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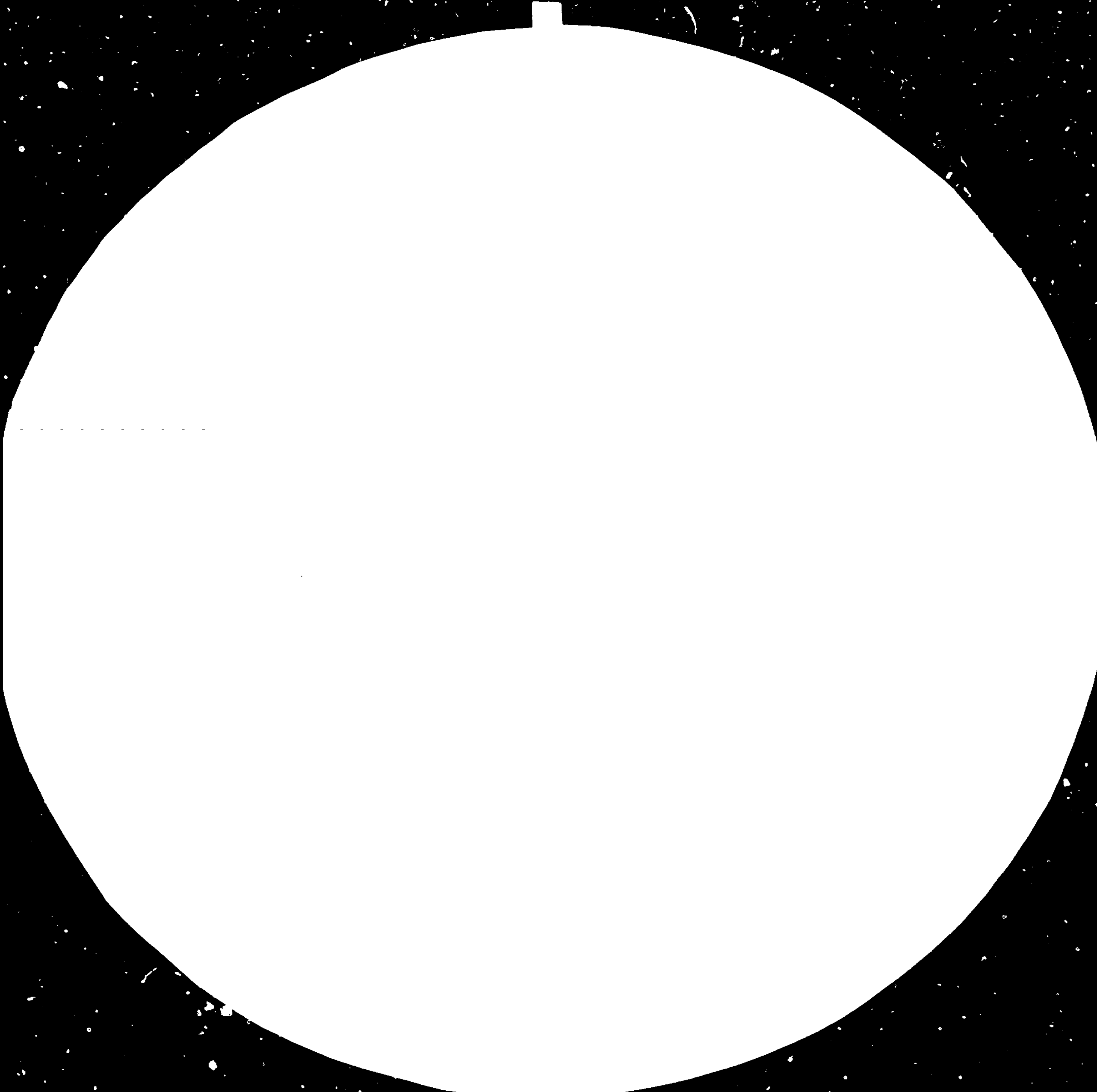

