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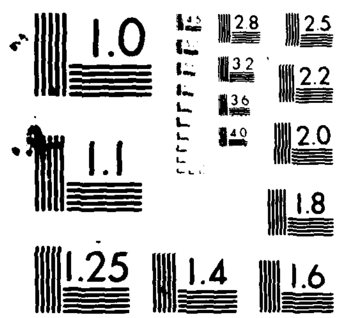

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TECHNICAL PAPER NO. 61

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TECHNICAL FACTORS IN SMALL HYDROPOWER PLANNING

by

DARRYL W. DAVIS

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The Hydrologic Engineering Center, Corps of Engineers, is preparing a document entitled "Manual for the Determination of the Feasibility of Adding Small Hydroelectric Power to an Existing Facility." The manual is designed for use by public agencies (federal, state and local), public and private utilities, and private investors. It focuses upon the concepts, technology, and economic and financial issues unique to small hydropower additions.

This paper discusses issues related to engineering and economic considerations in planning small hydropower additions. (CONTINUED)

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TECHNICAL FACTORS IN SMALL HYDROPOWER PLANNING [1/]

Darryl W. Davis[a], Member, ASCE

INTRODUCTION

The recent focus on our national energy resources has generated significant renewed attention in hydroelectric power development. In particular, recent studies (1), (2) that analyze the undeveloped hydroelectric potential at existing reservoir sites indicate that detailed studies are warranted. An attractive feature is that many of the difficulties in developing new power sites have already been dealt with (e.g., an impoundment exists). Another finding (3) was that the need exists for updating and refining analysis data and methods, especially for small power additions of 15,000 kilowatts or less.

To meet this need, the Hydrologic Engineering Center, Corps of Engineers, is preparing a document entitled "Manual for the Determination of the Feasibility of Adding Small Hydroelectric Power to an Existing Facility." The project is being sponsored by the U.S. Department of Energy through the Corps Institute for Water Resources. The manual is designed for use by public agencies (federal, state and local), public and private utilities, and private investors. The major thrust is to assemble technical data and develop procedural guidance for the systematic appraisal of the viability of potential small hydropower additions. It focuses upon the concepts, technology, and economic and financial issues unique to small hydropower additions.

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[1] Presented at the Water Systems Specialty Conference, American Society of Civil Engineers, 25-28 February, 1979, Houston, Texas.

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This paper discusses issues related to engineering and economic considerations in planning small hydropower additions, presents an overview of significant findings of the investigation to date, and provides a status report on manual preparation.

CHARACTER OF SMALL HYDROPOWER

Small hydropower projects include installations that have 15,000 kilowatts (kW) or less capacity. The concept is not limited to additions to existing impoundments, although major activities by federal, state, local agencies and private organizations seem to be so focused. "Small hydro" and "low head" hydro are not synononous even though the tendency in published documents is to avoid the distinction (4). Small hydro as defined above has been an informal breaking point used for various federal agency statistical tabulations and informal communications. It has now been defined by law (5) to be 15 megawatts (MW) for purposes of special handling for licensing, loans, incentives, and other promotional programs. Low head hydro is a term emanating from a research and development program managed by the Department of Energy that is designed to advance the technology for generating hydropower from sites with heads of less than 20 meters (66 feet). A large number of the presently identified small hydro sites fall within the low head criteria. This distinction between small and low head hydro will be preserved herein for convenience in communication and consistency with existing and emerging federal and state programs.

The underlying basis for small hydro as a concept (apart from hydropower in general) is that the impacts of implementation are likely to be modest and thus projects will be essentially non-controversial so that simpler licensing and permit granting are appropriate, and that physical facilities can likewise be kept simple and functional.

Existing and Potential Development. A significant number of existing hydropower installations in the United States could be classified as small hydro. Current installed hydropower capacity is about 60 million kW in about 1400 plants, which results in an average installed capacity of about 40 MW per plant. The latest published inventory (1) lists 142 plants as having installed capacities greater than 100 MW. Deducting the sum of the capacities for plants in excess of 100 MW from the total results in the average plant size for the remaining 1260 plants dropping to 12 MW. There are, therefore, a great number of existing plants that meet the small hydro criteria and, it would seem that the U.S. should have a considerable body of technology and technical expertise. On the other hand, the smaller plants tend to be the older plants. It should be noted as well that 385 MW (3) of hydropower, mostly small plants, have been retired from service in the last 15 years, a trend that present activities are designed to reverse.

Reported power potential at existing non-hydropower dams is about 30,000 MW (3), and this sum may exist at greater than 2000 sites. Other potential sites not identified in previous studies include irrigation canal drops (significant in the west), municipal water supply delivery systems such as in southern California and the north Atlantic, and waste management systems, such as the Chicago tunnel plan. Data from the national dam inventory (50,000 dams) indicate that about 1/3 have heads in the 6-20 foot range (considered quite low in the "low head" literature), about 2/3 have intermittent flow (inflow ceases some time during the year), and that several significant obstacles exist that inhibit bringing a large number into service. The economically attractive sites under current conditions would total significantly less than the 30,000 MW reported potential but it is generally agreed that several hundred economically attractive sites are probably available for development. The growing cost of fossil fuels is expected to continue to increase the economic viability of hydropower in general, and especially small hydropower such that within the next ten years, upwards of 1000 sites could be considered as a reasonable count for the number of small hydro sites warranting serious study for implementation.

Implementation Issues. A significant major positive feature of small hydro is that many of the important environmental issues have been resolved (e.g., an impoundment exists and is likely to remain in service). This suggests that it will be easier to propose, acquire permits, initiate, and construct small hydro additions to existing impoundments than to begin from scratch for other hydro projects or alternative thermal power generation plants. The lag time from conception to implementation could be as little as 3 years (Fig. 1) compared to the often 15-20 years for major projects. The current trend in small hydro is to take advantage of the head and existing flow release patterns to avoid the complexities that would ensue with altering water use, release patterns, and adding storage (thus increasing pools levels). The inferred judgement is that the problems that would be generated by altering the existing release patterns and use to enable more power generation, and perhaps permitting development of some dependable capacity, are not worth the time delays and added implementation complexity that would ensue. A very preliminary estimate (3) is that perhaps 15 percent of usable power output is all that is foregone by using existing release patterns. In effect the thrust is "let's develop what's presently lost through energy dissipation structures and get it on line quickly, since we are at least aiding in meeting near term energy requirements."

The belief that there will not be instances of important environmental issues is not correct, however. Any alteration of the flow pattern and release quality will require careful documentation and analysis. Also, and perhaps most important, past mitigation ommissions will generally need to be corrected. A specific case in point is that fish passage facilities (especially for anadromous fisheries) are likely to be insisted upon for sites in which they were ommitted in a prior era and preliminary studies (5) indicate the statutes exist to substantiate the insistence. Small hydro offers an opportunity for engineers to provide the leadership early in project development to identify and formulate solutions to potential environmental problems. The key point is to define issues early in investigations so that they may be included as a normal component of project feature planning.

