SECTION 3
HYDRAULIC TURBINE SELECTION AND COST GUIDELINES

Classification of Turbines

General. The net head available to the turbine dictates the selection of type of turbine suitable for use at a particular site. The rate of flow determines the capacity of the turbine.

Hydraulic turbines have two general classifications, impulse and reaction. Reaction turbines are by far the most widely used within the head range addressed by this volume.

Reaction turbines are classified as Francis (mixed flow) or Propeller (axial flow). Propeller turbines are available with both fixed blades and variable pitch blades (Kaplan). Both Propeller and Francis turbines may be mounted either horizontally or vertically. Additionally, Propeller turbines may be slant mounted. Trade names have been applied to certain Propeller turbine designs such as Tube, Bulb and Straflo. The runner design principals, however, are the same.

Impulse turbines may have some application for small hydropower installations. However, there are very few manufacturers interested in developing a standardized product line. In general the cost to manufacture a reaction turbine of comparable head and capacity is less.

Proprietary turbines (i.e., rim and crossflow) are available and discussed further in this section. These turbines have unique characteristics which may be beneficial for some projects.

Cross-sections of the various types of turbines commercially available are shown in Figure 3-1.

Francis Turbines. A Francis turbine is one having a runner with fixed buckets (vanes), usually nine or more, to which the water enters the turbine in a radial direction, with respect to the shaft, and is discharged in an axial direction. Principal components consist of the runner, a water supply case to convey the water to the runner, wicket gates to control the quantity of water and distribute it equally to the runner and a draft tube to convey the water away from the turbine.

A Francis turbine may be operated over a range of flows from approximately 40 to 105 percent of rated discharge. Below 40 percent rated discharge, there can be an area of operation where vibration and/or power surges occur. The upper limit generally corresponds to the generator rating. The approximate head range for operation is from 60 to 125 percent of design head. In general, peak efficiencies of Francis turbines, within the capacity range of 15 MW, will be approximately 88 to 90 percent. The peak efficiency point of a Francis turbine is established at 90 percent of the rated capacity of the turbine. In turn, the efficiency at the rated capacity is approximately 2 percent below peak efficiency. The peak efficiency at 60 percent of rated head will drop to near 75 percent.

The conventional Francis turbine is provided with a wicket gate assembly to permit placing the unit on line at synchronous speed, to regulate load and speed, and to shutdown the unit. The mechanism of large units are actuated by hydraulic servomotors. Small units may be actuated by electric motor gate operations. It permits operation of the turbine over the full range of flows. In special cases, where the flow rate is constant, Francis turbines without wicket gate mechanisms may be used. These units will operate at a fixed load dependent upon the net head. Start up and shut down of turbines without wicket gates is normally accomplished using the shut off value at the turbine inlet.

Francis turbines may be mounted with vertical or horizontal shafts. Vertical mounting allows a smaller plan area and permits a deeper setting of the turbine with respect to tailwater elevation without locating the generator below tailwater. Generator costs for vertical units are higher than for horizontal units because of the need for a larger thrust bearing. However, the savings on construction costs for medium and large units generally offset this equipment cost increase. Horizontal units are often more economical for small higher speed applications where standard horizontal generators are available.

The water supply case is generally fabricated from steel plate. However open flume and concrete cases are often used for heads below 50 feet. Concrete and open flume cases are discussed in a subsequent section. Closed concrete and steel cases are also known as spiral cases.

Francis turbines are generally provided with a 90 degree elbow draft tube which has a venturi design to minimize head loss. Conical draft tubes are also available, however the head loss will be higher and excavation may be more costly.

Propeller Turbines. A propeller turbine is one having a runner with four, five or six blades in which the water passes through the runner in an axial direction with respect to the shaft. The pitch of the blades may be fixed or movable. Principal components consist of a water supply case, wicket gates, a runner and a draft tube. Figure 3-2 illustrates a stay ring and wicket gate assembly and Figure 3-3 illustrates a fixed blade propeller runner.

The efficiency curve of a typical fixed blade Propeller turbine forms a sharp peak, more abrupt than a Francis turbine curve. For variable pitch blade units the peak efficiency occurs at different outputs depending on the blade setting. An envelope of the efficiency curves over

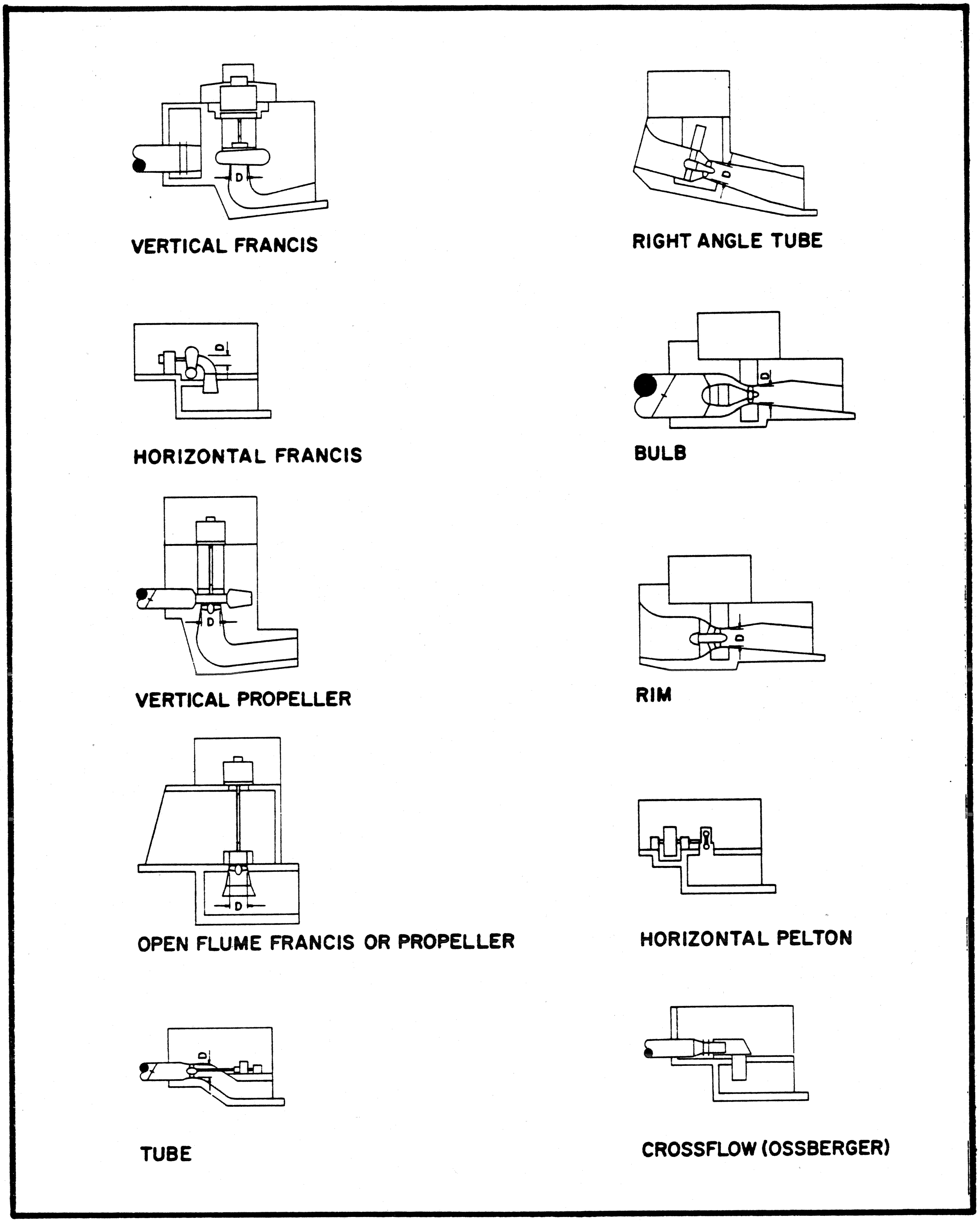


Figure 3-1. Turbine cross sections

the range of blade pitch settings forms the variable pitch efficiency curve. This efficiency curve is broad and flat. Fixed blade units are less costly than variable pitch blade turbines; however, the power operating ranges are more limited.

Turbine manufacturers have developed runner designs for a head range of 15 to 110 feet. Four blade designs may be used up to 35 feet of head, five blade designs to 65 feet and six blade designs to 110 feet. In general, peak efficiencies are approximately the same as for Francis turbines.

Propeller turbines may be operated at power outputs with flows from 40 to 105 percent of the rated flow. Discharge rates above 105 percent may be obtained; however, the higher rates are generally above the turbine and generator manufacturers' guarantees. Many units are satisfactorily operated beyond these limits; however, for purposes of feasibility studies, it is suggested that these limits be maintained. Head range for satisfactory operation is from 60 to 140 percent of design head. Efficiency loss at higher heads drops 2 to 5 percentage points below peak efficiency at the design head and as much as 15 percentage points at lower heads.

The conventional propeller or Kaplan (variable pitch blade) turbines are mounted with a vertical shaft. Horizontal and slant settings will be discussed separately. The vertical units are equipped with a wicket gate assembly to permit placing the unit on line at synchronous speed, to regulate speed and load, and to shutdown the unit. The wicket gate mechanism units are actuated by hydraulic servomotors. Small units may be actuated by electric motor gate operators. Variable pitch units are equipped with a cam mechanism to coordinate the pitch of the blade with gate position and head. The special condition of constant flow, as previously discussed for Francis turbines, can be applied to propeller turbines. For this case, elimination of the wicket gate assembly may be acceptable. Variable pitch propeller turbines without wicket gates are discussed in a subsequent section.

The advantages and disadvantages discussed above with regard to vertical versus horizontal settings for Francis turbines apply also to propeller turbines.