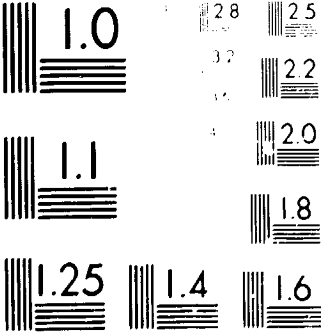

MICROCOPY RESOLUTION TEST CHART

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MINI-HYDROPOWER STATIONS
(A Manual for Decision Makers)

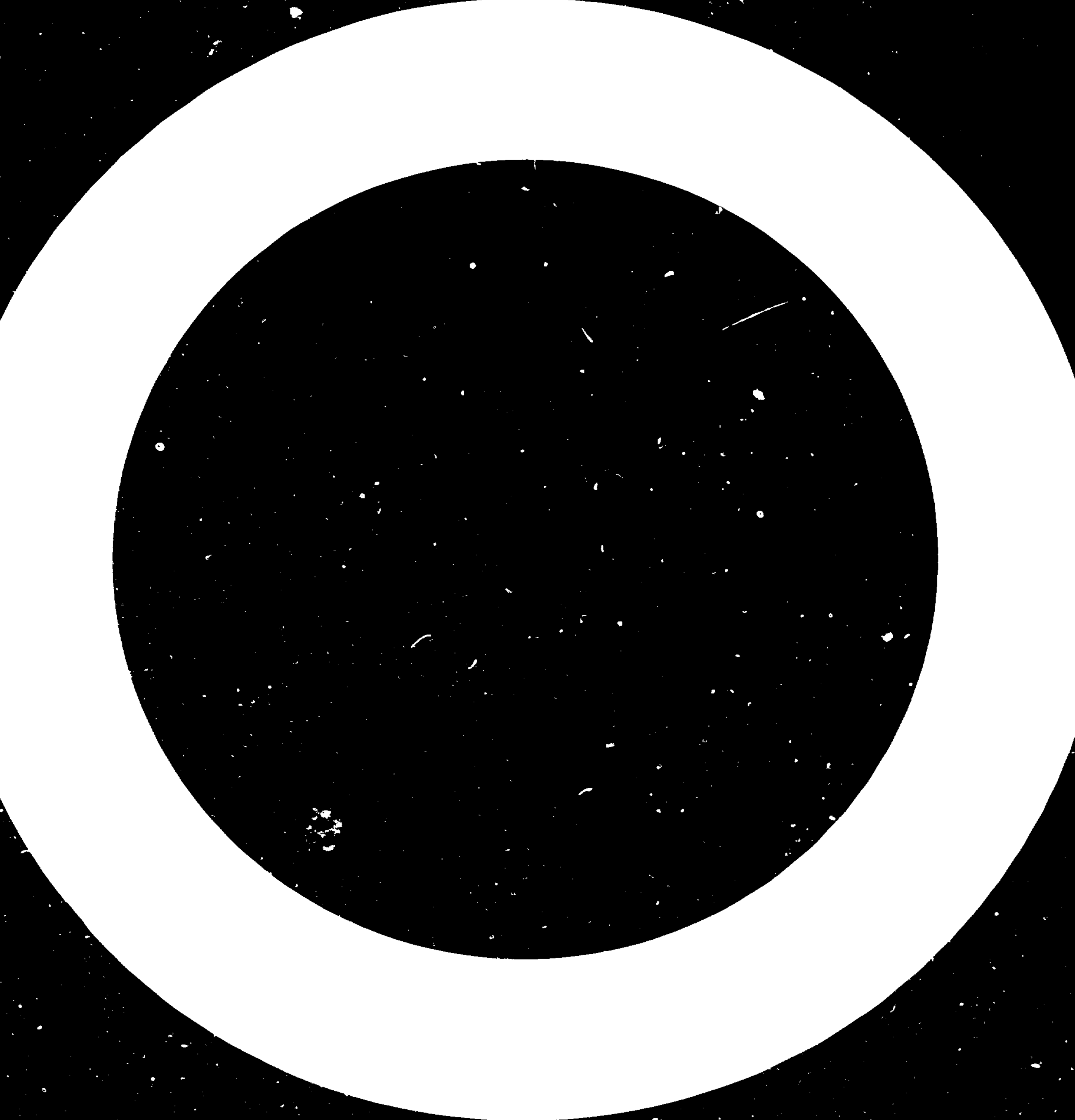
UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna

