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SITE SELECTION METHODOLOGY FOR SMALL HYDROELECTRIC POWER PLANTS

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LIST OF ABBREVIATIONS

CDE	Compañía Dominicana de Electricidad
CEA	Consejo Estatal del Azúcar
CNPE	Comisión Nacional de Política Energética
FORESTA	Dirección Nacional Forestal
FUDECO	Fundación para el Desarrollo Comunitario
IAD	Instituto Agrario Dominicano
INDESUR	Instituto para el Desarrollo del Suroeste
INDRHI	Instituto Nacional de Recursos Hidráulicos
INAPA	Instituto Nacional de Aguas Potables y Alcantarillado
INVI	Instituto Nacional de la Vivienda
IICA	Instituto Interamericano de Ciencias Agrícolas
ODC	Oficina de Desarrollo Comunitario
SHPP	Small Hydroelectric Power Plant
SOFRELEC	Société Française d'Etudes et de Réalisations d'Equipement Electriques.

Definition of Terms

KW - kilowatt

MW - Megawatt (or 1000 kilowatts)

Load Factor - Ratio of annual energy produced to installed KW capacity times number of hours per year.

$$\left[{}^{MWH}/_{(KW \times 8760)} \right]$$

Introduction to the Methodology

This site-selection methodology has been custom designed for professionals in the field in the Dominican Republic, taking into account the technical, social, economic, institutional and environmental characteristics of the country.

The state-of-the art methodology design icorporates *inter alia*

- field-tested procedures for the evaluation of the quality of available data.
- field research and national, social and economic parameters as well as
- the recent experience of the agencies of the Dominican Republic charged with the development of small hydroelectric resources.

1.0. Establishment of Basic Site Selection Criteria

This is an in-depth site selection methodology that has been developed to rank possible sites for the installation of small hydroelectric power plants (SHPP) using a mix of technical, economic, social, institutional and environmental criteria. The sites that have been ranked as the most attractive will be eligible for a more detailed feasibility analysis and for actual SHPP installation.

The site selection methodology has been so organized that essentially the same activities will be carried out for the feasibility analyses, albeit in greater detail. It incorporates state-of-the art appraisal or reconnaissance techniques that have been developed for low head small hydroelectric systems in the range of 100 KW to 1 MW capacity plus available data on high head SHPP's.

The methodology has been developed by a team of USAID consultants in conjunction with professionals of national agencies responsible for the development of small hydroelectric resources in the Dominican Republic including the National Energy Policy Commission (CNPE), the Dominican Electricity Corporation (CDE) and the National Hydraulic Resources Development Institute (INDRHI).

The Site Selection Criteria are as follows:

- Technical Viability Criteria are dependent upon the streamflow regime and the available head at the site and on whether the flow is regulated (through construction and operation of a dam) or unregulated.

- Economic and Financial Criteria include benefit-cost ratio and internal rate of return while net present worth is used for ranking projects.
- The Social Desirability of a project is measured by utilizing as a proxy criterion the level of community participation in the project.
- The Institutional Criteria will reflect the degree of cooperation that exists between the different government agencies charged with the management of the nation's water resources as reflected in the current and planned water utilization projects in the watershed.
- The Environmental Criteria will favor those projects that include a component of management of the watershed upstream from the site to minimize silting and to ensure a satisfactory stream flow regime for meeting the technical viability criteria.

2.0. Selection of Specific Sites

The set of sites that will be eligible for site selection studies and possible subsequent feasibility studies and plant installation will initially be chosen from the set of 39 small hydroelectric sites (of capacity in the range of 100 KW to 1 MW) that have been identified in the report entitled "Inventario Nacional de Recursos Hidroeléctricos, Fase I: Proyectos Hidroeléctricos Conocidos" that was published by the CNPE in May 1980. This list is subject to further amplification once the Master Plan for the Development of the Hydroelectric Resources of the Dominican Republic has been developed by the CNPE.

For the moment, it is assumed that the global number of possible sites is 39 with a projected total capacity (by CNPE) of 37 MW. This number will be reduced further by the following considerations:

(i) As a result of a (forthcoming) technical agreement between the Governments of the Republic of China (GOROC) and the Dominican Republic (GODR), the company Sinotech Engineering Consultants Inc., in conjunction with the INDRHI will conduct site selection and feasibility studies for small hydroelectric projects in the following areas:

a) the eastern zone of the country limited to the west by the rivers Casuí and Chavón,

b) the upper basin of the Yaque del Sur River, upstream from the Sabaneta and Sabana Yegua Dams.

c) the middle part of the Yaque del Sur River that extends from the Sabaneta and Sabana Yegua Dams to the Llanura de Barahona.

d) the upper reaches of the Caña River, upstream from the Los Mesa Dam.

(ii) A "first pass" reconnaissance study will have been performed through exchange of information and preliminary site visits focussing on project technical feasibility.

Thus the final global set of projects that will be eligible for site selection will be the original 39 mentioned above (less projects that are covered by the GODR--GOROC Agreement) that survived the "first pass reconnaissance study."

3.0 Compiling Existing Information

An important initial step in the conduct of a site selection study is the compilation of pertinent existing technical, social, institutional and environmental data. With this information at hand, the subsequent field visit to the site of the proposed small hydro development will be dedicated exclusively to filling the data gaps that are identified in this step.

3.1. Technical Information

The following procedure is suggested in making an inventory of the existing technical information for analyzing the hydroelectric potential of a site (Linsley 1958):

a) Assemble the best available maps of the region, piecing together, if practical, a simple master map of the largest possible scale. Draw on the map the outline of the river basin under study.

b) Assemble all pertinent hydrometeorological and hydrographic data files. Institutions that have extensive hydrometeorological and hydrological data collection networks such as the Meteorological Dept., INDHRI, and the State Sugar Council (CEA) should be consulted. Locate on the master map the site of all observation stations using appropriate symbols to indicate the nature of the observation. Determine (from the literature or by interview) the methods of observation and types of instruments employed. Evaluate the reliability of the various items of data available. Prepare a bar chart showing the period of record for each item of data at each station. Indicate on the chart, changes in frequency or method of observation and the estimated reliability of data.

c) Survey all existing literature on the hydrology, climatology, geology and geography of the region. A good data source is the bibliography of the Environmental Profile of the Dominican Republic (USAID, 1981). Prepare a bibliography of this material, annotated for future reference during the survey. On reading this material, note any pertinent information or conclusion.

3.2. Social Information

It will be necessary to characterize the community that will be served by the SHPP in terms of population, energy demand and economic resources. The following procedure is suggested for making an inventory of existing information.

a. Contact agencies such as the National Housing Institute (INVI), the Dominican Agrarian Institute (IAD), the Community Development Office (ODC), National Institute of Potable Water and Sewage (INAPA) and the Foundation for Community Development (FUDECO) as well as regional institutions such as the Institute for the Development of the Southwest (INDESUR) or international agencies such as the Interamerican Agricultural Science Institute (IICA), that may have on-going projects in the community.

b) Consult the following references for pertinent information:

   i) National Household Survey, made by the Central Bank (Banco Central) in 1976.

   ii) Rural Household Energy Survey, made by Practical Concepts Incorporated in 1980.

   iii) Survey of Economic Resources of Small Farm Households, Secretariat of Agriculture, 1976.

3.3. Institutional Information

It is important to find out if any other projects are being planned or executed in the watershed upstream from the site that may affect the quality or quantity of water available at the site. As a minimum the following institutions should be consulted on their current or planned future projects in the watershed in question:

   i) The National Hydraulic Resources Development Institute (INDRHI)

   ii) The Dominican Electricity Corporation (CDE)

   iii) The National Potable Water and Sewage Institute (INAPA)

   iv) The National Forestry Directorate (FORESTA)

3.4 Environmental Information

It is vitally important to gather information on the state of the watershed upstream from the site. In particular, any information on factors that would be useful in indicating the degree of soil erosion such as soil, land use (including forest reserves), agricultural practices (are slash and burn practices in vogue?), slope of the watershed, and microclimate should be highlighted.

4.0. The Site Visit

The site visit will be designed to familiarize the engineer with the site, the condition of the watershed upstream from the site and to gather other pertinent data, when deemed necessary. As far as possible, check the details of the topographic maps, especially the direction of flow of streams. Use photographs to illustrate the various types of terrain, vegetal cover and stream channel characteristics of the watershed. Special note should be taken of the practices of road building and agricultural management in the watershed insofar as they affect soil erosion. Visit the watershed hydrometeorological and runoff stations noting condition of equipment and the techniques of observation to support the evaluation of data reliability.

If available data are limited, it is prudent to augment the data base through the immediate installation of gauging stations. Crude rain gauges can be fabricated from tin cans, small gauges can easily be made by painting scales on existing structures or on planks and float measurement of streamflow can be easily accomplished.

5.0. Field Survey

The field survey incorporates data gathering on technical, socio-

economic, institutional and environmental aspects of the potential SHPP development.

The field questionnaire has been formulated by CNPE with additional input from the USAID consulting team. It has been designed to summarize all pertinent information on the site for convenient reference. (See Appendix 1).

Optimally, the survey team will consist of a field engineer, an expert in natural resources management (such as a soil scientist), and a sociologist. This team can start gathering pertinent information before the site visit (e.g. hydrological data, census data, etc.). The survey can be conducted in 1 or 2 days, provided local authorities may be interviewed at that time. (Also consult Section 3).

6.0 Processing of Hydrological Information

Hydrological information will be processed with the objective of generating information on the available streamflow through the preparation of a flow duration curve --an important tool in the preliminary design of hydroelectric systems. In many areas, streamflow records will be defective or non-existent. In such cases, it will be necessary to express the streamflow records using techniques that enable one to use available information from other sources such as streamflow records of adjoining watersheds. Likewise it is prudent to analyze the data for changes in the flow regime caused by changing land use patterns or by the introduction of projects that involve the consumptive (such as potable water supply, irrigation) and non-consumptive (such as other hydroelectric projects) use of water upstream from the site in question.

6.1. Generation of a Flow Duration Curve

Assuming the availability of a flow record at the site under study, a two-step hydrological analysis is used to calculate the available flow:

1) An appropriate record of flow versus time period (year, month, day) is generated. In statistical terms this record is called a time series.
2) A flow duration curve is generated.

The methodology for preparing a flow duration curve is first to rank order the time series by daily, monthly or annual mean flows according to magnitude. The rank ordered values are then assigned order numbers, the largest beginning with order 1. The order numbers are then divided by the total number in the record and multiplied by 100, thereby representing the percent of days that a particular mean flow has been equaled or exceeded during the period of record analyzed.

The flow duration curve represents graphically the results of the above analysis where the flow (Q) is plotted against the percent exceedance. References to flow duration curves are usually made as Q_{50}, Q_{30}, Q_{10} etc., indicating the flow values at the percentage point subscripted. Fig. 6.1 is an example of a flow duration curve.

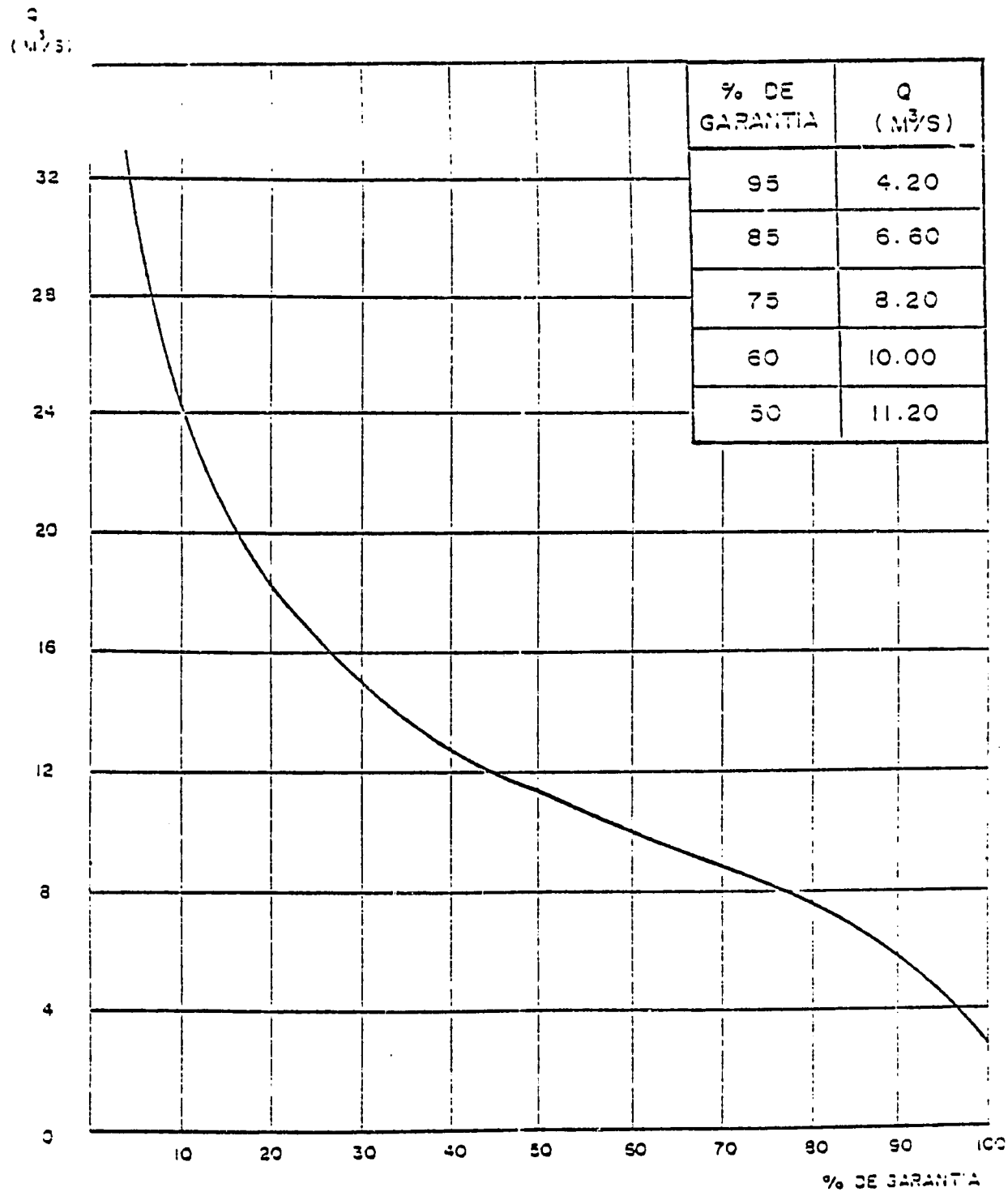
Because flows at specific sites generally follow cyclical variations as a function of within-year periods, it is recommended that the analysis be based on monthly flow durations.

6.2. Extending Streamflow Information

Extending streamflow information through correlation or regression analysis must be handled with extreme care on the understanding that simple regression analyses produce estimates of means of the missing values.

LAMINA 3-3-1

FIGURE 6.1 CURVA DE DURACION DE LOS CAUDALES MEDIOS MENSUALES DEL RIO BOBA EN LA ESTACION DE LOS JENGIBRES



% DE GARANTIA	Q (M³/S)
95	4.20
85	6.60
75	8.20
60	10.00
50	11.20

Multiple regression techniques can be used to relate flow characteristics with pertinent physical or hydrological characteristics using a relationship such as the following (Gladwell, 1980)

$$DS_i = a_o X_1^{a1} X_2^{a2} X_3^{a3} \ldots X_n^{an}$$

where,

DS_i =the flow statistic of interest; e.g., mean, standard deviation, mean annual flood, etc.

X_i =catchment hydrological characteristics.

a_i =regional coefficients.

A simple example of the use of this kind of relationship is the case of relating the mean discharge to the watershed area.

6.3. Maintaining Data Quality

The use of hydrological data for design purposes is based on the simplifying assumption that future conditions may be represented approximately by past records provided that data are homogenous and of long-enough duration to be statistically manageable. The following discussion deals with these factors.

. Homogeneity of Data. The primary requirement of hydrologic data is that they be homogenous, i.e. samples taken from the same population. There are two types of non-homogeneity of concern in hydrologic data analysis; 1) mixed (data) population and 2)trend and cycling Data from mixed populations usually result from human activities in the watersheds such as the construction of a dam upstream or the denuding of the land cover through a forest fire or bad agricultural practices. The existence of this type of inconsistency is readily detected from a plot of a hydrological parameter, such as flow, with time

Another method for detecting inconsistencies in hydrologic data is the double mass curve which is a graph of the cumulative data of one variable versus the cumulative data of another related variable. As long as the physical conditions (such as land use practices in the watershed) remain the same, the relationship between the variables is a fixed ratio. Breaks in the double mass curve indicate data inconsistencies. Careful analysis of the cause of the data inconsistencies should lead to appropriate corrective action, especially for runoff data (Searcy and Hardison, 1960).

Existence of persistent trend and cycling in the data may also be detected from simple time plots if sufficiently long records are available or through the use of regressing moving averages.

Length of records should span periods of extreme events to facilitate the planning needed to yield solutions that would be most effective in providing for future critical periods. All possible information sources should be consulted, including written and oral records, to learn about the flood and drought history of the catchment area under study.

7.0. Social, Institutional and Environmental Guidelines

These guidelines are useful in evaluating the "human" and "natural" context of the SHPP development. They aim at a clear evaluation of the management capabilities which are required to put in place (including the appropriate timing of construction) and later administration of the SHPP.

For example, consumptive uses of water originating in the watersheds may be such that there is insufficient water available for operating the SHPP satisfactorily. Alternatively, the watershed may be in such a poor condition to preclude the installation of an SHPP until restoration measures are in place and are seen to be working.

7.1. Social Analysis

The results of the survey will be used to conduct the social analysis of the site. The analysis will consist mainly of the assessment of two aspects of the community:

a) the degree of participation of its members in the decision-making and implementation process.

b) the present and future demand for electricity. This point will be covered in section 8.

The degree of community participation in the cycle of the SHPP project will indicate the social desirability of the plant in the community. The greater the level of community organization and participation in the implementation of the project, the clearer the indication of desirability and, presumably, of willingness to use the service.

The social analysis must look for possible adverse effects of the SHPP installation and operation such as:

a) the aggravation of an skewed income distribution pattern in the community, (in most rural economies the land tenure system can be used as an indicator of wealth distribution). For instance, this could happen if cheaper energy prompts mechanization to the detriment of rural employment opportunities. Cheaper energy could also have a negative impact on candles and kerosene merchants; this impact would be a function of the number and wealth of those merchants.

b) the impact of rural electriciation on migration is difficult to evaluate in the absence of hard data.[1/] On the one hand, it can be argued that electrification brings urban amenities to the village which can contribute to stem migration.

1/ Turvey and Anderson, p. 164

7.2. Institutional Considerations

An important institutional consideration is determining the current and future action by national, provincial and local institutions that affect the availability of water at the site in question. Thus the information gathered on this topic at the data compilation stage should be cross-checked against information provided by local citizenry to the survey interviewers.

Another institutional consideration is determining the degree of involvement of the SHPP customers in protecting their SHPP watershed. In many cases, a citizenry that has demonstrated a high degree of participation in the whole process of getting an SHPP on line will be very receptive to suggestions that they should protect 'their' watershed (by providing guards for example) from any actions that might deteriorate the watershed. A written statement by the local Council or Ayuntamiento agreeing to executing appropriate watershed protection measures when necessary should be provided.

7.3. Environmental Considerations

Environmental considerations include: i) consideration of the SHPP catchment area and ii) location of the SHPP civil works and appurtenances.

Characterization of the SHPP catchment area

As has been mentioned earlier, the site visit will gather information to characterize the SHPP site in terms of the suspended stream sediment as a result of the indigenous characteristics of the watershed(such as slope, soils, climate and forest resources) and the intervention of man (through land use and deforestation). An extensive record of sediment levels should be compiled.

A judgement will have to be made if present and projected sediment levels are such that a SHPP should be installed at the present time or postponed until the watershed has been restored to a satisfactory level.

The location of the SHPP and appurtenances should be excluded from projected areas such as national parks, forest reserves, wildlife preserves and sanctuary refuges.

8.0. Demand Calculation and Forecast

These calculations are necessary for:

a) estimation of the required size of the plant.

b) determination of the tariff structure

c) calculation of the financial and economic benefits.

8.1 Calculation of Present Demand

In order to calculate the potential present demand it is useful to disaggregate the demand into the different types of consumers:

1) households (h/h)

2) industry and commerce

3) agriculture

4) public services

Census data will provide information on the population size. This must be updated with survey data.

The number of h/h will be the population divided by the average number of members per h/h (6.4 per h/h)[1/]

The existing public, industrial, commercial and agricultural use of energy will be provided by the survey.

1/ AID-CDSS FY 83, p.3.

Tables 8-1 and 8-2 provide the energy requirements of h/h appliances as well as demand ranges for small scale enterprises. The aggregate of known (if village is already electrified) or estimated existing demand plus the immediate incremental demand will yield the "present" electricity demand at inauguration of the plant.

8.2. Household Affordability Calculations

A grosso modo estimation of household affordability can be obtained by calculating the average monthly energy expenditure (including only items which will be replaced by electricity such as candles, kerosene, perhaps oil fuel and batteries) less the estimated average h/h expenditure in electricity. The measure of affordability gives an indication of the least amount of cash a h/h would be willing to pay for electricity. This calculation does not include the "willingness to pay" consideration due to the higher quality of lighting provided by electricity.

8. 3. Demand Load Forecast

In situations of information shortages, forecasting demand involves a good deal of judgement, especially in areas hitherto without service. It is therefore necessary to complement survey data with information from different sources. The following procedure for the calculation of projected demand is suggested:

> Historical data from comparable villages within the region: the most concrete basis for forecasting is the growth pattern in electricity demand in nearby comparable sites supplied by electricity.[1/] Given the existing demand and the growth rate, 10 year projections can thus be extrapolated.

This methodology assumes a conservative demand growth rate of 3% per year.[2/]

1/ This information can be obtained at CDE.

