constructing a bifurcation in this conduit, one branch becoming the upstream end of the penstock.

Several factors should be considered in the project layout. Ideally, it is best to locate the powerhouse as close to the downstream side of the dam as possible, minimizing the length of penstock. The site should have a minimum overburden, allowing the powerhouse to be founded on rock. The general site should be above a once in a hundred year flood stage. The switchyard site should also be above this flood stage and located for an easy electrical access to the power grid.

Intake. The intakes for small hydroelectric installations are generally already existing as part of the impoundment structure. Occasionally, it may be necessary to construct a new intake. This volume does not include intake construction costs. If a new intake is required, it should be placed high enough to prevent silt from being deposited on the intake floor. A high intake decreases the distance gates must be lifted and simplifies the task of cleaning the trash racks. Intakes must have trash racks and either slide gates or stop logs (depending on the project design) for shutting off the flow of water. The intake opening is generally rectangular or square. The flow passageway must have a transition constructed to match the shape of the penstock or tunnel to which the intake structure is connected. This passageway requires careful design. The water velocity through the trash racks should be realtively low and then gradually increase to the tunnel or penstock velocity without having the flow subjected to sharply converging surfaces or other features creating turbulence.

The trash racks should be designed for a differential pressure of twenty feet of water. The size of each trash rack is dependent on the size of the lifting facilities that are to be provided. The gate which is used for emergency closure should be placed in the intake structure at a point where the water veloctiy does not exceed ten feet per second. The gates may have fixed wheels and anti-corrosion, anti-friction bearings. Care must be exercised in the selection of bearings and gate material if the gate is to be stored in a submerged position. Stop logs or a bulkhead gate may be provided upstream of the emergency closure gate for proper maintenance of the emergency closure gate tracks or slots. However, it is not normally possible to position all the stop logs unless the water velocity in the passageway is near zero.

Water Passage. Often, the existing waterway from the impoundment to the downstream channel may be adapted for use in the small hydroelectric installation. The water passageway to the turbine should be as smooth and direct as possible. Any bends should be sufficiently upstream of the turbine to allow streamline flow at the turbine entrance. If a proposed water passageway would appear to deliver water to the turbine in an asymmetrical pattern, it is prudent to make a model study for determining the expected flow conditions (Davis and Sorensen 1969 Section 22). Design modifications can be made as a result of a model study and the model study costs are minor when compared to the potential savings in project costs.

Provisions must be made to permit venting of the tunnel and/or penstock downstream of the emergency closure gate. This prevents high negative pressures in the penstock if the gate is closed with the unit in operation.

Powerhouse. There are generally three main areas in a powerhouse; an area for the turbine/generator, a maintenance or erection area, and a service area.

The main area, housing the turbine/generator, is normally the central area around which the service and erection areas are positioned. In multiple unit hydroelectric installations, the service areas may be either at one end of the plant or grouped around each unit. The arrangement will depend on the site characteristics. A similar determination must be made for the erection areas.

Within the turbine/generator area, it is good practice to have walls at least ten feet from the turbine generator on those sides from which access for maintenance purposes is required. The ceiling heights for any interior area must be carefully coordinated with the height of the equipment to be located or removed during normal maintenance or replacement periods. Methods for removal, and clearances required for the replacement of any part of the main generating unit and its supporting equipment must be given consideration in the powerhouse design.

The area required for the erection area is normally determined by providing an area for each individual part which may be removed during an overhaul period. Vertical clearance requirements should be determined by consideration of not only the turbine/generator equipment but also the switchyard equipment. Depending on the location of the main service facilities, it may at times be necessary to disassemble the main transformer or remove the transformer bushings for removal from the plant area.

Space for service requirements is normally minor in small hydroelectric installations. Frequently, a separate service area building can be constructed at a saving in project cost. Many of the service activities can be accomplished in this separate building, where it is often easier to maintain an acceptable working environment, away from the noise and heat of the turbine/generator. However, some area must always be set aside within the main powerhouse structure for the service equipment required by the generating unit.