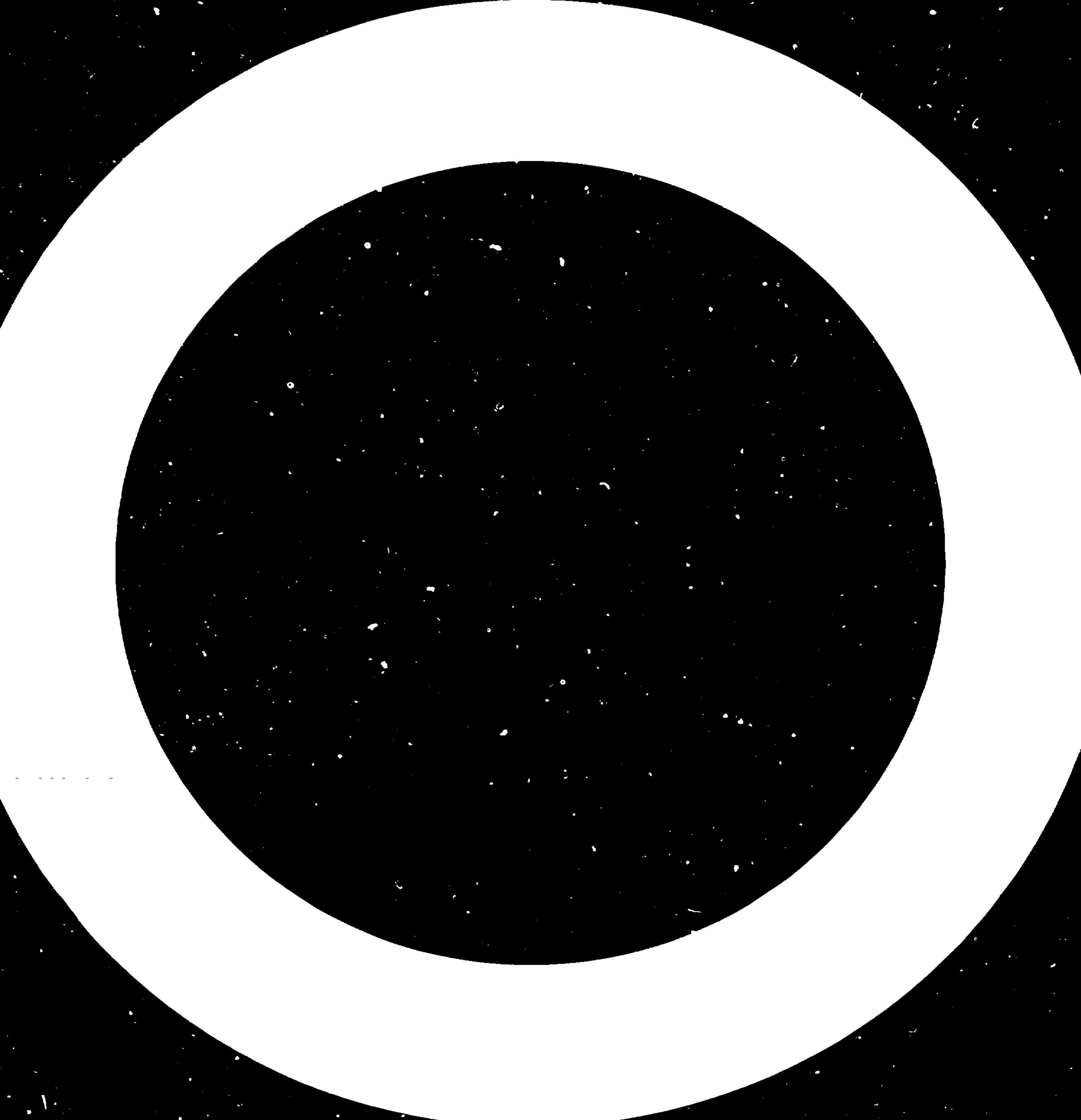
Small Hydropower Series No. 1

MINI-HYDROPOWER STATIONS
(A Manual for Decision Makers)