2/ For a more detailed methodology the CDE-SOFRELEC Plan de Expansión del Sistema Eléctrico, December 1980, pp. 44-83 can be consulted.

TABLE 8-I - DEMAND LOAD FOR HOUSEHOLD ITEMS

Light bulbs	25, 50, 75 or 100 w.
Fluorescent lamp (equivalent to 100 w.)	20 w.
Radio	5 w.
Television (18")	14 w.
Refrigerator (6 ft.)	180 w.
Blender	100 w.
Fan	35 w.
Sewing machine	100 w.
Small clothes iron	300 w.

SOURCE: O. Chaquea Blanco et.al. Viabilidad de las Microcentrales Hidroeléctricas en Colombia, Fundación Mariano Ospina Pérez, Bogotá, Octubre 1979, pgs. 21 and 23.

TABLE 8-2 DEMAND LOAD FOR SMALL SCALE ENTERPRISES

ACTIVITY	REQUIRED CAPACITY (Kw)
CARPENTRY	3 - 15
BAKERY	2 - 5
CRAFTS	1 - 2
SMALL SAWMILLS	15 - 30
GRINDERS	10 - 20
LOOMS	0.5 - 6
COFFEE GRINDER (COMMERCIAL	5 - 30
QUARRY MILL	6 - 30
ICE MAKING	6 - 60
IRRIGATION PUMP	2 -100
BRICK FACTORY	1 - 5
ALBERGUE (20 guests)	2 - 5
RESTAURANT	1 - 2
VEGETABLE CANNING	5 - 20
DAIRY PRODUCTS	2 - 10
MILK (cooling and pre-evaporation)	5 - 20
ELECTRICAL AND MECHANICAL WORKSHOPS (repairs)	5 - 15
GAS PUMPS	2 -100
SILOS	3 - 5

SOURCE: PROGRAMA REGIONAL DE PEQUEÑAS CENTRALES HIDROELECTRICAS DE OLADE, REQUERIMIENTOS Y METODOLOGIAS PARA LA IMPLEMENTACION MASIVA DE PEQUEÑAS CENTRALES HIDROELECTRICAS EN LATINO AMERICA, DOCUMENTO DE TRABAJO, QUITO, 26 DE JUNIO DE 1980, ANEXO VIII.

TABLE 8-3: ILLUSTRATIVE ANNUAL ENERGY DEMAND GROWTH RATES

I. SOFRELEC' Estimates of Average Annual Energy Demand Growth rates for different rural sectors (1978-1992) 1/

- Method 1: Using explicit (economic) variables.

  For this method, SOFRELEC doesn't break down rural consumption into the different types of consumers.

  Average annual growth rate: 12.9%

- Method 2: Using predetermined objectives

  The rural consumption is broken into the following categories with the respective average annual growth rates:

  - Residential 9.5%
  - Commercial and small industry 8.4%
  - Government 4.7%
  - Agriculture 36.3%

1/ Source: Calculated from SOFRELEC, op. cit. pp 59-74.

II. CNPE's Estimates of Average Annual Energy Demand Growth rates for all sectors (1978-2000) 1/

SECTOR	1978 - 1990	1991 - 2000
Industry	6%	6%
Commercial	9	5
Agriculture	3	2
Residential	6	2

1/ Source: Calculated from CNPE, Energy Strategies for the Dominican Republic, op 40-51.

Table 8-3 gives annual energy demand growth rates as calculated by SOPRELEC and CNPE.

8.4. Re-evaluation of Preferred Design

After the final scheme selection, if proposed installed capacity exceeeds the 10-year demand projection, calculations of present and future load of nearby villages which could be included in the SHPP system should be taken into account. In the absence of these villages, go back to the design stage and redesign the plant by scaling down plant capacity considering a multiple-unit installation or grid interconnection.

9.0 Alternative Layout Schemes

The first level analysis that is presented in the methodology is intended to address all possible development alternatives of a potential hydroelectric site. The initial step in the technical evaluation of a given resource is accomplished with the derivation of an approximate flow duration curve as described in the sixth task. This information combined with the gross head available at the site is a starting point for the delineation of alternate project layouts. This section will deal with:

- The determination of available head
- Guidelines for alternate project layouts
- Graphical selection of turbine type

9.1. Determination of Available Head

The first step in evaluating the available head is to establish the location of the powerhouse geographically. This should be accomplished with the use of topographic maps in conjunction with a visual inspection of the site. Criteria to be considered in its location would include accessibility for construction equipment, length of tailrace to return discharge to the stream or conduit and geological conditions. The gross static head is then determined by the difference in elevation between the proposed tailwater and headwater. In the case of very high head installations (greater than 100m) this can be accomplished to a reasonable degree of accuracy with an altimeter accurate to $\pm$ 5m. Topographic maps with 10m contours are sufficiently precise for elevation differences between 20 and 100 meters. Below 20 meters a sight level or surveying equipment should be employed.

The head available for power production should be reduced by 5% to account for conduit losses. If the upstream water surface (head water) varies by 10% or more as a result of upstream regulation due to irrigation or other hydro installation, or if the proposed schemes include an active storage capability necessitating daily or weekly drawdowns, 90% of the adjusted head should be used for power determination.

9.2. Guidelines for Alternate Layout Schemes

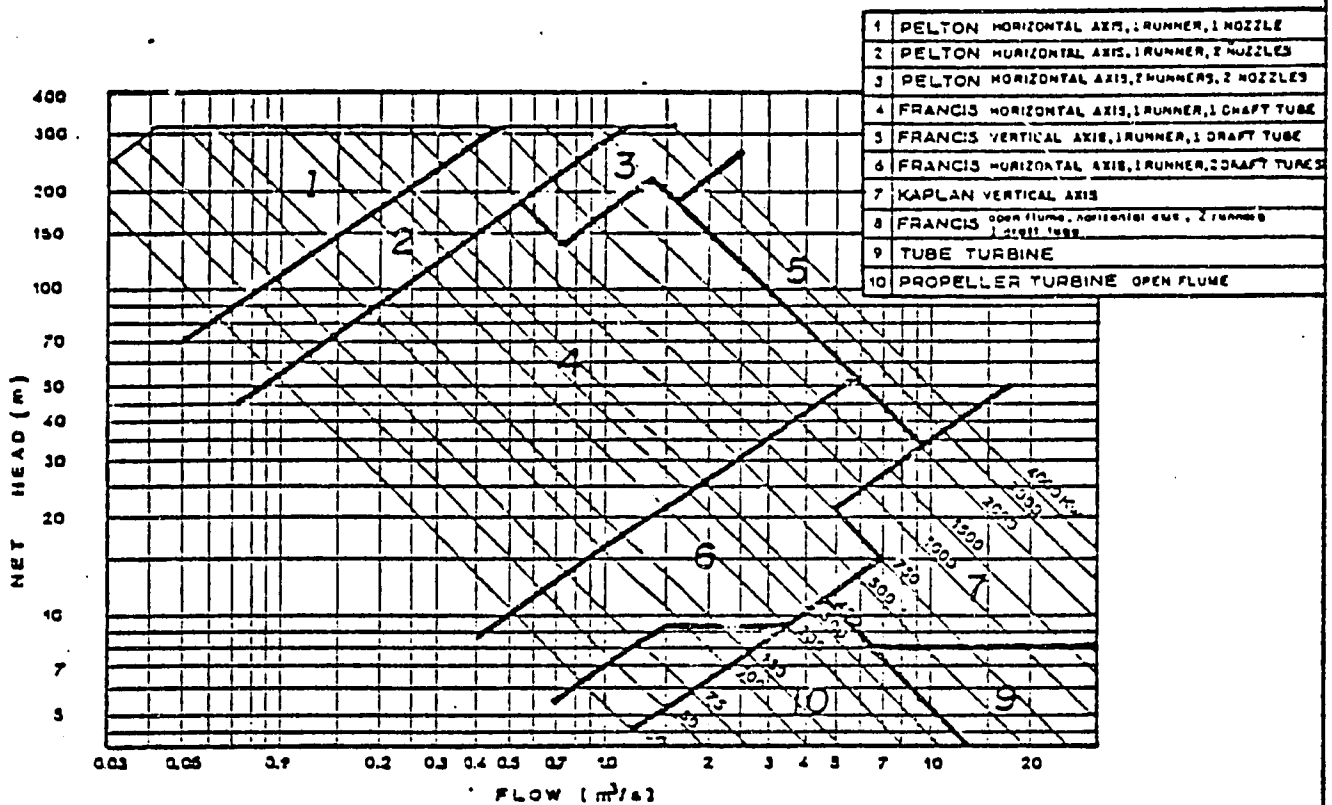
Alternate schemes for the development of the resource may vary in number from a single development to a possible four or five satisfactory alternatives. In order to optimize the resource it is proposed that all possibilities are sketched on a first-pass basis. The alternatives are of course, very site specific and will include some or all of the following considerations:

- Accessibility of the powerhouse
- Transmission line routing to the distribution system or grid.
- Dual or competitive use of water resource.
- Local power and energy requirements.
- Possibility of future connection with the grid.
- Seasonal flows or flows regulated by irrigation.
- Availability of local labor.
- Existing impoundment facilities or natural geological formations.
- Downstream environmental considerations, i.e. fisheries, community water supply.
- Condition of upstream watershed.

Alternative layout scheme that result from the preceeding may include:

- High head installation.
- Low head installation.
- Power canal configuration.

FIGURE 9-1 THE SELECTION AND CAPABILITIES OF SMALL HYDROELECTRIC TURBINES



EXAMPLE For a flow (Q) = 2.1 m^3/s and a net head (H_N) = 20 m. find the point of intersection of the vertical line, that corresponds to Q= 2.1 and the horizontal line, that corresponds to H= 20. The graph indicates that the small hydroelectric system has a potential capacity of 300 Kw and that the proper type of turbine for this situation is a horizontal Francis turbine with 1 runner and 2 draft tubes

TYPE OF TURBINE

Reaction Turbine Propeller Turbine	Penstock Open Flume	Horizontal axis Vertical axis	Runners with fixed position blades (propeller) Runners with adjustable blades (Kaplan	
Reaction Turbine Francis Turbine	Penstock	Horizontal axis	One runner	One draft tube Two draft tubes
			Two runner	One draft tube Two draft tubes
	Open Flume	Vertical axis	One runner	One draft tube
(Impulse Turbine) Pelton Turbine		Horizontal axis	One runner	One nozzle Two nozzles
			Two runners	Two nozzles Four nozzles
		Vertical axis	One runner	Several nozzles

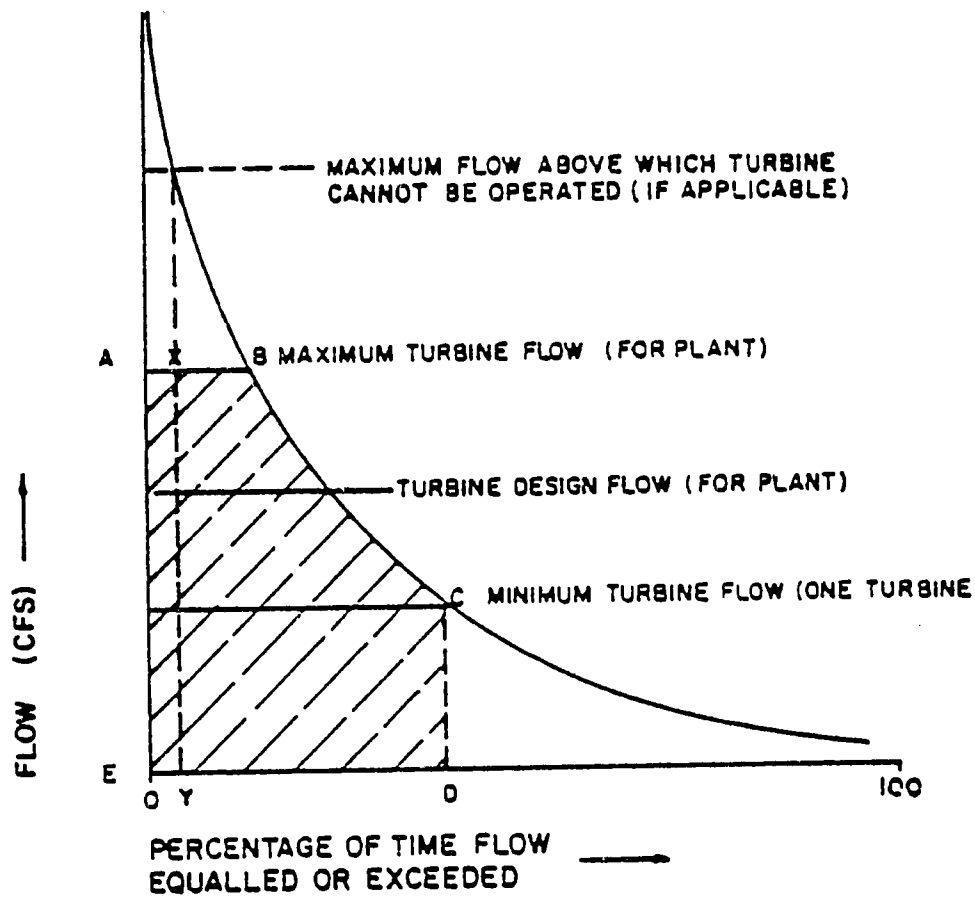


Figure 10-1 Procedure for Use of Flow-Duration Curve

- Installed capacity less than that which the resource could support.
- Configuration involving some storage capability.
- Installation of multiple equal or unequally sized units.

This task is not intended to produce detailed drawings or to include refinements of the layout. It is intended to present a relationship between the geography of the area, competing water uses and power generation as it relates to the community to be served. Gross dimensions as to approximate length of penstock and/or canal, length and height of dam, approximate location of irrigation works, rough distances to grid and community and other pertinent information should appear on the sketch. It is possible, if not probable, that during the course of the sketching an alternative may be eliminated due to conflicting circumstances. The plan sketches should be drawn to a rough scale and the gross head and available flow noted on each.

9.3. Preliminary Turbine Selection

Each alternative project arrangement is evaluated as to the most efficient turbine for that layout. Figure 9-1 will be used to determine the turbine or turbines that are applicable to the specified head and the flow corresponding to Q_{20} from the flow duration curve of Figure 6-1

10.0. Estimation of Power & Energy

The installed capacity of the turbine must be selected with two major factors in mind: a) Optimization of the resource and b) projected demand of the community to be served. This task will be performed at two distinct junctures in the methodology. First, as the step following the identification of all possible alternatives, it will be utilized to estimate the optimal capacity and energy production of each scheme. Secondly it will be revisited following

the selection of the preferred scheme to re-examine the recommended installed capacity in light of local demand requirements. The latter consideration may result in a re-sizing of the turbine or re-examination of multiple unit installation due to unacceptable decrease in turbine efficiency caused by reduced loading.

10.1. Use of the Flow Duration Curve - Preliminary

The flow duration curve prepared in task number 6 may be employed with a reasonable degree of accuracy to predict the annual energy production of an installation. It is generally accepted that the 15% exceedance flow should be used for the maximum turbine flow. This is illustrated in Figure 10-1. The flow duration curve is entered at the 15% exceedance point and a horizontal line A-B constructed. The turbine design flow (Q_D) will then be Q_{max} /1.15. The minimum flow Q_{min}, below which the turbine cannot be operated, is assumed to be at a rate $.3Q_D$ or 30% of the design flow. This minimum flow will vary with the efficiency characteristics of the turbine. For example, a fixed blade propeller unit will have a Q_{min}, equal to 50% of the design flow or $.5Q_D$. At the intersection of the minimum flow and the curve, a vertical line C-D is constructed. The area ABCDOA will then represent the average flow available for power production 100% of the time. This area may be calculated in a variety of ways:

1) A mathematical integration of the curve
2) Laying-out a grid and counting the squares
3) Straight line approximations employing triangles and rectangles.

The area will have the dimensions of flow as the abcissa is dimensionless. This flow value Q_{av}, can then be used to calculate the average annual energy for each scheme as follows:

$E_{av} = Q_{av} \times H_{eff} \times 9.804 \times \eta \times 8760 \times .95$

where Q_{av} = Average annual power flow (m^3/ sec.)

H_{eff} = effective head available for power production (m.)

η = average turbine efficiency (.85)

8760 = # of hours / year

.95 = reduction factor to account for unavoidable water losses.

The installed capacity P_c can then be determined

$P_c = Q_D \times H_D \times 9.804 \times \eta$

where Q_D = design flow (m^3/sec)

H_D = design head (m.)

The foregoing procedure for determination of installed capacity and average annual energy is presented for a run-of-river installation. The use of multiple turbines will have the effect of being able to utilize higher flows and lower flows than predicted above. As a result, the average annual energy will increase as well as the installed capacity. Similarly, regulated flows, such as on an irrigation canal will enable the Q_D to be equal to the Q_{max} if the higher value is available at a 10 - 15% exceedance level. An installation utilizing a storage capacity will have the same average annual energy as calculated but the installed capacity can be varied depending on the length of time of power discharges for peaking requirements. These factors can be weighted and estimated in the preliminary determination of power and energy for each alternative.

10.2. Final Power and Energy Determination

Following the selection of the preferred scheme and conceptual design in task 13, a review of the installed capacity and annual energy production should be made. Various refinement will be introduced to the sketch of the selective alternative and Table 10-1 will be completed.

Table 10-1

Power & Energy Output Summary

Site location / name: _____

Preferred Scheme: _____

Turbine discharge

Maximum	115% Q_D	Qmax	_____ m^3/sec.
Minimum	30% Q_D	Qmin	_____ m^3/sec.
Design		Q_D	_____ m^3/sec.

Gross Head

Maximum (highest headwater, lowest tailwater)		_____ m.
Minimum (lowest headwater, highest tailwater)		_____ m.
Average	H_{av}	_____ m.
Design	H_D	_____ m.

Head Losses

Penstock (D=____ : V=____ : L=____)		_____ m.
Miscellaneous		_____ m.
Value		_____ m.
Total	H_2	_____ m.

Effective Head

Design Head ($H_D - H_2$)	H_{eff}	_____ m.

Plant Capacity

Design ($Q_D \times H_{eff} \times 9.804 \times .85$)	P	_____ Kw.

Average Annual Energy

Average Flow (Flow-Duration Curve)	Q_{av}	_____ m^3/sec.
Average Energy ($Q_A \times H_{eff} \times .95 \times 8760 \times 8.33$)	E	_____ Kwh
Plant Factor E/(P x 8760) x 100	FP	_____ %
Load Factor		
Year 1 (Annual energy Cons.)/E	LF_1	_____ %
Year 10	LF_{10}	_____ %

SOURCE: Tudor Engineering

TABLE 10-2

PENSTOCK HEAD LOSS

	FRICTION IN HEAD LOSS PER 100 FEET OF PENSTOCK											
Diameter (FT) / Velocity (FT/SEC)	2	4	6	8	10	12	14	16	18	20	Misc. Loss (FT)	Valve Loss (FT)
10	1.38	.55	.31	.22	.16	.13	.10	.09	.07	.06	0.75	.80
12	1.99	.79	.46	.31	.23	.18	.15	.12	.11	.09	1.00	1.10
14	2.71	1.07	.63	.43	.32	.25	.20	.17	.15	.13	1.30	1.50
16	3.54	1.40	.82	.56	.41	.32	.26	.22	.19	.16	1.60	2.00
18	4.47	1.78	1.03	.70	.52	.41	.33	.28	.24	.21	2.00	2.50
20	5.52	2.19	1.28	.87	.65	.51	.41	.35	.30	.26	2.50	3.00

NOTES:

1. Friction head loss is given in feet per 100 feet of steel penstock, based on Manning/Strickler formula with n = 0.11. For concrete the above values should be multiplied by 1.62.

2. Miscellaneous losses include intake and conduit loss and an allowance for the trashrack, entrance, transition and two bends.

3. Valve loss is based on one butterfly valve at the turbine inlet, assuming the same velocity as for penstock.

4. To obtain head loss select diameter (D), velocity (V) and length (L) compute friction loss then add miscellaneous loss and the valve loss if applicable.

EXAMPLE: Gross head = 60 ft; diameter = 10 ft; velocity = 12 ft/sec; length = 200 ft.

$$\text{Head loss} = \frac{200}{100} \times .23 + (1.0) + (1.10)$$

$$= 2.56 \text{ ft.}$$

$$\text{Net Head} = 60 - 2.56 = \underline{57.44 \text{ ft.}}$$

Decisions will be made as regards penstock configuration, valve arrangement and headworks equipment. The result of these preliminary design considerations will enable the use of Table 10-2 to calculate a more refined determination of head loss. Following the completion of Table 10-1 the load factor in year one and year ten should be analyzed qualitatively. Curves for turbine efficiency are available and they should be consulted to determine the effect of the load factor on turbine performance.

Reaction turbines are restricted on the low side by unstable operation and vibration that severely curtail the useful life of the unit. Normally this condition occurs between 20 and 40% of rated load. For this reason the demand and energy requirements of the community must be considered fully. The preferred scheme may be altered at this point in any of the following ways should this condition exist:

- Modify plant capacity to fall within reasonable operating range according to demand.
- Retain capability of optimal development of resource by installation of part of the installed capacity at initial construction with provisions for a second or third unit as demand grows or likelihood of system grid connection increases.
- Select another development option that may be more cost effective although not optimizing resource.
- Installation of a constant load to provide an additional community or national service not considered heretofore.