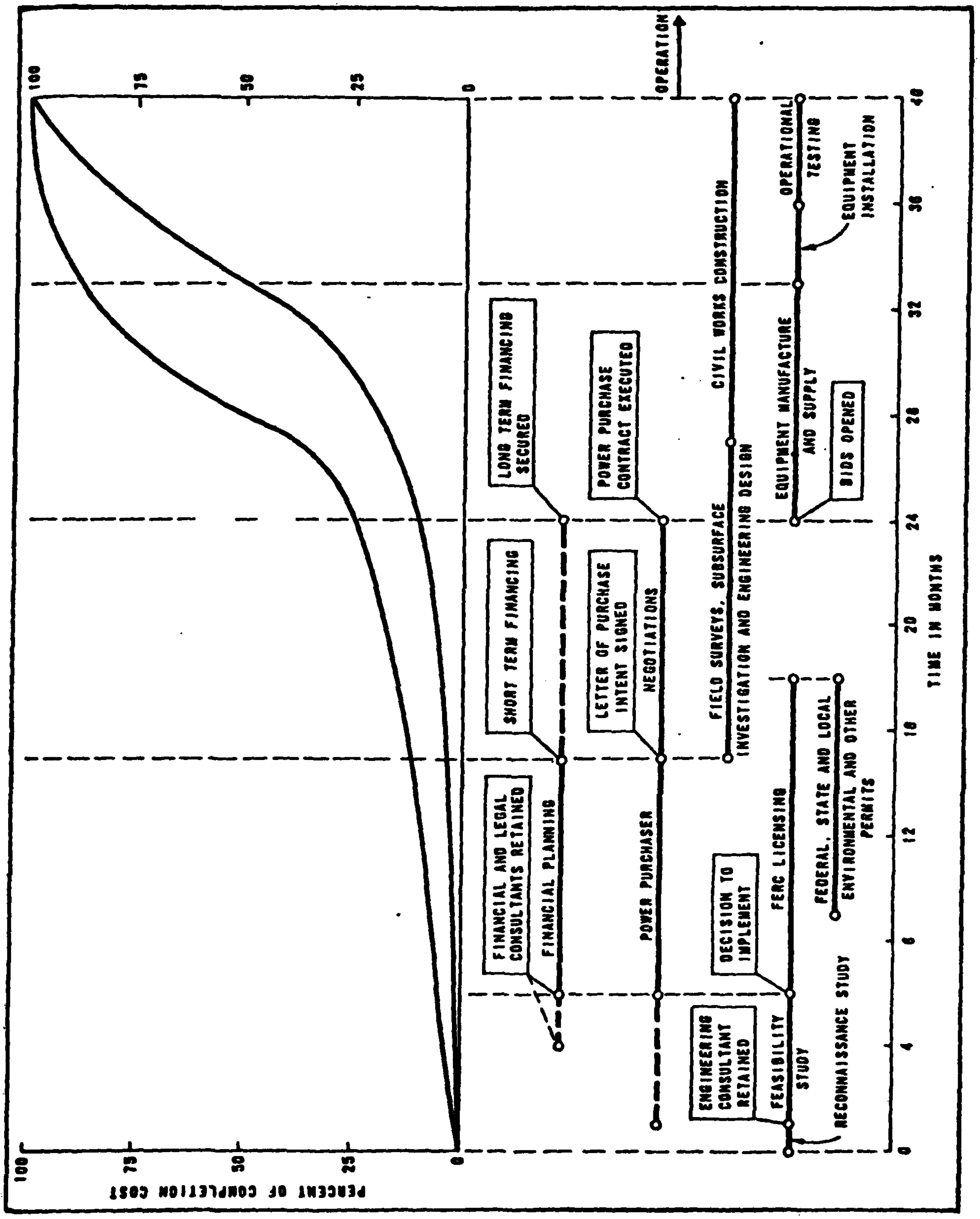


Figure 1. Typical project implementation schedule and expenditure pattern.

Factors Important for Feasibility. Several important issues that can be inferred from the previous discussion are pertinent to establishing the conceptual base for the feasibility guide manual to be discussed subsequently. Most prominently is understanding the reason for the major national attention that is focused on small hydro, an admittedly small element of the national energy array. Simply stated they seem to be: the national desire to move to energy independence, the current national concern for resource conservation, the potential for quick results from public and private efforts (an increasingly rare commodity in today's world), and most assuredly, non-firm energy (used to be referred to with the tainted label "dump energy") is now worth 20 to 30 mills per kilowatt hour as compared to 1 to 2 mills per kilowatt hour several years ago.

The greatest potential seems to be at existing sites with the major civil works already in place. The sites typically are in non-federal ownership (about one-half of existing hydropower plants are in non-federal ownership). The sites are often in the low head range (under 60 feet), with a significant number falling in head ranges less than 20 feet. The marketable output will likely be energy only with little, if any, dependable capacity. This means the value of small hydro output will be primarily due to fuel cost savings and not due to offsetting the need for new power plants to supply capacity.

The feasibility of projects is expected to be quite sensitive to site specific conditions, e.g., the quantity of power produced will not likely support the usual array of "incidental" items such as long transmission lines, access roads, significant site preparation, etc. The nature of the market area load characteristics and present generating facilities servicing the load are critical to the value of power output. Areas served with major fossil fuel based plants will likely be more attractive for small hydro because of the fuel that can be displaced. An important issue to project feasibility, and the engineering profession for that matter, is that investigation, design, construction management, administration and contingencies (the non-hardware elements of a project) are a major project cost burden. Fig. 2 schematically illustrates the cost elements in small hydro projects. In fact, the feasibility study itself is likely to be viewed as a significant financial burden warranting an investment type decision by the project sponsor prior to initiation of the study. This is especially the case with private investors and is an important reason for the recently passed legislation that includes a loan program for performance of feasibility studies (6).

FEASIBILITY MANUAL CONCEPT

The previous paragraphs have characterized the small hydro potential as existing at a relatively large number of existing sites, probably in non-federal ownership, primarily of low head, likely to generate "non-essential" power, be sensitive to site specific conditions, requiring investigations whose cost is a significant project burden, and is a concept presently in the national limelight. The guide manual (5) has been formulated to be responsive to these characteristics and to provide a foundation to encourage relatively quick, efficient formulation and assessment of attractive projects.

The guide manual describes procedures and includes cost curves, performance curves and other technical data to permit quick reconnaissance investigations (to determine whether an investment in a feasibility study is warranted) and procedural guidance and more detailed information for performance of feasibility studies (to formulate a project and to permit a definitive recommendation on project implementation). The manual is comprised of six volumes: Volume I - "Technical Guide" that overviews the investigation process and documents case study applications; Volume II - "Economic and Financial Analysis" that includes criteria and procedures for marketing and valuing power output and for analyzing financial requirements and issues critical to implementation; Volume III - "Hydrologic Studies" that describes investigations necessary to evaluate the hydrologic integrity of the dam and to estimate the power output of plant additions; Volume IV - "Existing

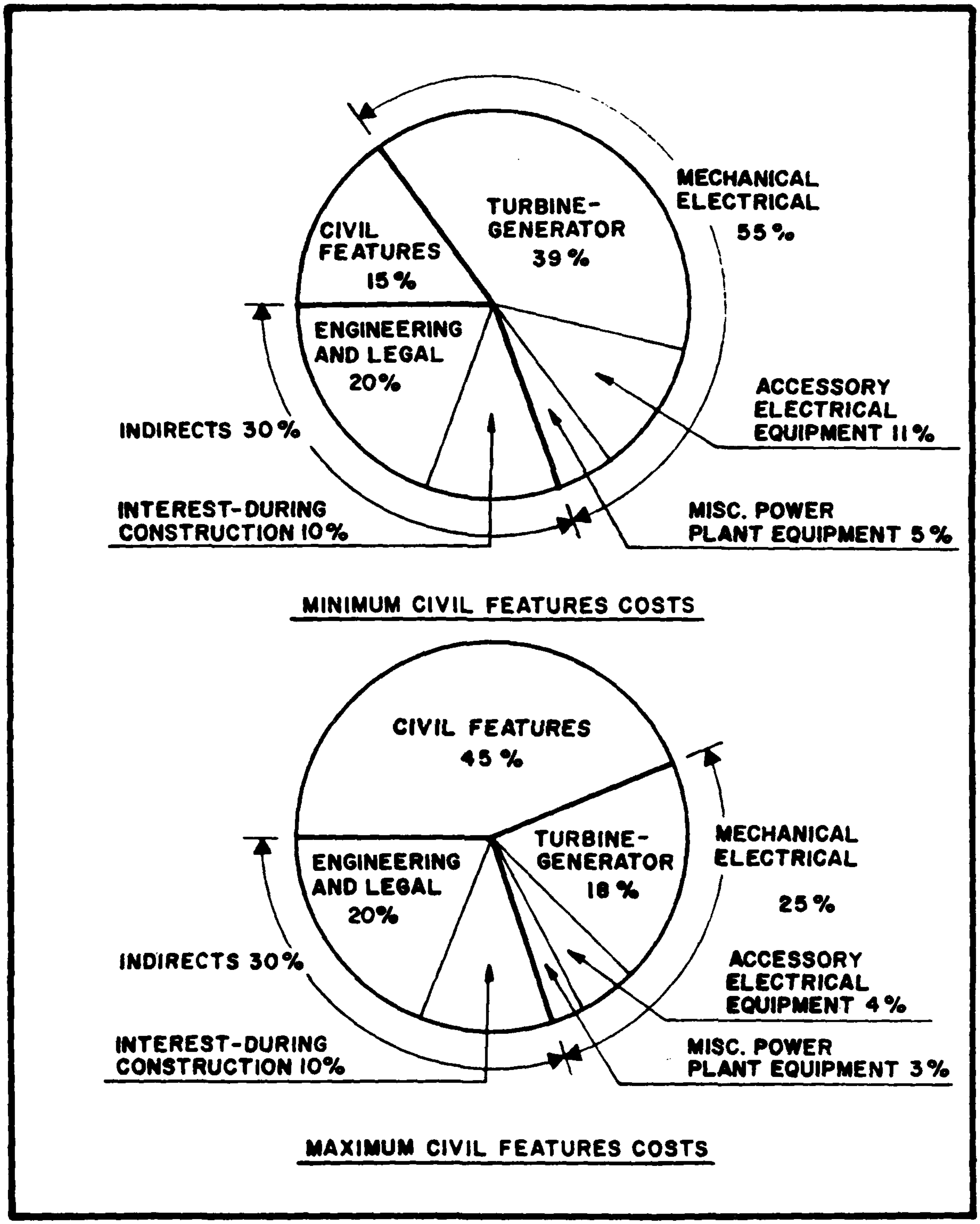


Figure 2. Range of Civil Features Costs

Facility Integrity" that provides guidance for assessing the ability of a site to safely accommodate a power addition (the thesis is that existing dams will be required to meet dam safety standards before power additions would be practical); Volume V - "Electromechanical Equipment" that describes selection criteria and performance characteristics of small hydro generation and ancilliary equipment; and Volume VI - "Civil Features" that provides design and cost guidelines for the civil features of power additions. The following sections provide a brief overview of each volume and provide samples of the data and guidance included in each.