Prepared in co-operation with
the Latin American Energy Organization (OLADE)

UNITED NATIONS
New York, 1983





Preface

The development of new and renewable sources of energy has become a matter of priority in many countries all over the world. In particular, increased attention has been paid to the development of small-scale, mini- and micro-hydropower generation units which could, under certain circumstances, contribute to the industrial and economic development of rural and remote areas.

In places where limited hydropower is available, mini-hydropower generation (MHG) units offer a readily accessible source of renewable energy. They use proven technologies that in many cases need only adaptation, require limited investment and obviate excessive transmission costs.

As part of its programme of action on appropriate industrial technology, UNIDO has been actively involved in promotion of MHG development and application in developing countries. It has organized three projects related to the subject:

(a) Group study tour to China in the field of medium- and small-scale hydropower plants, 14 May-2 June 1979;

(b) Seminar-Workshop on the Exchange of Experiences and Technology Transfer on Mini Hydro Electric Generation Units, Kathmandu, Nepal, 10-14 September 1979;

(c) Second Seminar-Workshop/Study Tour in the Development and Application of Technology for Mini Hydropower Generation, 17 October-2 November 1980 at Hangzhou, China, and 3-8 November 1980 at Manila, Philippines.

The Seminar-Workshop held in Nepal recommended that UNIDO should encourage the preparation of manuals providing guidelines for the development of MHG units in developing countries.

As a first step, it was considered useful to prepare a manual on MHG for the guidance of decision-makers in this field at central or regional government level or at the planning and project implementation stages. The Manual is intended as a working tool to help in decision-making on the establishment of small and mini-hydropower stations and in the formulation of comprehensive and coherent policies and programmes for this purpose.

The preparation of the Manual was made possible through the financial support of the Swedish International Development Agency.

The Manual was prepared by the Latin American Energy Organization (OLADE) under the general leadership of G. Rodriguez Elizarraras, Executive Secretary of OLADE, through a group of its experts, including C. A. Hernandez, I. E. Machado and L. A. Suarez, with Enrique Indacochea, head of the Regional Programme on Small Hydropower Stations, as the technical co-ordinator. The Manual also benefited from inputs provided by Guo Ruizhang, Chief Engineer, Bureau of Water Conservancy, Shanghai, and Thovild Persson, VAST, Sweden.

It is hoped that the Manual will serve as a practical and useful reference for those involved in working in the field of mini-hydropower generation. It should, however, be considered as a first volume to be updated and expanded in the future to enhance its usefulness. Any constructive suggestions or proposals in this regard are welcome.

EXPLANATORY NOTES

References to dollars ($) are to United States dollars.

Besides the common abbreviations, symbols and terms, the following have been used:

EEG	extension of an existing grid
MHG	mini-hydropower generation
OLADE	Organización Latinoamericana de Energia (Latin American Energy Organization)
PVC	polyvinyl chloride

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Introduction

This Manual is intended to be a working tool for decision-makers at different levels. Since the main potential users of the Manual will not necessarily have a specialized engineering background, the technical elements have been restricted to descriptive aspects and elementary concepts, with more emphasis being given to questions of mini-hydropower generation (MHG) development, policy, planning and programming than to engineering, technology, the organization of institutions and training.

The Manual proposes specific approaches to MHG and, in some cases, alternative solutions to its problems. However, for every aspect of MHG development the optimum solutions may vary considerably from country to country as a result of differences in socio-economic systems, political organization, level of development, history and culture. The specific conditions of each country or region must therefore be taken into account when recommendations presented in the Manual are implemented.

The Manual comprises six chapters. The first two chapters contain general information, including the definition and classification of MHG units, the advantages and limitations of MHG in solving energy and industrial development problems in rural and remote areas and at the country level, and a comparison of MHG with alternative energy systems.