11.0 Technical Evaluation of Alternative Schemes

At this point of the site selection process, sound engineering judgement is used to evaluate the relative effectiveness of alternative schemes assuming a given power and energy demand profile. The technical input to the evaluation process will be based on the alternative sketches and preliminary calculations previously developed plus experience in civil construction in the Dominican Republic . Special emphasis shall be put on

- Suitability of each proposed scheme for multiple water use (potable water supply, irrigation as well as the generation of electricity) where pertinent.
- Conducting a tradeoff analysis of major flow conduction items (e.g. a comparison of the appropriate relative lengths of the conduction canal and the penstock).
- Conducting a tradeoff analysis of major equipment items (e.g. turbine selection)
- Construction considerations - contrasting the construction of a short conduction canal over difficult terrain with the putting in place of a long conduction canal over easy terrain.
- Location of the powerhouse - comparing the location of the power house at a site that optimizes head utilization versus a site that is more accessible but less efficient in head utilization.
- Major quality considerations in turbine selection - reaction turbine are more sensitive to pitting and cavitation cables by water than impulse turbines.

11.1. Final Evaluation of the Proposed scheme

Following the choice of the recommended development (See Task 12) and subsequent to review under the criteria of tasks 7,8 and 10, an additional

evaluation based on any pertinent new criteria or inputs will be undertaken.

12.0. Selection of Preferred Scheme

Based on the evaluation of the preceding task, the preferred scheme will be designated. The scheme will be fleshed out under Task 13 and will be re-evaluated under the procedures outlined in Tasks 7,8,10 and 11.

13.0 Conceptual Design of Preferred Scheme

A final layout will be prepared of this stage that will specify the following:

- Turbine type
- Estimated dimensions of civil works based on experience and available curves
- Generator (induction or synchronous)
- Transmission Requirements (length, voltage level)
- Highlighting of any extraordinary feature or equipment that may be necessary for development.

13.1 Turbine Selection

The designs and performance of turbines available from manufacturers vary and it is impractical to perform a detailed analysis of all the various units offerred when evaluating the feasibility of a nydro-electric power project on an appraisal level. The variance in design and performance generally occur at the off-rated conditions and have a negligible effect on the accuracy of the study.

Descriptions of available turbines and their general characteristics are listed in Appendix II. While the choice of machinery is by no means a final determination, the turbine type (impulse or reaction) should be decided. Many manufacturers are standardizing turbine sizes

which represents a considerable cost saving over a custom made turbine. While most standardized designs fall in the low-head category in the U.S., some European manufacturers are offering standard impulse turbines. A list of turbine manufacturers, the types of turbines they produce and whether standard designs are available is presented in Appendix 3.

13.2. Civil Works

The choice of turbine or turbines will influence the civil works of the powerhouse and the amount of excavation required for the tailrace. Rough dimensioning of the powerhouse and tailrace is advisable for high head (greater than 60m) installations as composite curves for cost analysis are not available at the time of this printing. If a multiple unit installation is proposed the number of bifurcations will be noted. The headworks and intake structure will also be approximately specified. This will be a function of conduit size that can be determined by using the design flow (Q_D) and an average velocity of 4.3m./sec (14ft/sec) and the relationship:

$$Q_D = AV$$

where A = crossectional area of conduit = $\frac{D^2}{4}$

V = velocity

Q_D = design flow

solving for diameter yields:

$$D = \sqrt{\frac{4Q_D}{V}}$$

The length and width of the power canal (if applicable) and the crest length and height of the diversion dam should be specified. Again these dimensions do not require a detailed design exercise. Rather, an estimate of these quantities is sufficient.

13.3. Generator Selection

In most cases where the installation will be isolated from the power grid a synchronous generator will be specified for the electrical equipment. Many manufacturers of turbines will quote a package price on a turbine-generator set as the generator must be compatible with the specific speed of the turbine. Inherent in the decision to employ a synchronous unit is the inclusion of an excitor and speed regulating governors. The specification of electrical design, protection equipment and speed control is beyond the scope of this analysis
Should the facility under consideration have the capability of being connected to the grid an induction generator should be considered. Excitation, frequency control and voltage regulation are provided by the line and thus the electrical equipment costs can be reduced significantly.

13.4. Transmission Requirements

An approximate transmission line routing will be sketched and a qualitative judgement made as to the difficulty of construction in the given terrain. The voltage level of the transmission line and length will be indicated. If there is an existing distribution system or a grid connection is proposed, voltage and capacity should be noted and transformation requirements indicated.

13.5. Miscellaneous Features

Any additional civil or electrical features that require consideration in the costing phase should be noted. These features may include the necessity for construction of a sedimentation pool, a small tunnel, or any extraordinary electric equipment that might be required for the development of an specific site.

14.0. Final Cost Estimation, Financial & Economic Analysis

An important aspect of determining the preliminary feasibility of a potential hydroelectric development is an estimate of the costs involved in the construction and an analysis of the annual operating expenses. This, combined with an estimate of demand and a delineation of alternative generation with associated costs is necessary for the prioritization of resources.

Cost curves have been compiled by Tudor Engineering Co. for construction and equipment expense for low-head hydroelectric projects in the U.S. that enable one to quickly estimate project capital cost. These curves (See Appendix IV) were derived for four general project arrangements and consist of composite costs for specific construction tasks. It is realized that these curves are not particularly appropriate to small hydroelectric development in the Dominican Republic due to the following observations:

- Civil works involved in powerhouse construction are considerably decreased for high head installations.
- The cost of labor in the Dominican Republic is not comparable to U.S. cost resulting in the use of labor intensive construction methods in the D.R.
- Equipment requirements and thus costs for high head sites vary at different rates than for low head sites.
- Shipping costs must be considered.

14.1. Costing Procedure

The project data sheet as presented in Appendix IV will be helpful in obtaining a listing of components of the project that have the greatest impact on the total cost. This will be completed using the preferred scheme as revised by previous reviews of demand, potential generation and capacity and socio-economic factors.

The cost compilation sheets presented in Appendix IV pages 4-4 through 4-7 will serve as an example for the depth of cost breakdown required for this analysis. For instance, the power plant account, item 4, page 4-5, list the items to be considered on a per unit basis. Civil features are dependent on the turbine type and installed capacity which, in turn, is a function of head and flow. The curves provided in the remaining pages of Appendix IV provide the costs for each of the categories as a function of an estimated design paramenter, i.e. power-house & equipment costs as a function of effective head and installed capacity.

It is strongly recommended that cost data, particular to the Dominican Republic, be compiled in a form similar to the curves prepared by Tudor Engineering and presented in Appendix IV. The compilation will require cost information from manufacturers (foreign & domestic), unit cost data for civil works based on experience and generalized design schemes that will be representative of the major part of the proposed projects. Data will be drawn from a variety of sources including some of the applicable curves presented herein. An index will be adopted that relates the costs to the year of pricing that will enable the curves to be easily updated for future use.

14.2. Analysis of Cost Effectiveness

The cost effectiveness of a hydroelectric project is dependent upon the alternatives available to supply the same demand. In the Dominican Republic the available alternatives differ on a site-specific basis and must be considered as such. The following list identifies the major options for electrification or augmentation of existing electric service with the development of a hydro-electric resource. The options represent 3 general categories and will serve for the majority of situations.

a) Rural electrification of a community or region that previously has not had central electric service and has a low probability of being connected to the system grid.

b) Rural electrification of a community or region that has a definite possibility of being connected to the system grid.

c) Replacement by a hydroelectric source or part of an existing, isolated electric system currently supplied by fossil fuel sources or a historical energy mix.

Cost effectiveness analysis will attempt to identify the least costly alternative scheme to satisfy a projected demand (as derived in section 8) over a certain planning horizon.

The following assumptions will be made:

1. All costs will be in constant 1981 prices
2. Capital cost
   a) include cost of plant, equipment, construction and contingencies and distribution system when pertinent
   b) All capital costs will be incurred prior to the first year of operation.
3. Recurrent cost
   a) Includes the cost of operations and maintenance (O&M),

administration and general expenses (A&E) as percentages of capacity, cost, plus energy cost.

In order to reflect these costs the methodology chooses the percentages used by the institution with the most expertise in accounting for the type of expense. Therefore, for O&M expense 1.28% of capital cost can be used (INDRHI) and 0.1% of capital cost for A&G expense (CDE) when applicable. O&M and A&G expenses for a diesel generating plant will be 4.5% of capital cost.

b) Energy cost for hydro will be zero.

c) Energy cost for a diesel alternative will be escalated for fuel price increase (over and above 1981 constant prices) by 3% per year[1/] and 3% per year to account for the growth of the demand.[2/]

4. Time-span of the analysis

The time span over which values will be discounted will be the life of the shortest-lived alternative, i.e. 20 yrs. for a diesel plant.

5. Discount Factor

The discount factor represents the opportunity cost of capital, officially 12%.

A. Initial Electrification of Rural Communities

This situation will be analyzed using a diesel unit as the alternative electric source. The cost comparison will employ a new diesel generator set that will have the same installed capacity and will supply the same amount of energy as the proposed hydroelectric alternative.

B. Rural Electrification with Probability of Inter-connection

This analysis will weigh the comparable costs involved in hydroelectric development versus those associated with electric service

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1/ Tudor estimate

2/ As assumed in Section 8.

provided by the national grid. The cost of service provided by interconnection with the grid will include the following:

1. An average capacity charge (in RDS/KW) based on the CDE resources most likely to supply the power to the community. Initially, the total capacity expense will be for the estimated peak demand; then this will be escalated at the projected rate of demand growth (3%)
2. An average energy charge (in RDS/KWH) based on the system bulk tariff structure. This total energy expense will be the product of the predicted annual energy consumption escalated at the energy growth rate and the average tariff (escalated according to CDE policy, which includes an increase rate of 2%/month or 27%/yr for the 16-month period starting December 1980)
3. A connection charge to the grid. This includes the cost of construction of the transmission line, the cost of protection equipment and the cost of voltage transformation to the same hydroelectric generator.

A further alternative to the above would be constructing a hydroelectric plant that optimizes the resource and provides more capacity and energy than required in the isolated situation. Here a benefit would be derived from the sale of capacity and energy to the grid. The amount of such a benefit would be the subject of negotiations with the utility to determine an acceptable capacity credit and energy buy-back rate. For this analysis historical rates for utility purchases from Falconbridge or sugar producers may be used.

Also attention must be paid to the reliability of service. A run-of-river hydro unit will experience times of low flow during which no electricity can be generated. A constant tariff structure, in the case of hydro, must be weighed against continuity of service at an escalated tariff rate.

C. Incorporation of an SHPP into an Existing Electric System

The third general category for economic comparison of alternatives deals with the installation of a small hydro-electric plant to replace existing diesel generating capacity. The assumption is made that the existing diesel unit is in need of replacement therefore it is recommended that the alternative cost and comparison procedures used in Case A be employed in this case.

See worksheet 14-1

14.3 Financial Analysis

The Financial Analysis will calculate measures of project worth at market prices.

Besides the assumptions made in Section 14.2, the following will be added:

1. The foreign component will be evaluated at the official exchange rate of 1 RD$ per US$.
2. Benefits will be calculated as the estimated annual median generation of the plant times the rate per Kwh. This analysis assumes a tariff of 5¢/Kwh.
3. Cost and benefits will be discounted at the official opportunity cost of capital of 12% for the estimated life of the plant of 30 years. It is noted that the 30 year estimate is a conservative one for mini-hydro plants.
4. Financial Benefit/Cost Ratio, Net Present Worth and Internal Rate of Return will be calculated on the basis of the discounted cash flow analysis.

See worksheet 14-2.

14.4 Economic Analysis

The economic analysis attempts to evaluate project costs and benefits at their efficiency price to evaluate its contribution to the national economy.

Additional Assumptions

1. Foreign costs will be converted to domestic prices by using the shadow price of foreign exchange of 1.36 according to the latest (unofficial) Banco Central estimates.
2. The foreign/local breakdown will be specific for the procurement at each site. For this depth of analysis, costs can be categorized as civil works, equipment and transmission costs.
3. Costs and benefits will be discounted at the official opportunity cost of capital of 12%, for the estimated life of the plant of 30 years.
4. Economic B/C ratio, NPW and IRR will be calculated on the basis of the discounted cash flow analysis.
5. Benefits will be calculated as per the following section.

See Worksheet 14-3

Benefits

Again as in the forecast of the demand load, calculation of benefits require a great deal of judgement. Three categories of benefits will be identified, of which the third will be described but not quantified.

1) revenues from sales
2) resource savings
3) consumer surplus

1) <u>Revenues for Sales</u>. Multiply the Kwh generated by the tariff rate which reflects the true cost of production and delivery of electricity, i.e. without taxes or subsidies. If original demand is below installed capacity, the energy in Kwh will be escalated by its estimated growth rate (3%)

2) <u>Resource Savings</u>. Cost savings can be calculated as the cash savings realized by producing electricity with hydro rather than from other energy sources.

As a first approximation annual resource savings may be calculated by multiplying the annual median energy generation of the hydroelectric plant by the difference between the unit generating cost of the alternative under consideration (i.e. conversion to the grid or using a diesel generating plant) and the unit cost of production of the SHPP.

The CDE system wide generating costs per KWL are published on a monthly basis in a publication called "Banco General y Estados Balances Suplementarios". Data are also available for the unit diesel generating costs. SHPP production costs must be calculated taking into account capital and annual cost discounted at 2% over 30 years divided by the product of the estimated annual median generation and the life of the plant:

$$\text{Cost per Kwh} = \frac{C + \sum^{30} R_i \left(\frac{1}{1 + \ } \right)^i}{G \quad .30}$$

C = Capital Cost in RD$
R_i = Recurrent Cost in Year i = O&M + A&G
G = Annual Median Generation (Kwh)
t = Life of the Hydro = 30 years
= Discount Rate

A sample calculation appears in Section 4.4 of the Financial and Economic Analysis.

3) Consumer Surplus is the excess amount a consumer is prepared to pay for a good (rather than go without it) over the amount he/she actually pays for it. This benefit will accrue to villages previously not connected with the grid. This willingness to pay" decreases as units consumed increase which indicates that satisfaction derived from the last unit consumed is lower too. However, this analysis rests on the contestable assumption that utility is a measurable quantity in the same way as profit, income and output are measurable. In this methodology a more relevant concept of "ability to pay" will be adopted. The conditions in the rural areas are such that "willingness to pay" and "ability to pay" are not always the same. The affordability calculated in Section 8.2 indicates the ability to pay. However, this ability to pay has been taken into account in the determination of the social tariff and therefore will not be calculated. Other benefits that can be assimilated in the consumer surplus are those ones associated with the presence of a cheap energy source, i.e. the capacity to power machines, the higher quality lighting, the greater scope of productive possibilities that open up with the advent of electricity.

14.5 Sensitivity Analysis

In order to test the vulnerability of the projects' financial and economic feasibility, the sensitivity analysis evaluates measures of project worth under changing conditions.

A likely scenario would be a construction delay of 1 yr. with 10% cost overruns.

WORKSHEET 14-1: ANALYSIS OF COST EFFECTIVENESS

HYDRO OPTION	$Year_0$	Y_1	Y_2	Y_3	Y_{20}
Capital Cost	---				
Recurrent Cost	—	—	—		—
Total Discounted at 12%					

$$= c + \frac{\sum_{i=1}^{T} R_i}{(1+r)^i}$$

WHERE

c = capital cost (incurred in year 0) in RDS

r = discount rate (12%)

T = life of diesel alternative (20 yrs)

y_i = ith year

R_i = recurrent cost incurred in year i = O&M + A&G

DIESEL OPTION	$Year_0$	Y_1	Y_2	Y_3	Y_{20}
Capital Cost	---				
Recurrent Cost O&M + A&G		---	---	---	---
Energy Cost (compounded at (1.03)	—	—	—	—	—
Total Discounted at 12%					

$$= c + \sum_{i=1}^{T} \frac{R_i}{(1+r)^i}$$

WHERE

c = capital cost (incurred in year 0) in RDS

r = discount rate (12%)

E_i = energy cost incurred in year i (RDS)

$= E_0 (1.03)^2$

R_i = O & M + A&G + $(1.03)^{2i}$

T = 20 years

Y_i = ith year

CONNECTION TO THE GRID OPTION

Connection Costs

Transmission line (material and labor

Protection Equipment

Voltage Transformer

Service Cost

Avge. Capacity Charge (RDS/KW) X Capacity (KW)

compounded at (1.03)

Avge. Energy Cost (RDS/KWh) X Energy Demand (KWh)1/

compounded at (1 + CDE tariff annual escalation rate)^i

Total Discount at 12%

$$= C_o + \sum_{i=1}^{T} \frac{S_i}{(1+r)^i}$$

WHERE

C_o = connection costs (incurred in year 0) in RDS

r = discount rate (12%)

T = time planning horizon (20 year)

$(C_a)_i$ = Avge. capacity charge in year i (RDS) = $(C_a)_o (1.03)^i$

E_i = Avge. energy cost incurred in year i (RDS)

= E_o (1+CDE tariff annual escalation rate)^i $(1.03)^i$

E_o = CDE bulk tariff for year 0

S_i = service cost incurred in year i (in RDS) = $(C_a)_i + E_i$

The option with the least discounted cost will be the preferred scheme.-

1/ Assuming the load factor remains the same

WORKSHEET 14-2: FINANCIAL ANALYSIS

	COST STREAM				BENEFIT STREAM			
Yr.	Capital	Annual	Discount Factor	Total Cost	Sales KWh x Avg Tariff		Discount Factor	Total Benefit
0								
1								
2								
				= Total Cost				= Total Benefit

Benefit Cost Ratio = $\frac{\text{Total Benefits}}{\text{Total Cost}}$

Net Present Worth = Total Benefit - Total Cost

Internal Rate of Return = Discount rate at which total benefit = total cost

WORKSHEET 14-3 ECONOMIC ANALYSIS

Cost Stream	Foreign Cost	Shadow fgn.exch.	local Cost	Total Cost
Capital		1.36		
Equipment				
Civil Works				
Contingencies				
Distribution System				
Total Capital Cost				
Recurrent Cost				
O & M (1.28%)				
A & E (0.1%)				
Total Cost				

Yr.	Capital Cost	Recurrent Cost	Total	Discount at 12%
0				

30

$$\text{Discounted Total Cost} = \text{Capital Cost} + \sum_{i} \frac{(\text{Recurrent Cost})_i}{(1 + r)^i}$$

WORKSHEET 14-4 ECONOMIC ANALYSIS

BENEFIT STREAM

	Sales	Cost Savings	Total	Discount Factor 12%	PW
0					
1					
30					

TOTAL =

A B/C ratio greater than 1 indicates an economically viable project.

The NPW can be used to rank project on the basis of their economic returns

An IRR indicates the return on investment. An attractive project, from the economic standpoint, will have an IRR greater than the opportunity cost of capital

15.0 Report Writing

Once the technical, social, economic, institutional and environmental analyses have been conducted, the evaluating team will write the final report on the site with recommendations for or against the selection of the site for SHPP development. The grounds for the recommendations should be clearly stated.

As a minimum the report will cover the following topics:

15.1 Technical Analysis

a) Gross head / Design head

b) Flow duration curve (include source of data)

c) Selected design flow

d) Proposed installed capacity

e) Estimated annual energy generation

f) Project layout (brief description including sketch)

g) Turbine type

h) Approximate load factor

i) Proposed transmission facilities

g) Summary of project cost

15.2 Social Analysis

a) Community Assessment

(The community is or is not prepared to organize and/or participate in the planning and implementation of the project)

b) Load demand forecast

Present demand is:

Future demand is:

15.3. Financial and Economic Analysis

	Financial	Economic
B/C		
NPW		
IRR		

15.4. Sensitivity Analysis

	Financial	Economic
NPW if		
10% cost overruns		

15.5. Environmental Analysis

a) indicate if there are conflicting water uses (irrigation, potable water, etc.)

b) indicate if SHPP development might hinder fisheries developments or other economic activity.

c) Use of upstream watershed area.

15.6. Institutional Analysis

This section must indicate whether the implementing agency has the capability to carry out the SHPP development, and that no insurmountable institutional water use conflicts exist.

16.0. Typing and Printing of the Report

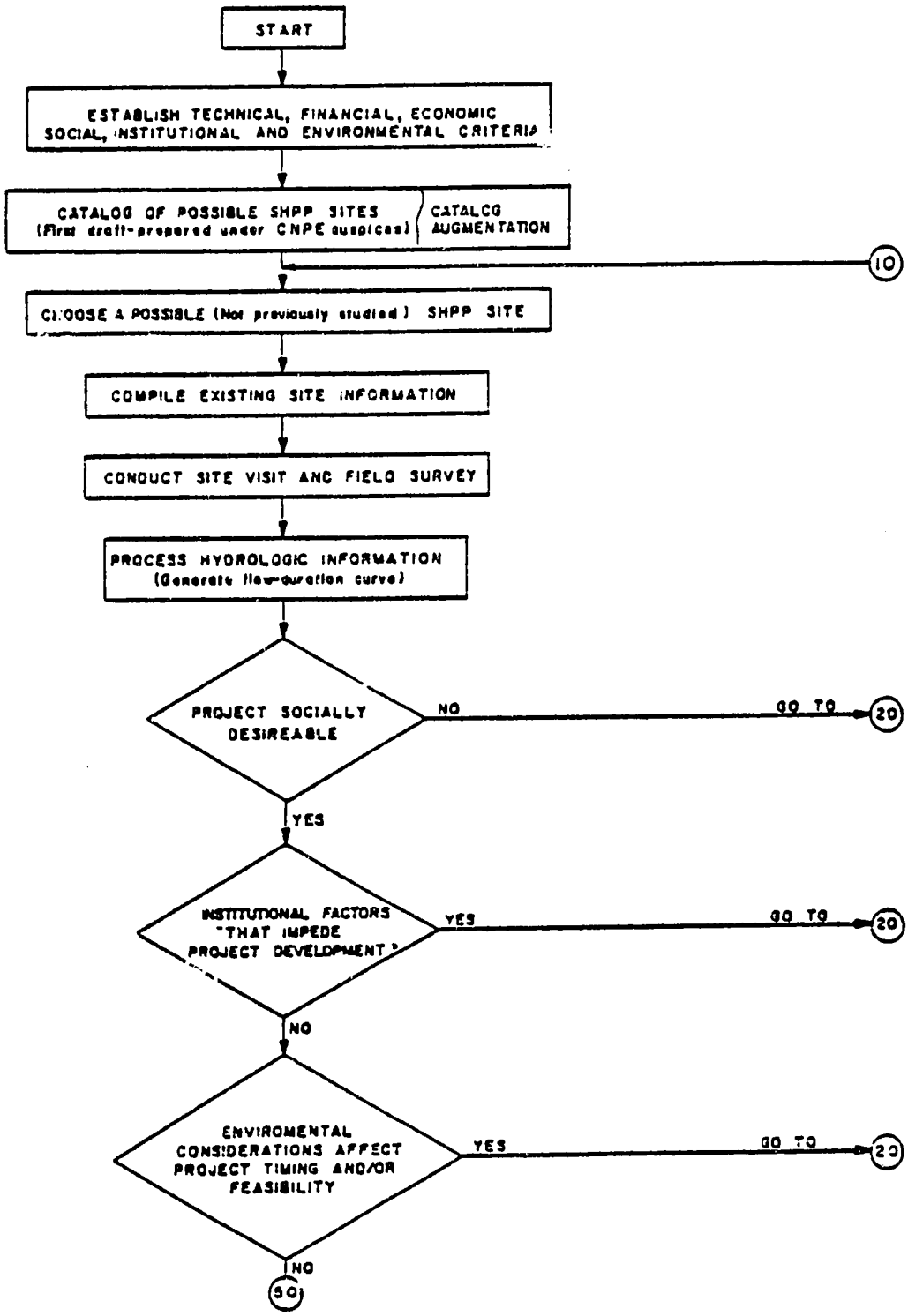
Time allocation of support staff for typing and reproduction of the report must be planned ahead to avoid delays and conflicting time schedules with other activities of the institution.