Tailrace. A tailrace is necessary for the proper operation of a hydroelectric plant. The purpose of the tailrace is to convey the water leaving the power plant back to the stream channel. Depending on the site characteristics, the tailrace can vary from a short, unlined excavation to a long, concrete-lined channel. The tailrace is also constructed to maintain the water surface elevation at a level specified by the turbine manufacturer. This is usually accomplished by adjustment of the tailrace profile to approximate a weir-type structure. Finally if necessary, the tailrace can be designed to dissipate any excess energy of the water leaving the power plant to prevent erosion of the mainstream banks.

Switchyard. Usually the location of the switchyard is the result of an economic balance between construction costs and operating energy losses. See Volume V for switchyard siting details.

Limitation of Data

The data provided within this volume regarding cost and dimensions was obtained from manufacturers, federal agencies, engineering consultants, and contractors. The data was analyzed and factored to represent reasonable costs to be used for the intended purpose of this volume.

There are many factors which can cause the construction costs to vary, some of which are material availability, labor market, and site conditions. Material shortages and construction site remoteness may increase the costs. Unusual labor market conditions, shortage of skilled craftsmen or low labor productivity, subsistance payments and portal to portal pay may also increase the construction costs. Judgement must enter into the cost analysis process for these types of cost increases. The costs given in Sections 2, 3, and 4 are for a July, 1978 cost level.

SECTION 2
SITE PREPARATION DESIGN AND COST GUIDELINES

General

Site preparation for a small hydroelectric development involves the modification of the existing terrain and results in changes in both the topography (cuts and fills), and in the natural or existing drainage pattern. This section describes the items that need to be considered in the evaluation of the site preparation activity. Both the technical design and the costs are considered.

Drainage and Erosion Control

The construction of a new hydroelectric facility usually involves changes in both the topography and the drainage patterns of the project area, which in turn may result in the accumulation, at specific locations, of excessive surface and/or subsurface water. Removal of the excess water is the main objective of a drainage design. Drainage design varies from project to project, and cannot be generalized as to the best method to be used. However, a combination of proper grading plus a system of collection points (catch basins) is generally the most effective method for removal of surface water. Removal of ground water requires the design of an underground drainage system, which will include a network of subdrains for the collection of subsurface water. The subdrain network would be connected to a main collector or the surface water collection system.

Proper grading should prevent accumulation of water at any location within the project area. However, if water flows over the side slopes of cuts or fills, erosion can become a problem. The effect of the water that flows directly over the slope can be minimized by sodding or terracing. If, because of the nature of the cut or fill, none of these solutions is applicable, it is often possible to divert water by means of a ditch (in cut) or a berm (in fill) along the top of the slope, with a pipe spillway arrangement at specific locations for the discharge of surface runoff over the slope.

The costs for grading, drainage collection and erosion control systems are shown on Figure 2-1. Utilizing the area requiring grading, the construction cost is estimated using the grading curve on Figure 2-1.

The drainage cost for any of the site area or parking area subject to ground water and thus requiring the installation of a network of subsurface drains and catch basins, is estimated using the drainage system from Figure 2-1.

Finally, the construction cost for erosion control is estimated using Figure 2-1. This construction cost is estimated using the erosion control cost curve and the slope area that is being considered. Drainage systems, with erosion control costs are not usually significant cost items on small hydroelectric installations.

Access Roads

Access to the project area is an important feature of project planning, both for construction and for operation. Existing impoundments are provided with access to locations where existing structures are located (i.e., dam, intake, spillway, energy dissipator). When planning a hydroelectric addition at an existing impoundment, use can be made of existing access to serve the new facility if appropriate, or new access can be developed as required. An existing access road may require upgrading before being used for construction access. In either case, since hydroelectric developments often involve the transportation of large and heavy pieces of equipment, certain minimum standards for access roads need to be set. Standards for access roads are given in Table 2-1.