The water supply case is generally concrete. Either an open flume or a closed conduit type of construction may be used. Open flume construction may be economical when heads are below 35 feet. At higher heads the turbine shaft length becomes excessive. Also open flume construction is disadvantageous with regard to maintenance costs. The wicket gate assembly and guide bearing are water lubricated causing additional maintenance particularly when silt or debris is in the water. At

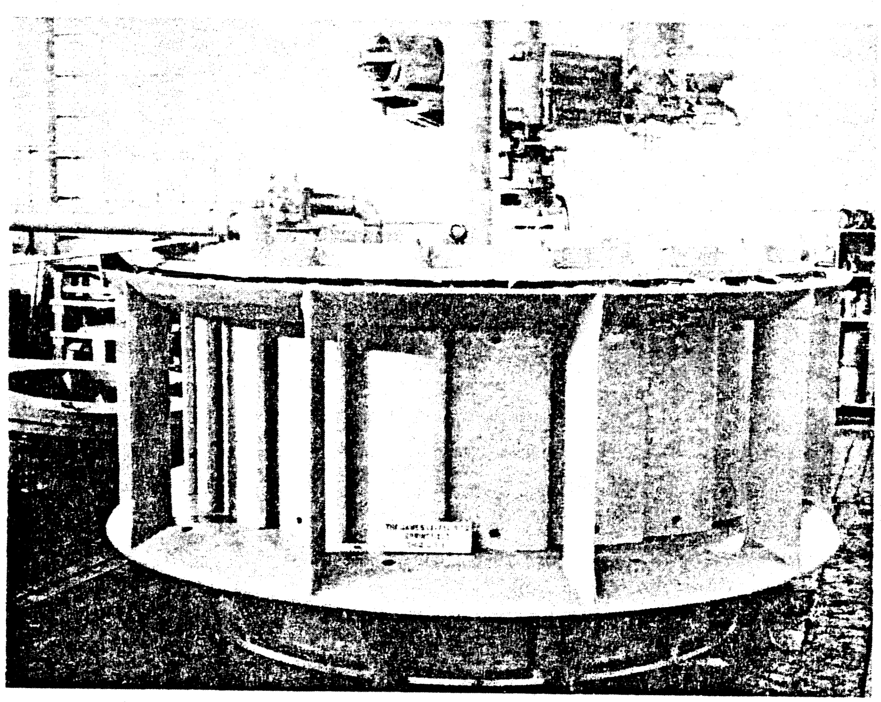


Figure 3-2. Wicket gate and stay ring assembly for an open flume turbine. (Courtesy of James Leffel and Company)

capacities above 1500 kW, wicket gate and guide bearing loading are such that an open flume may not be a satisfactory choice. For closed conduits, spiral cases of steel or concrete may be used. The concrete case is generally less costly. The cross-section of a concrete case, taken in a direction radial to the shaft is usually rectangular.

The draft tube designs discussed for Francis turbines apply also to propeller turbines.

Tubular Turbines. Tubular or tube turbines are horizontal or slant mounted units with propeller runners. The generators are located outside of the water passageway. Tube turbines are available equipped with fixed or variable pitch runners and with or without wicket gate assemblies.

Performance characteristics of a tube turbine are similar to the performance characteristics discussed for propeller turbines. The efficiency of a tube turbine will be one to two percent higher than for a vertical propeller turbine of the same size since the water passageway has less change in direction.

The performance range of the tube turbine with variable pitch blades and without wicket gates is greater than for a fixed blade propeller turbine but less than for a Kaplan turbine. The water flow through the turbine is controlled by changing the pitch of the runner blades.

When it is not required to regulate turbine discharge and power output, a fixed blade runner may be used. This results in a lower cost of both the turbine and governor system. To estimate the performance of the fixed blade runner, use the maximum rated power and discharge for the appropriate net head on the variable pitch blade performance curves.

Several items of auxiliary equipment are often necessary for the operation of tube turbines. All tube turbines without wicket gates should be equipped with a shut off valve automatically operated to provide shut- off and start-up functions. Tube turbines may also be equipped with an air clutch between the turbine and generator when the generator is not designed for turbine runaway speed. The clutch is normally set to disengage at 125 percent of design speed and is used to prevent damage to the equipment if a runaway condition occurs. This aspect is further discussed in Section 5.

Tube turbines can be connected either to the generator or to a speed increaser. The speed increaser would allow the use of a higher speed generator, typically 900 or 1200 r/min, instead of a generator operating at turbine speed. The choice to utilize a speed increaser is an economic decision. Speed increasers lower the overall plant efficiency by about one percent for a single gear increaser and about two percent for double gear increaser. (The manufacturer can supply exact data regarding the efficiency of speed increasers.) This loss of efficiency and the cost of the speed increaser must be compared to the reduction in cost for the smaller generator.

The required civil features are different for horizontal units than for vertical units. Horizontally mounted tube turbines require more floor area than vertically mounted units. The area required may be lessened by slant mounting, however, additional turbine costs are

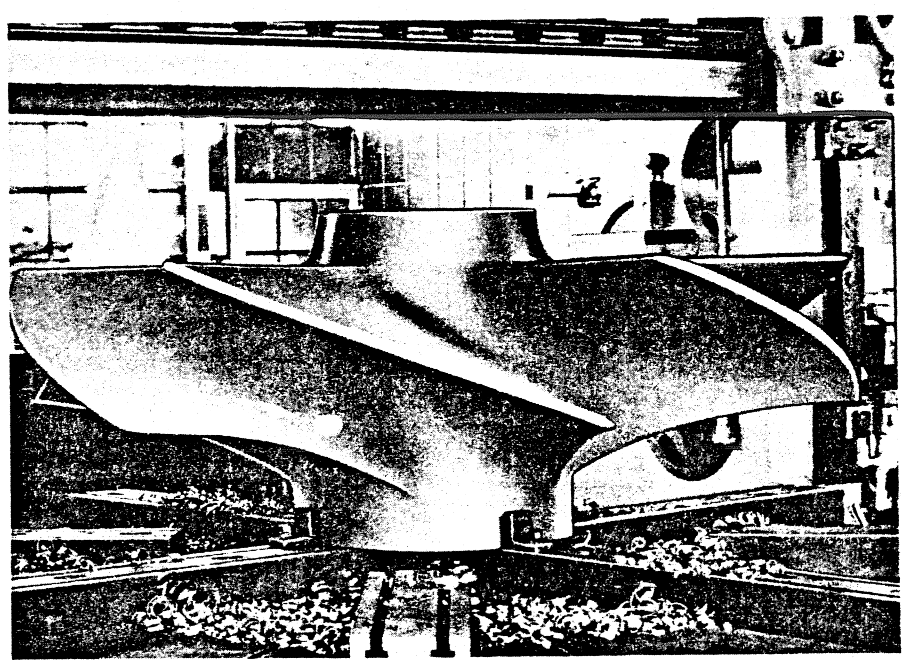


Figure 3-3. Fixed blade propeller runner. (Courtesy of James Leffel and Company)

incurred as a larger axial thrust bearing is required. Excavation and powerhouse height for a horizontal unit is less than that required for a vertical unit.

Standardized tube turbines are available from a domestic turbine manufacturer. Ten sizes are currently available with up to 7000 kW of capacity and for heads up to 60 feet. Standardization should provide lower costs and shorter delivery periods. Figure 3-4 shows the shop assembly of a standardized tube turbine.

Bulb Turbines. Bulb Turbines are horizontal units which have propeller runners directly connected to the generator. The generator is enclosed in a water-tight enclosure (bulb) located in the turbine water passageway. The bulb turbine is available with fixed or variable pitch blades and with or without a wicket gate mechanism. Performance characteristic are similar to the vertical and tube type turbines previously discussed. The bulb turbine will have an improved efficiency of approximately two percent over a vertical unit and one percent over a tube unit because of the straight water passageway.

Due to the compact design, powerhouse floor space and height for Bulb turbine installations are minimized. Maintenance time due to accessability, however, may be greater than for either the vertical or the tube type turbines.

Standardized bulb turbines are offered by some foreign manufacturers.

Rim Type Turbines. A rim type turbine is one in which the generator rotor is mounted on the periphery of the turbine runner blades. This turbine has been developed by Escher Wyss Ltd. of Zurich, Switzerland and given the name "Straflo". The concept was developed 40 years ago and approximately 75 units are now in service. Capacities range from 1000 to 1900 kW at heads of 26 to 30 feet. All units built to date have fixed blade propeller runners. The existing seal design, to prevent leakage of water into the generator annulus, is a rubber "lip" seal type. This design is not satisfactory for variable pitch runner nor for capacities over 2000 kW. A new seal design has been developed which will permit Escher Wyss to offer units with runner diameters up to

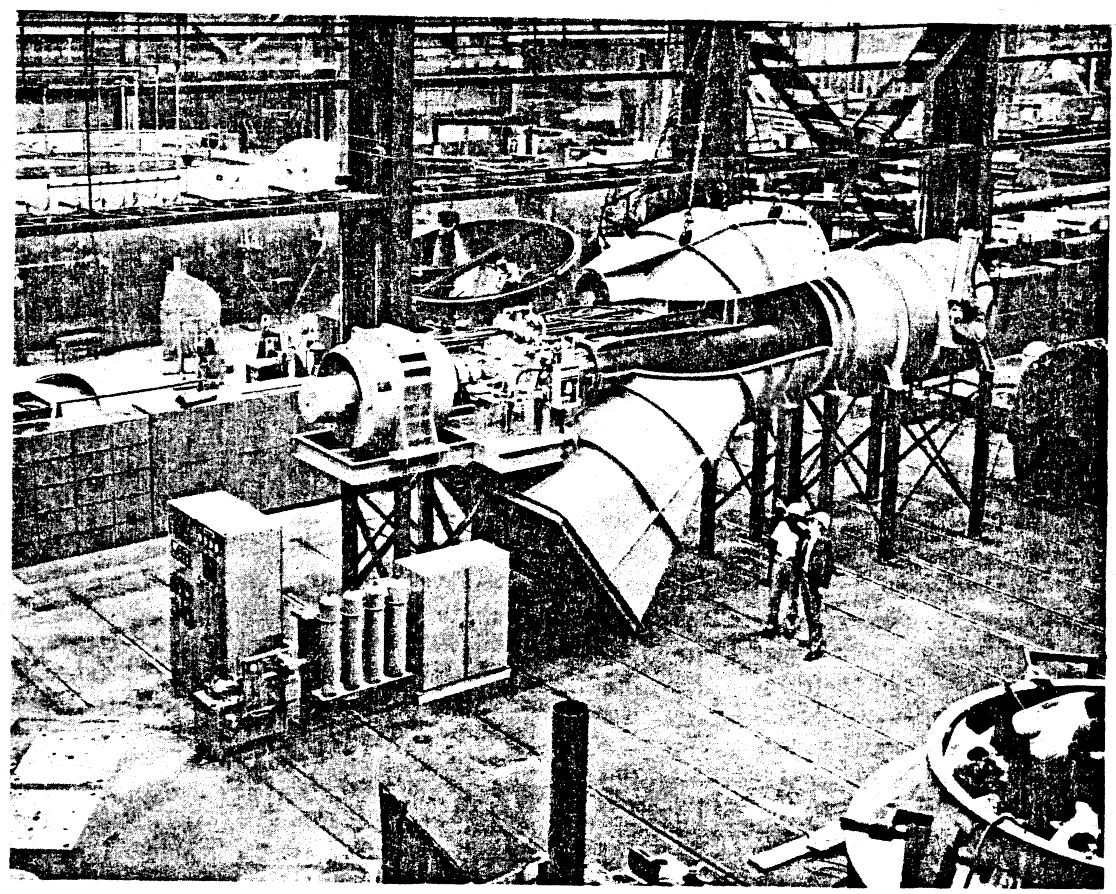


Figure 3-4. Shop assembly of a standardize tube turbine. (Courtesy of Allis Chalmers Corporation).