Figure 16.1 is a flow chart of the site selection methodology.

Gráfico No. 1 is a bar chart for all the activities carried out under a site selection study.

16:1.

FIGURE FLOW CHART OF THE SITE SELECTION METHODOLOGY



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16.1

FIGURE (CONTD.)

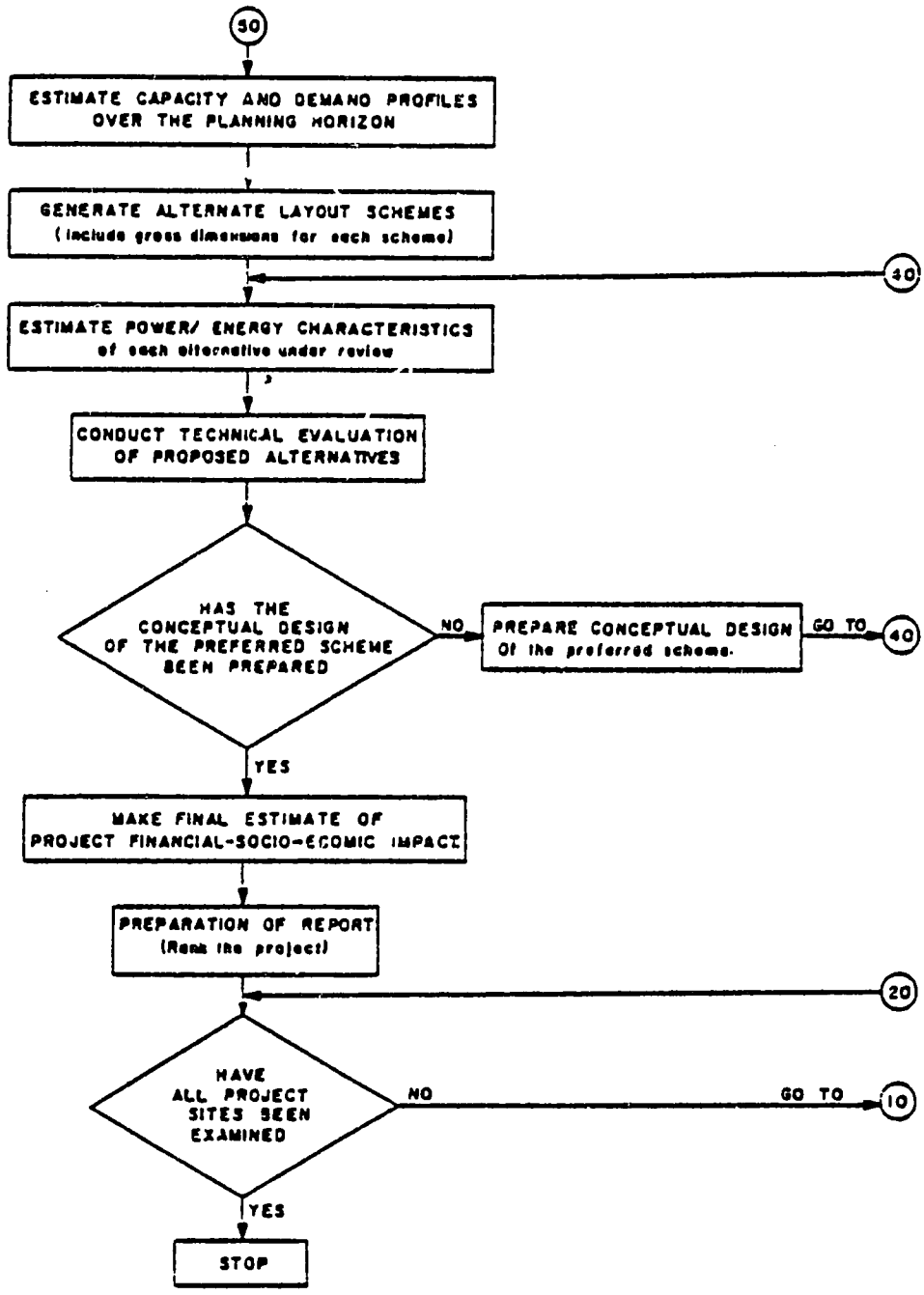

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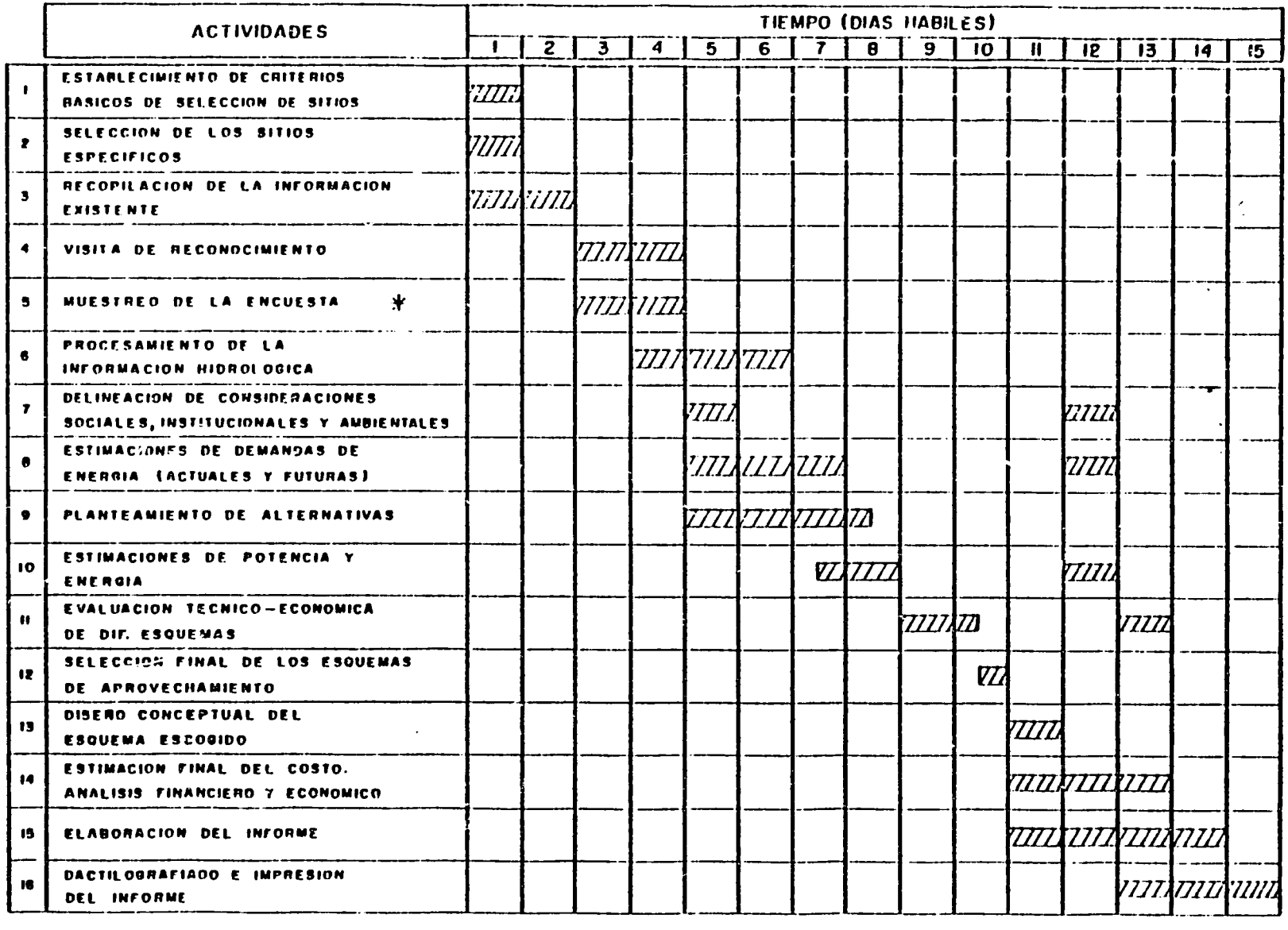
GRAFICO NO. I PROGRAMA MINI CENTRALES HIDROELECTRICAS (AID-CNPE-CDE-INDRHI)

CRONOGRAMA DE ACTIVIDADES



* LA ENCUESTA ESTA DISEÑADA PARA RECOGER DATOS DE INDOLE TECNICA, ECONOMICA, SOCIAL, INSTITUCIONAL Y AMBIENTAL

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Turvey, R. and Anderson, D., Electricity Economics, World Bank/ John Hopkins University Press, Baltimore/London, 1977

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APPENDIX I

EVALUACION DE RECURSOS HIDROELECTRICOS DE PEQUENA ESCALA

COMISION NACIONAL DE POLITICA ENERGETICA

EVALUACION DE RECURSOS HIDROELECTRICOS

DE PEQUEÑA ESCALA

FORMULARIO No. _____

NOMBRE DEL INGENIERIO DE CAMPO _____

FECHA DE RECONOCIMIENTO _____

1. LOCALIZACION
   - 1.1 Nombre de la Corriente de Agua _____
   - 1.2 Afluente de _____
   - 1.3 Provincia _____
   - 1.4 Municipio _____
   - 1.5 Sección _____
   - 1.6 Paraje _____
   - 1.7 Propietario de la Parcela _____
   - 1.8 Nombre de la Parcela _____

2. CARACTERISTICAS FISICAS
   - 2.1 Determinación de Salto Bruto _____
     - 2.1.1 Nivel Normal de Agua en Posible Sitio de Obra de Toma _____
     - 2.1.2 Cota Inferior o de Localización de la Casa de Máquinas _____
     - 2.1.3 Distancia a lo Largo de la Corriente de Agua entre la Posible Ubicación de la Obra de Toma y la Casa de Máquinas _____
     - 2.1.4 Esquema del Tramo Considerado de la Corriente de Agua al Reverso de esta Hoja _____
   - 2.2 Sección Transversal del Sitio de la Obra de Captación _____
     - 2.2.1 Altura de la Banquina, Margen Izquierdo _____
     - 2.2.2 Altura de la Banquina, Margen Derecho _____

Ave. John F. Kennedy Km. 6 1/2. Edif. Plaza Compostela 5to piso
Apartado Postal 304-2 • Tel. 565-5090 • Telex 346 4148 COENER DR • Santo Domingo, República Dominicana

2.2.3 Ancho de la Sección a la Altura de la Corona de la Obra de Captación _____

_____

2.2.4 Esquema de la Sección Transversal al Reverso de Esta Hoja _____

2.3 Aforo de Caudal

2.3.1 Ancho del Río a Nivel de su Superficie ____

_____

2.3.2 Altura de los Tirantes Decididos _____

_____ _____ _____ _____

2.3.3 Ancho de las Secciones de Areas Decididas _

_____

2.3.4 Esquema de la Sección con los Tirantes Medidos

2.3.5 Cálculo del Area (aproximación por trapecios)

2.3.6 Cálculo de la Velocidad

2.3.6.1 Longitud del Tramo Medido

2.3.6.2 Tipo Flotador Utilizado

2.3.6.3 Velocidad Computada V1= _____

2.3.6.4 Velocidad Computada V2= _____

2.3.6.5 Velocidad Computada V3= _____

2.3.6.6 Velocidad Promedio $\bar{V}$

2.3.7 Cálculo de Caudal (aproximación)

$$Q = A \times V$$

2.3.8 Preguntar el Tiempo Transcurrido desde la Ultima Lluvia. _____ Días.

2.4 Descripción del Lecho del Río

2.5 Observaciones Generales sobre la Topografía

2.6 Investigación sobre Nivel Máximo Alcanzado por el Río Durante Crecidas

2.6.1 Nombre de la Persona que da la Información*

_____

2.6.2 Edad _____. Tiempo que Tiene Residiendo en el Lugar _____.

2.6.3 Observaciones

2.7 Observaciones sobre la Disponibilidad de Materiales Aridos para Construcción (arena, canto rodado, etc.)

---

* Investigar con Más de una Persona

2.8 Acceso al Lugar del Aprovechamiento

2.8.1 Carretera Importante Más Próxima

2.8.2 Camino Vecinal Entre _____
y _____

2.8.3 Cómo Llegó al Sitio (medio de transporte)

2.8.4 Si no Hay Camino, Describa la Topografía del Acceso por Donde Llegó

2.8.5 Esquema de la Ubicación con Relación a Algún Hito Importante, Carretera o Camino

3. CARACTERISTICAS DE LA POBLACION MAS CERCANA

3.1 Servicios Públicos Existentes

3.1.1 Agua Potable

3.1.2 Escuelas

3.1.3 Centros de Salud

3.1.4 Edificios Públicos

3.1.5 Fuentes de energía disponibles (diesel, carbón, etc)

3.2 Actividades Económicas

3.2.1 Agricultura y Ganadería.

3.2.2 Agroindustrias

3.2.3 Minería

3.2.4 Comercios

3.2.5 Otras Actividades

3.2.6 Posibilidades de desarrollo de actividades económicas adicionales.

3.3 Población

3.3.1 Población estimada

3.3.2 Número de viviendas

3.3.3 Número promedio de cuartos en esas viviendas

4. EVALUACION DE LA COMUNIDAD

4.1 Organizaciones y Servicios comunitarios activos

Nombre	funciones

4.2 Organizaciones externas que trabajan en la comunidad

Nombre	funciones

4.3 Experiencia de trabajo comunitario

Organizador	trabajo que se realizó (tiempo)

4.4 Capacidad de la comunidad de organizarse y contribuir con mano de obra a la realización de partes específicas del projecto

4.5 Capacidad de la comunidad de mantener y administrar la planta.

4.6 Gasto promedio(en RDS por vivienda y por mes) en energía. (p.ej: velas, baterías, kerosene, diesel)

4.7 Número y tipo de comercios e industrias en el poblado

4.8 Número y uso de bombas de riego.

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5. OBSERVACIONES ADICIONALES

5.1 Explique si hay o podría haber alguna instalación para uso de agua que interfiera con el proyecto (acueducto, canal, etc)

5.2 Describa el estado de deforestación en la cuenca aportadora y si hay reforestación en la actualidad.

APPENDIX II

POWER PLANT EQUIPMENT

APPENDIX B

POWER PLANT EQUIPMENT

TYPES OF TURBINE

The basic factor affecting the powerhouse layout cost and performance is the choice of turbine. Figure B-1 shows typical cross sections of powerhouses for different turbine types. Figure B-2 shows the operating head range of the different turbines. A brief description of the different types available follows.

Francis Turbines. A Francis turbine is one having a runner with fixed vanes. The water enters the turbine in a radial direction, and is discharged in an axial direction. Principal components are the runner, a water supply case (spiral 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 which conveys the water from the turbine to the tailrace. In special cases, where the flow rate is constant, Francis turbines without wicket gate mechanisms may be used provided due consideration is given to overspeed conditions. These units will operate at a fixed load depending upon the operating head. Start-up and shut-down of turbines without wicket gates is normally accomplished using the shut-off valve at the turbine inlet.

A Francis turbine may be operated over a range of flows from approximately 30 to 115 percent of design discharge. Below the minimum discharge, vibrations and power surges can occur. The approximate head range for operation is from 60 to 125 percent of design head although with proper design the upper limit could be increased to 150 percent. In general, peak efficiencies of Francis turbines, within the capacity range up to 15 mW, will be approximately 90 to 92 percent.

Francis turbines may be mounted with vertical or horizontal shafts. Vertical mounting requires a smaller plan area and facilitates a deeper setting for the turbine with respect to tailwater elevation. Generator costs for vertical units are higher than for horizontal units but the savings in construction cost for medium and large units generally offsets the 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. Concrete and open flume cases may also be used. Francis turbines are generally provided with a 90 degree elbow draft tube which is designed to recover part of the velocity head. Conical draft tubes are also used for small machines but have a higher head loss.

Propeller Turbines

A propeller turbine is one having a runner with four, five or six blades through which the water passes 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.

The efficiency curve of a typical fixed blade Propeller turbine has a sharper peak than does 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 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 but, the power operating range is more limited. Propeller turbines may be operated using flows ranging from 30 to 115 percent of the design flow for adjustable blade units and 50 to 115 percent for fixed blades. The head range for satisfactory operation is from 55 to 140 percent of design head for adjustable blades and from 65 to 140 percent for fixed blades although the latter could be increased to 140 percent with proper design. In general, the peak effeciency would range from 90 to 92 percent.

The conventional propeller or Kaplan (variable pitch blade) turbines are mounted with a vertical shaft. Horizontal and slant settings are also possible. The vertical units like Francis units are equipped with wicket gates. As with the Francis turbines, elimination of the wicket gate assembly may be acceptable in some limited cases. The spiral case is generally of concrete though steel may also be used. Open flume construction may prove to be economical when heads are below 35 feet. At higher heads the turbine shaft length becomes excessive. At capacities above 1500 kW an open flume may cease to be a satisfactory choice. The draft tube for a propeller turbine is similar to that of a Francis turbine.

Tubular Turbines

Tubular turbines may be horizontal, vertical or slant mounted units and have propeller runners. The generators are located outside of the water passageway. Tubular turbines are available with fixed or variable pitch runners and with or without wicket gate assemblies.

Performace characteristics of a tubular turbine are similar to those of propeller turbines. Where it is not necessary 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. However, the performance range of the tubular 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.

Several items of auxiliary equipment are often necessary for the operation of tubular turbines. Tubular turbines without wicket gates should be equipped with a shut-off valve automatically operated to provide shut-down and start-up functions. Tubular turbines may also be equipped with an air clutch between the turbine and generator so that the generator need not be designed for turbine runaway speed.

Tubular turbines can also be supplied with a speed increaser to allow the use of a higher speed generator. Speed increasers however, lower the overall plant efficiency by about one percent for

a single gear increaser and about two percent for double gear increaser. This loss of efficiency and the cost of the speed increaser should be balanced against the reduction in cost for the smaller generator.

Horizontally mounted tubular turbines require more floor area than vertically mounted units. The area required may be lessened by slant mounting, but additional turbine costs are incurred as a larger axial thrust bearing is required. Excavation and powerhouse height for a horizontal unit is less than for a vertical unit.

Standardized tubular turbines are available from the leading domestic turbine manufacturer. Ten sizes are currently available with up to 7000 kW of capacity and for heads up to 60 feet. Standardization may provide lower cost and shorter delivery periods.

Bulb Turbines

Bulb turbines are horizontal units with propeller runners directly connected to a generator which is housed in a water-tight enclosure (bulb) within the turbine water passageway. The bulb turbine is available with fixed or variable pitch blades and with or without a wicket gate mechanism. Performance characteristics are similar to the vertical and tubular 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 tubular 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 poorer accessibility, however, may be greater than for either the vertical or the tubular type turbines.

Standardized bulb turbines are offered by some foreign manufacturers.

Rim Type

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 in Europe and given the name "Straflo". The concept was

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developed 40 years ago and approximately 75 units are now in service. Capacities of units so far developed range from 1000 to 1900 kW at heads of 26 to 30 feet but recent designs indicate that capacities up to 6000 kW are obtainable. All units built to date have fixed blade propeller runners.

Performance characteristics of the rim 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 rim turbine provides the smallest power house dimensions of all the turbine types considered in this volume. The rim design is attractive because of simplicity and compactness, however, experience with large units is limited. Consideration of this type of unit can usually be deferred until a more definitive stage of project design.

Crossflow Turbines

A crossflow, (Ossberger) turbine may best be described as an impulse type turbine with partial air admission. Performance characteristics of this turbine are similar to an impulse turbine. It has 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 the other turbine types previously discussed. Maximum efficiency is in the range of 82 to 85 percent. The unit can be operated over a range of flows of 10 to 115 percent of design discharge.