As regards the classification of MHG, it should be noted that at the time of writing there is no united and generally accepted classification of MHG units. Different organizations and countries have different approaches. Some of the systems of MHG classification are described in chapter I, including the system proposed at the UNIDO Seminar-Workshop on the Exchange of Experiences and Technology Transfer on Mini Hydro Electric Generation Units, held in September 1979 at Kathmandu, Nepal.

Chapter III presents an analysis and methodology of MHG development, including an assessment of possible applications and an evaluation of resources and demand, and providing decision-makers with useful information on the operation and maintenance of MHG units.

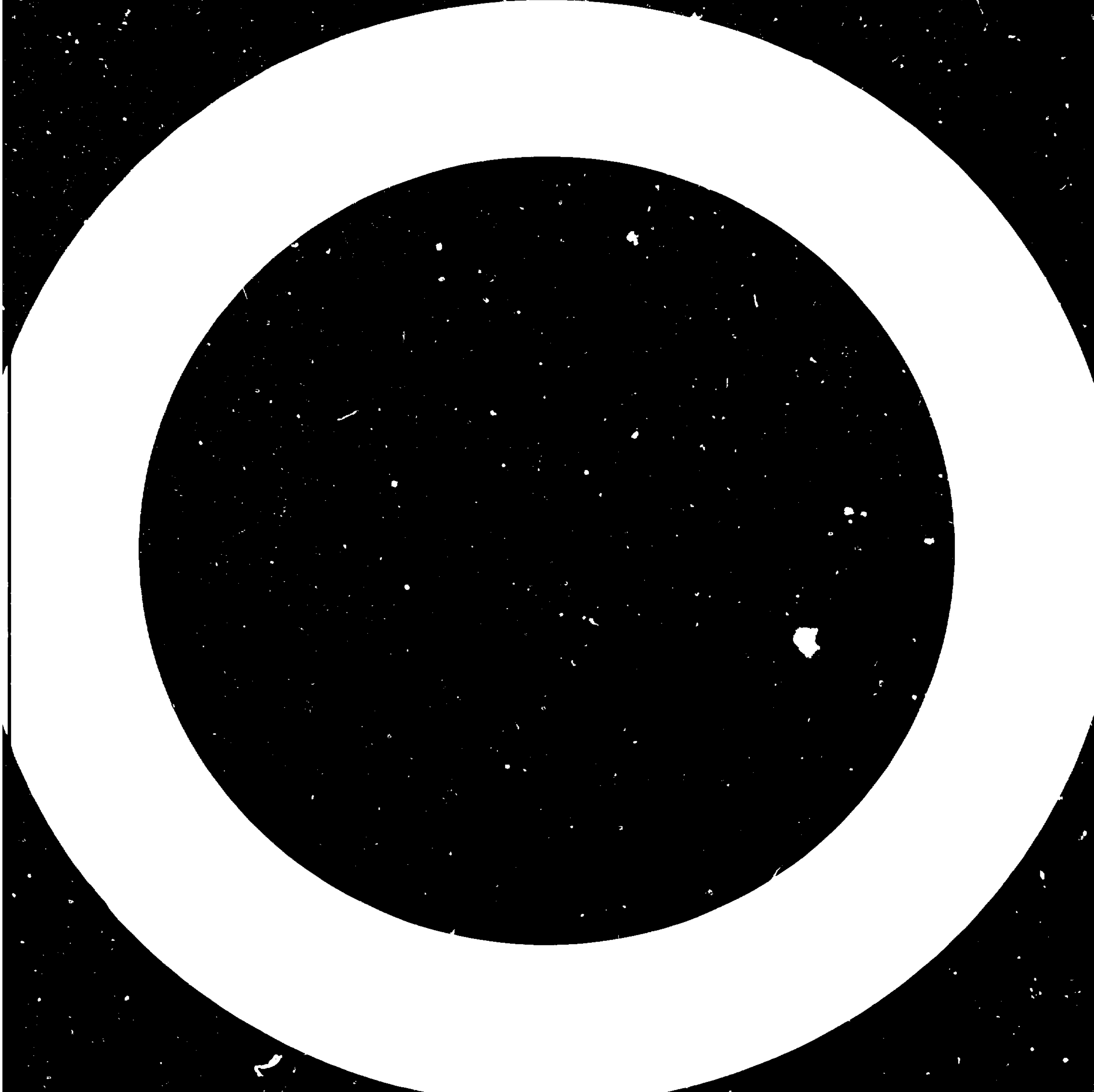
Chapters III and IV form the core of the Manual, suggest a methodology for considering the possibilities of MHG development, and identify a number of aspects which should be taken into account before a final decision is made.