TABLE 2-1
ACCESS ROAD DESIGN STANDARDS

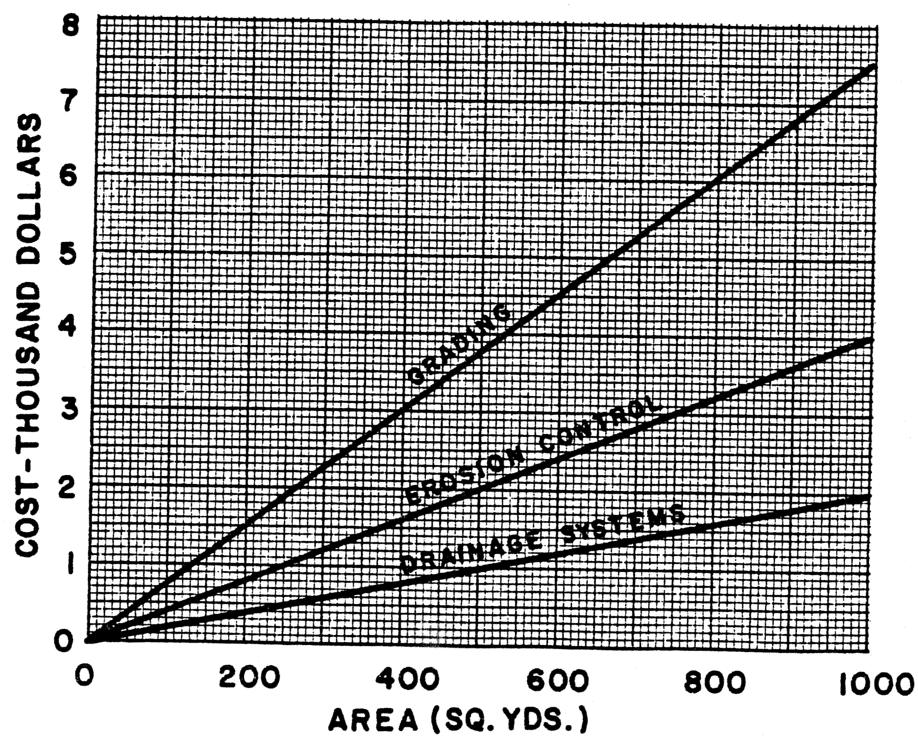
Design Speed	40 mph
Minimum Width	10 feet (one lane)
Maximum Grade	10 percent
Minimum Curve Radius	50 feet
Minimum Sight Distance	400 feet

Bridges on existing roads may be restrictive as to the size and weight of equipment that can be transported across them, and could result in additional handling and equipment assembly costs. Any new bridges which may be required should be designed to adequately accomodate future construction and equipment loads.

The estimated construction cost per mile of new paved access road of single lane width is $125,000, and of two lane width is $250,000. This cost is based on a two-inch asphalt concrete pavement, a four-inch subbase and a four-inch base. A single lane unpaved access road has a construction cost of $75,000 per mile. If an existing road requires upgrading, a cost of $50,000 per mile should be used. For a single span access road bridge, constructed of standard prestressed I girders, use $50 per square foot. This bridge cost includes excavation, substructure on piles and superstructure (Table 2-2).

Parking and Miscellaneous Site Features

Site preparation for small hydroelectric installations involves the design of various related features, such as parking areas, equipment erection area, fencing, and landscaping. Depending on the size of the project, the



NOTES:

1. Drainage Systems include surface and subsurface systems
2. Erosion Control includes seeding, terracing, dikes, trenches, and pipe spillways
3. Cost Base July 1978
4. Use Site Area for Grading and Drainage
5. Use Area with Slopes Greater than 4:1 for Erosion Control

Figure 2-1. Grading, Drainage and Erosion Control Costs

equipment erection area may be converted into a parking area after all equipment installation is completed. Whether one area serves both purposes, or a different area is assigned for each purpose, the main consideration in the layout of the facility is the relative location of each with respect to the area to be served. The erection area must be located so that the equipment may be moved easily to the installed location. Consideration should also be given to the dimensions of the facility, which will depend on the expected use (number and type of vehicles to be parked, and size of equipment to be erected). The cost for paving the parking and equipment erection area with two inch asphalt concrete pavement and four inch each of base and subbase is approximately $7 per square yard (Table 2-2).