At the present time, the largest size runner produced is 4 feet in diameter. This limits the unit capacity but multi-unit installations can be used. Allowable heads range from 20 to 600 feet. Crossflow turbines are equipped with a conical draft tubular creating a pressure below atmosphere in the turbine chamber. Therefore the difference between the turbine centerline elevation and the tailwater is not lost to a crossflow turbine as is the case for an impulse turbine. Floor space requirements are more than for

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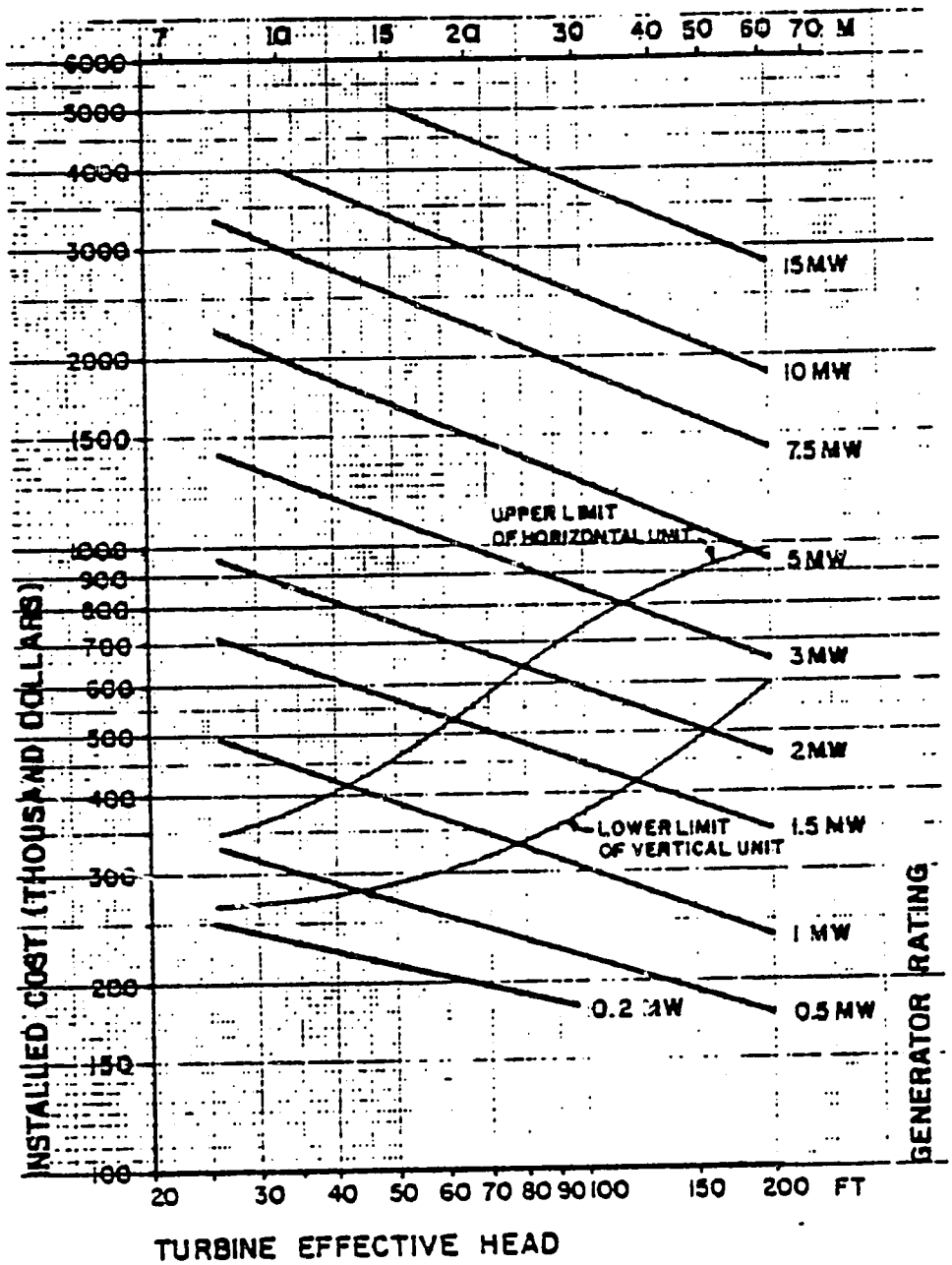
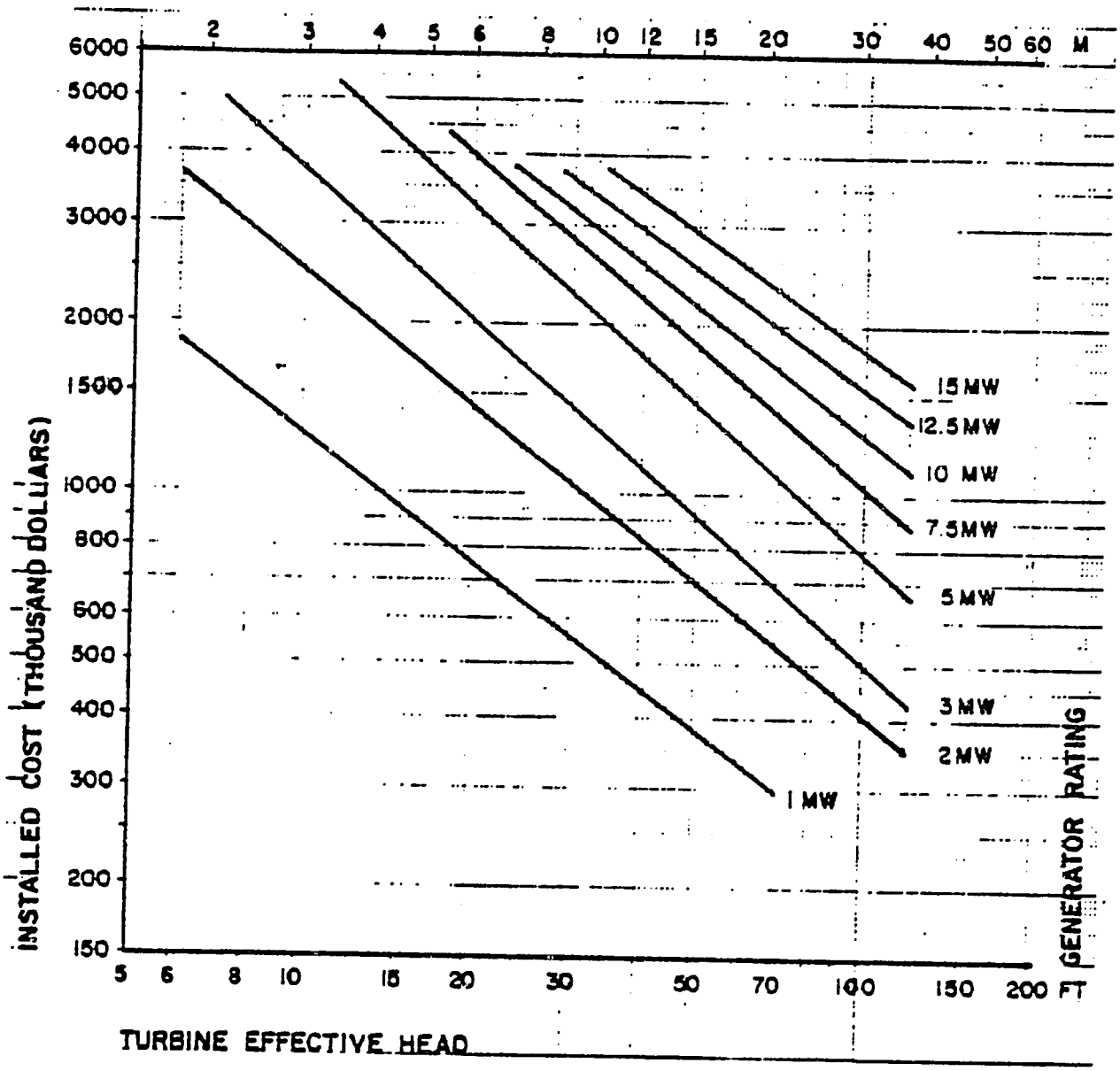


NOTES:

1. Date of costs is April 1979.
2. Estimated costs are based upon a typical vertical turbine direct coupled to the generator.
3. Cost includes turbine, generator, exciter, inlet valve, non-speed regulating governor and installation.
4. Installation costs estimated at 15% of total equipment cost.
5. Add $60,000 for speed regulating governor.
6. For horizontal mounting deduct 7%.

Figure B-3 Francis Turbine Unit Costs



NOTES:

1. Date of costs is April 1979.
2. Estimated costs are based upon a typical vertical Kaplan turbine, with concrete spiral case, direct coupled to generator.
3. Costs include turbine with variable pitch blades and wicket gates, generator exciter, speed regulating governor and installation.
4. No inlet valve is provided for. If an inlet valve is required, use Figure 4-6 for costs.
5. Installation costs estimated at 15% of total equipment cost.
6. For fixed blade propeller turbine deduct 10%.
7. If steel spiral case is required increase costs by 10%.

Figure 3-4 Vertical Propeller Turbine Unit Costs

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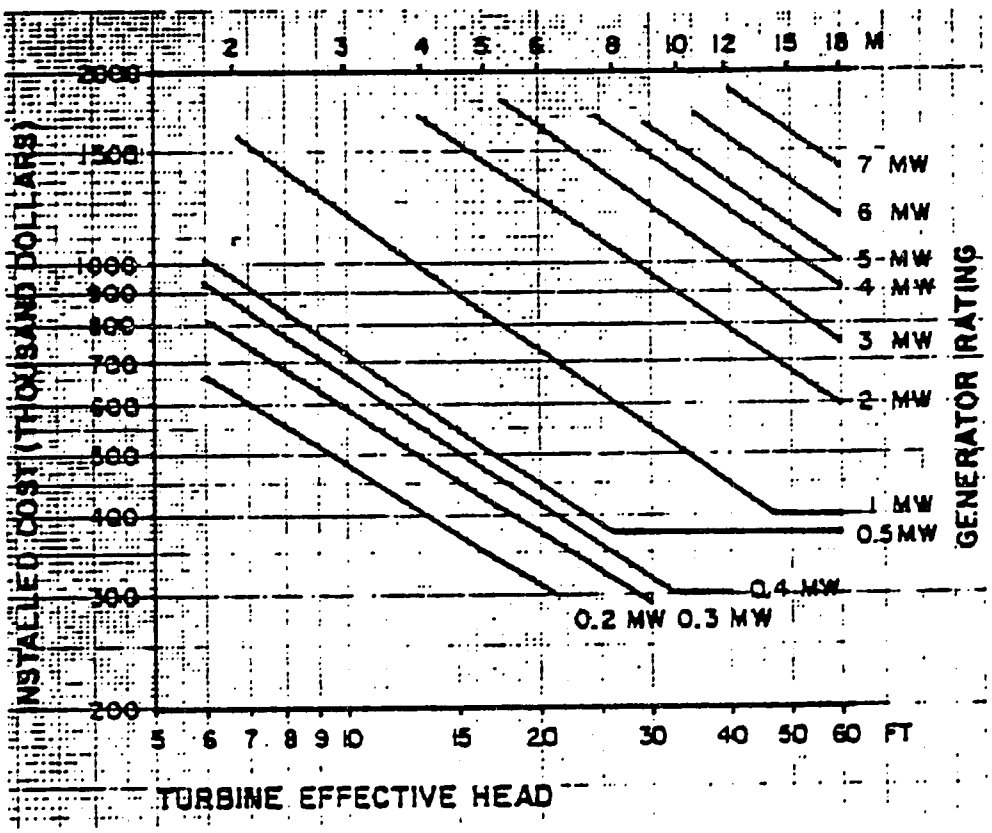

NOTES:

1. Date of costs is April 1979.
2. Estimated costs are based upon a standardized tubular turbine coupled to the generator through a speed increaser.
3. 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.
4. Installation costs estimated at 15% of total equipment costs.
5. For turbines with fixed blades deduct $28,000.

Figure B-5 Standard Tubular Turbine Unit Costs

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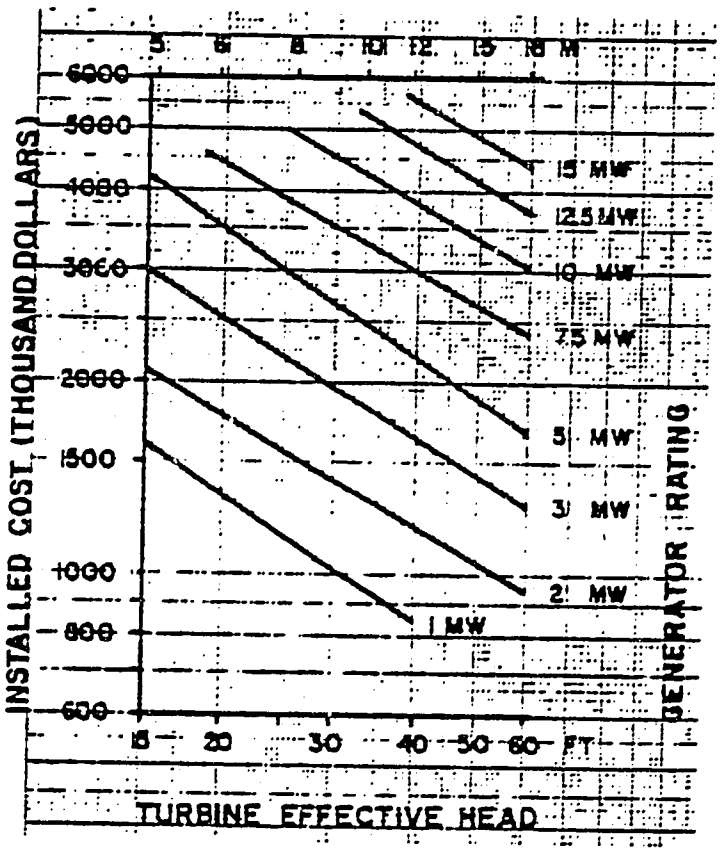
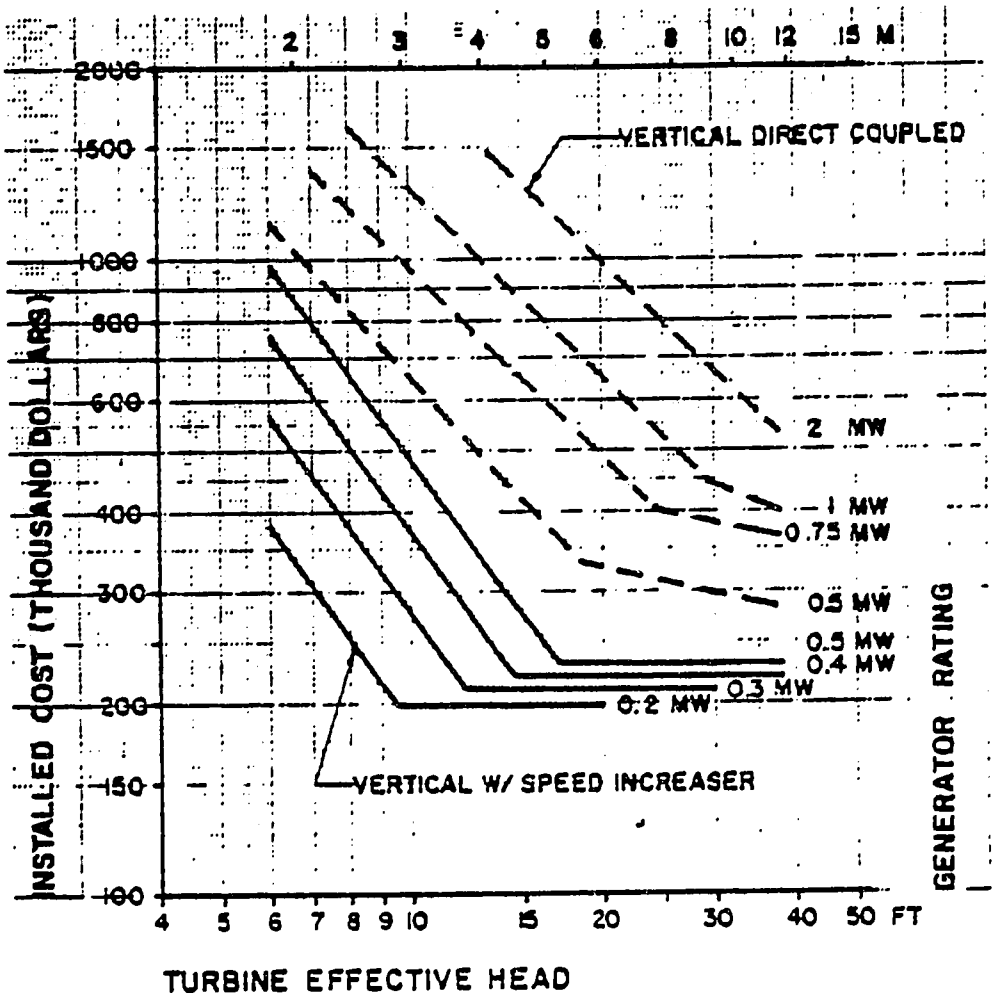


NOTES:

1. Date of costs is April 1979.
2. Estimated costs are based upon a typical horizontal bulb turbine with variable pitch blades and wicket gates directly coupled to the generator.
3. Cost includes turbine, inlet butterfly valve, generator, exciter, speed regulating governor and installation.
4. Installation costs are estimated to vary from $260,000 for the large units, to $78,000 for the small units.
5. For fixed blade units, deduct 10%.

Figure B-6 Bulb Turbine Unit Costs



NOTES:

1. Date of costs is April 1979.
2. Estimated costs are based on a typical vertical propeller turbine with fixed blades, directly coupled to the generator.
3. Cost includes turbine, wicket gates, generator with exciter, speed regulating governor and installation.
4. Installation costs estimated at $40,000 for each unit.

Figure B-7 Open Flume Turbine Unit Costs

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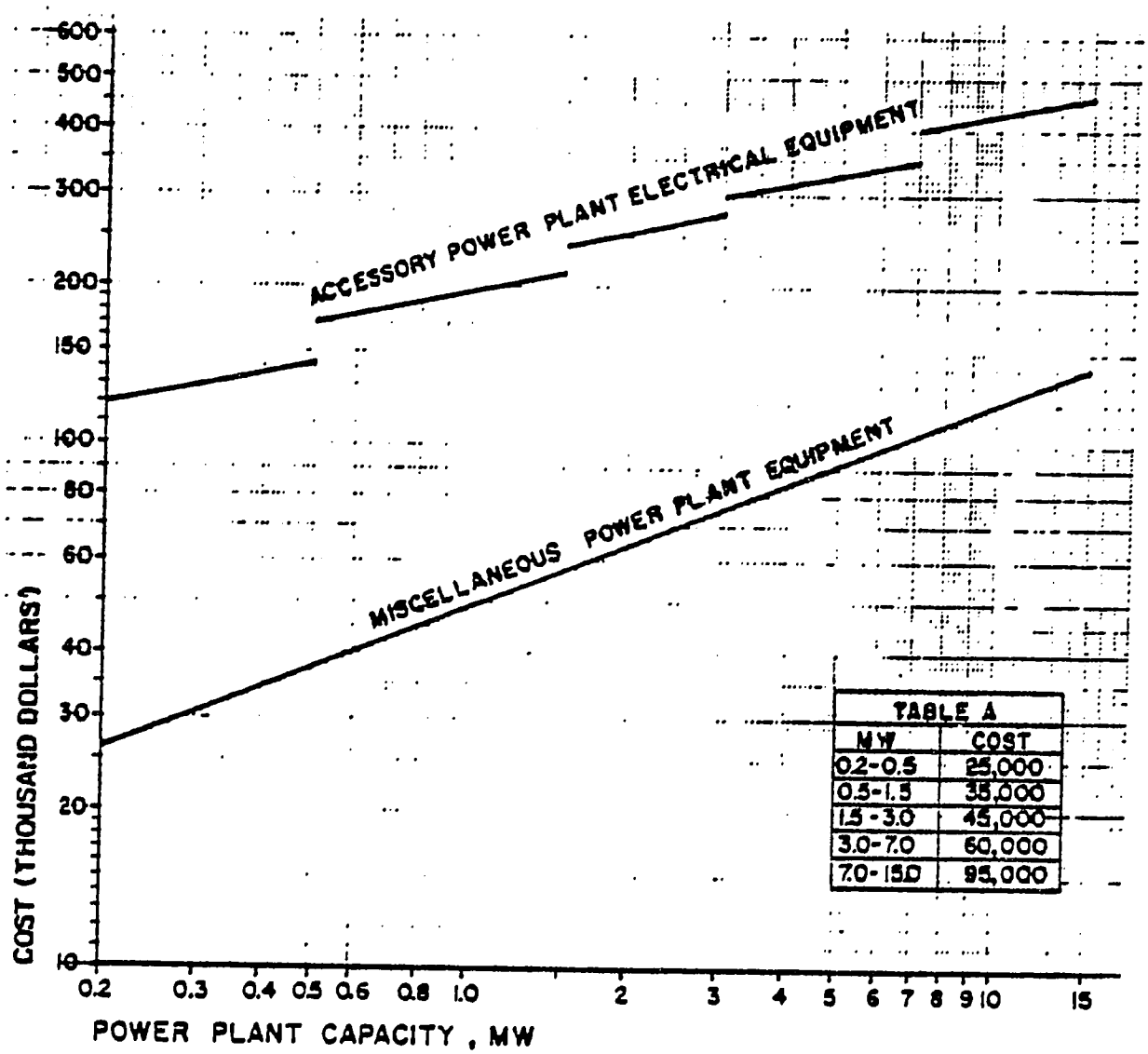

TABLE A	
MW	COST
0.2-0.5	25,000
0.5-1.5	35,000
1.5-3.0	45,000
3.0-7.0	60,000
7.0-15.0	95,000

NOTES:

1. Date of costs is April 1979.
2. Estimated costs for accessory electrical equipment are for a single unit plant.
3. For multiple unit electrical equipment costs:
   a) Determine cost from chart for plant capacity.
   b) Subtract cost for plant capacity given in Table A.
   c) Add cost from Table A for unit capacity multiplied by the number of units.
4. The estimated cost for miscellaneous power plant equipment for multiple units may be taken as the cost for a single unit of the same total plant capacity.