32 feet and head up to 130 feet. The old lip seal design will be used on units with runner diameters of 11.5 feet or less at heads of less than 50 feet.

Performance characteristics of the Straflo turbine are similar to those of the bulb unit. Rim turbines are offered with or without wicket gates, and are also available with partial closure wicket gates, which require shut-off valves as discussed previously. The compact design of the Straflo turbine provides the smallest power house dimensions of all the turbine types considered in this volume. The "Straflo" design is attractive because of simplicity and compactness, however, the design for large units has limited application experience.

Crossflow Turbines. A crossflow turbine may best be described as an impulse type turbine with partial air admission. This type of turbine is offered by Ossberger Turbine Fabrik Co. of Weissenburg, Germany and has the name "Ossberger Turbine."

Performance characteristics of this turbine are similar to an impulse turbine, and consist of a flat efficiency curve over a wide range of flow and head conditions. The wide range is accomplished by use of a guide vane at the entrance which directs the flow to a limited portion of the runner depending on the flow. This operation is similar to operation of multi-jet impulse turbine.

Peak efficiency of the Crossflow turbine is less than that of other turbine types previously discussed. Guaranteed maximum efficiency is 83 percent and expected peak efficiency is 85 percent.

At the present time, the largest size runner produced by Crossflow is 4 feet in diameter. This limits the unit capacity but multi-unit installations are often used. Allowable heads range from 20 to 600 feet.

Crossflow turbines are equipped with a conical draft tube creating a pressure below atmosphere in the turbine chamber. Therefore the difference between the turbine centerline elevation and the tailwater is not lost to an Crossflow turbine as is the case for an impulse turbine. Air is admitted into the chamber through an adjustable air inlet value used to control the pressure.

Crossflow turbines are free from cavitation, but are susceptible to wear when excessive silt or sand particles are in the water. Runners are self-cleaning and, in general, maintenance is less complex than for the other types of turbines discussed in this volume.

Floor space requirements are more than for the other turbine types, but a less complex structure is required and a savings in cost might be realized.

Impulse Turbines. An impulse turbine is one having one or more free jets discharging into an aerated space and impinging on the buckets of a runner. Efficiencies are often 90 percent and above. Application of the impulse turbine within the capacity and head range of this volume is limited. In general, an impulse turbine will not be competitive in cost with a reaction turbine below 1000 feet of head. However, certain hydraulic conditions or surge protection requirements may warrant investigation into the suitability of an impulse turbine in the 100 foot range.

Single nozzle impulse turbine have a very flat efficiency curve and may be operated down to loads of 20 percent of rated capacity with good efficiency. For multi-nozzle units, the range is even broader because the number of operating jets can be varied.

Control of the turbine is maintained by hydraulically operated needle nozzles in each jet. In addition, a jet deflector is provided for emergency shut down. The deflector diverts the water jet from the buckets to the wall of the pit liner. This feature provides surge protection for the penstock without the need for a pressure release valve because load can be rapidly removed from the generator without changing the flow rate.

Control of the turbine may also be accomplished by the deflector alone. On these units the needle nozzle is manually operated and the deflector diverts a portion of the jet for lower loads. This method is less efficient and normally used for speed regulation of the turbine under constant load.

Runners on the modern impulse turbine are a one-piece casting. Runners with individually attached buckets have proved to be less dependable and, on occasion, have broken away from the wheel causing severe damage to powerhouse. Integral cast runners are difficult to cast, costly and require long delivery times. However, maintenance costs for an impulse turbine are less than for a reaction turbine as they are free of cavitation problems. Excessive silt or sand in the water however, will cause more wear on the runner of an impulse turbine than on the runner of most reaction turbines.

Draft tubes are not required for impulse turbines. The runner must be located above maximum tailwater to permit operation at atmospheric pressure. This requirement exacts an additional head loss for an impulse turbine not required by a reaction turbine.

Impulse turbines may be mounted horizontally or vertically. The additional floor space required for the horizontal setting can be compensated for by lower generator costs on single nozzle units in the lower capacity sizes. Vertical units require less floor space and are often used for large capacity multi-nozzle units.

Selection of Turbine Efficiency Curves

General. A calculation of the annual energy must be made in order to determine the feasibility of a hydroelectric power installation. The calculation consists of the product of multiplying flow, head and efficiency over a specific period of time. There are several methods for estimating the energy, including flow duration curves and systematic routing studies that simulate the operation of the plant. The simulated operation studies can be performed either by hand calculation or more commonly by a digital computer. There are many computer programs available to simulate the operation of a hydroelectric power plant. (Reservoir System Analysis for Conservation - HEC Program)

If the head and discharge rate are relatively constant, an overall turbine, generator, station use and deterioration, and transformer efficiency of 85 percent can be used for estimating the energy from a flow duration curve. Whenever the flow rate and/or the head varies, a more precise analysis of the efficiency of the hydraulic turbine is required. A value of 95 percent may be used for all other losses including generator, station use and deterioration, and transformer. Therefore, the total efficiency to be used in the power operation studies is the product of the turbine efficiency and all other losses (0.95). If the turbine and generator are coupled together with a speed increaser, the losses, other than the turbine, may be estimated as 93 percent.

Turbine Efficiency Curves. Typical efficiency curves of the various types of turbines are shown for comparison in Figure 3-5. These curves are shown to illustrate the variation in efficiency of the turbine through the load range at the design head. Performance of the various types of turbines when operated at heads above and below design head are discussed below. Approximate efficiencies at rated capacity for the reaction turbines are shown for a turbine with a throat diameter of one foot. Rated efficiency will increase as the size of the turbine increases. The bottom curve shows the relationship of efficiency to throat diameter. The rated efficiency for turbines with throat diameters larger than one foot may be calculated in accordance with this curve. This curve was developed from model test comparisons with field-tested prototype units. It is common practice to apply the step-up value to all efficiency values throughout the operating range.

The efficiency curves shown are typical expected efficiencies. Actual efficiencies vary with manufacturer and design.

To find the approximate efficiency for a reaction turbine, determine the approximate throat diameter from Figure 3-6 or 3-7, and find the size step up factor in the bottom curve. Add this value to the rated efficiency values given for the appropriate turbine type. Size step up efficiency factors do not apply to impulse or cross flow type turbines. The values asshown may be used. Note, that these curves can only be used when the head on the turbine does not vary and less precise results are warranted. For more precise results, see the following section on turbine performance curves, USBR Engineering Monograph No. 20 or consult with turbine manufacturers.

Turbine Performance Curves. Figures 3-8 and 3-9 show performance characteristics for Francis, Kaplan (variable pitch blade Propeller with wicket gates) Propeller (fixed blade with wicket gates) and Tube (variable pitch blades without wicket gates) type turbines. These curves were developed from typical performance curves of the turbines of a specific speed that was average for the head range considered in this volume. The data used was obtained from turbine manufacturers' data and USBR Engineering Monogram No. 20. Comparison of performance curves of various specific speed runners were made and the average performance values were used. The maximum error occurs at the lowest kW_R and was approximately three percent. These curves may be used to determine the power output of the turbine and generator when the flow rates and heads are known. These curves are proposed herein because they are easily adapted for use in a digital computer instead of the more conventional "contour-type" performance curve often found in literature on turbines. The curves show percent turbine discharge, $\%Q_R$, versus percent generator rating, $\%kW_R$, throughout the range of operating heads for the turbine.

Following determination of the selected turbine capacity as discussed in Section 2, the power output at heads and flows above and below rated head (H_R) and flow (Q_R) may be determined from the curves as follows:

Calculate the rated discharge Q_R using the efficiency values discussed previously.

$$Q_R = (11.81 \times kW_R) \ / \ (H_R \times E_R \times E_g), \text{ (cfs)}$$

Compute the percent discharge, $\%Q_R$ and percent head, $\%H_R$, for the various flow and head requirements of the site.