Fencing is provided to protect the project facilities from vandalism and the public from accidents. Normally the cost for fencing is not an important cost item and will not materially influence the final project cost. However, if for some unusual siting conditions it is required to fence off a much larger area than normal, then the cost for the usual chain link type fence eight feet high with a one foot extension arm may be based on a unit cost of $16 per lineal foot. (Table 2-2)

Preserving the natural characteristics of the project area is of importance. Consequently, the area should be landscaped in an attempt to restore the original vegetative condition. The approximate landscaping cost for seeding, planting and fertilizing is $2800 per acre. (Table 2-2)

Environmental Controls During Construction

Environmental problems associated with small hydroelectric projects during construction are generally minor. However, they involve the following types of events:

1. Removal of vegetation, disposal of spoil and change of the land form by grading to provide access roads and level areas for the powerhouse, switchyard and parking areas.
2. Noise and dust created by construction activities including blasting. These disturb recreation areas which may be near the site.
3. Temporary disturbance of the stream caused by building in the streambed, which may result in temporary increase in stream turbidity. Construction may also require an interruption to releases, which could affect aquatic wildlife and downstream users.
4. The long-term commitment of land and part of the streambed for project facilities, thereby preempting use of the area as "wildlife habitat".

Costs associated with mitigation of the above effects are generally insignificant. Damping for dust control, reseeding of vegetation, spacing of blasting to avoid disturbance if recreation areas are nearby, along with other necessary measures, would generally amount to an additional estimated project cost of $10,000 (Table 2-2). Depending on the design of the existing outlet works, cost increases might also result where the releases from the reservoir must be maintained during the construction period.

TABLE 2-2
SITE PREPARATION COSTS
(Cost Base July 1978)

Access Roads		
	Paved Single Lane	$125,000/mile
	Paved Two Lanes	$250,000/mile
	Unpaved Single Lane	$ 75,000/mile
	Single Span Bridge	$ 50/ft^2
Parking and Miscellaneous Site Features		
	Parking Lot Paving	$ 7/yd^2
	Fencing	$16/ft
	Landscaping	$2,800/Acre
Environmental Controls During Construction		
	Noise, Dust and Stream Turbidity Control	$10,000

SECTION 3

HYDRAULIC FACILITIES DESIGN AND COST GUIDELINES

General

Existing impoundments are provided with hydraulic facilities for the normal operation of the project. This may involve water releases for domestic use, irrigation use, fish life, stream flow maintenance or flood control. These hydraulic facilities are normally the following: intake, tunnel or outlet works conduit, valves, energy dissipator, flumes, canals, or penstocks. If a new hydroelectric facility is to be added, additions to or modifications of the existing hydraulic facilities and other related works will be necessary.

Intake

Intake structures at existing impoundments can generally be used for small hydroelectric additions, provided they meet the criteria required for power intakes. Presently, because of new environmental controls, criteria for intakes may have changed from those that were in effect at the time existing impoundments were designed.

For protection of the hydroelectric equipment, there should be the capability to stop the flow of water through the intake structure during emergencies. Most existing impoundments have an emergency closure system, either at the intake itself or at some point along the outlet works conduit under the dam (valve chamber). However, if the existing facility does not have the capability to shut off the flow of water under emergency conditions, an emergency closure system should be included in the design of the hydroelectric facilities. This closure system is usually located just downstream of the intake. The closure device is usually a vertical slidegate that can be remote control operated under a power failure condition; for example, a gravity operated slide gate, or a hydraulic cylinder operated gate provided with an accumulator system.