VOLUME I - TECHNICAL GUIDE

This volume defines small hydropower and discusses the issues and technology associated with power additions to existing impoundments. The introductory material contained in this paper is included in an expanded form in early sections of the volume. The Guide provides an overview of the manual, presents the purpose, concept, and configuration of the manual, and describes the components of a feasibility study and their relationships. Feasibility investigations are characterized as a continuim that begins with generalized resource assessments, such as the many resource assessments underway across the U.S., and concludes when construction is initiated. Decision points exist at several critical stages. The guide manual provides guidance for the reconnaissance stage (should a feasibility study be initiated) and the feasibility stage (should an implementation commitment be made) decision points. It is recognized that subsequent findings could alter the implementation decisions; such as undiscovered site problems of integrity, or foundation competance or financing difficulties (problems in bond marketing for instance), or unfavorable bid openings (the price of equipment presently fluctuates considerably because of the small market for equipment and limited production capability). The manual is sufficiently complete that unpleasant surprises should be minimized.

The volume includes an outline and flow chart of major task elements needed to perform the reconnaissance and feasibility studies. Emphasis is placed on the fact that the planning studies need to be considerably detailed and specific noting that site specific conditions are important and investigation costs must be kept to a minimum. The contents and use of the other volumes are described (much as in this paper) and their use conceptually integrated into the analysis process. The several key elements of licenses and permits, environmental issues, and implementation considerations are catalogued and discussed.

Included as exhibits to the "Technical Guide" are two case studies of existing projects, one from the West nearing completion of construction and start up and one from the Northeast currently in the final design stage. The case studies reformulate the two projects following the data and guidance in the manual and serve both as a test of the manual and illustrated examples of manual use.

VOLUME II - ECONOMIC AND FINANCIAL ANALYSIS

This volume provides documented procedures for performing the economic and financial studies necessary for feasibility determination. The three major subjects covered in the volume are market analysis, economic feasibility determination, and financial feasibility determination. The perspectives appropriate for public agencies, public and private utilities, and private investors are presented.

Market Analysis. The potential markets for output from small hydro are public and investor owned utilities (IOU's), private industrial users and other lesser important entities. The market analysis takes the perspective of an owner/project sponsor evaluating the benefits and costs of the sale of power from the small hydro project. Industrial users and publicly owned utilities and cooperatives are characterized as potentially more favorable markets than IOU's simply because of the prevailing profit regulatory methods (e.g., unless more capital is invested by an IOU, profits may not significantly increase). The character of the available power is important, especially in the event that some dependable capacity might be available. A proposed concept for crediting hydropower with equivalent thermal capacity is presented in which an adjustment for thermal equivalent forced outage is proposed. The seasonal and annual availability of energy are important parameters in market negotiations. The value of a small hydro project is determined by the power purchasers opportunity to reduce existing cost while maintaining equivalent service. Examples of power value calculations for an industrial purchaser and a utility purchaser are included.

The types of marketing arrangements are described and comments on the significant features of each are identified. The four types of arrangements discussed are: (a) Cost Plus Percentage of Debt Service - in which the project sponsor (owner) agrees to deliver all or part of the output, and, in return, the purchaser agrees to pay "in all events" a prorata share of "all costs" of the plant, plus an additional fixed percentage of the prorata share of debt service; (b) Cost Plus a Royalty Subject to Escalation - in which the difference from the previous arrangement is that in lieu of having the project sponsor receive a fixed percentage of debt service as compensation, the sponsor receives a minimum per kWh payment, which is subject to escalation; (c) Sales per Kilowatt-Hour - in which output is sold as power is generated, with the price subject to adjustment based on an index. The difficulties in assuring debt service payments because of widely fluctuating annual revenues will usually preclude obtaining project financing for a small hydro project; (d) Sales per Kilowatt-Hour with Cost Guarantee and Balancing Account - in which the weakness in the previous sales per kilowatt-hour arrangement is managed to increase revenue security to enhance financing possibilities. In effect, the power purchaser is providing periodic short term financing.

Economic Analysis. Economic feasibility is clearly distinguished from financial analysis. Economic feasibility is defined as positive when project benefits exceed project costs. Project benefits are defined as the increase in economic value (the sponsor's perspective taken) generated by the project that is often limited in small hydro analysis to the stream of costs that would be representative of the least costly source of equivalent power. Project costs are defined as the time stream of economic value required to produce hydroelectric power from the project and is often limited to management and construction costs required to develop the power plant, and the administration, operations, maintenance and replacement costs required to continue the power plant in service. Conventional constant price level economic concepts are presented and discussed as representative of most current federal and other public agency evaluation procedures. In addition, a strategy for incorporating general price escalation and resource cost inflation (in which important commodities (e.g., fuel) escalates at rates different from other factors) in benefit cost analysis is presented and illustrated with an example. Concepts of risk and uncertainty are presented and an analytical structure for dealing with each is proposed. The several methods of determining feasibility and project ranking of Net Present Value (discounted benefits minus costs), Internal Rate of Return (discount rate at which the present value of cost and benefit streams are equal) and Benefit to Cost Ratio (discounted benefits divided by discounted costs) are presented, discussed and examples included. The internal rate of return is emphasized as a common private sector analysis method.

Financial Feasibility. Financial feasibility is defined as positive when it can be demonstrated that the project can secure the needed financing for implementation and that the revenue receipt pattern will provide debt service for loans that may be incurred. In effect, the task is to show that the project is self-liquidating with acceptable risk at realistic interest rates. Financial analysis is particularly important in small hydro because of the likelihood of private investment and the variety of potential sponsors. Inflation is discussed to identify its role in determining financial feasibility and to provide guidelines in its accommodation in project financing. The range of funding of sources are presented: (a) federal programs - U.S.

Department of Energy (feasibility and construction loans); (b) financing by public entities that include issuance of general obligation bonds and revenue bonds (these are discussed in detail), (c) investor owned project financing that includes a range of bond types, warrants, and stock.

Implementation factors are discussed as related to economic and financial issues. Fig. 1 is an example implementation schedule displaying important tasks and a range of possible expenditure patterns.

A detailed discussion of the need for and nature of the financial advisors role in a feasibility study and project implementation is presented. The financial specialty area of bond consultants is presented to encourage that feasibility study managers allocate adequate resources for the performance of this important phase of financial analysis.

VOLUME III - HYDROLOGIC STUDIES

This volume describes the studies needed to determine the integrity of the existing structure during the passage of major flood events and to determine the capacity and energy potential at the site. The topics of spillway adequacy, basic streamflow development methods, and capacity and energy calculations are discussed in major sections.

Spillway Adequacy. The spillway is the safety valve of a dam and is the primary facility protecting its integrity from failing from overtopping from occurrences of large hydrologic events. The current criteria for needed spillway performance as a function of reservoir capacity, dam height, and vulnerability of downstream areas that has emerged from dam safety studies by the Corps of Engineers is described (Table 1). The hydraulic characteristics of spillways and outlet works are described and technical references for analysis procedures included. Flow-exceedance frequency and hydrograph techniques to enable calculation of the range of events tabulated in Table 1, part C are presented.

TABLE 1

SPILLWAY PERFORMANCE CRITERIA

a. Size Classification

Category	Impoundment Storage (Ac. Ft.)	Impoundment Height (Ft.)
Small	50 to 1,000	25 to 40
Intermediate	1,000 to 50,000	40 to 100
Large	over 50,000	over 100

b. Hazard Classification

Category	Development Downstream	Economic Loss
Low	No Permanent Structures	Minimal
Significant	Few Inhabitable Structures	Appreciable (Ag. & Industry)
High	More than a few	Extensive (Urban, Ag, Industry)

c. Spillway Design Floods

Hazard	Size	Spillway Flood
Low	Small	50 yr. to 100 yr. frequency
	Intermediate	100 yr. to 1/2 PMF*
	Large	1/2 PMF to PMF
Significant	Small	100 to 1/2 PMF
	Intermediate	1/2 PMF to PMF
	Large	PMF
High	Small	1/2 PMF to PMF
	Intermediate	PMF
	Large	PMF

* Probable Maximum Flood

Basic Streamflow Data. Streamflow data are needed to permit capacity and energy computations. Small hydro proposals in which the release pattern is not to be changed and for which adequate observed historic release patterns exist are the most simple for which to assemble needed streamflow data. It might also be noted that these instances are not the most common. The degree to which records are short, contain gaps, poorly recorded or to which changes in operating policy have occurred or are possible in the future, determines the added complexity and effort needed to assemble a representative record. On one extreme, reconstruction of a long period of record by simulation of the hydrologic process and operation of the project is possible but could be beyond the effort appropriate for a specific small hydro study. On the other extreme, adaptation of processed synthetic data from generalized studies such as flow duration curves requiring minimal effort are possible and useful but could potentially be of poor quality. The appropriate strategy for a small hydro study will certainly vary between sites but is likely to include a mid-point between the two extremes requiring using one or more simple approaches and eventually adopting a likely representative record. Some elementary level of correlation and regional analysis can often be appropriate and are described in the volume. Techniques for constructing records given various difficiencies are presented and methods for processing the adopted record to characterize the variability of flow are described. Several examples are included using correlation, simulation and transfer methods.