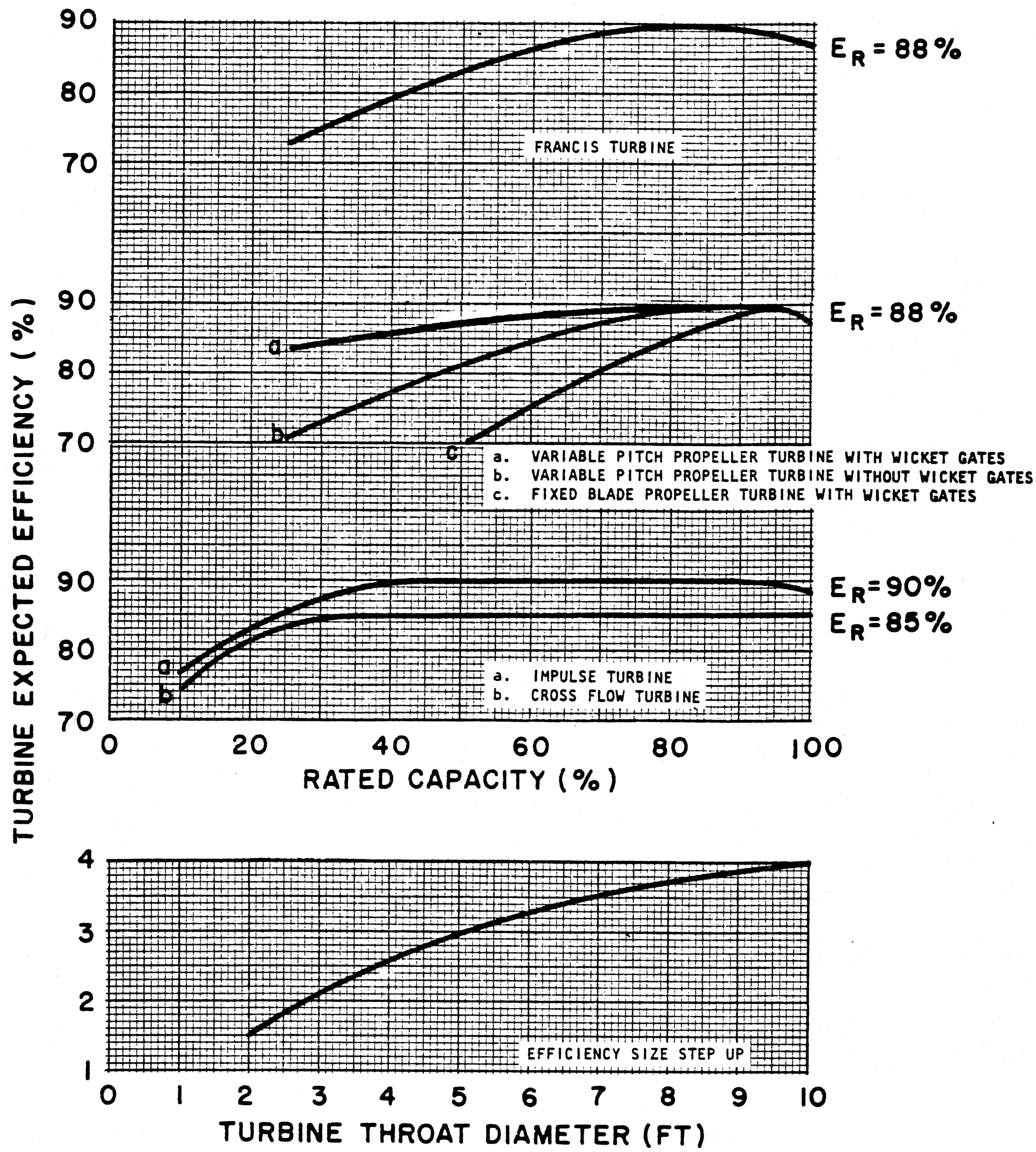
$$\%Q_R = (Q/Q_R) \times 100, \text{ (\%)}$$
$$\%H_R = (H/H_R) \times 100, \text{ (\%)}$$

Enter the curves with the $\%Q_R$ and find the %kW on the appropriate H_R line. Calculate the power output.

$$P = (\%kW_R) \times (kW_R), \text{ (kW)}$$

The heavy lines at the border of the curves represent limits of satisfactory operation within normal industry guarantee standards. The top boundary line represents maximum recommended capacity at rated capacity. The turbine can be operated beyond these gate openings, however, cavitation guarantees generally do not apply beyond these points. The bottom boundary line represents the limit of stable operation. The bottom limits vary with manufacturer. Reaction turbines experience a rough operation somewhere between 20 to 40 percent of rated discharge with vibration and/or power surges. It is difficult to predict the magnitude and range of the rough operation as the water passageway configuration of the powerhouse affects this condition. Where operation is required at lower output, straightening vanes can be placed in the draft tube below the discharge of the runner to minimize the magnitude of the disturbance. These modifications reduce the efficiency at higher loads. The right-hand boundary is established from standard generator guarantees of 115 percent of rated capacity. The head operation boundaries are typical, however, they do vary with manufacturer. It is deemed that these typical performance curves are satisfactory for preliminary feasibility assessments.

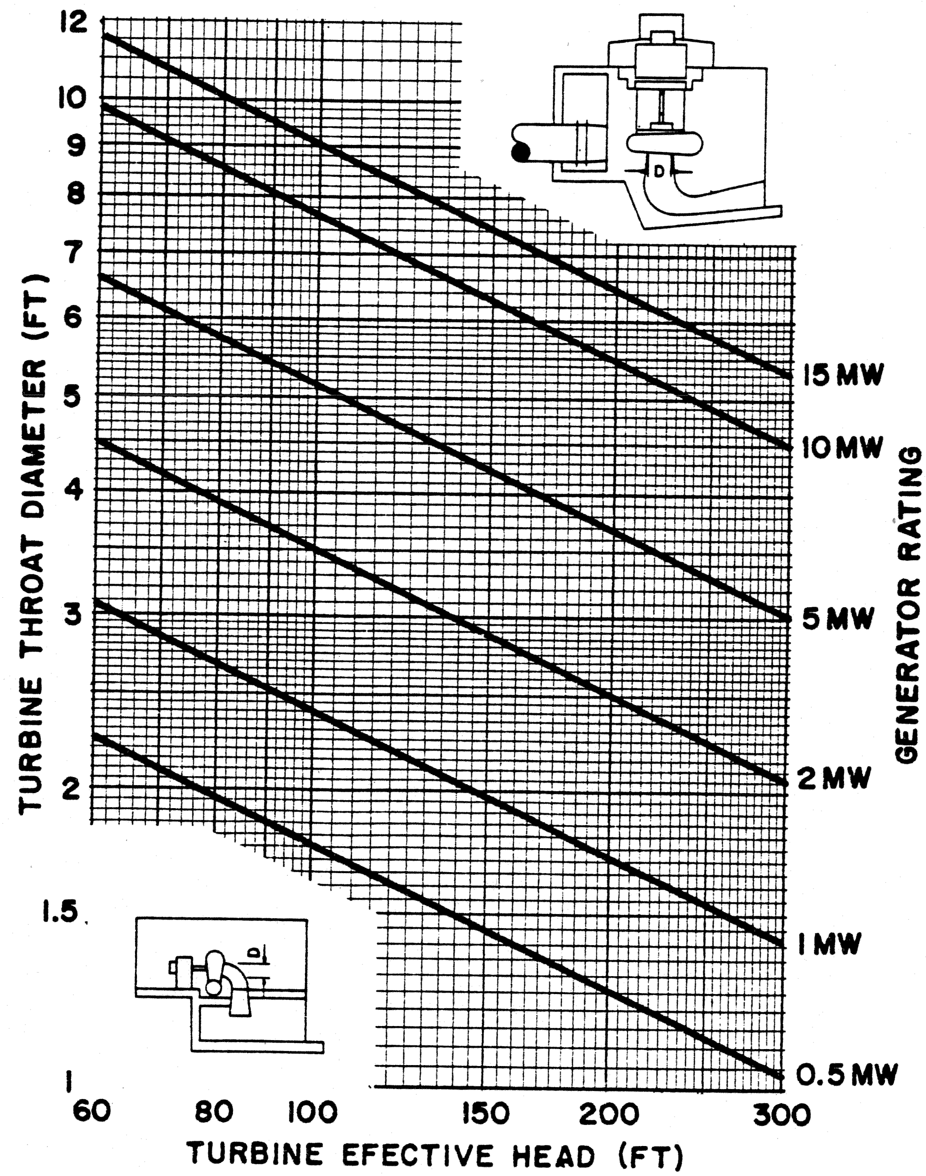
When the $\%Q_R$ for a particular selection is beyond the curve boundaries, generation is limited to the maximum $\%kW_R$ for the $\%H_R$. The excess water must be bypassed. When the $\%Q_R$ is below the boundaries, no



NOTES:

1. E_R = Turbine Efficiency at rated output, kW_R and head, H_R
2. The values shown are typical for a turbine with a 1 foot diameter runner. The values shown in the size step up curve may be added to the E_R values for larger units. Values apply for Francis, fixed and variable pitch propeller, tube, slant, bulb and rim turbines. Do not apply step up on impulse or cross flow turbines.