There should always be a minimum of two closure devices upstream of the hydraulic turbine. One would be the intake gate and the second is usually a valve on the turbine inlet. The cost of the turbine valve is given in Volume V where it is included in the turbine cost. The cost of a slide gate may be estimated at $20,000. (Table 3-1)

TABLE 3-1
MISCELLANEOUS COSTS
(Cost Base July 1978)

Cost Item	Cost
Slide Gate	$20,000
Tunnel, 7 ft. Diameter Steel Lined	$ 1,300 pl ft.
Penstock Bifurcations	
Flow Less Than 200 cfs	$ 5,000
Flow 200 cfs to 600 cfs	$10,000
Flow Over 600 cfs	$20,000

Tunnels and Penstocks

Many types of pressurized tunnels and conduit systems have been developed and used on various hydroelectric applications.

The design and preliminary costs of these facilities are discussed below. Most existing impoundments already have a water conveyance facility in service. If possible, use of the existing tunnel or conduit for the proposed power generation facility should be made. The cost of a new tunnel or conduit will often make a proposed project infeasible. However, new conduit facilities are often required.

If a new tunnel is determined to be necessary, a cost of $1300 per linear foot (Table 3-1) may be assumed for a feasibility cost assessment. This cost is for a seven foot diameter steel-lined tunnel. As this is the minimum diameter that can be achieved with standard boring equipment, no cost savings can be realized by specifying a smaller tunnel.

Penstocks are pressurized, low-friction water conveyance conduits which carry water from the lower end of the existing impoundment outlet works or the tunnel exit portal to the powerhouse. Penstock design is a complicated process involving aspects of economics, turbine regulation requirements, plant siting and materials (Bier, 1966). These items will be presented briefly in this volume in order to permit a better understanding of the costs presented, in case modifications are required. A single figure to estimate penstock costs is presented at the end of the following discussion. Penstocks can be constructed of wood, concrete or steel. Steel is usually the preferred material and costs will be given for only this material. Penstock design must consider the stresses caused by internal pressure (static head plus water hammer), external pressure, temperature, erection and installation.

The elevation of the hydraulic turbine with respect to the surface elevation of the impoundment determines the static head in the penstock. Additionally, a pressure wave, which is termed water hammer, is produced whenever there is an increase or decrease in the penstock velocity (Davis and Sorensen, 1969, Section 27). Water hammer adds to the internal pressure on the penstock. Minimizing the additional head due to water hammer is a design consideration. Using a penstock design velocity of ten feet per second for a small hydroelectric installation rather than the higher velocities often used, will minimize the water hammer effects. One major cause of water hammer is the action of the turbine wicket gates, which can operate over their full range in a matter of seconds, thereby stopping the flow and causing large water hammer effects. The closure time may be increased so that a significant water hammer is not produced. A turbine shutoff valve normally requires minutes for its operating cycle and may not produce a significant water hammer. On hydroelectric installations with short penstocks, the water hammer is often not a major design consideration as it is on hydroelectric projects having long penstocks (Davis and Sorensen, 1969, Section 28). A surge chamber may be constructed to reduce the effects of water hammer. For those projects having long tunnels and/or penstocks, a surge chamber offers other advantages which are discussed later in this Section.

External pressure exists on a penstock whenever it is buried or the internal pressure is below atmospheric pressure. If a penstock is placed in a tunnel and backfilled with concrete, then the design must include stiffener rings or special internal supports during the erection phase. For the penstocks buried in earth, external reinforcing rings are usually required. Even for penstocks placed above ground, it is often required to add external stiffener rings if there is any possibility, including operator error, of having the internal pressure substantially below atmospheric pressure.

A penstock held firmly at each end or bend point will have longitudinal stresses caused by temperature changes. Penstock design must include this consideration or have expansion joints provided. The maximum temperature differential generally occurs when the penstock is unwatered.