Capacity and Energy Calculations. Power analysis procedures of duration curve analysis, mass inflow curves, low flow frequency and sequential period of record routing are described and examples included. Duration curve analysis is characterized as the most approximate but easiest to perform (and many times is entirely adequate) and sequential period of record routing as the most accurate (depending on the quality of the available record) but requiring the most effort. Fig. 3 is an example power computation using flow duration analysis techniques. Computational aids in the form of references and computer programs are described.

FIGURE 3

EXAMPLE POWER COMPUTATION-DURATION CURVE METHOD

Flow-cfs	% Time Flow Exceeded
20	85
50	48
100	28
150	19
200	15
300	12
500	9
1000	6
1500	4
2000	3
3000	2

Turbine Design

a. Head = 30 ft, Q = 15% Exceedance Flow

b. $kW = \frac{QHE}{11.8} = \frac{(200)(30)(.86)}{11.8} = 437\ kW$

c. Turbine Flow Range 30 to 110% design
Flow < 60 cfs - 58%

d. High Tail Water above 3000 cfs - 2%

e. Energy generated 58+2 or 60% of time
Weighted duration flow = 54.5 cfs
@ 100% time

$$Energy = \frac{(54.5)(30)(8760)}{11.8}(.86) = 1.04 \times 10^6\ kWh$$

for 2 turbines @ 100 cfs, Energy is added 200,000 kWh

VOLUME IV - EXISTING FACILITIES INTEGRITY

It is clear that a prerequisite to serious consideration of a site for a small hydro addition is that it be capable of meeting current dam safety standards. If the dam meets requirements as is, then other investigations can be pursued in earnest. If deficiencies exist, it is likely that unless the problems can be remedied with a modest investment, the site will not be attractive for adding power facilities, at least in the near term. The small hydro addition could be expected to make modest improvements to meet integrity deficiencies but would not often generate adequate benefits to "carry" significant remedial work. This observation changes if alternative financing for safety related remedial work is separately provided.

The integrity volume is designed to identify early in the feasibility study, any deficiencies that might exist and thus provide a decision point for study termination. Guidance for formulating a range of suitable remedial measures is included.

The volume can by no means provide inexperienced engineers the capability to perform definitive safety studies. The intent is to provide a strategy that will alert investigators to potential problems. Should the problems appear critical, the volume recommends terminating the power addition feasibility study and notifying appropriate state and federal authorities of the existence of the identified integrity deficiencies.

The volume classifies and describes the principal dam types (concrete, masonry, earth and rockfill) likely to be encountered in a small hydro addition feasibility study. The appurtenant works associated with dams (spillway, outlet works, power plants, locks and fish ladders) are described by type and function.

The typical deficiencies and failure modes of dam overtopping, uncontrolled or excessive seepage, foundation instability, embankment slope instability, slope protection deterioration on embankment dams, concrete deterioration, excessive uplift pressures, spillway/outlet works failure, and erosion are described and the principal mechanism causing the deficiencies are discussed. Potential adverse effects of power additions are highlighted to alert investigators to problems that may be created by the modification of existing facilities to accommodate a power plant.

The integrity investigation is outlined as a three staged process; the first consisting of records collection and examination, the second includes supplemental data collection and analysis to support conclusions relative to integrity, and the last the formulation of repair schemes, if they prove necessary, for rehabilitation work. The elements of each stage and strategy for their performance are outlined.

Rehabilitation measures suitable for the several dam types and typical deficiencies are described and guidelines are included for estimating their cost. The dam and appurtenances, and foundation are discussed in separate sections but the emphasis is placed on the need to consider the integrity of the dam as a function of *all of its interrelated* components.

Appended as exhibits are (a) "Universal Checklist for Inspections", adapted from the U.S. Bureau of Reclamation (7) and (b) "Considerations and Procedures for Impoundment Integrity Evaluations", also adapted from the USBR

VOLUME V - ELECTROMECHANICAL EQUIPMENT

Electromechanical equipment are the features and systems needed to harness the energy, both potential and kinetic, available in impounded or flowing water, to convert it to electrical energy, to control it, and to transmit it to a regional power grid. The major equipment items are the hydraulic turbine, the electric generator, and a switchyard consisting of a transformer, circuit breaker, and switch gear. Included are supporting systems which control and protect these major equipment items. Maintenance facilities such as a crane for lifting, are also included in a broad definition of electromechanical equipment.

Several domestic and foreign equipment manufacturers have historically provided small turbines and are active in standardizing unit sizes and packaging relatively complete generating sets for marketing. These curr trends are defined. Relaxing the need for some control and protection eq ment is becoming accepted as the scaling down to small facilities takes r within the industry. Simpler low cost governors and similar items are app ing on the market. Smaller hydroelectric plants can also be designed with less flow control than larger plants. The flow of water to most turbines controlled by a set of wicket gates. These gates are regulated by signals from the governor to control the amount of power produced. Where power c trol is not needed (many small plants) the gates can be eliminated and th cost of the turbine reduced by as much as 10%.

The volume outlines a procedural strategy for sizing and selecting the generating equipment (Fig. 4), and includes description, cost, and performance data for Francis, Crossflow, Propeller, Tube, Bulb, Slant and Rim turbines suitable for the range of heads and power output for a small plant. A common parameter used among data and relationships within the electromechanical volume is the turbine throat diameter. This parameter is carried forward to the Civil Features volume (discussed next) as the indexing parameter to determine powerhouse layout dimensions and costs. The series of example curves (Figs. 5, 6, 7, 8) illustrate the type of data included and manner of performance and cost data presentation. Each turbine type is characterized by a set of similar functions.

A section describing generators suitable for small hydro is included and data on dimensions and weight tabulated. Descriptive data, performance curves, and cost are likewise included for generation control and protection equipment, and switching, transmission and miscellaneous equipment.

A cost summary form that is catagorized by the Federal Energy Regulatory Commission (FERC) Account Number is included to encourage systematic use of the material presented in the volume.

VOLUME VI - CIVIL FEATURES

The civil features of small hydropower additions include site preparation works, hydraulic conveyance facilities, and 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, inlet and 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.