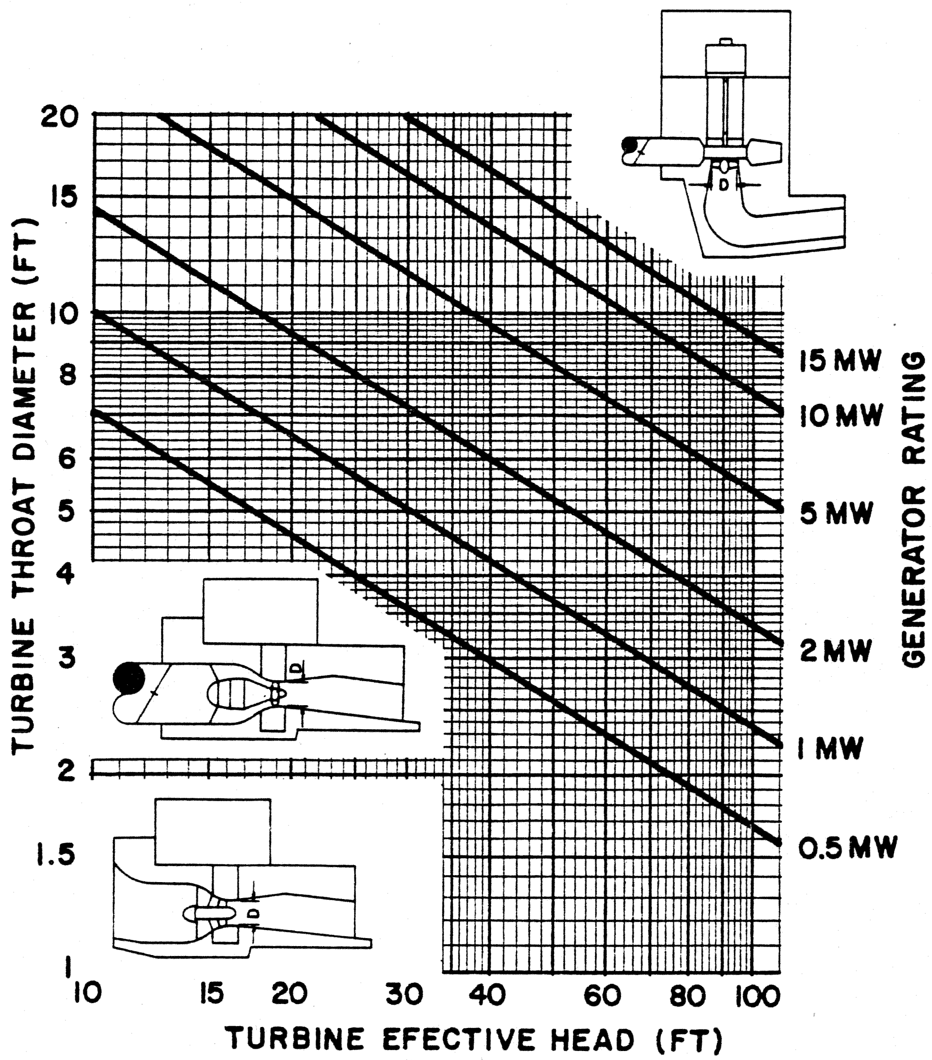
Figure 3-5. Turbine efficiency curves



NOTES:

1. The approximate throat diameters are based upon typical values for the turbine set with the centerline of the runner at minimum tail water elevation. Actual diameters vary with turbine manufactuers.
2. The estimated diameters may be used for vertical or horizontal Francis turbines.

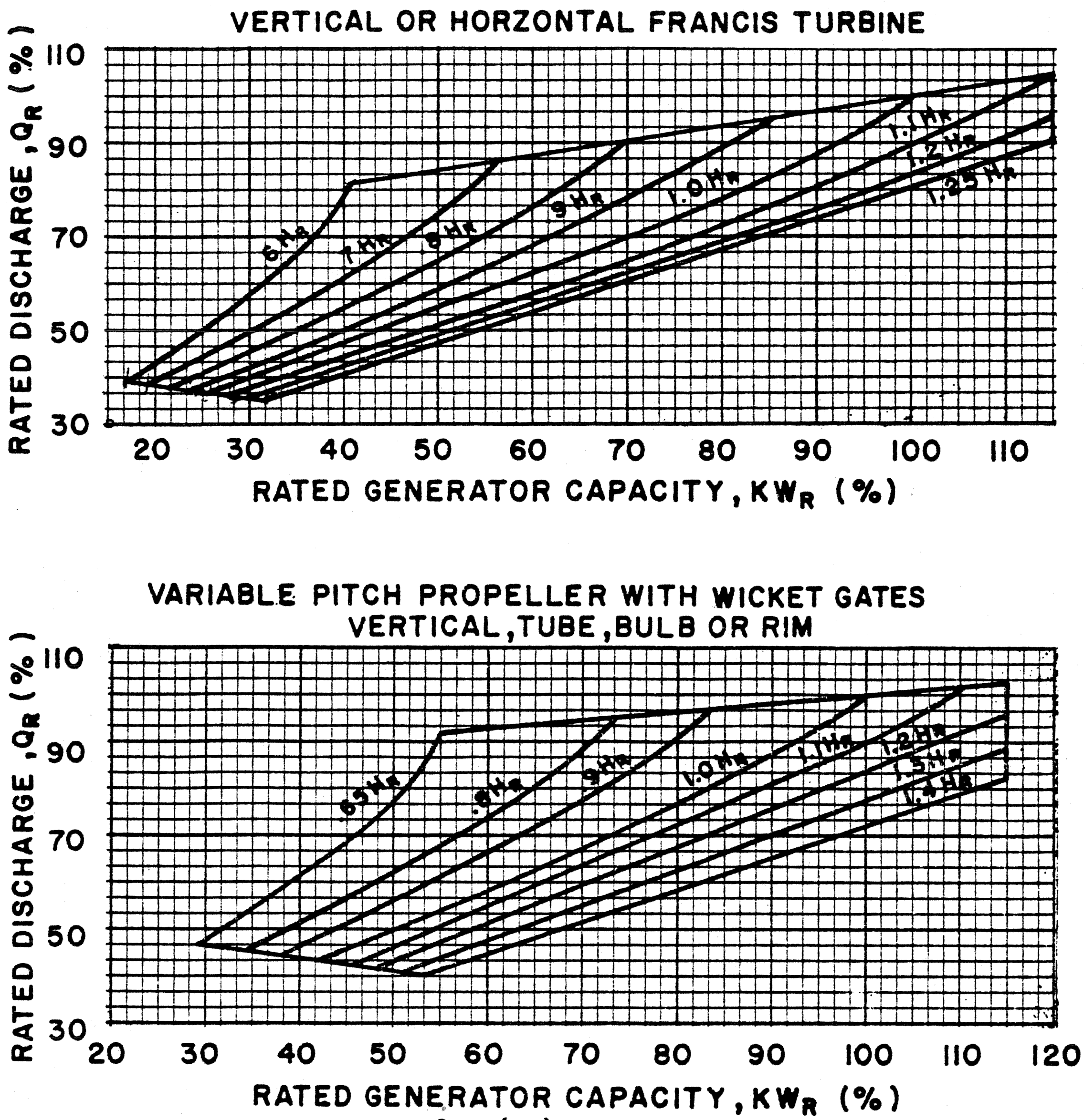
Figure 3-6. Francis turbine throat diameters



NOTES:

1. The approximate throat diameters are based upon typical values for the turbine set with the centerline of the runner at minimum tail water elevation. Actual diameters vary with manufacturers.
2. The estimated diameters may be used for both fixed and variable pitch propeller turbines, vertical, tube, slant, bulb and rim types. Dimensions for standardized tube turbines are shown on a separate sheet.

Figure 3-7. Propeller turbine throat diameters



$kW_R = H_R \, Q_R \, E_R \, E_G / 11.81$, (kW)

where:

kW_R = Rated capacity at H_R

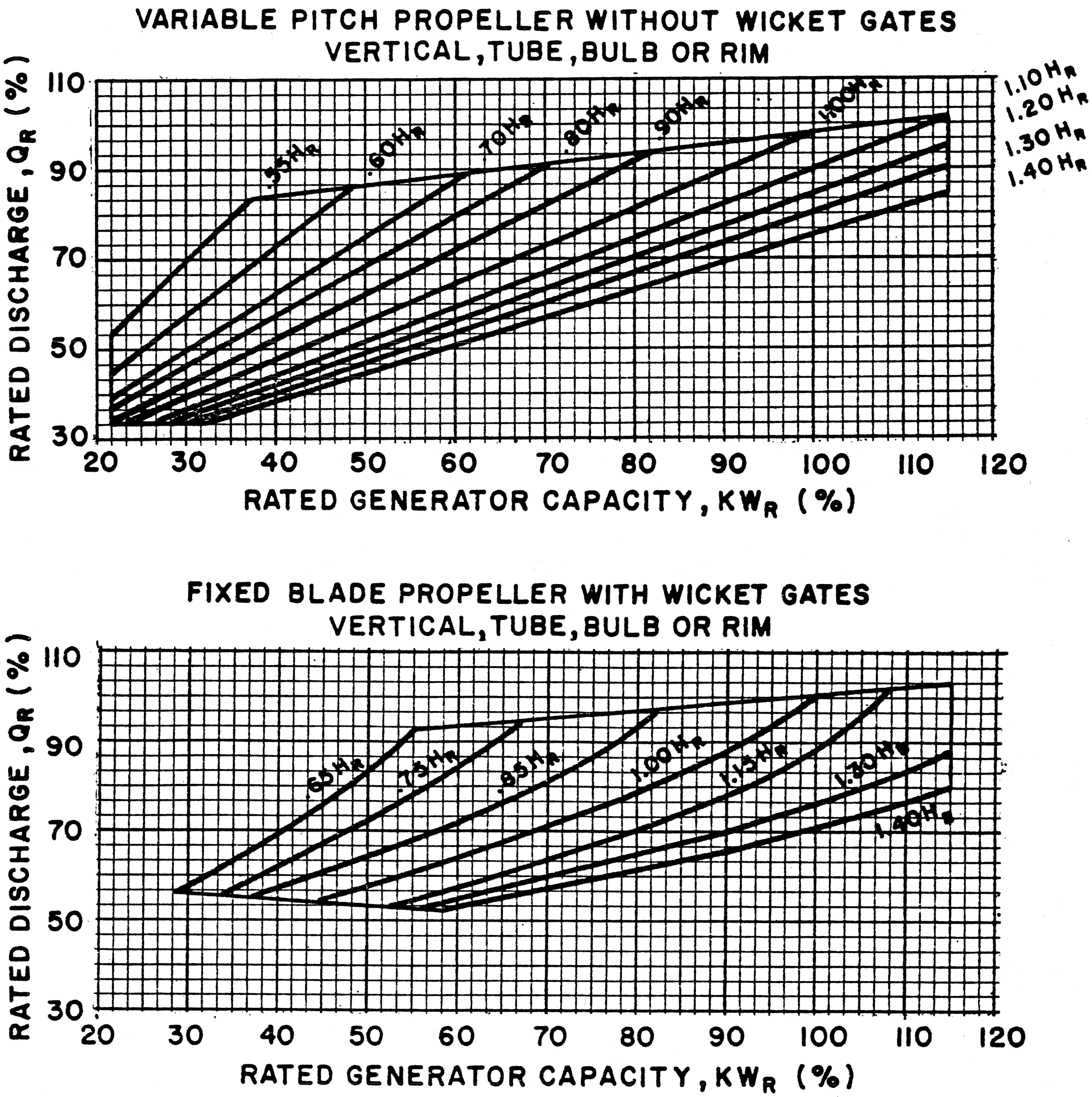
H_R = Selected Design Head, (ft.)