Beam stresses occur in the penstock pipe whenever it is placed on supports. These stresses are a function of the distance between supports.This distance is often assumed to be fifty feet for preliminary design then modified in final design. At the support points, it is generally necessary to locally reinforce the penstock, especially when it is relatively thin, as is often the case for small hydroelectric installations.

The final consideration in the penstock design is the stresses caused during the handling and erection phase. A minimum handling thickness, as a function of penstock diameter, is required and is usually the governing factor in penstock design for small hydroelectric power plants as defined in this Volume. Minimum handling thicknesses, over a range of penstock diameters, are shown below in Table 3-2.

Figure 3-1 shows the installed penstock costs for a small hydroelectric installation. The costs include fabrication and erection, including supports, for a steel penstock. The costs are based on a penstock velocity of ten feet per second and a pipe thickness equal to the minimum thickness required for handling. A corrosion allowance, that is an additional thickness, has not been used, as it is normal to coat the interior of the penstock, usually with coal tar enamel, to decrease the hydraulic friction losses and the effects of corrosion.

TABLE 3-2
Steel Penstock Minimum Thickness

Thickness Inches	Maximum Diameter Inches
0.125	30
0.1875	55
0.25	80
0.3125	105
0.375	130
0.4375	155
0.5	180

If the static head on the penstock is greater than 225 feet, it is possible that the minimum handling thickness will no longer govern the penstock design and the penstock costs will be higher than given in Figure 3-1.

Figure 3-1 costs are based on a relatively flat penstock gradient. If the penstock is placed on a gradient of more than fifteen degrees with respect to the horizontal, then corrections must be made as noted on Figure 3-1.

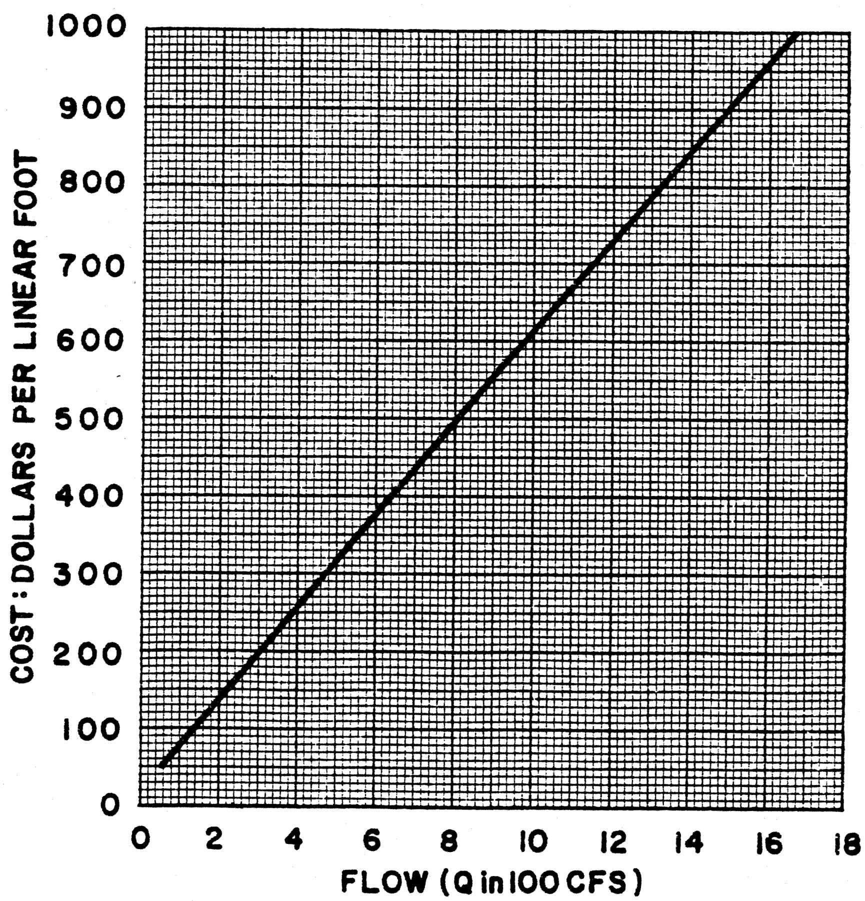
The unit cost of the penstock is determined from the Figure 3-1 cost curve and the rated turbine flow obtained from Volume V. The total overall penstock cost is the product of the penstock length times the unit cost.