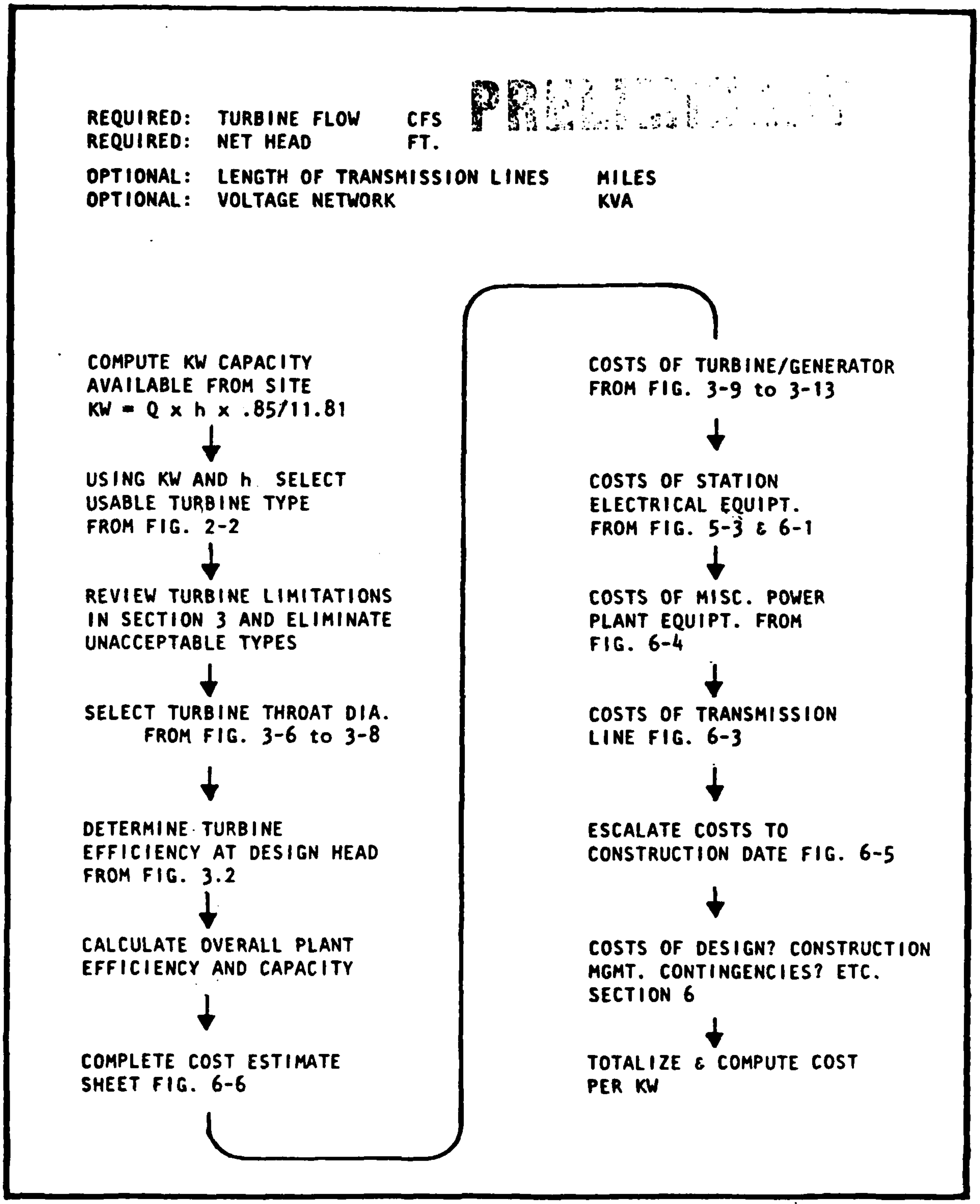


Figure 4. Turbine selection methodology

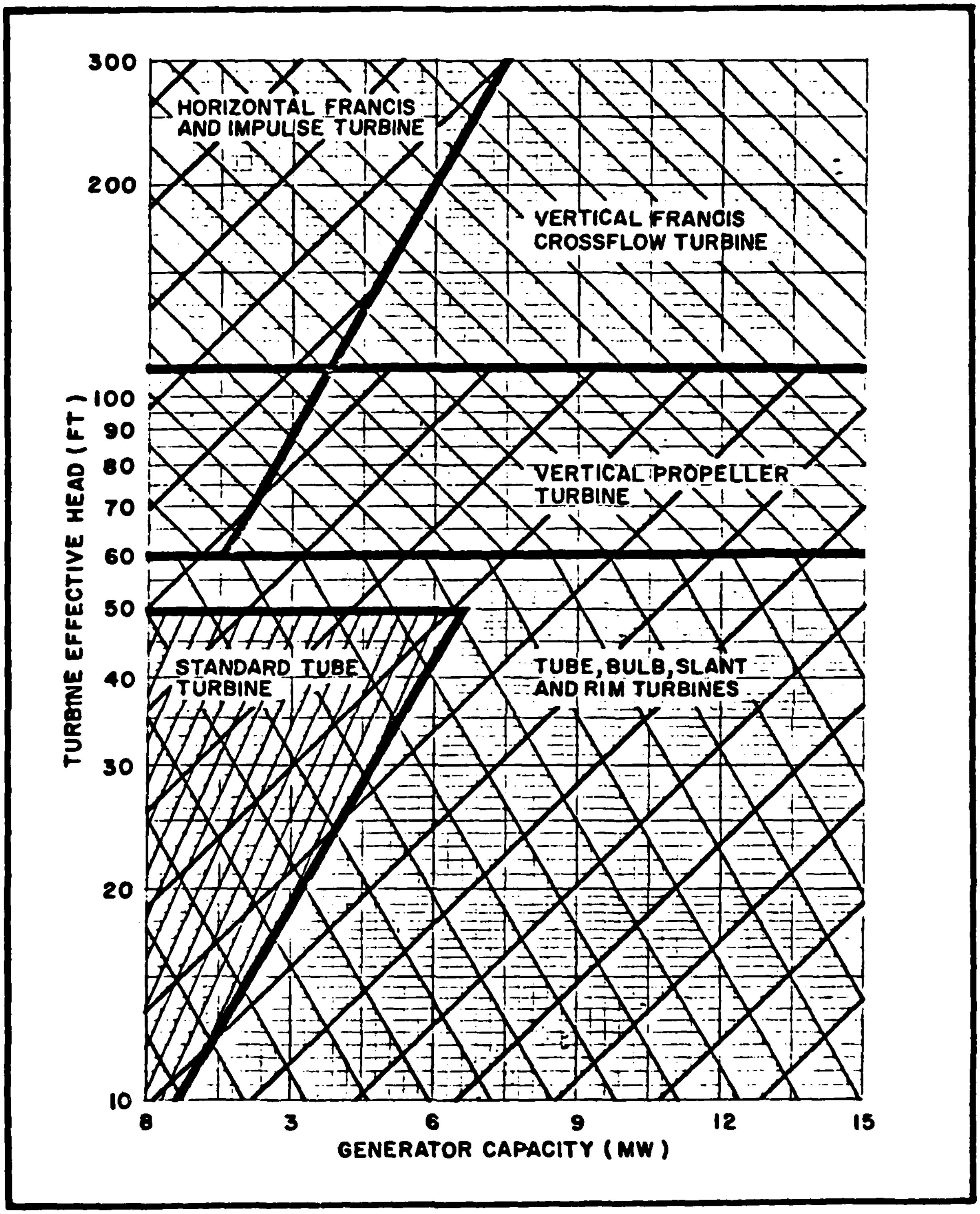
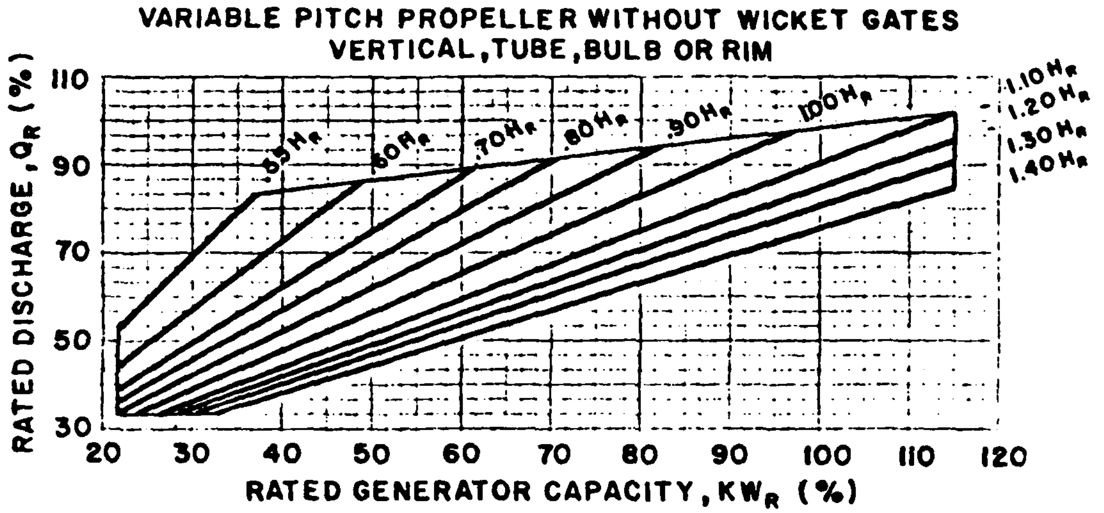
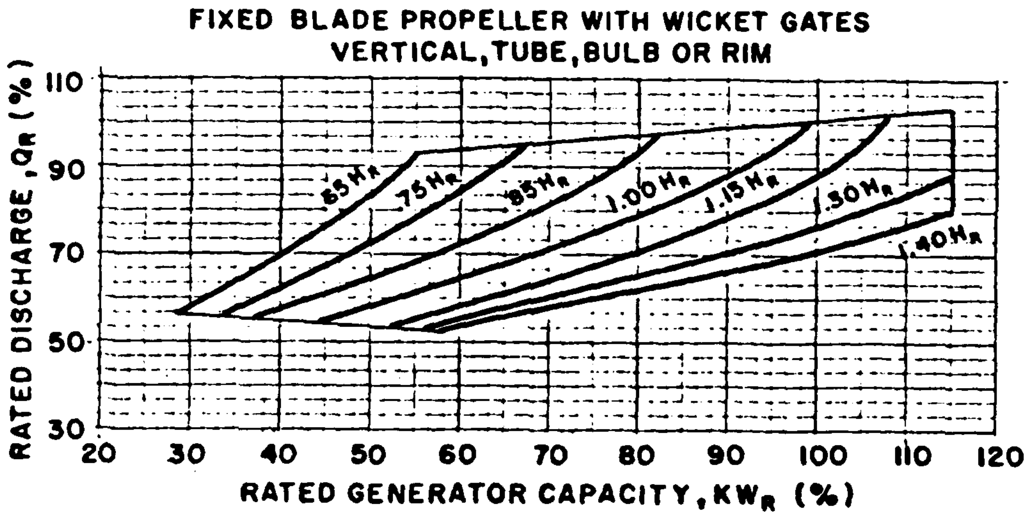