Chapter V is addressed to those responsible for organizing and supervising projects and describes the development of specific MHG projects.

The annex contains basic MHG calculations which may be of interest to those who have engineering training.

Although the approaches to the problem and the recommendations made in the Manual apply mainly to MHG of less than 1,000 kW, they may also be relevant to the higher power ranges, provided that the limited application of some concepts, particularly in the technology field, are clearly borne in mind.

The Manual will have achieved one of its objectives if it succeeds in making it clear that a mini-hydropower station is more than just a small-scale model of a large hydroelectric plant.



I. Definition and classification

An MHG station is an installation where hydraulic power is used to generate small quantities of electricity by means of one or more turbine-generator units or groups. The main components of an MHG station are described below.

Main components of an MHG station

Description	
Dam	A structure built across the main watercourse in order to maintain or raise the level of the water. In MHG it is usually used to raise the water level and is of simple construction. *Materials:* concrete, earth, rock, wood, plastics
Intake works	A structure to facilitate the entry of water to the conduit system. It may or may not be submerged. For MHG it may be of permanent or artisan construction. *Materials:* concrete, masonry, rubble (artisan construction).
Conduit conduction system	The water is taken from the intake to the forebay by means of a canal or tunnel. For MHG, irrigation canals may be used. *Construction:* lined or unlined.
Forebay	Structure which facilitates the entry of the water to the penstock. *Materials:* concrete, lean-mix concrete, asbestos-cement, ferrocement.
Silt basin	A system for protecting the turbine by preventing solid particles from entering the penstock; may be installed as part of the intake works or the forebay, depending on flow, terrain and the material from which the channel is constructed.
Civil engineering accessories	Screens (for controlling solids), gates, spillways, etc.
Surge tank	A structure for compensating overpressure; not often used in MHG, depending on the head, length of penstock, velocity of water in the penstock, materials of which penstock is made and time needed to close the main valve; may form part of the forebay.
Penstock	Pressure pipe for conveying the water from the forebay to the turbine.
Powerhouse	Structure in which the generators and other electromechanical equipment are housed.
Tail-race	Structure which returns the water from the powerhouse either downstream of the river from which it was taken or to a neighbouring basin.
Turbine	A hydraulic motor that converts the energy of the water (head, or drop, and flow) into mechanical energy. *Types* Pelton: a free-jet impulse turbine used for high heads; low cost; Michell-Banki: cross-flow impulse turbine used for medium heads; low cost, low efficiency; Francis: reaction turbine (operates filled with water) used for medium heads; high cost, high efficiency; Axial: reaction turbine (variants: Kaplan with adjustable blades, fixed-blade propeller-type, tubular-type, bulb-type etc.) used for low heads. An alternative to the turbine would be the water wheel, which is low-cost but of low efficiency. It is slow and operates with small heads. Artisan construction is possible.
Speed regulator	A servo-mechanism which keeps the turbine revolving at a constant speed and consequently maintains the electrical energy generated at a constant frequency. *Types* Mechanical: almost never used; Oleo-mechanical: the standard type; Electro-electronic with flow regulation; Electro-electronic with energy dispersion; *Alternatives:* manual control.
Generator	An electrical machine that converts the mechanical energy into electrical energy;

	Types Alternator: synchronous generator, the most frequently used in MHG. Asynchronous generator: induction motor.
Transformer	Electrical equipment varying the voltage which enables energy to be transported over distances economically.
Electromechanical accessories	Main valve (gate or butterfly); turbine-generator transmission by direct coupling or by transmission systems (V-belt, chain or gears); hydraulic instrumentation (manometers); lightning conductors.
Transmission line	In MHG, low and medium voltages are used to transmit the electric energy from the plant to the point of consumption.