Final penstock design may indicate there could be an overall saving in owning and operating costs by increasing the penstock velocity above the value of 10 feet per second used for Figure 3-1. It is not necessary to consider this possibility in a feasibility analysis.

One specialized type of penstock should be mentioned. Many existing dams have concrete outlet conduits which are designed for unpressurized conditions. When downstream controls are provided, conduit pressures will increase accordingly and measures must be taken to protect the existing outlet conduit structure against failure under the higher pressures. The most effective and least costly method to increase the pressure capacity of the existing outlet structure is to install a relatively thin, welded steel liner inside the existing concrete outlet conduit. This liner may be fabricated in place when the tunnel is in an unwatered condition. The annulus between the liner and the existing concrete conduit is then backfilled with concrete. The cost for this type of modification may be estimated from Figure 3-1, using the unit cost increased by fifty percent.

Valves, Gates, Outlet Works and Other Hydraulic Works

Depending on the project configuration selected, various other hydraulic equipment will be needed for the operation of a small hydroelectric installation. The nature and cost of this additional equipment is presented below.



NOTES:

1. Cost Base July 1978
2. Penstock Velocity 10 feet per second
3. Steel Cost at $1.10 per pound
4. Based on Minimum Handling Thickness and Maximum Head of 225 feet
5. If Penstock Gradient is over 15°, add 1% of total for each degree over 15°
6. Valves and Bifurcations not included

Figure 3-1. Installed Penstock Costs

Energy dissipation valves such as the "Howell-Bunger" and the hollow jet are typically used to bypass water when the power house is inoperative. The Howell-Bunger valve is a fixed cone, movable cylinder type valve. Due to lack of streamlining of the cylinder and cone the Howell-Bunger is excessively noisy but serves as an effective energy dissipater. The hollow-jet valve, developed by the United States Bureau of Reclamation, is essentially a movable needle valve with streamlined needle and housing and is thus much quieter. Both valves are available for conduit sizes up to 96 inches. Costs for either valve may be estimated from Figure 3-2.

Butterfly valves up to 12 feet in diameter are used almost exclusively to open or close flow into the turbine spiral case. Butterfly valves are not normally used as flow control valves due to the stresses and flow patterns imposed when they are partially open. It is not necessary to include a butterfly valve in the cost estimate, as the turbine inlet valve is included in the turbine cost (see Volume V). However, in accordance with the requirement that two closure devices are needed on the conduit upstream of the turbine, a butterfly valve may occasionally be required. The cost of a butterfly valve may be estimated from Figure 3-2.

As discussed earlier in this Section, the rapid closure of either turbine valve or turbine gates may cause a water hammer and increase the penstock water pressure which under extreme conditions can cause the conduit to rupture. A surge chamber, placed either at the upper end of the penstock or near the tunnel outlet, reduces the effects of the water hammer. Effects of water hammer may also be minimized by the use of a pressure relief valve connected to the turbine spiral case. If there is a relatively long tunnel ahead of the penstock, a surge chamber at the upstream end of the penstock may also assist in supplying water to the turbine during start-up. Normally, however, a small hydroelectric installation will have a relatively short tunnel and penstock, and a surge chamber will not be required. No costs are presented for either the surge chamber or the pressure relief valve as they must be specially designed for each site, and are seldom used for small hydroelectric projects as defined by this volume.