Figure 5. Turbine operating range

PRELIMINARY





$KW_R = H_R \, Q_R \, E_R \, E_G / 11.82$, kw

where:

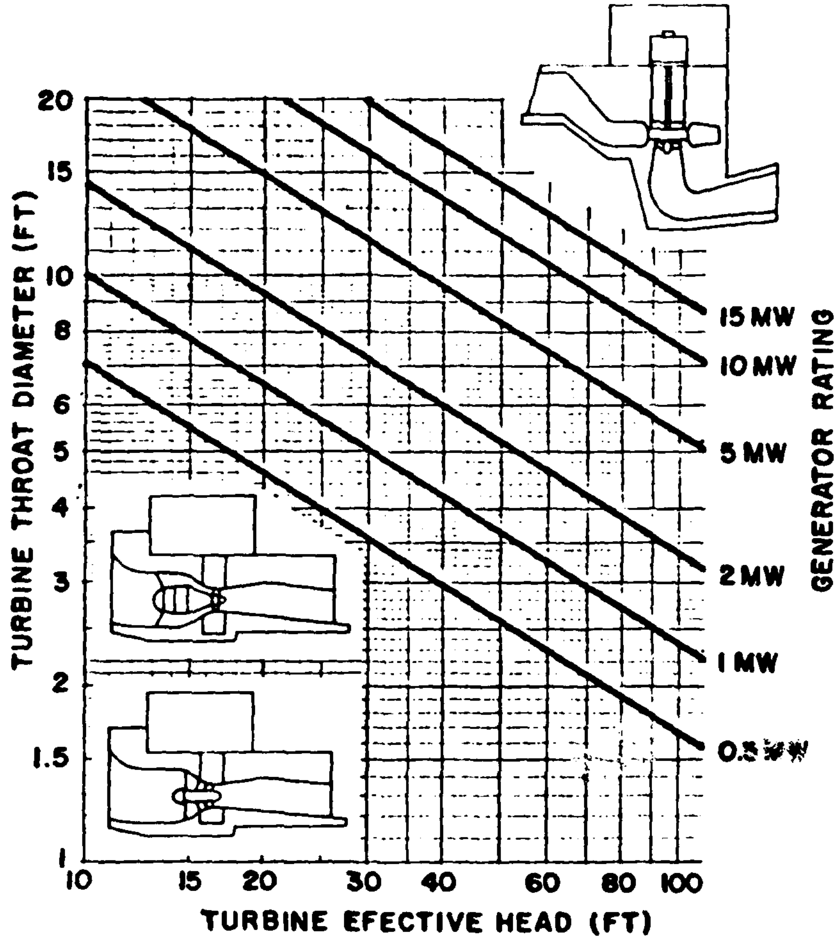
H_R = Selected Design Head, (ft)

Q_D = Turbine Discharge at H_D & KW_R, (cfs)

E_R = Turbine efficiency at H_D & KW_R, (%)

E_G = Generator efficiency, (%)

Figure 6. Propeller turbine performance curves

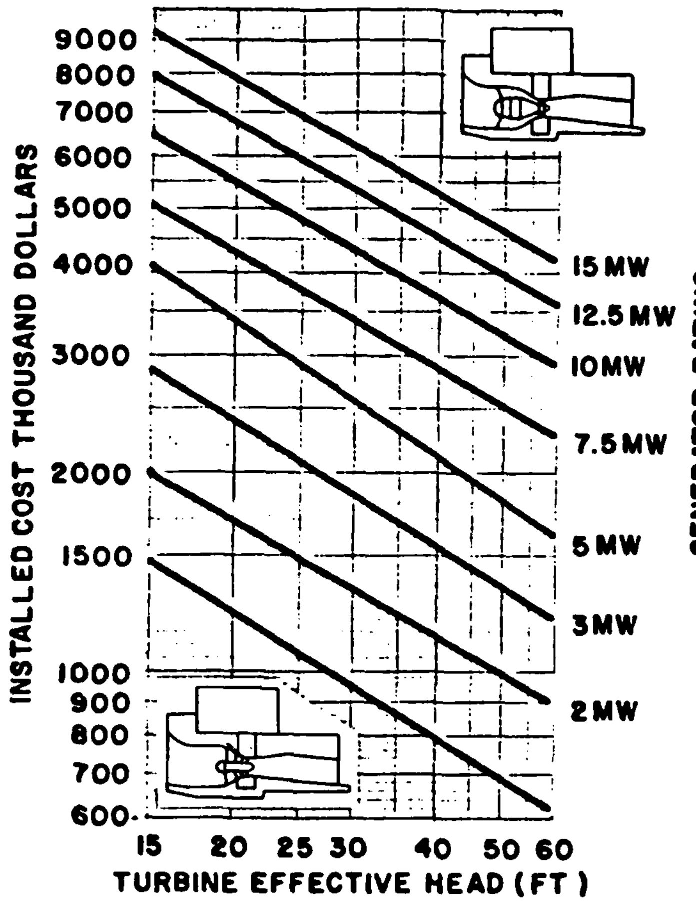


1. The approximate throat diameters are based upon typical values for the turbine set with the centerline of the distribution or centerline of runner at minimum tail water. Actual diameters vary with manufacturers.

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 7. Propeller turbine throat diameters

PRELIMINARY



PRELIMINARY

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.