Figure 3-3 Miscellaneous Power Plant and Accessory Electrical Equipment Costs

APPENDIX III

INDEX OF MANUFACTURERS - HYDROELECTRIC EQUIPMENT

INDEX OF MANUFACTURERS - HYDROELECTRIC EQUIPMENT

Manufacturer - Country Representative Address	Turbines										Valves			
	Propeller & Kaplan	Francis	Tubular	Bulb	Rim	Crossflow	Impulse	Pump	Governor	Generator	Butterfly	Spherical	Energy Dissipation	Gates
ALLIS-CHALMERS - USA Allis-Chalmers Hydro-Turbine Division P.O Box 712 York PA 17405	B	B	C	B			B	B			C	B	B	
ALSTHOM - ATLANTIQUE/NEYRPIC - FRANCE Alsthom-Atlantic. Inc. 50 Rockerfeller Plaza Suite 916 New York. NY 10022	C	B	C	C			B	B	B	C	C	B	B	C
ARMCO - USA Armco Inc. Metal Products Division Middletown. Ohio 45043											C			C
ASEA - SWEDEN Asea Inc. 4 New King Street White Plains. N Y. 10604				B					C	C				
ATELIERS BOUVIER - FRANCE Anchor Darling Industries Inc 1 Belmont Avenue Bala Cynwyd. PA 19004	B	B	A				C		C		B			B
BELOIT - USA Beloit Power Systems 555 Lawton Avenue Beloit. Wisconsin 53511											A			

Symbols
- A - Standard Design
- B - Custom Design
- C - Both Standard & Custom Designs

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INDEX OF MANUFACTURERS - HYDROELECTRIC EQUIPMENT

Manufacturer - Country Representative Address	Turbines										Valves			
	Propeller & Kaplan	Francis	Tubular	Bulb	Rim	Crossflow	Impulse	Pump	Governor	Generator	Butterfly	Spherical	Energy Dissipation	Gates
INDEPENDENT - USA Independent Power Developers Route 3 Box 285 Sandpoint Idaho 83864	B						B							
KATO - USA Kato Engineering Co. 1415 First Avenue Mankato, MN 56001										A				
KMW - SWEDEN Axel Johnson Corp. One Market Plaza San Francisco, CA 94105	B	B	C	B			B	B	B					
KOSSLER - AUSTRIA Kossler Ltd. 1923 Magellan Drive Oakland, CA 94611	C	C	C				C		A					C
KVAERNER-BRUG - NORWAY Kvaerner-Moss Inc. 800 3rd Avenue New York, NY 10022	C	B		C	B		C	C	C		C	C	C	C
LEFFEL-TAMPELLA - USA/FINLAND The James Leffel & Co. 426 East St. Springfield, Ohio 44501	C	C	C	B			C							

Symbols
- A - Standard Design
- B - Custom Design
- C - Both Standard & Custom Designs

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INDEX OF MANUFACTURERS - HYDROELECTRIC EQUIPMENT

Manufacturer - Country Representative Address	Turbines										Valves			
	Propeller & Kaplan	Francis	Tubular	Bulb	Rim	Crossflow	Impulse	Pump	Governor	Generator	Butterfly	Spherical	Energy Dissipation	Gates
LIMA - USA The Lima Electric Co. 200 East Chapman Road Lima, Ohio 45802										A				
LITOSTROJ - YUGOSLAVIA Arbanas Industries 24 Hill Street Xenia, Ohio 45385	B	B	B	B			B	B	C		B	B		B
MITSUBUSHI - JAPAN Mitsubushi International Corp 50 California St. San Francisco, CA 94111	B	C	B	B			B	B	C	B	C	B	B	B
NEBB - NORWAY Brown Boveri Corp 1460 Livingston Ave. North Brunswick, NJ 08902										C				
NOBLE - USA Noble Automated Systems 226 Phelan Ave. San Jose, CA 95112							B							
OSSBERGER - GERMANY F.W.E. Stapenhorst Inc. 285 Labrosse Ave. Pointe Claire, Que H9R1A3						C								

Symbols
- A - Standard Design
- B - Custom Design
- C - Both Standard & Custom Designs

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INDEX OF MANUFACTURERS - HYDROELECTRIC EQUIPMENT

Manufacturer - Country Representative Address	Turbines										Valves			
	Propeller & Kaplan	Francis	Tubular	Bulb	Rim	Crossflow	Impulse	Pump	Governor	Generator	Butterfly	Spherical	Energy Dissipation	Gates
WESTINGHOUSE - USA Westinghouse Eletric Corp Hydro Generator Department 700 Braddock Avenue East Pittsburgh. PA 15112										C				
WOODWARD - USA Woodward Governor Co. 5001 North Second Street Rockford. IL 61101									C					
WORTHINGTON-NEYRPIC - USA/FRANCE Worthington-Neyrpic Inc. 270 Sheffield Street Mountainside, NJ 07092			A											

Symbols
- A - Standard Design
- B - Custom Design
- C - Both Standard & Custom Designs

APPENDIX IV

PROJECT DATA SHEET

TABLE 4-1

PROJECT DATA SHEET

Project: _____ Date: _____

Description	Unit	Project Data	Remarks
Location:			
Cost Zone Coefficient			
Project Type (A,B,C,D)			
Drainage Area	acre		
General Items:			
Land Required:			
For Power Plant	acre		
For Reservoir	acre		
For Transmission Line	acre		
Access Road Required:			
Permanent	mile		
Construction	mile		
For Transmission Line	mile		
Facility To Be Relocated:			
Care of Water - Condition:			
Head Data:			
Headwater Elevation:			
Maximum	ft		
Minimum	ft		
Tailwater Elevation at Design Discharge	ft		
Gross Head:			
Maximum	ft		
Minimum	ft		
Design	ft		
Design Net Head	ft		
Turbine:			
Type			
Design Discharge	cfs		
Unit Capacity	kW		

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Description	Unit	Project Data	Remarks
Waterways:			
Intake Structure Required	No		
Penstock:			
Length: Main	ft		
Branch	ft		
Bifurcation Required	No		
Maximum Velocity	ft/sec		
Diameter	ft		
Bypass Structure Required	No		
Bypass Discharge	cfs		
Tailrace Length	ft		
Transmission Line:			
Voltage	kV		
Capacity	MW		
Length	mile		
New Site Developments:			
Embankment Dam:			
Height W.S. Above Streambed	ft		
Length	ft		
Spillway:			
Average Annual Flow	ac-ft		
Existing Facilities:			
Degree of Difficulty of Alteration			
Remedial Work Required			

TABLE 4-3

CONSTRUCTION COST INDEXES OF THE
BUREAU OF RECLAMATION
April 1979

COMPOSITE INDEX	2.48
DAMS	
Earth	2.37
Structures	2.24
Spillway	2.47
Outlet Works	2.59
STEEL PENSTOCKS	2.61
CANALS	2.43
Earthwork	2.39
Structures	2.48
CONDUITS (Tunnels, Conc-lined)	2.47
POWER PLANTS, HYDRO	
Building and Equipment	2.45
Structure, Rein, Conc and Improv	2.46
Equipment	2.47
Turbine and Generators	2.48
Accessory Elec and Misc Equip	2.41
PIPELINE, CONC	2.34
SWITCHYARDS	2.40
TRANSMISSION LINES	
Wood Poles, 115 kV	2.69
Steel Tower, 230 kV	2.58
ROADS	
Secondary	2.55
BRIDGES, STEEL	2.34

BASE: 1967 = 1.0

83

TABLE 4-4

COST COMPILATION SHEET

Date: _____

Description	Unit	Quantity	Unit Cost $	Amount April 1979 $	Cost Indexes 1979	Cost Indexes 198( )	Escalated Amount 198( ) $
1. New Dam and Spillway:							
Embankment Dam	LF						
Spillway	LS						
Reservoir Clearing	acre						
SUB-TOTAL.							
2. Intake:							
Intake, Type A	No						
Intake Gate & Hoist	No						
SUB-TOTAL.							
3. Penstock:							
Penstock	LF						
Penstock Branch	LF						
Bifurcation	No						
SUB-TOTAL.							

24

Date: _____

Description	Unit	Quantity	Unit Cost $	Amount April 1979 $	Cost Indexes 1979	Cost Indexes 198( )	Escalated Amount 198( ) $
4. Power Plant (Type A, B, C & D Projects)							
Total Cost, Single Unit	LS						
Equipment Adjustments:							
For Governor	LS						
For Fixed Blade/Mounting	LS						
For Inlet Valve	LS						
For Spiral Case	LS						
SUB-TOTAL, UNIT							
By-pass Structure	LS						
Tailrace	LF						
Switchyard							
Civil Features	LS						
Equipment	LS						
SUB-TOTAL,							
5. Special Costs:							
SUB-TOTAL,							
SUB-TOTAL, - ITEMS 1 THROUGH 5							
6. Existing Facilities:							
Alterations to Connect Power Plant (0;5;8%)	LS						
Remedial Work	LS						
SUB-TOTAL,							

85

Date: _____

Description	Unit	Quantity	Unit Cost $	Amount April 1979 $	Cost Indexes 1979	Cost Indexes 198( )	Escalated Amount 198( ) $
7. General Costs:							
Land & Land Rights*	acre						
Water Rights	LS						
Relocations	LS						
Mobilization (1.5%)	LS						
Access Road *	mile						
Bridges	LS						
Care of Water (0;2;6%)	LS						
SUB-TOTAL							
8. Transmission Line:							
Line	mile						
Clearing	acre						
Land	acre						
Access Road	mile						
SUB-TOTAL							

* Excludes Transmission Line

TABLE 4-5

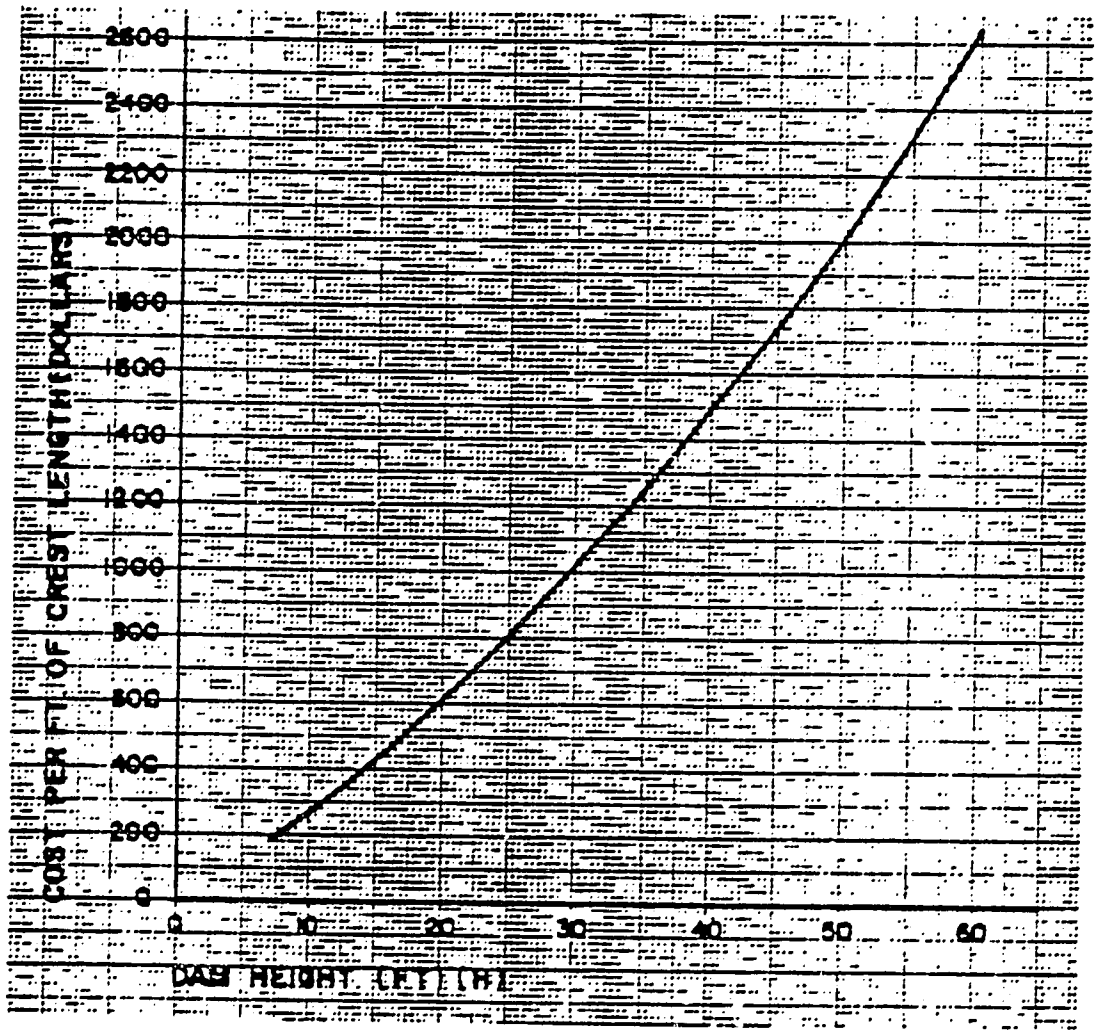
PROJECT COST SUMMARY

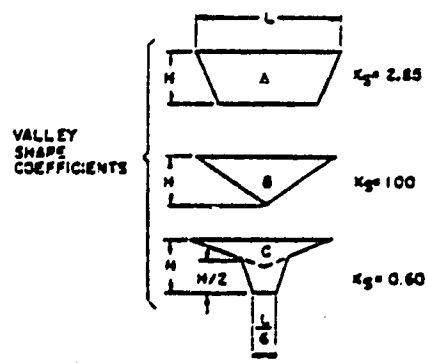
Base Date: /198( )

	ITEM	COSTS ($)
1.	New Dam and Spillways	_____
2.	Intake	_____
3.	Penstock	_____
4.	Power Plant	_____
5.	Special Structures	_____
6.	Existing Facilities	_____
7.	General Costs	_____
8.	Transmission Line	_____
9.	TOTAL DIRECT COST	_____
10.	Contingencies (20%)	_____
11.	Sub-Total	_____
12.	Engineering, Administration and Construction Management (20%)	_____
13.	TOTAL CONSTRUCTION COST:	$_____
14.	TOTAL CONSTRUCTION COST X Zone Factor * = _____*	$_____

* See Figure 4-19

87





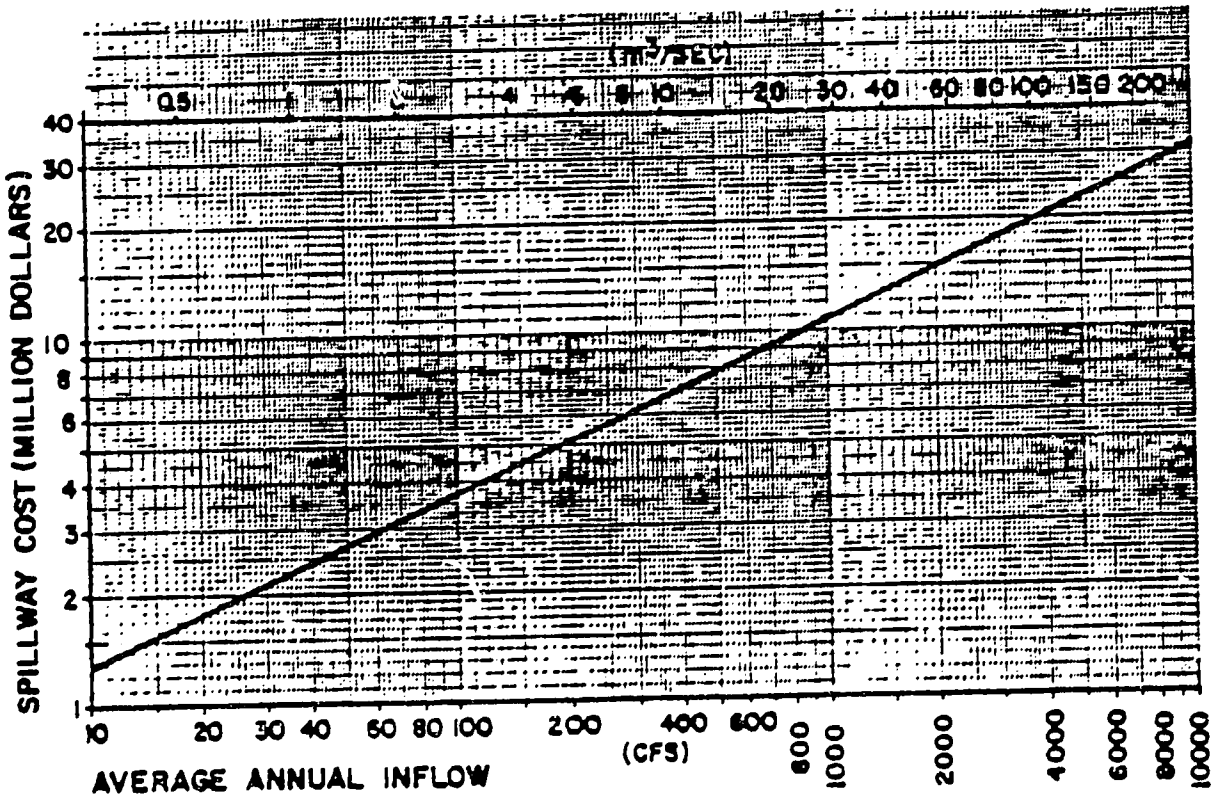
NOTES:

1. Date of costs is April 1979.
2. Total costs obtained by multiplying the cost per foot by the dam crest length.
3. The cost must be multiplied by the valley shape coefficients shown. See also Figure A-2.
4. The cost is based on a unit price of $10 per cubic yard for embankment fill.
5. Costs include 20 percent for excavation, foundation treatment, drainage and other minor items.

Figure 4-2 Embankment Dam Costs

Best Available Document

88

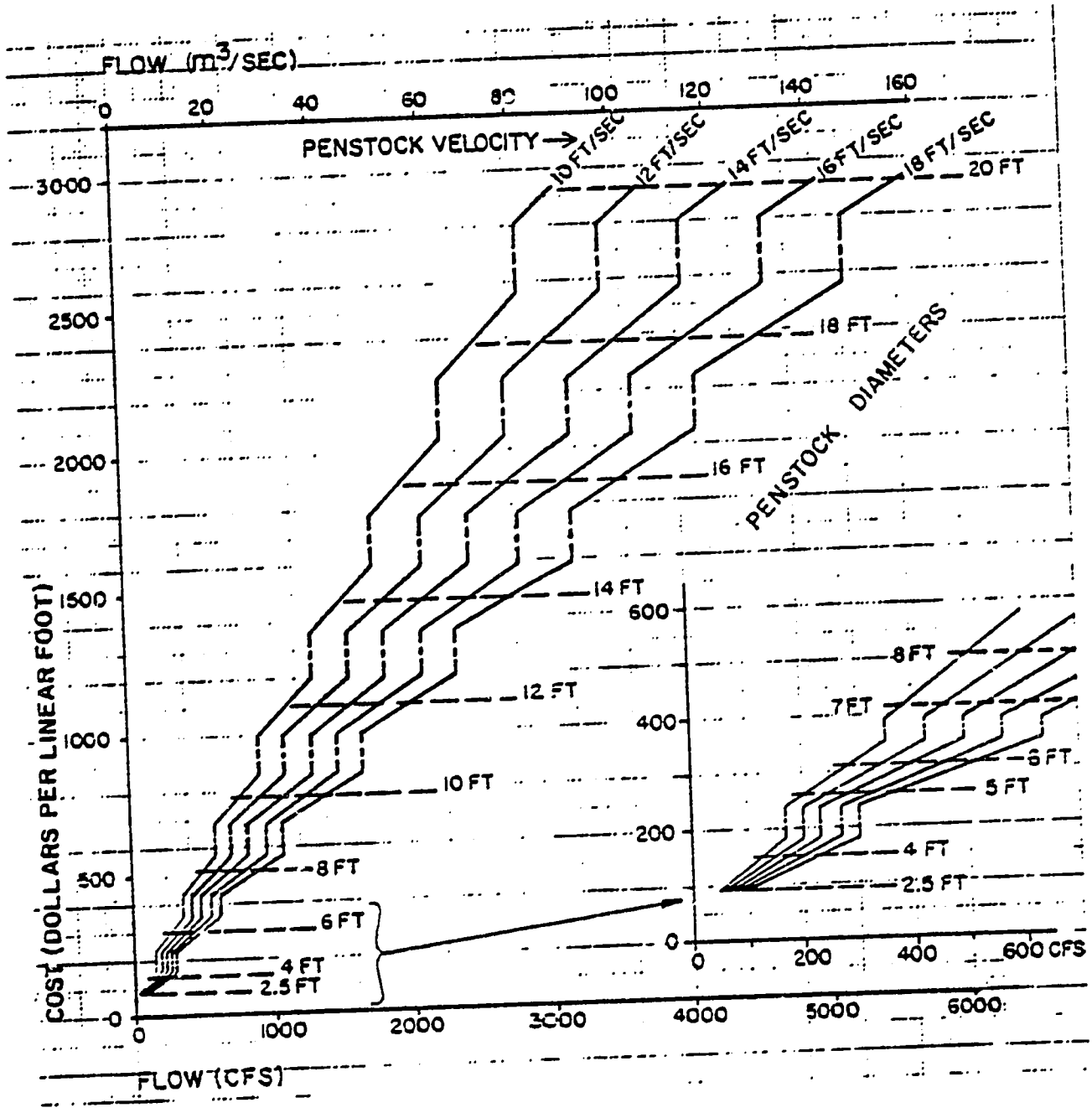


NOTES:

1. Date of costs is April 1979.
2. Costs are based on data of the U.S. Corps of Engineers.
3. Costs include 20 percent for excavation, foundation treatment, drainage and other minor items.