The amount of power (measured in kilowatts) that can be generated is equal to that available in the water after allowing for the losses of efficiency in each successive component of the MHG, and is proportional to the product of the net head and the flow, defined as follows:

Gross head: Difference in level from the upper surface of the water at the highest usable point to the lower level of its use by the turbine. Measurement: metres.

Net head: Equivalent to the gross head less the hydraulic losses in the different elements conveying the water to the turbine. Measurement: metres.

Flow: Quantity of water (volume) per unit of time. Unit: cubic metres per second.

MHG may be classified according to various criteria. A description of more than one system of criteria would be useful, not only because of the arbitrary elements that enter into every classification, but also because the specific characteristics and degree of development of each country may better be served by different classifications. Guidelines for the definition of criteria applicable to specific countries or regions are presented below:

1. Systems based on power and head are proposed in tables 1 and 2.

TABLE 1. CLASSIFICATION OF MHG STATIONS ACCORDING TO POWER CAPACITY

Country or organization	*Micro-hydropower generation (kW)*	*Mini-hydropower generation (kW)*	*Small hydropower generation (kW)*
China			
By unit			Up to 6 000
By installed capacity			Up to 12 000
Peru	5-50	51-500	501-5 000
Philippines			Up to 5 000
Romania			5-5 000
Sweden			100-1 500
Thailand		Up to 1 000	
Turkey	Up to 100	101-1 000	1 001-5 000
United States of America			Up to 20 000
UNIDO			
Kathmandu Seminar[a]	Up to 100	101-1 000	
Hangzhou-Manila Seminar[a]	Up to 100	101-2 000	2 001-10 000
Preparatory committee for the United Nations Conference on New and Renewable Sources of Energy (Panel on Hydropower)	Up to 1 000		1 001-10 000

[a] See preface

TABLE 2. MHG CLASSIFICATION SYSTEM PROPOSED BY OLADE FOR THE LATIN AMERICAN REGION AND THE CARIBBEAN

	Power range (kW)	*Head (metres)*		
		Low	*Medium*	*High*
Micro-hydropower stations	Up to 50	Less than 15	15-50	More than 50
Mini-hydropower stations	50-500	Less than 20	20-100	More than 100
Small hydropower stations	500-5 000	Less than 25	25-130	More than 130

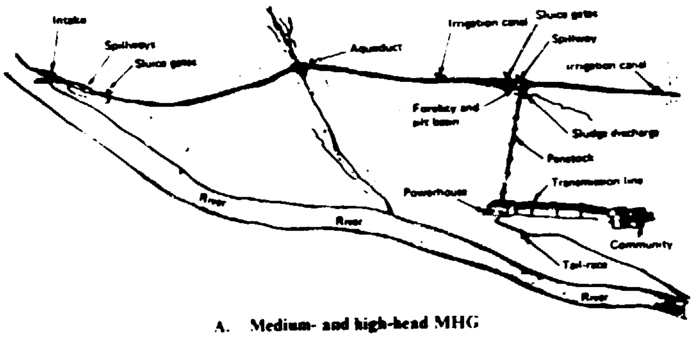
Notes: The low, medium and high heads correspond approximately to the employment of Axial, Francis or Michell-Banki, and Pelton turbines, respectively. Small hydroelectric power stations also include all plants with outputs of less than 5,000 kW.

The upper and lower head and output limits adopted for any classification are indicative only and should not be rigidly applied.