A bifurcation splits a single flow conduit into a pair of conduits. A bifurcation is used if a single penstock conveys water to two turbines or if a bypass must be provided off the main penstock. Multiple bifurcations are often used. Bifurcation costs are usually estimated by calculating the weight of the bifurcation and multiplying by a cost per pound for steel. For preliminary estimates, however, an approximate cost of $5,000 to $20,000 per bifurcation is used. (Table 3-1)

There are no other facilities for hydraulic conveyance that need to be considered in a feasibility assessment.

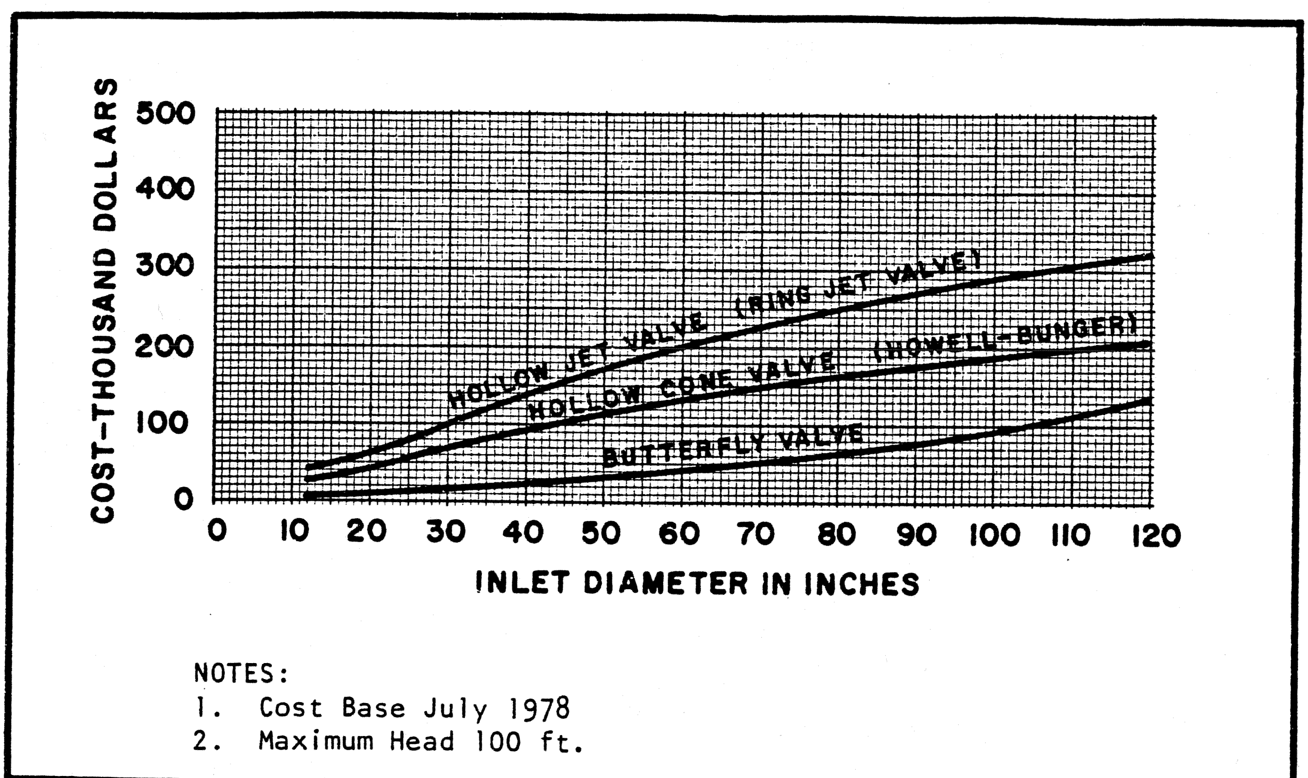


Figure 3-2. Costs for Butterfly, Hollow Jet, and Hollow Cone Valves