Figure 4-3 New Spillway Costs

89

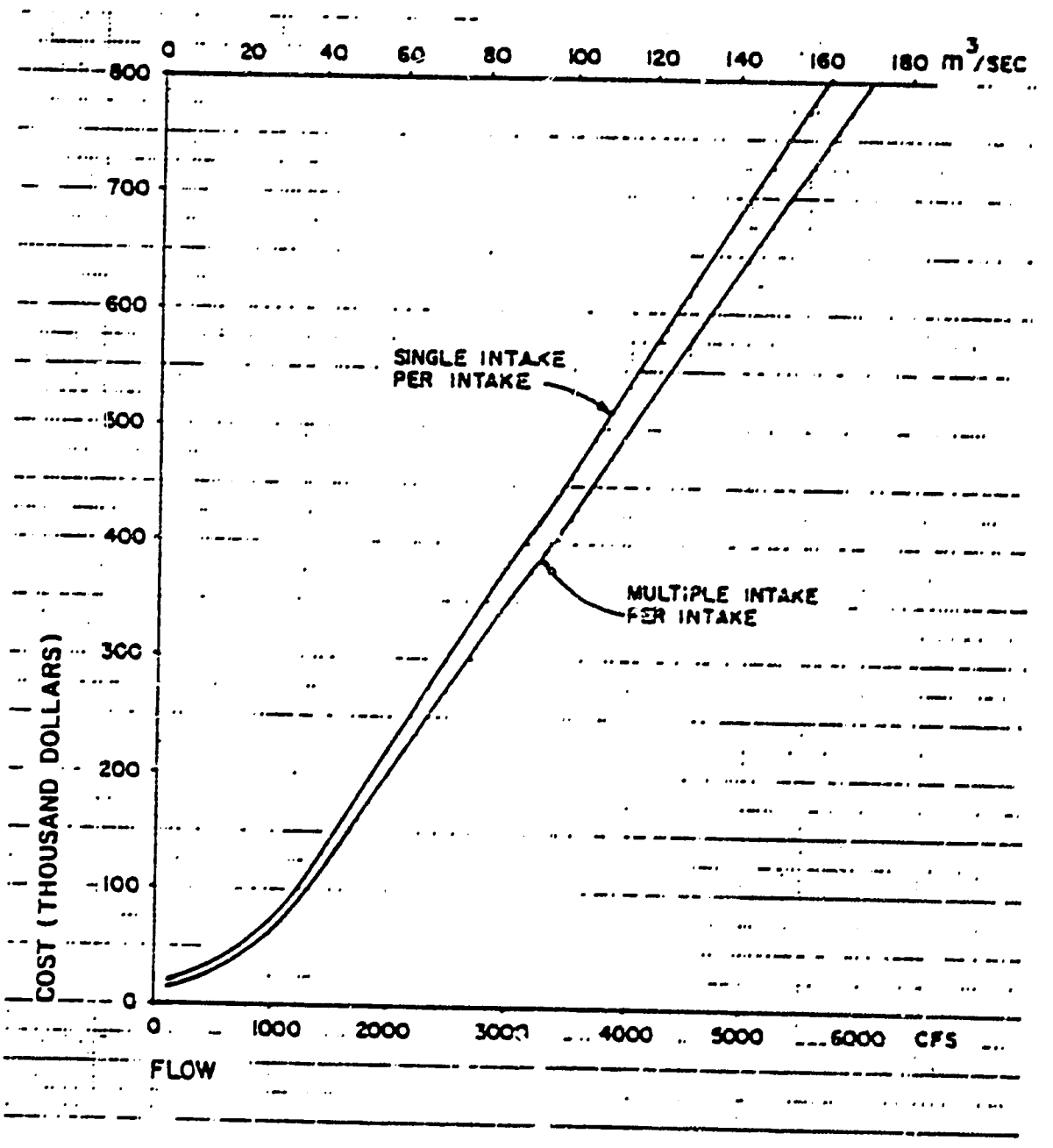


NOTES:

1. Date of costs is April 1979.
2. Cost includes penstock, excavation and concrete supports.
3. Costs based on the minimum handling thickness for steel penstock.
4. If penstock gradient is greater than 15°, add 1% cost for each degree greater than 15°.
5. Valves, Bifurcations and anchor blocks not included.

Figure 4-5 Penstock Costs

Best Available Document

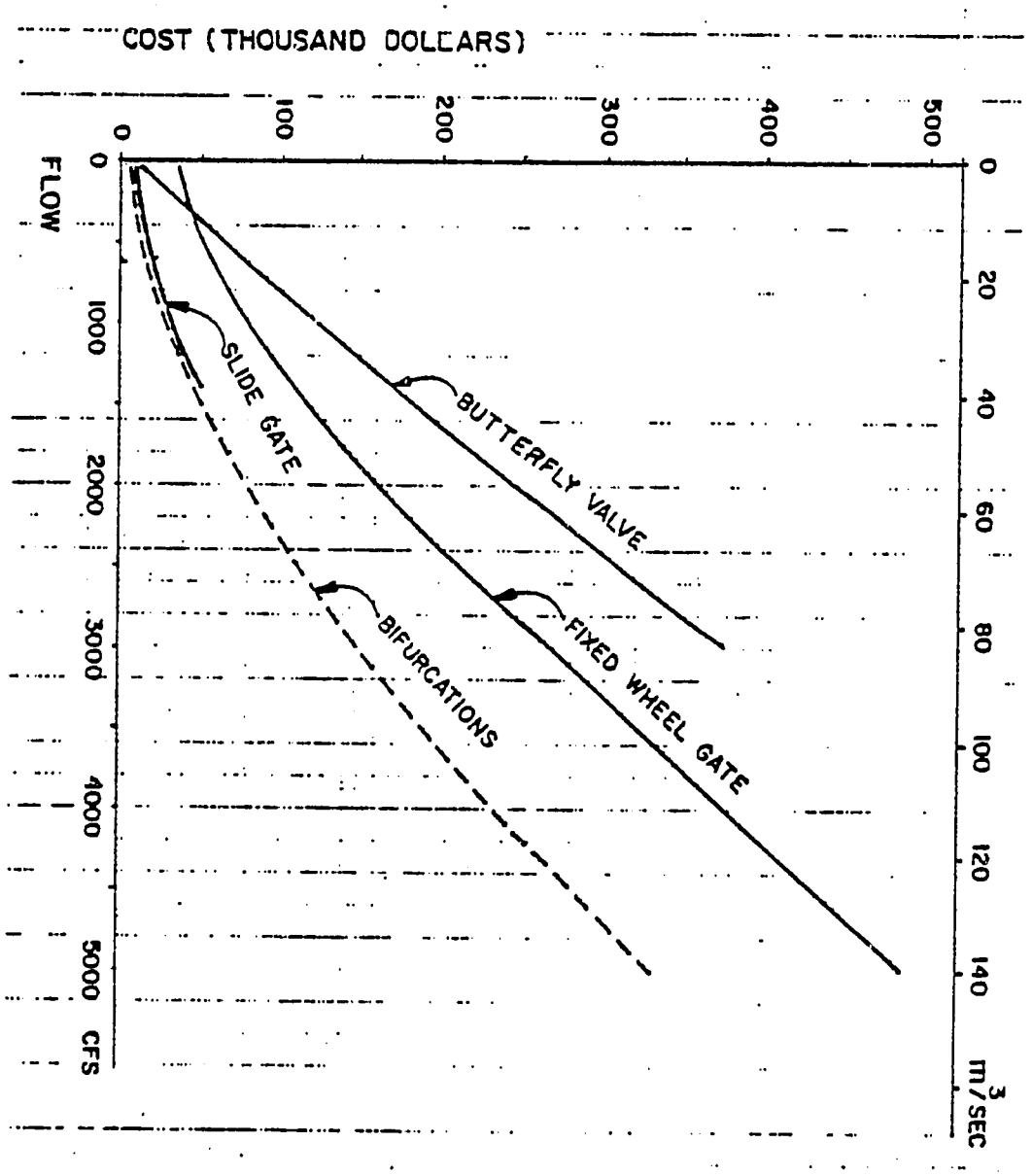


NOTES:

1. Date of costs is April 1979.
2. The estimated cost includes excavation, concrete, reinforcing steel, backfill, trash rack, miscellaneous metal and embedded metal.
3. No cost is included for an intake gate. The gate cost can be obtained from Figure 4-6.

Figure 4-4 Intake Costs

91

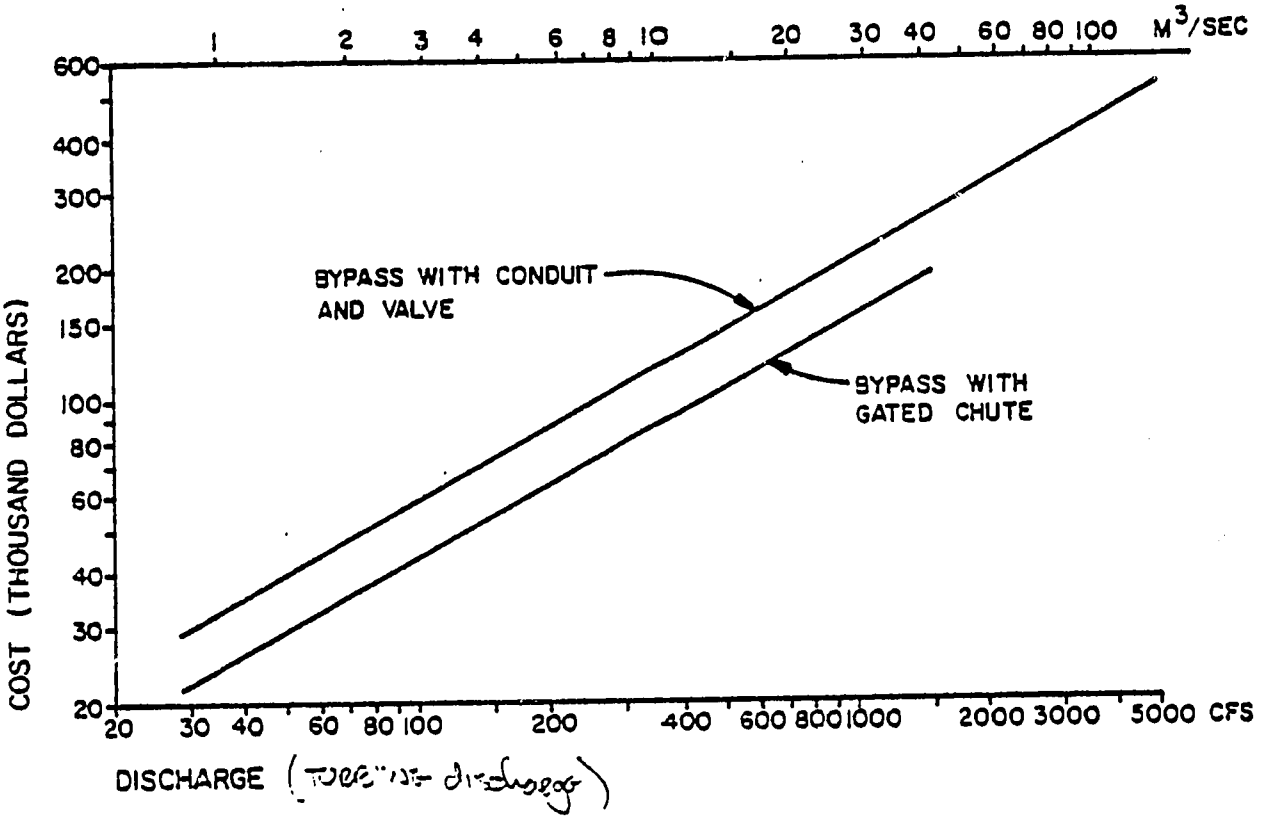


NOTES:

1. Date of costs is April 1979.
2. The estimated cost of the fixed wheel gate includes a hoist, gate frame, guides and installation.
3. The estimated cost of the slide gate includes an operator, gate frame, guides and installation.
4. The estimated cost of the butterfly valve includes a hydraulic operator and installation.
5. The bifurcation cost must be added to the cost of the equivalent length of steel penstock.

Figure 4-6 Valve, Bifurcation and Gate Costs

92

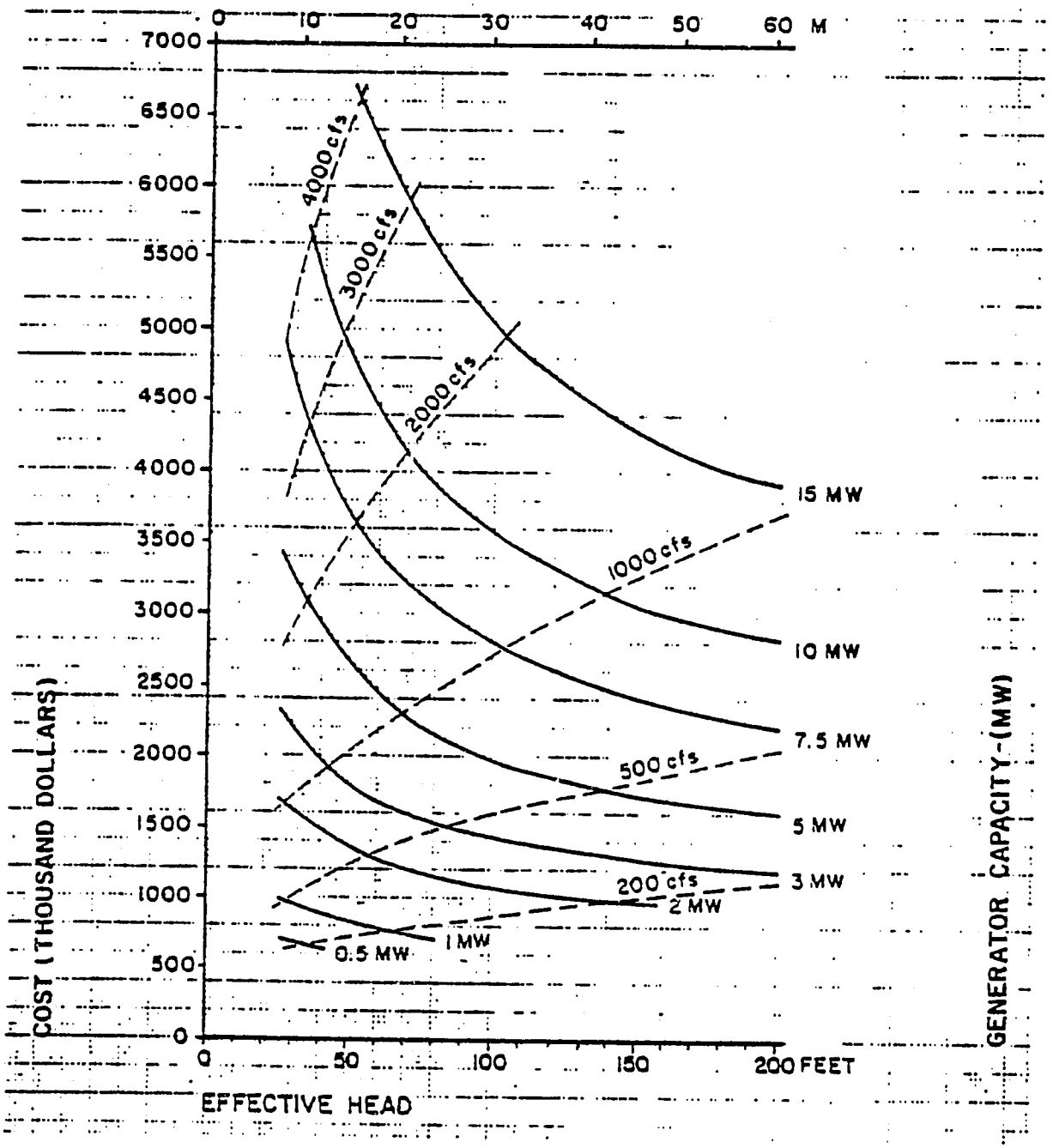


NOTES:

1. Date of costs is April 1979.
2. Cost of bypass with conduit and valve includes excavation, foundation preparation, reinforced concrete bypass structure, backfill, steel liner to dissipation chamber, miscellaneous and embedded metals, piping, fixed cone dispersion valve and operator.
3. The bypass with a gated chute consists of a gated intake, chute and stilling basin. Costs include excavation, foundation preparation, reinforced concrete structure, backfill, trashracks, miscellaneous and embedded metals, slide gate and operator. For flows greater than those given, use a multiple gated intake.

Figure 4-7 Bypass Structure Costs

93

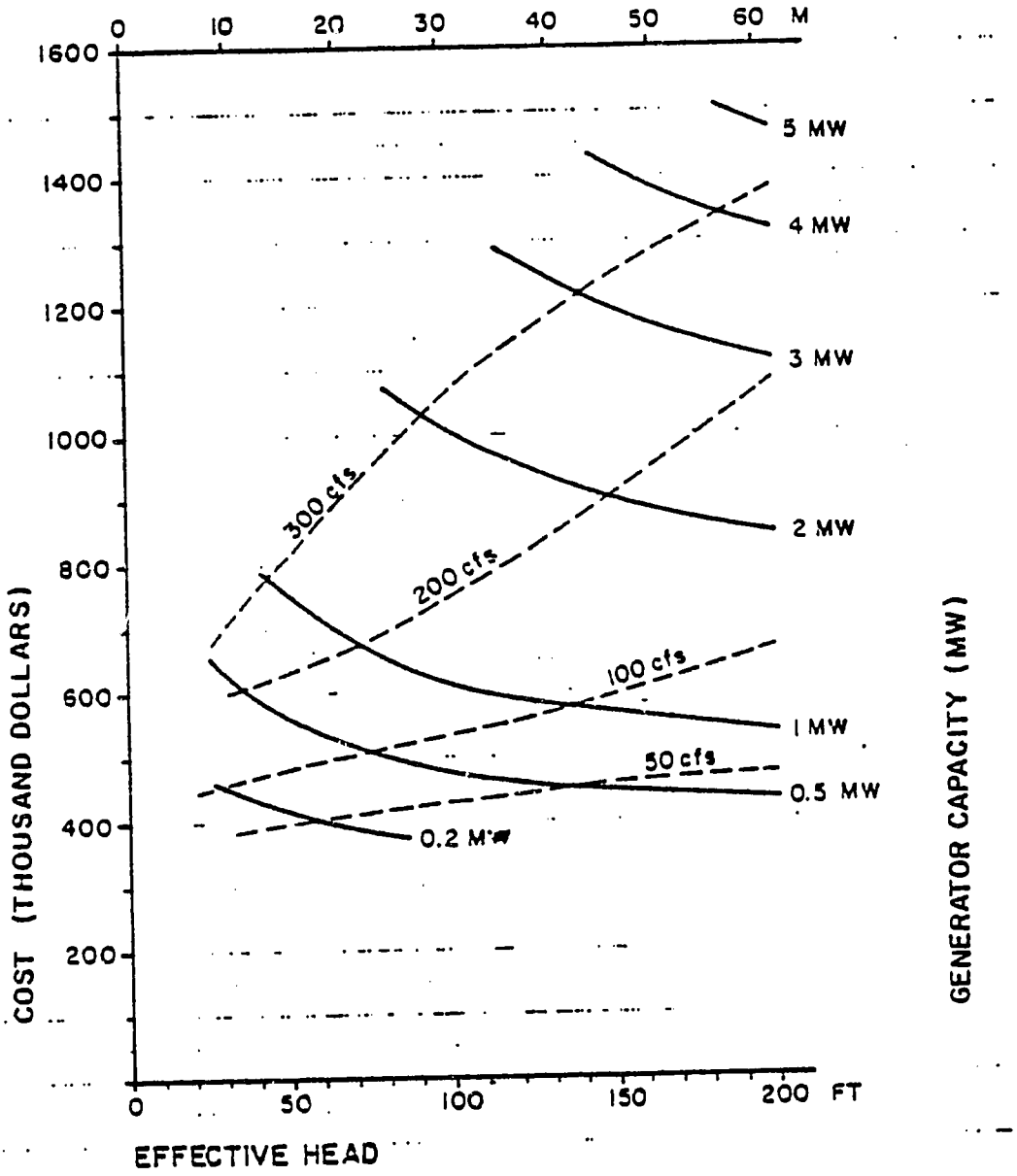


NOTES:

1. Date of costs is April 1979.
2. Costs include turbine and generator, site civil works, powerhouse civil works, miscellaneous power plant equipment, accessory electrical equipment and turbine shut-off valve.
3. Costs are for a single unit powerhouse.
4. Turbine discharges shown are based on a turbine efficiency of 0.85.