Q_R = Turbine Discharge at H_R & kW_R, (cfs)

E_R = Turbine efficiency at H_R & kW_R, (%)

E_G = Generator efficiency, (%)

Figure 3-8. Francis and Kaplan performance curves



$kW_R = H_R\ Q_R\ E_R\ E_G/11.81$, (kW)

where:

kW_R = Rated capacity at H_R

H_R = Selected Design Head, (ft.)

Q_R = Turbine Discharge at H_R & kW_R, (cfs)

E_R = Turbine efficiency at H_R & kW_R, (%)

E_G = Generator efficiency, (%)

Figure 3-9. Propeller turbine performance curves

power can be generated. When the $\%H_R$ is above or below the boundaries, no power can be generated.

The optimum number of turbines may be determined by use of these curves for an annual power computation. If power is being lost because the $\%Q_R$ is consistently below the lower boundaries, the annual power produced by lowering the kW rating of each unit and adding a unit should be computed. If the power increase is substantial, an approximate turbine cost of the alternatives may be approximated from the turbine costs curves and the incremental increase in cost per kWh compared. If the total construction cost of the powerhouse is assumed to roughly equal the cost of the turbine and generator, the cost per kWh derived above can be doubled and compared with the financial value of the energy. If the selection of more turbines seems favorable from this calculation, it should be pursued in further detail with more accurate studies. Conversely, the first selection of the number of turbines may be compared with a lesser number of units and compared on a cost per kWh basis as described above.

Following the establishment of the number of units, the rating point of the turbines can be optimized. This generally is done after an estimate of the total project cost have been made. Annual power production of turbines having a higher rating and a lower rating should be calculated and compared to the annual power production of the turbine selected. With the annual cost estimate, a cost per kWh may be calculated for the selected turbine. Total project costs for the lower and higher capacity ratings may be estimated by correcting the turbine/generator costs from the cost charts and correcting the remaining costs on a basis of a constant cost per kW capacity. Rates of incremental cost divided by incremental energy generation indicate economic feasibility. As an example, if a contemplated capacity increase would produce 1,000,000 kWh per year and would cost $20,000 per year in debt service and operation and maintenance, the incremental cost of energy is 20 mills/kWh. If energy is worth more than this, the capacity increase is justified.

The rated head of the turbine can be further refined by optimization in a similar manner. The annual power production is computed for higher and lower heads with the same capacity rating. The rated head yielding the highest annual output should be used.

The boundaries established on these curves are typical. Should energy output of a particular site be curtailed, it is suggested that turbine manufacturers be consulted as these boundaries can be expanded under certain conditions.

Standardized Tube Turbine. Performance curves for the Allis-Charmers units are shown on Figure 3-10. The same procedure for selection of turbines previously described is applicable for tube turbines. Following selection of the size, Figure 3-11 may be used for estimating power over the range of flow and head.

Dimensions of Turbines

General. The size of reaction turbines may be estimated after the capacity, kW_R, and effective head have been established. Figure 3-6 shows the approximate throat diameter of Francis turbines, both vertical and horizontal. Figure 3-7 shows the approximate throat diameter for Propeller turbines and may be used for both fixed and variable pitch blade units, vertical, tubular, bulb or rim types. Other dimensions of the turbine may be found in Volume VI, Civil Features. These dimensions are suitable for feasibility assessments. Actual dimensions vary with manufacturer and should be obtained from the manufacturers for final sizing studies.

Dimensions of Standardized Tube Turbine. Dimensions of the Allis-Chalmers units are shown in Figure 3-11.

Dimensions of Impulse and Crossflow Turbines. These turbine dimensions are not provided. Manufacturers should be contacted and dimensions requested when the application is suitable for these types of turbines.

Turbine/Generator Costs

General. Charts have been prepared for the various types of turbines and generators considered in this volume. The data used to prepare these charts were obtained from turbine, generator and governor manufacturers over the past five years and escalated to a July 1978 price level. Price lists are not available on turbines as most turbines are custom design. In general, turbine and generator costs per installed kW decrease as the capacity of the unit increases. However, the effective head available to the turbine has the greatest influence on the cost. The lower the head, the higher is the cost per installed kW. This increase is due to the larger size and lower synchronous speed turbine required for the low head application. The cost curves are suitable to indicate the feasibility of a project. However, it is recommended that prices be requested from manufacturers when final feasibility studies are made. It is also suggested that firm bids be received on the turbines and generators prior to the final design of the powerhouse. The bids would permit competition between the various types available and an evaluation of the overall generation cost be made including civil costs and average annual energy generation.

Turbine/Generator Cost Curves. The cost curves included in this volume are as follows:

Turbine Type	**Figure No.**
Vertical & Horizontal Francis	3-12
Vertical Kaplan (Variable Pitch Propeller)	3-13
Standardized Tube	3-14
Bulb and Rim	3-15
Cross Flow	3-16

Turbine Manufacturers. Exhibit I is a list of manufacturers which design small hydroelectric turbines within the capacity range of this volume.