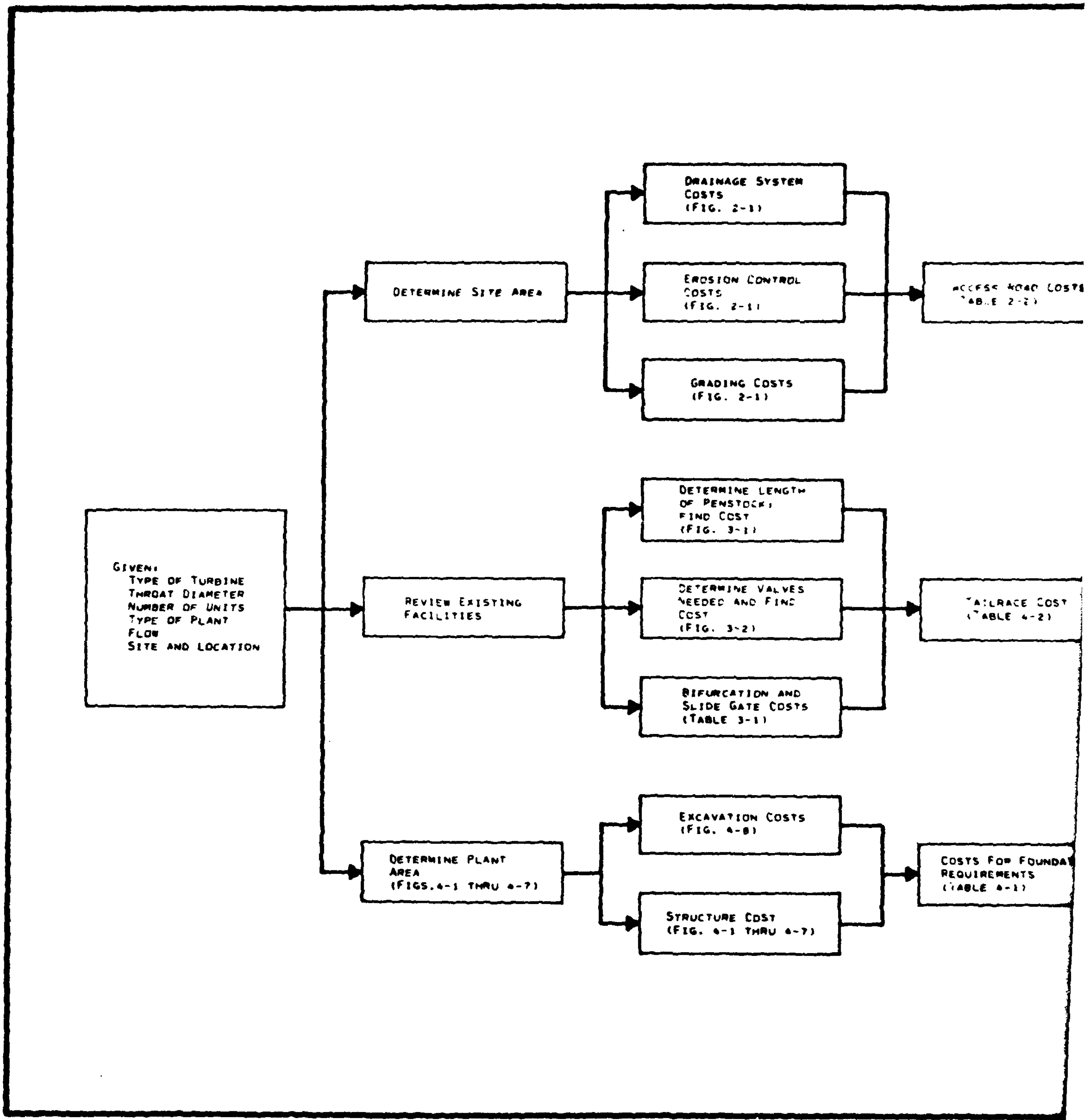
Figure 8. Bulbs and Rim turbine costs

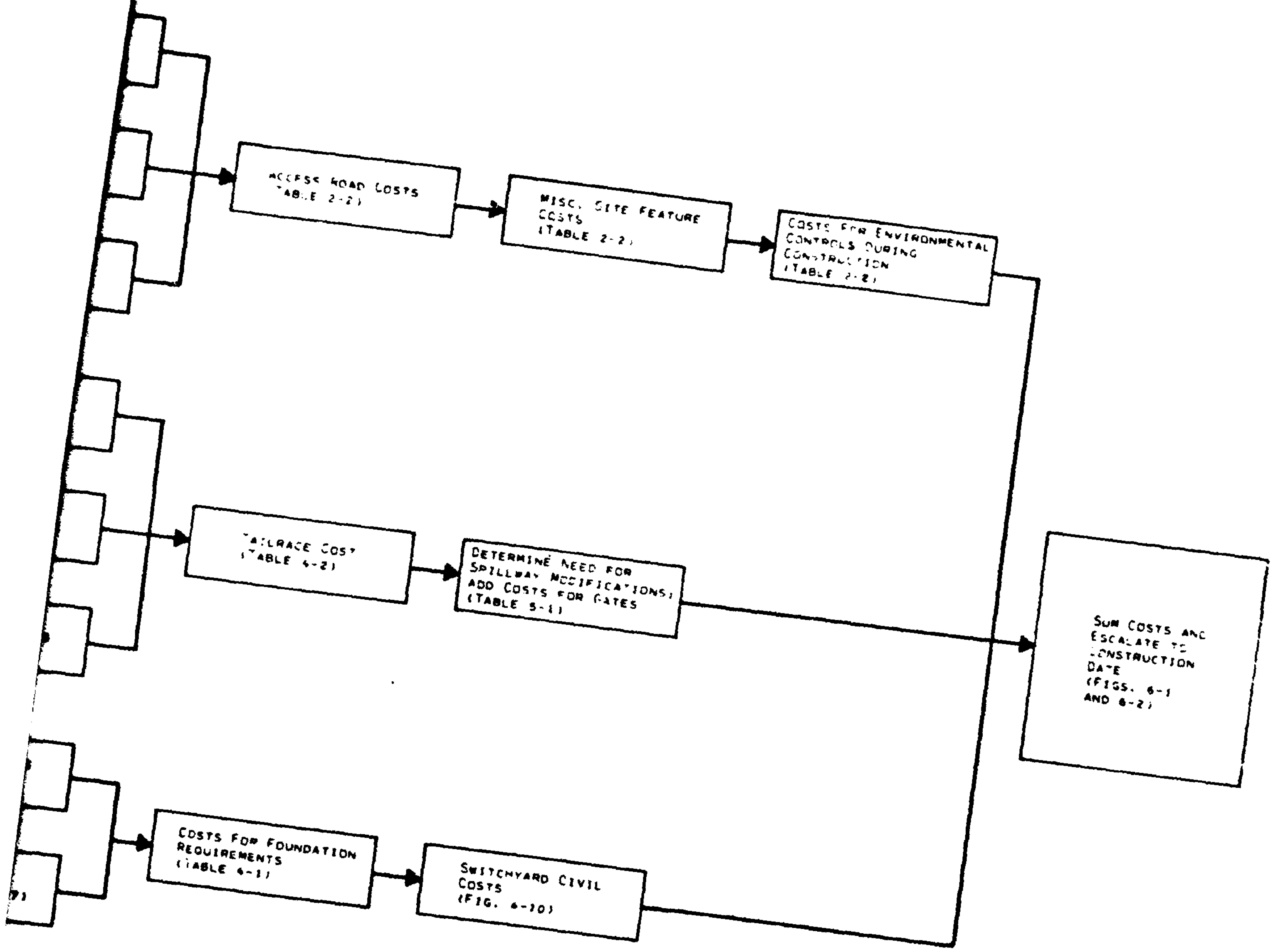
Civil features can at times comprise a significant component of construction cost of small hydro additions. Since major elements of the site are fixed (embankment, outlet works, spillway, etc.) it is important to approach the layout task with an open and innovative attitude. The difference between a feasible and infeasible project may be determined by the cleverness with which use is made of the existing site arrangement and features. The civil features differ from those of major hydropower plants both in scale and in substance. It is appropriate to design adequate outdoor type plants for small units and often portable lifting equipment will suffice for maintenance obviating the need for enclosing structures and fixed gantry cranes. Protection equipment can likewise often be minimized. Fig. 9 is a flow chart defining the civil features described and for which criteria, performance, and cost data are included. Figs. 10, 11, 12, and 13 are examples of the types of information included and the style of data presentation. Descriptive text is included to alert the project investigator to circumstances in which the generalized relationships are unreliable and guidance is given for developing alternative data when necessary.

Cost escalation indexes are included so that the cost data (all volumes are July 1978 dollars) may be scaled to the base period used for the feasibility analysis. A cost summary sheet is included that is keyed to the FERC Account Numbers.

STATUS OF MANUAL

The manual is presently (February 1979) in the advanced preparation stage. Several of the volumes have been completed and are presently undergoing final manuscript creation. Two volumes, the "Technical Guide" and "Hydrologic Studies" and the illustrated case studies for the "Technical Guide" are in the active preparation stage. The target for completion of all volumes including internal agency reviews and subsequent availability for limited within federal agency distribution is July 15, 1979. The present expectation is that


GIVEN:
TYPE OF TURBINE
THROAT DIAMETER
NUMBER OF UNITS
TYPE OF PLANT
FLOW
SITE AND LOCATION
DETERMINE SITE AREA
REVIEW EXISTING FACILITIES
DETERMINE PLANT AREA (FIGS.4-1 THRU 4-7)
DRAINAGE SYSTEM COSTS (FIG. 2-1)
EROSION CONTROL COSTS (FIG. 2-1)
GRADING COSTS (FIG. 2-1)
DETERMINE LENGTH OF PENSTOCK; FIND COST (FIG. 3-1)
DETERMINE VALVES NEEDED AND FIND COST (FIG. 3-2)
BIFURCATION AND SLIDE GATE COSTS (TABLE 3-1)
EXCAVATION COSTS (FIG. 4-8)
STRUCTURE COST (FIG. 4-1 THRU 4-7)
ACCESS ROAD COSTS TABLE 2-2)
TAILRACE COST (TABLE 4-2)
COSTS FOR FOUNDA REQUIREMENTS (TABLE 4-1)


ACCESS ROAD COSTS (TABLE 2-2)
MISC. SITE FEATURE COSTS (TABLE 2-2)
COSTS FOR ENVIRONMENTAL CONTROLS DURING CONSTRUCTION (TABLE 2-2)
TAILRACE COST (TABLE 4-2)
DETERMINE NEED FOR SPILLWAY MODIFICATIONS; ADD COSTS FOR GATES (TABLE 5-1)
SUM COSTS AND ESCALATE TO CONSTRUCTION DATE (FIGS. 6-1 AND 6-2)
COSTS FOR FOUNDATION REQUIREMENTS (TABLE 4-1)
SWITCHYARD CIVIL COSTS (FIG. 4-10)