Figure 4-8 Powerhouse and Equipment Costs - Vertical Francis Units (Type A, B, C Projects)

94

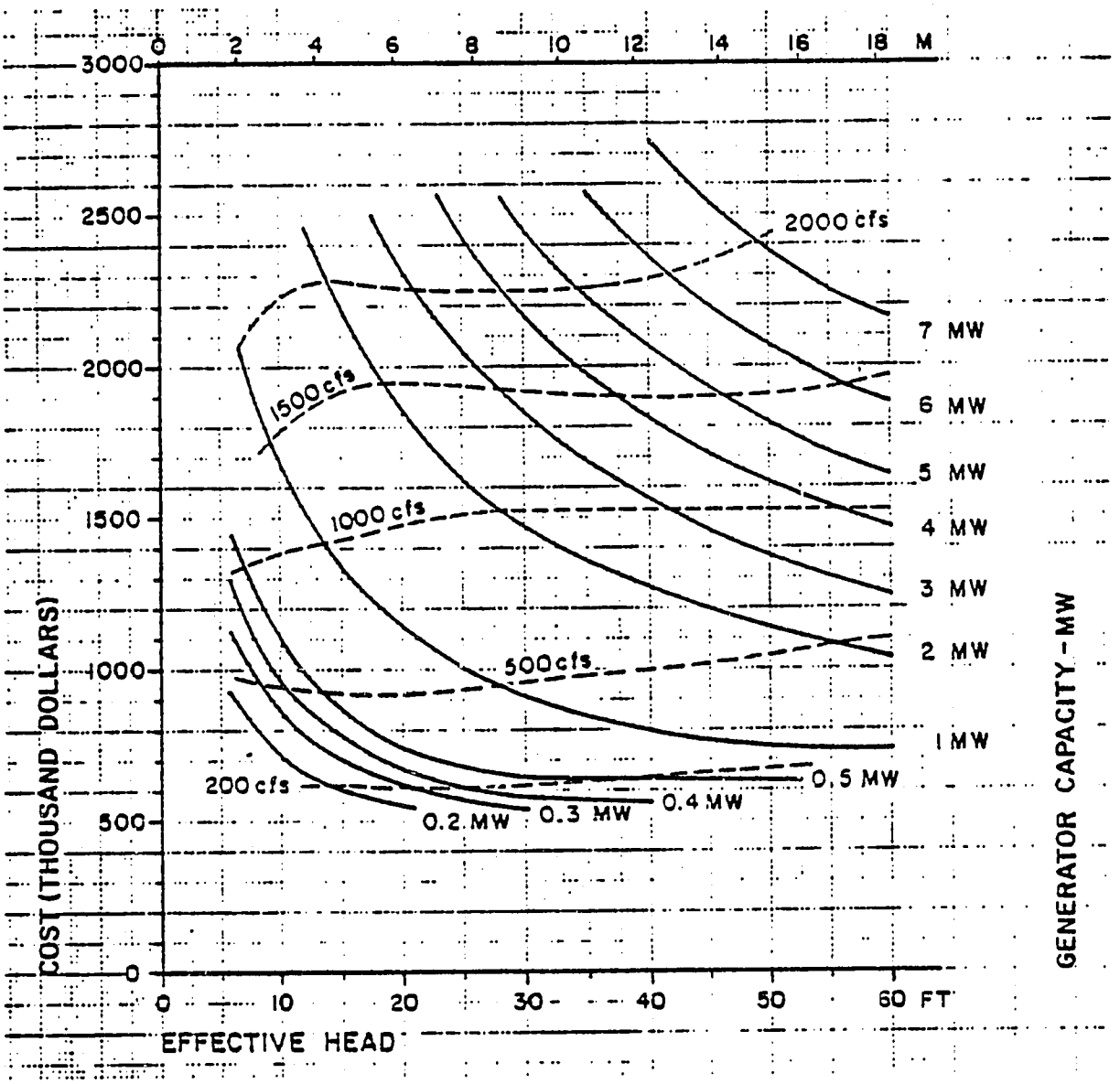


NOTES:

1. Date of costs is April 1979.
2. Costs include turbine and generator, site civil works, powerhouse civil works, miscellaneous power plant equipment, and accessory electrical equipment and turbine shut-off valve.
3. Costs are for a single unit powerhouse.
4. Turbine discharges shown are based on a turbine efficiency of 0.85.

Figure 4-9 Powerhouse and Equipment Costs - Horizontal Francis Units (Type A, B, C Projects)

95

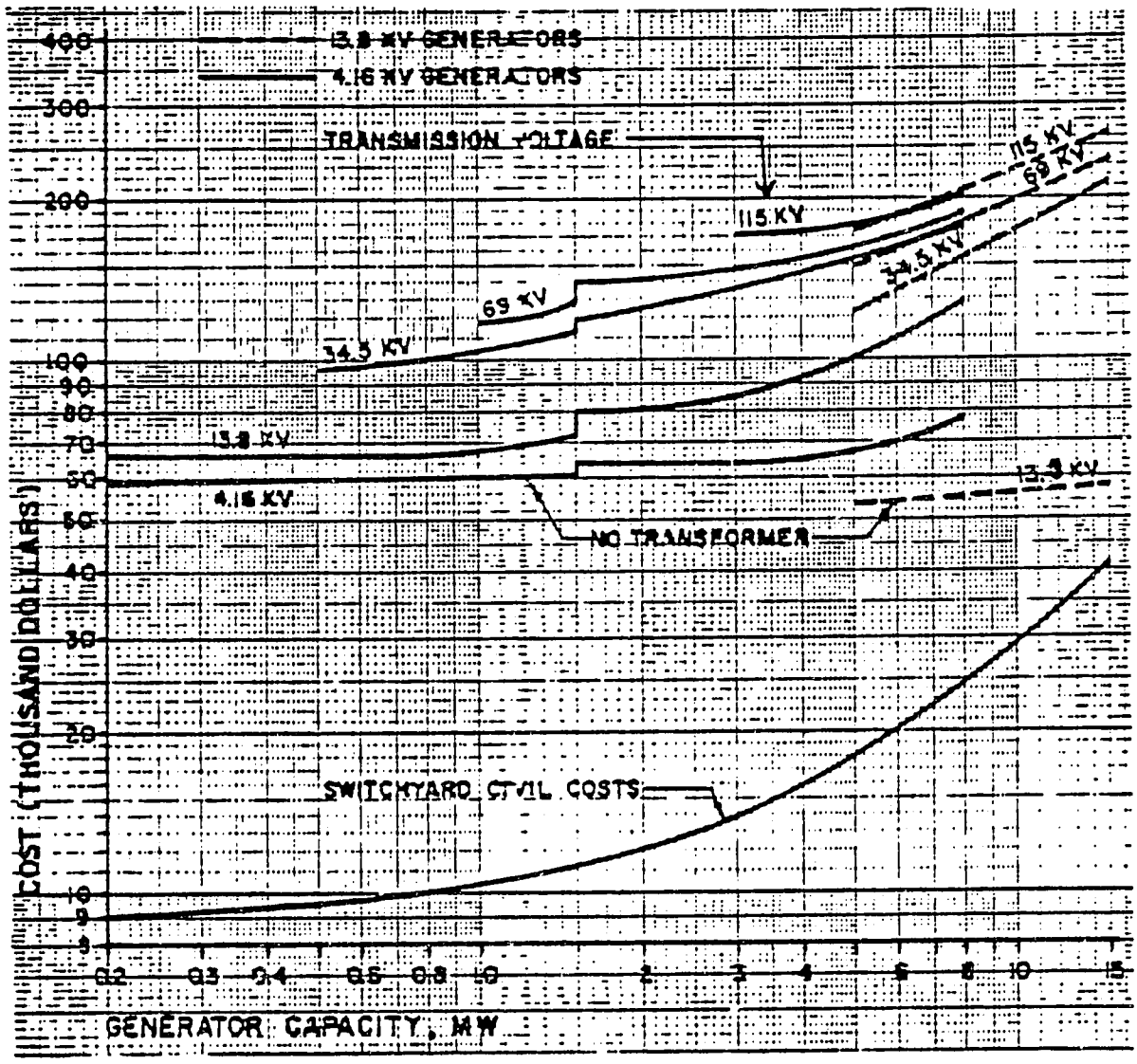


NOTES:

1. Date of Costs is April 1979.
2. Cost estimate includes turbine and generator, site civil works, powerhouse civil works, miscellaneous power plant equipment, accessory electrical equipment and turbine shut-off valve.
3. Costs are for a single unit power plant.
4. Turbine discharges shown are based on a turbine efficiency of 0.85.

Figure 4-11 Powerhouse and Equipment Costs - Tubular Units (Type A, B, C Projects)

96

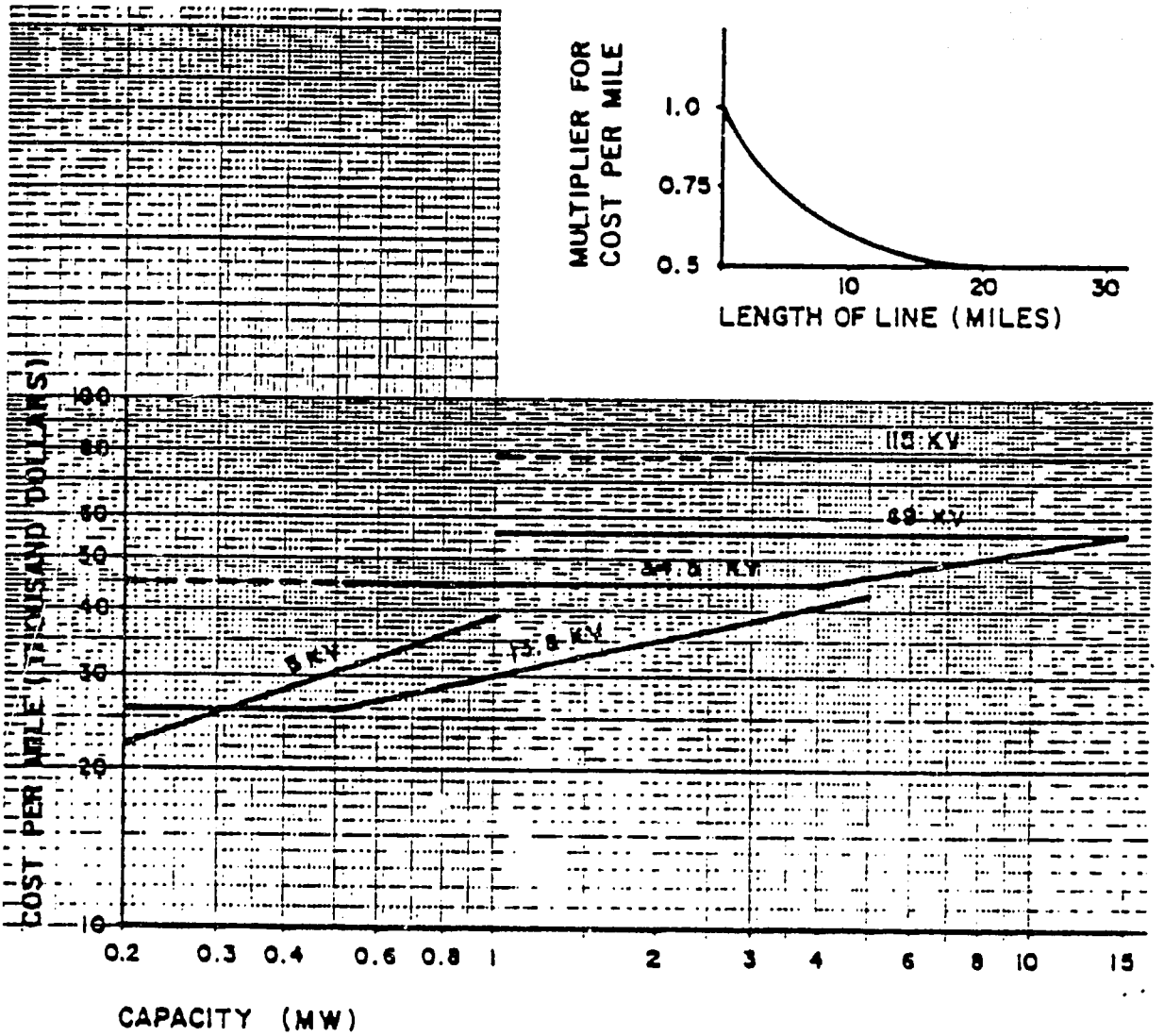


NOTES:

1. Date of costs is April 1979.
2. Costs are for a single unit.
3. For multiple units add $50,900 multiplied by (N-1), where N is the number of units.
4. Total switchyard cost is the sum of the civil cost and the equipment cost corresponding to the transmission voltage required.

Figure 4-17 Switch Yard Costs with Generator Voltage Circuit Breakers

97

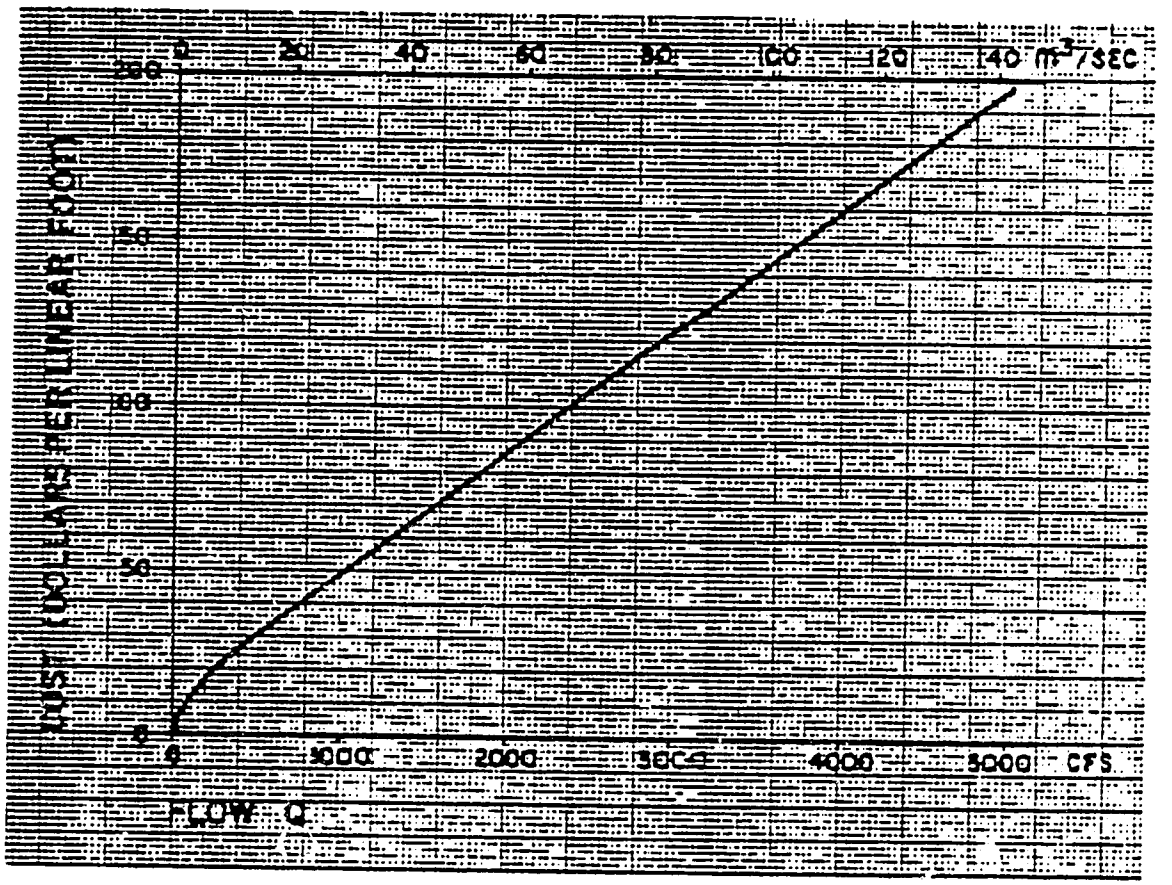


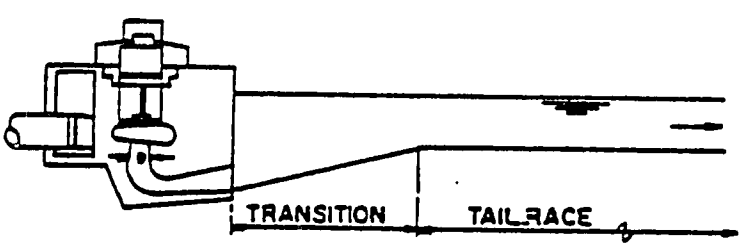
NOTES:

1. The date of costs is April 1979.
2. The cost per mile of transmission line should be adjusted according to the length of the line required using the multiplier shown above.
3. The estimated costs include wood poles, hardware, insulators, conductors, and construction roads. No clearing, land or right of way costs are included.
4. The estimated costs are based on single wood poles for the 5, 13.8 and 34.5 kV lines and wood pole H-frames for the 69 and 115 kV lines.
5. The estimated costs are for prairie type terrain with favorable foundation conditions. For foothill terrain add 10% of cost and for mountainous or swampy terrain add 30% of the cost.

Figure 4-18 Transmission Line Costs

98



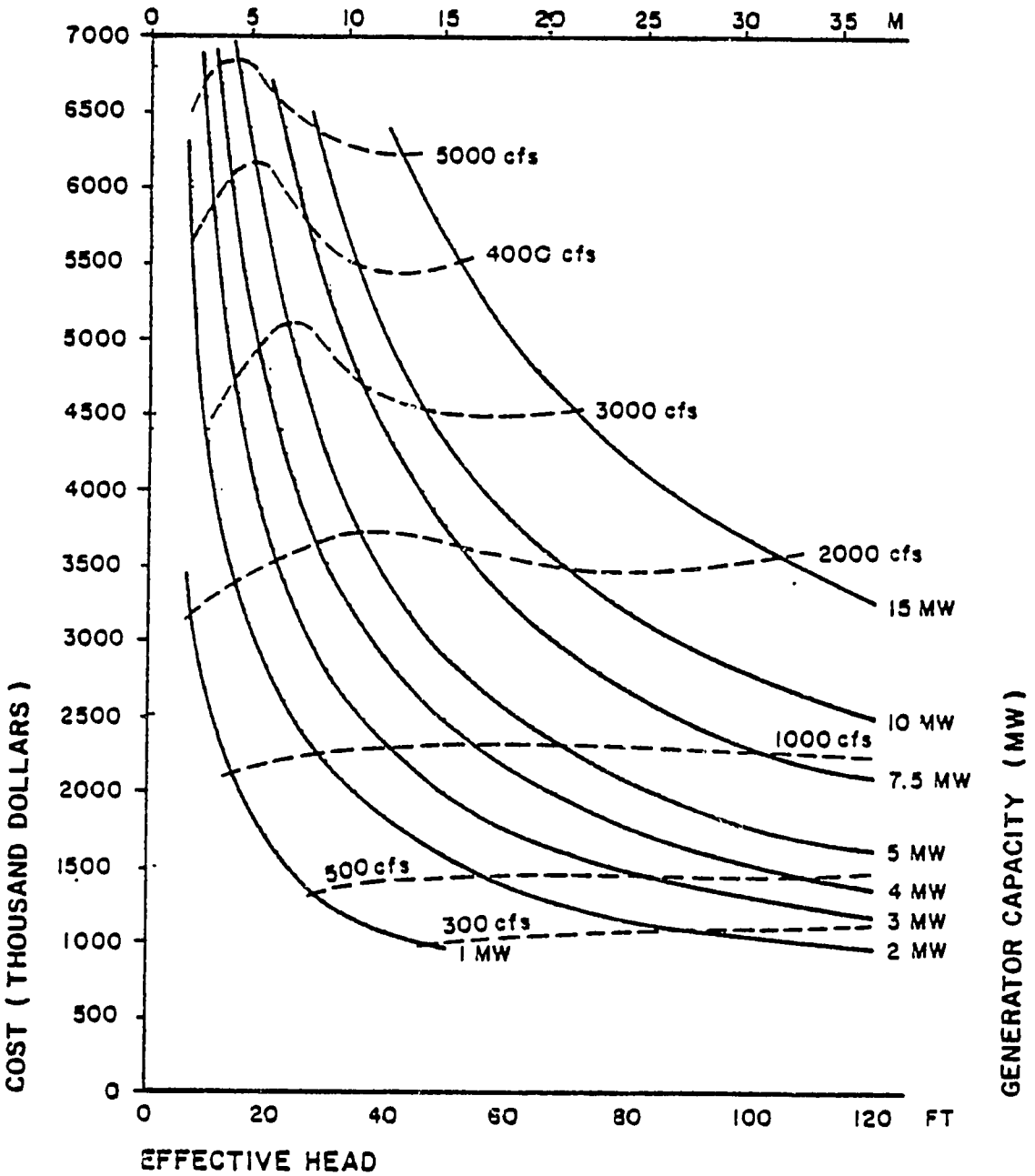


NOTES:

1. Date of costs is April 1979.
2. Excavation is assumed to be 50% rock and 50% common.
3. Tailrace transition excavation costs are included as part of the powerhouse costs. The tailrace length commences at the end of the transition.

Figure 4-16 Tailrace Excavation Costs

99



NOTES:

1. Date of Costs is April 1979.
2. Cost estimate includes turbine and generator, site civil works, powerhouse civil works, miscellaneous power plant equipment, accessory electrical equipment and turbine shut-off valve.
3. Costs are for a single unit power plant.
4. Turbine discharges shown are based on a turbine efficiency of 0.85.

Figure 4-10 Powerhouse and Equipment Costs - Vertical Propeller Units (Type A, B, C Projects)

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APPENDIX V

SAMPLE ECONOMIC CALCULATION

EXAMPLE OF ECONOMIC ANALYSIS

CASE 1

	HYDRO			DIESEL				COMPARISON		
YEAR	Capital 1. Cost	Recurring 2. Cost	Total	Capital 1. Cost	Recurring 2. Cost	Energy 3. Cost	Total	PW 4 Factor	Hydro PW	Diesel PW
0	225,600		225,600	44,000			44,000	1.0	225,600	44,000
1		3,400	3,400		4,000	42,000	46,000	.893	3,000	41,100
2						43,300	43,900	.797	2,700	35,000
3						44,600	48,600	.712	2,400	34,600
						45,900	49,900	.636	2,200	31,700
5						47,300	51,300	.567	1,900	29,100
6						48,700	52,700	.507	1,700	26,700
7						50,200	54,200	.452	1,500	24,500
8						51,700	55,700	.404	1,400	22,500
9						53,200	57,200	.361	1,200	20,000
10						54,800	58,800	.322	1,100	18,900
11						56,400	60,400	.287	1,000	17,300
12						58,100	62,100	.257	900	16,000
13						59,900	63,900	.229	800	14,000
14						61,700	65,700	.205	700	13,500
15						63,500	67,500	.183	600	12,400
16						65,400	69,400	.163	600	11,300
17						67,400	71,400	.146	500	10,400
18						69,400	73,400	.130	400	9,500
19						71,500	75,500	.116	400	8,800
20						73,600	77,600	.104	400	8,100
								TOTALS.....	251,000	456,600

EXAMPLE OF ECONOMIC ANALYSIS (CASE 1).....

1.- Capital cost for 200 KW plant.
Includes: 10% engineering and administration,
10% contingencies.

2.- Operation and Maintainence + interim replacements
1.28% of capital cost for Hydro,
4.5 % of capital cost for Diesel.

3.- Energy cost based on 600,000 KWH/year
Cost is escalated a 3%/year to reflect increasing fuel costs.

4.- Discount rate - 12%