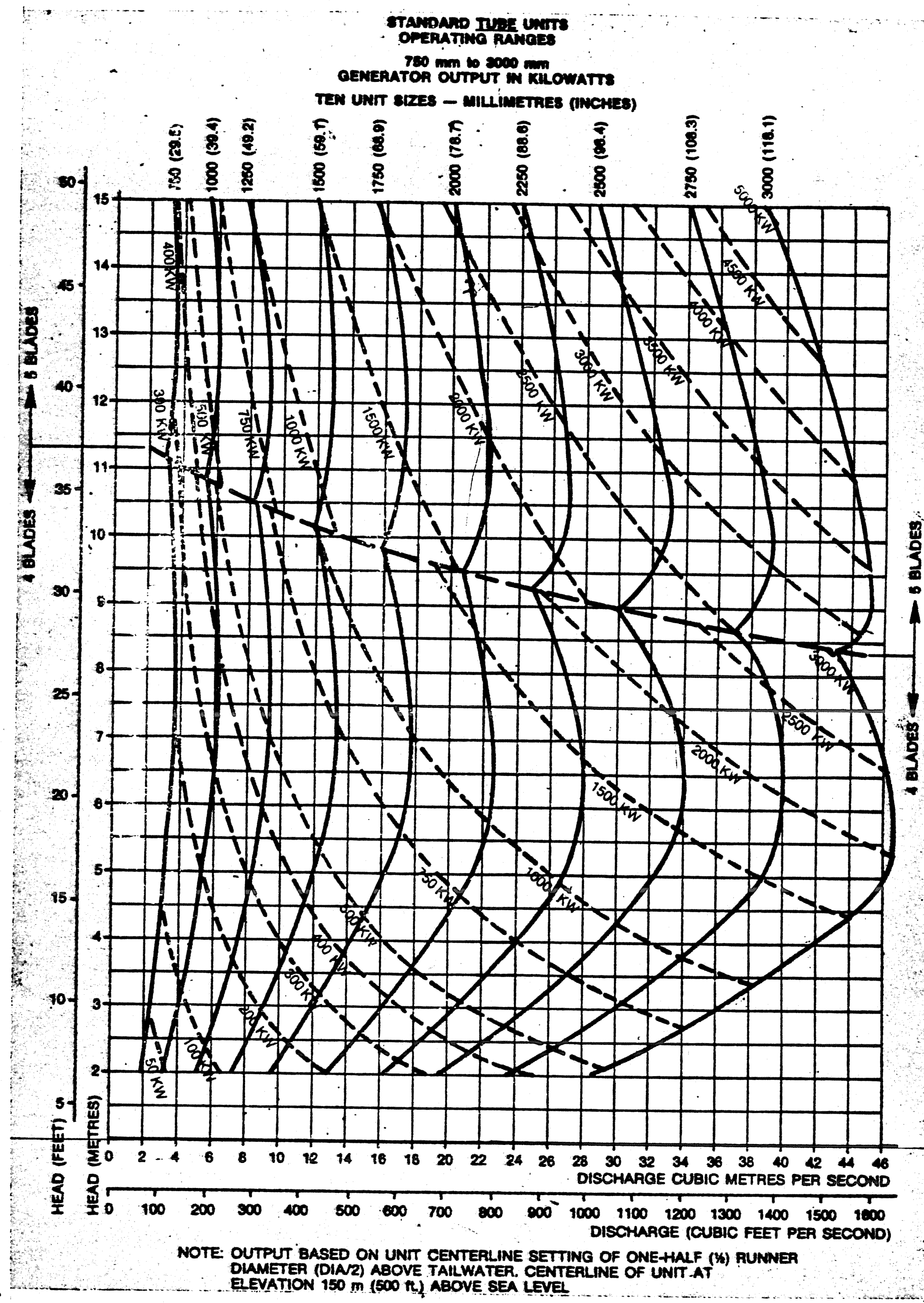


Figure 3-10. Allis Chalmers standardized Tube turbine performance curves

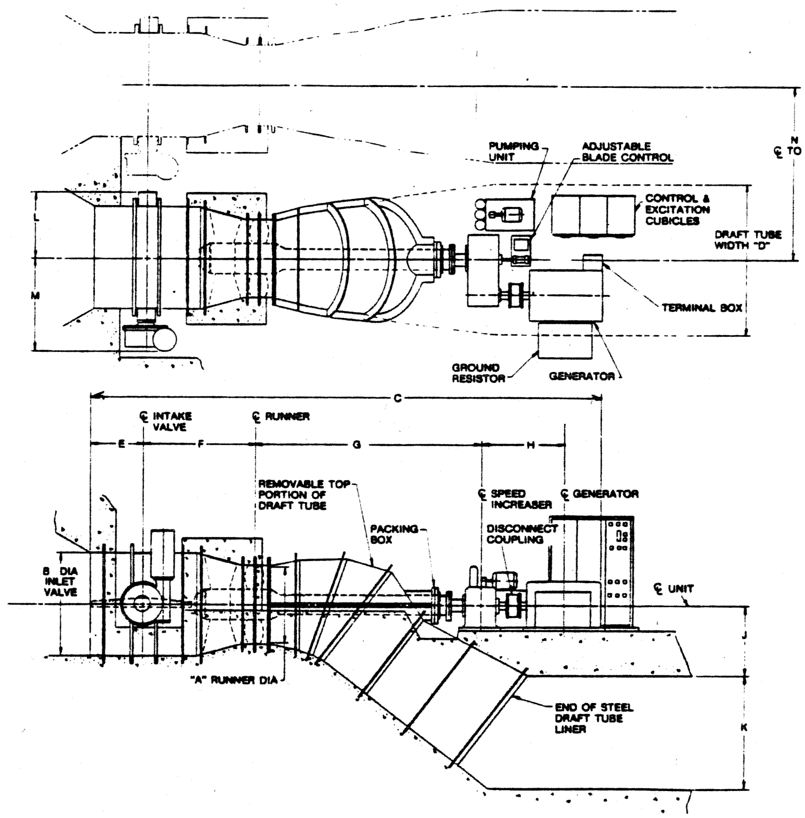


Figure 3

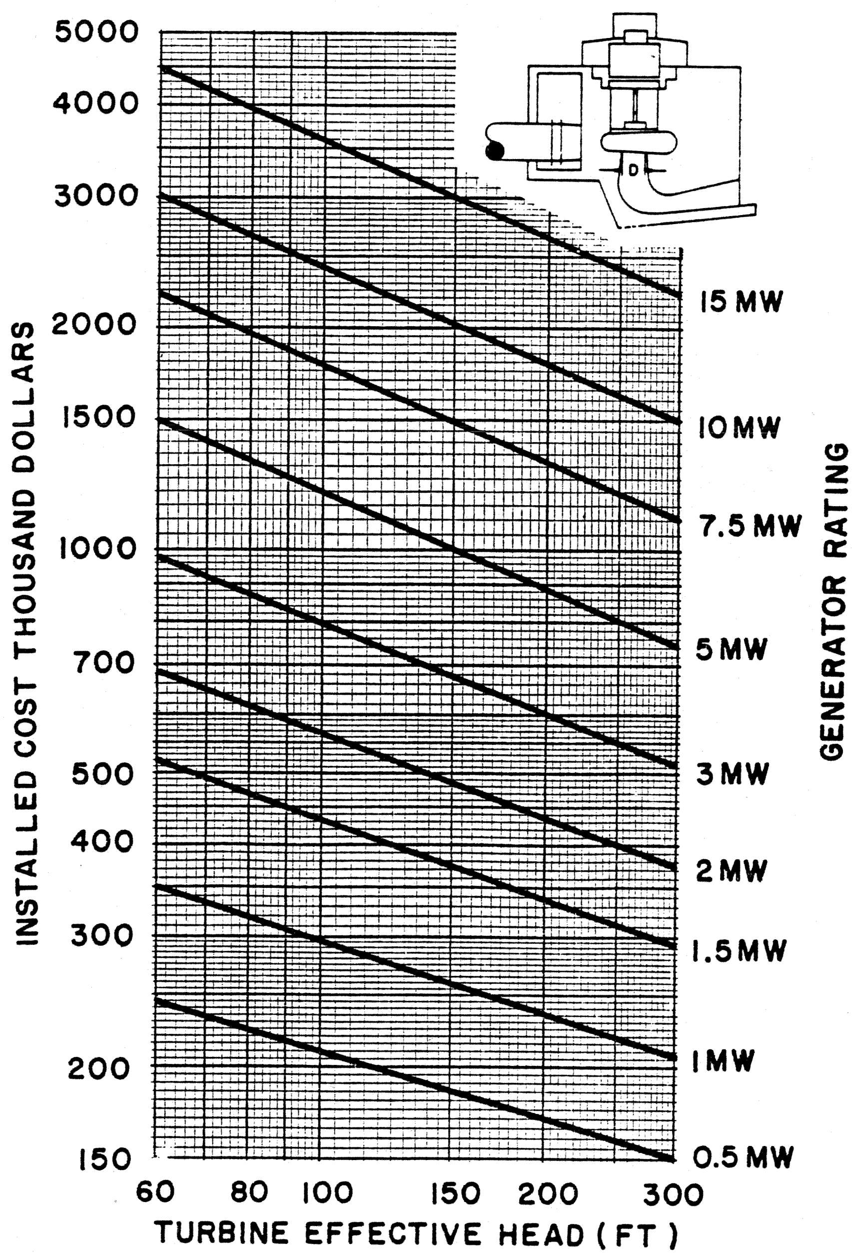
BASIC DIMENSIONS

A = Runner Diameter in millimeters (inches) = 1.00

All Other Dimensions Are In Proportion From Runner Diameter

A	750 (29.5)	1000 (39.4)	1250 (49.2)	1500 (59.6)	1750 (68.9)	2000 (78.7)	2250 (88.6)	2500 (98.4)	2750 (108.3)	3000 (118.1)
B	1.43	1.37	1.34	1.32	1.31	1.30	1.29	1.28	1.27	1.22
C	9.28	8.66	8.28	7.80	7.50	7.34	7.19	7.08	7.03	6.97
D	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
E	0.73	0.70	0.70	0.70	0.66	0.65	0.64	0.64	0.64	0.63
F	1.75	1.60	1.52	1.50	1.46	1.45	1.42	1.40	1.38	1.47
G	3.07	3.04	3.02	2.93	2.88	2.87	2.86	2.85	2.92	2.87
H	1.33	1.32	1.32	1.13	1.13	1.12	1.22	1.13	1.10	1.07
J	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93
K	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49
L	0.93	0.90	0.88	0.87	0.80	0.78	0.77	0.77	0.76	0.73
M	1.33	1.30	1.28	1.25	1.26	1.22	1.22	1.22	1.22	1.17
N	3.00	2.75	2.60	2.50	2.43	2.38	2.33	2.30	2.27	2.25

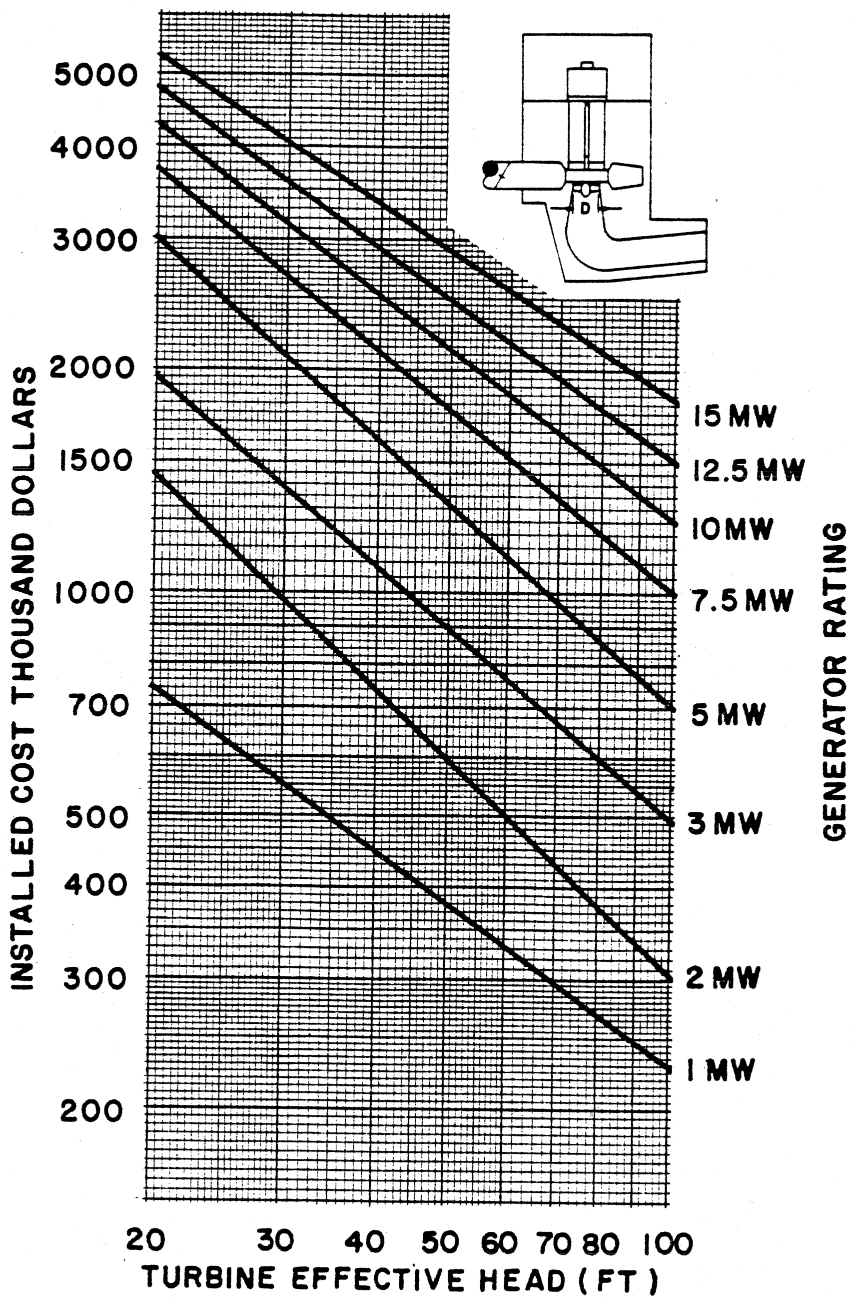
Figure 3-11. Allis Chalmers standard tube turbine dimensions



NOTES:

1. Estimated costs are based upon a typical vertical turbine direct coupled to the generator.
2. Cost includes turbine, generator, exciter, inlet valve non speed regulating governor and installation.
3. Installation costs estimated at 15% of total equipment cost.
4. Add $60,000 for speed regulating governor.
5. Horizontal Mounting Deduct 7%.
6. Cost Index is July 1978.