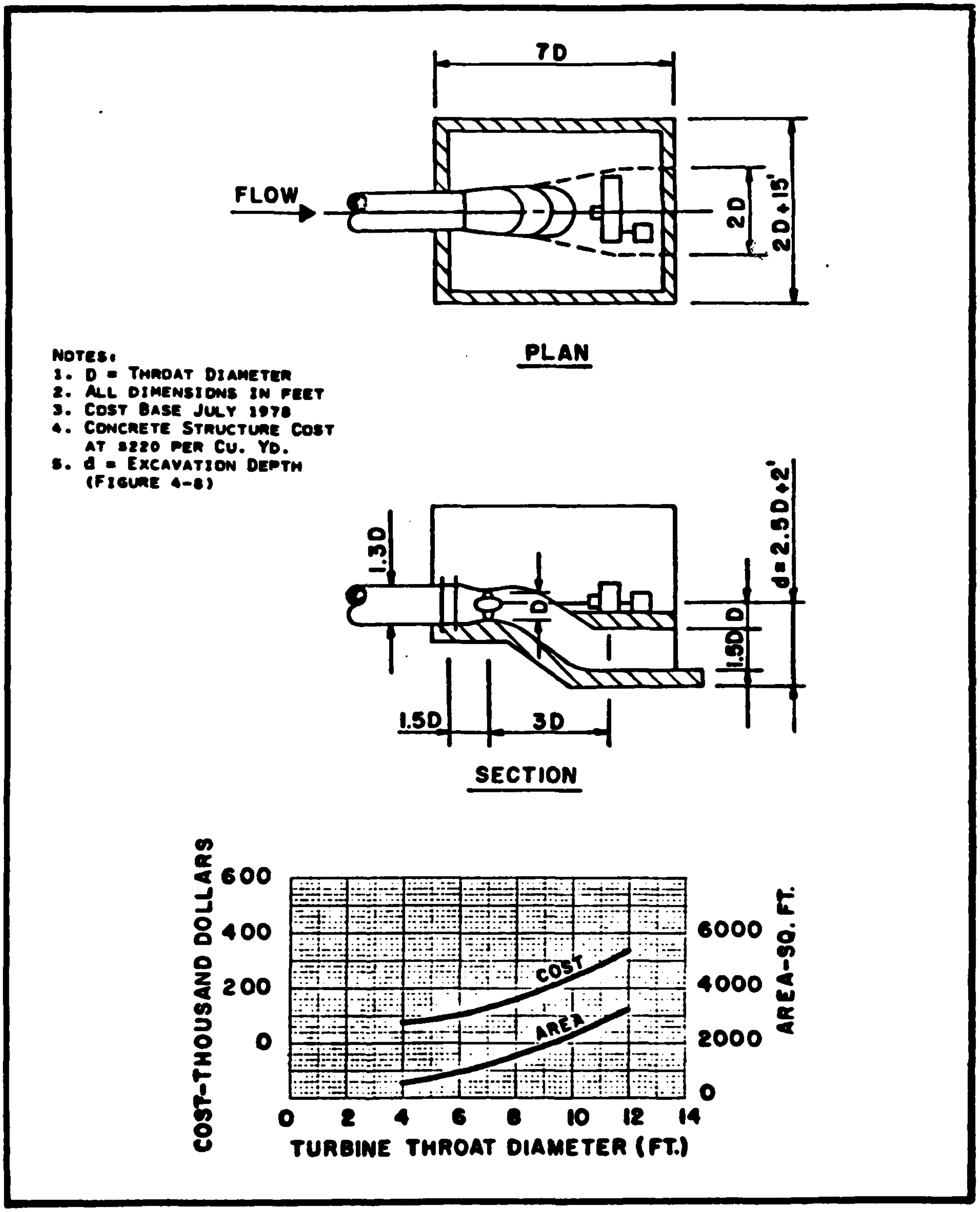
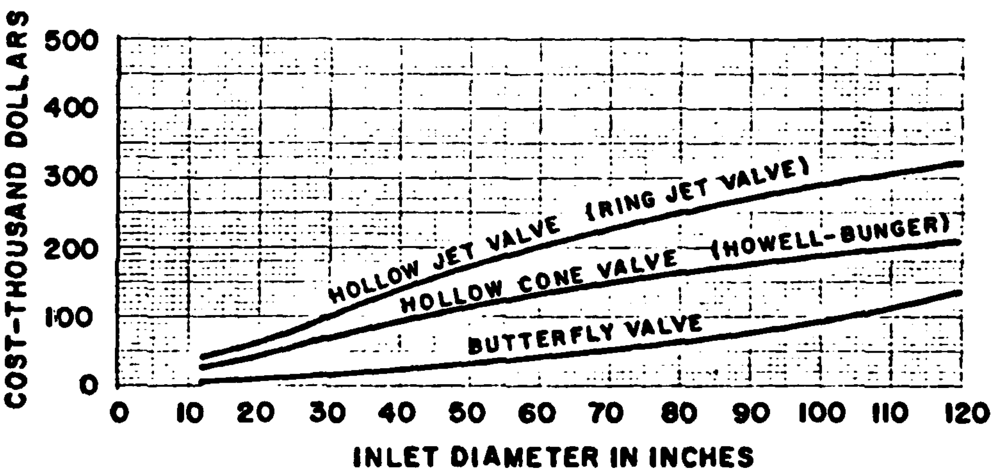


Figure 10. Tube Turbine Powerhouse Civil Cost and Area

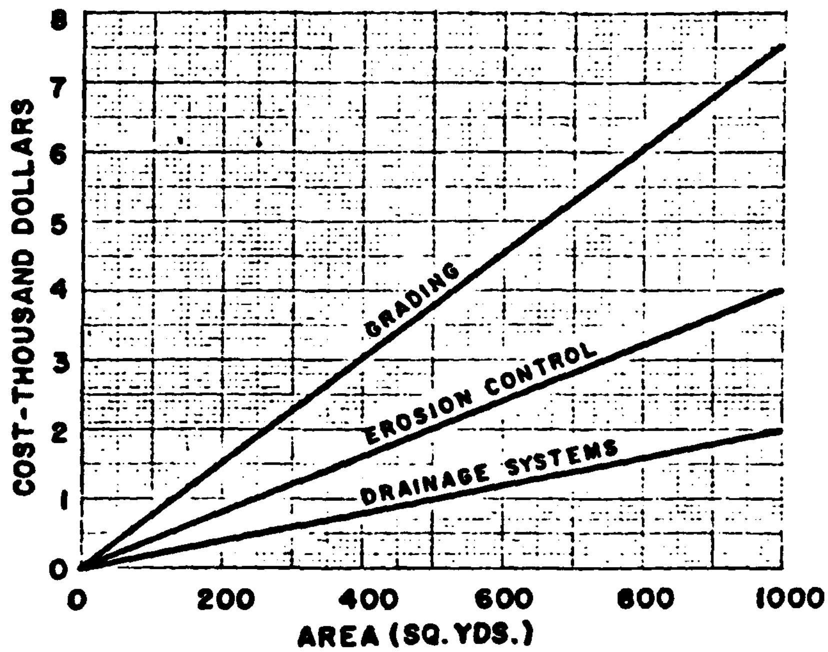
PRELIMINARY



PRELIMINARY

NOTE: COST BASE JULY 1978

Figure 11. Costs for Butterfly, Hollow Jet, and Hollow Cone Valves

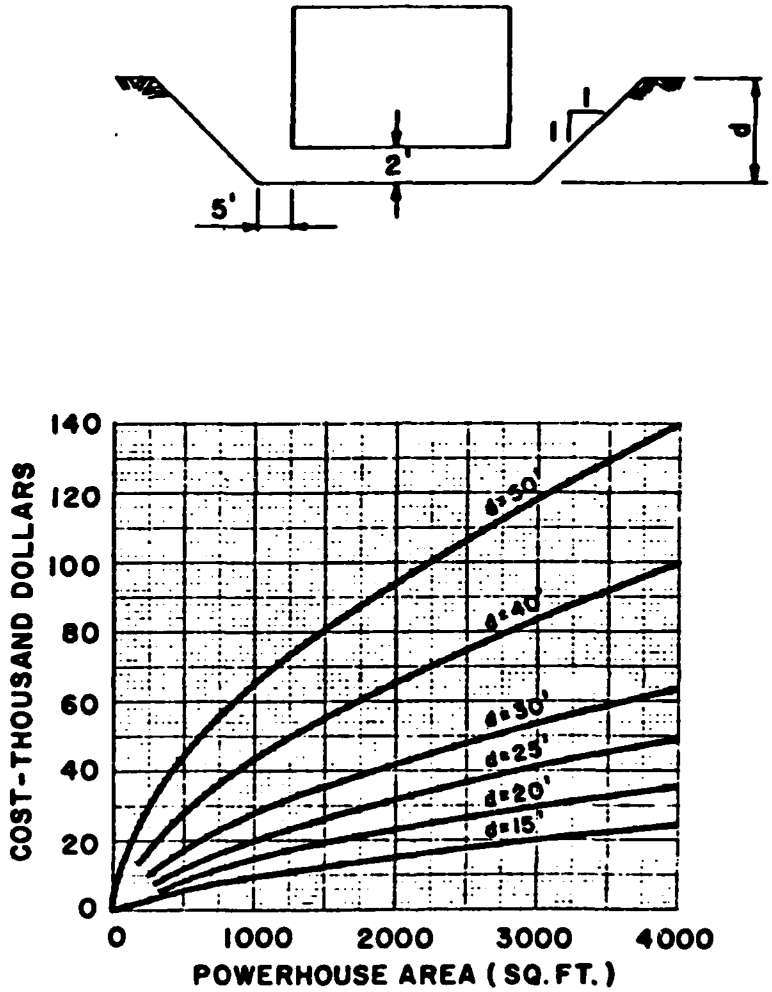


PRELIMINARY

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 12. Grading, Drainage and Erosion Control Costs



PRELIMINARY

NOTES:

1. COST BASE JULY 1978
2. EXCAVATION COSTS; 50% COMMON AT $2 PER CU. YD. AND 50% ROCK AT $10 PER CU. YD.

Figure 13. Powerhouse Excavation Costs

general public distribution will be possible within the 60 days following July 15.

ACKNOWLEDGMENTS

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