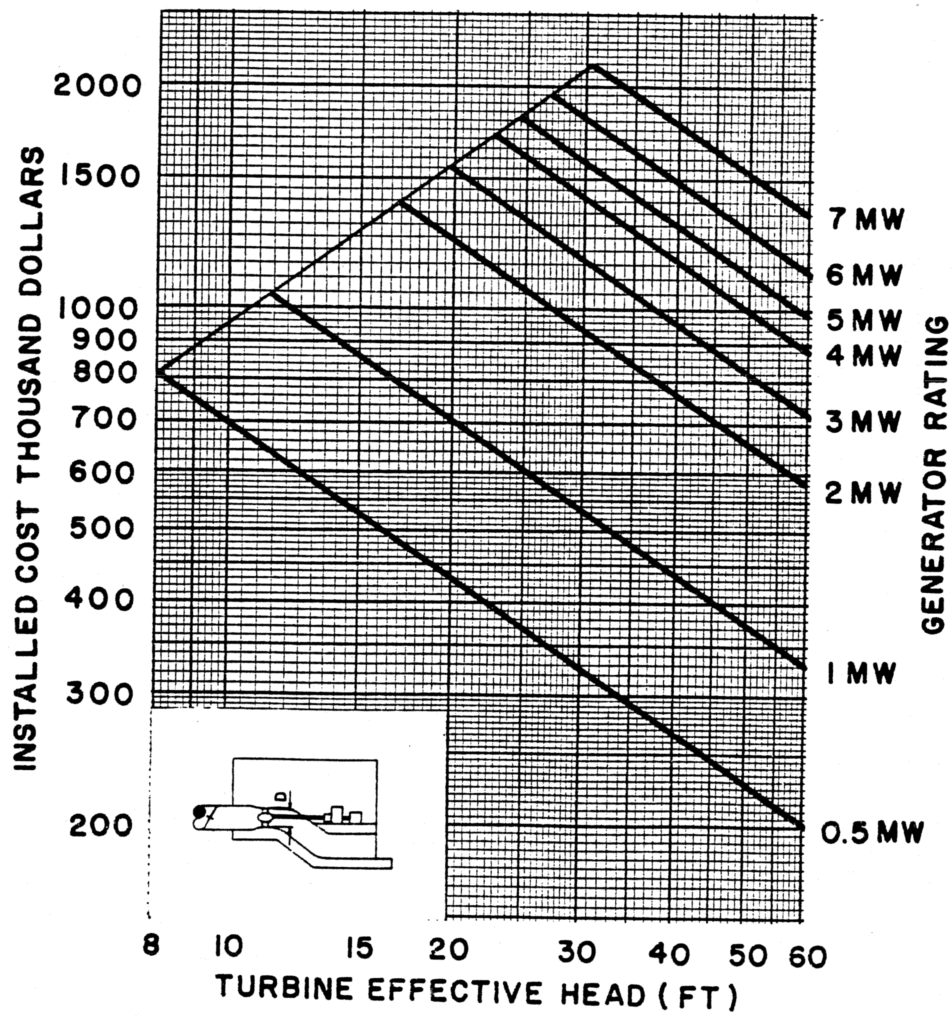
Figure 3-12. Francis turbine costs



NOTES:

1. Estimated costs are based upon a typical vertical Kaplan turbine with concrete spiral case direct coupled to the generator.
2. Cost includes turbine with adjustable blades and wicket gates, generator exciter, speed regulating governor and installation.
3. Installation costs estimated at 15% of the total equipment cost.
4. For fixed blade Propeller turbine deduct 10%.
5. Cost Index is July 1978

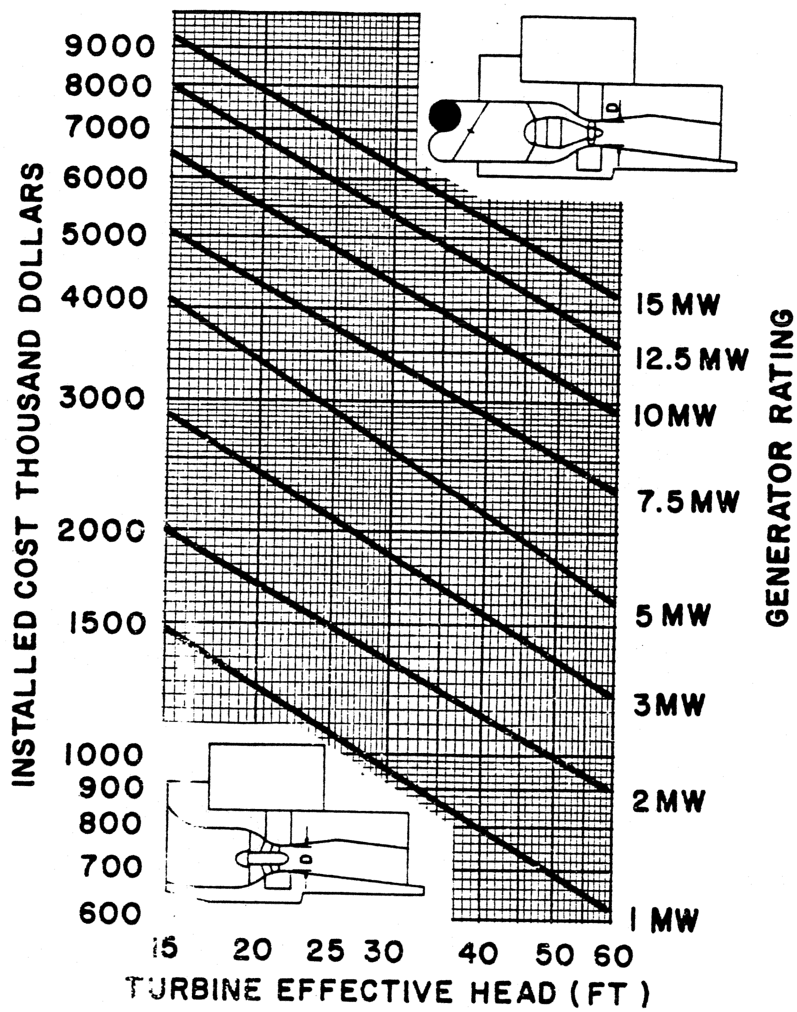
Figure 3-13. Vertical Kaplan and Propeller costs



NOTES:

1. Estimated costs are based upon standardized tube turbines coupled to the generator through a speed increaser.
2. Costs include turbine with variable pitch blades and fixed guide vanes, inlet Butterfly Valve, air clutch, speed increaser, generator with exciter, speed regulating governor, controls and installation.
3. Installation costs were estimated at 15% of total equipment costs.
4. Deduct $27,000 for fixed blade type.
5. Cost Index is July 1978

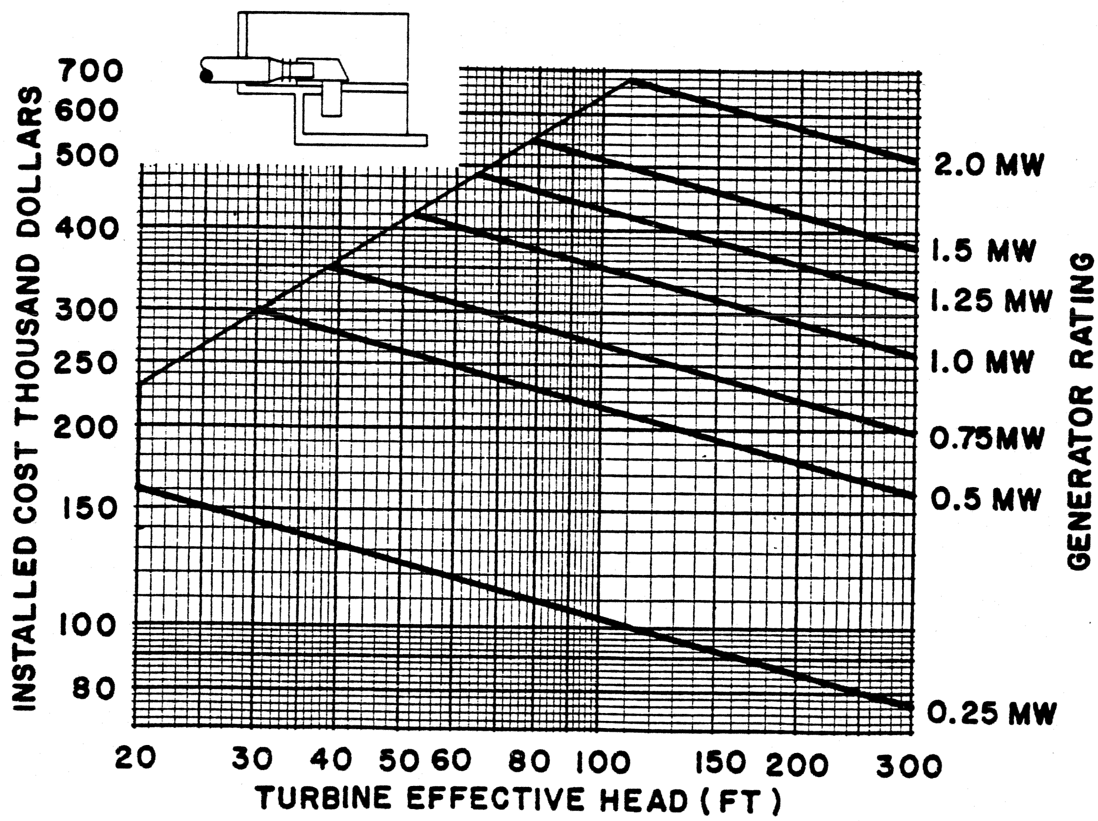
Figure 3-14. Standard Tube turbine costs



NOTES:

1. Estimated costs are based upon typical-horizontal bulb turbines with variable pitch blades and wicket gates direct coupled to the generator
2. Cost includes turbine, generator, exciter, speed regulating governor and installation.
3. Installation costs estimated at $250,000 for the large units, to $75,000 for the small units.
4. For fixed blade units, deduct 10%.
5. Cost of rim turbines are approximately the same as bulb turbines and the above chart may be used for preliminary costs of same.
6. Cost Index is July 1978

Figure 3-15. Bulbs and Rim turbine costs



NOTES:

1. Estimated costs are based upon a typical single turbine direct coupled to the generator at high heads and coupled through a speed increaser at low heads.
2. Costs include turbine, generator, exciter, inlet valve, non speed regulating governor and installation.
3. Add $60,000 for speed regulating governor.
4. Cost Index is July 1978

Figure 3-16. Crossflow turbine costs