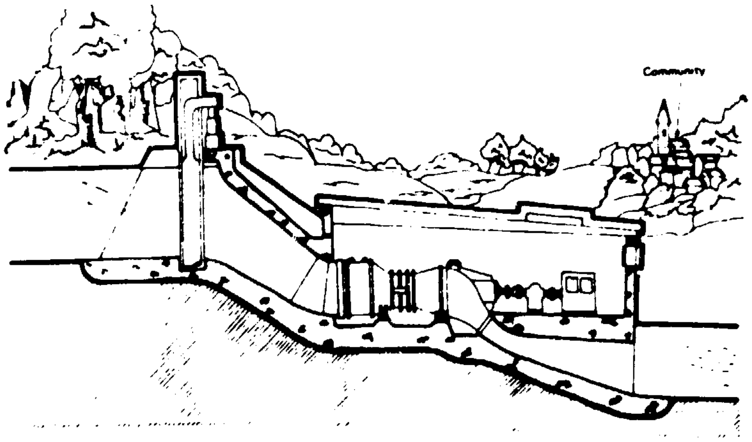
For very small outputs, generally less than 5 kW, and where the water resources and characteristics of the country justify it, the use of waterwheels, particularly for direct mechanical power, is also possible.

2. According to intake:
   Run of river (lateral intake from a main watercourse);
   With reservoir or dam.
3. According to its regulation:
   Adjustable flow (control of the flow at the turbine intake), which may be either manual or automatic;
   Constant load, whether because of the actual nature of the load or through dissipation of the excess energy.
4. According to its links to the grid:
   Isolated plants;
   Plants connected to small electrical grids;
   Plants connected to major zonal or national networks.
5. According to technological concept:
   Plants using conventional technology. This implies quality civil engineering works for the intake, canal and forebays; silt basin at the intake, steel piping, expensive electro-mechanical equipment constructed to strict material and manufacturing criteria, and fully instrumented switchboards;
   Plants using non-conventional technology. They often use intakes from existing irrigation canals which are improved, the forebay installed in line on the canal and incorporating the silt basin, electro-mechanical equipment designed and constructed with technologies appropriate to the level of industrial development of the country and the availability of local materials, standardized equipment, and modular switchboards with minimum instrumentation.

Examples of the layout and main components of MHG stations are illustrated in figures 1-7.

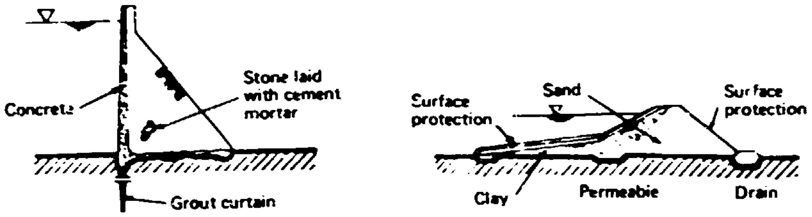


A. Medium- and high-head MHG



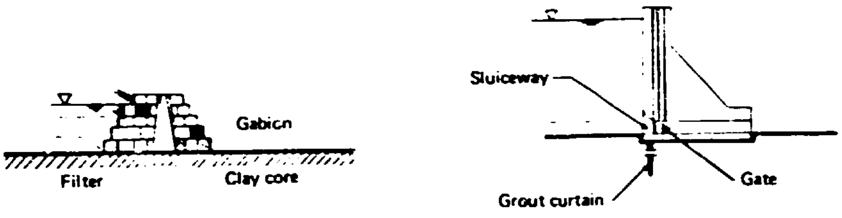
B. Low-head MHG

Figure 1. Schematic diagrams of mini-hydropower stations



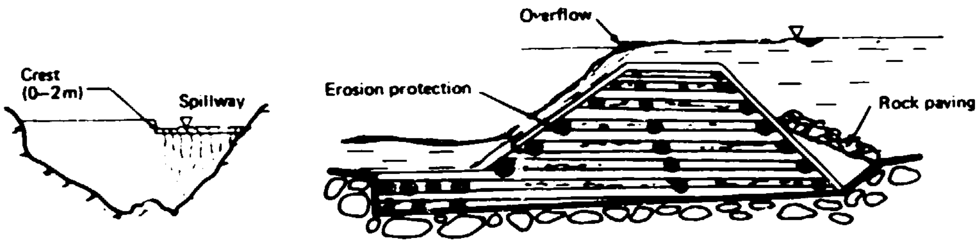
A. Stone dam with cement fill

B. Sloping clay dam



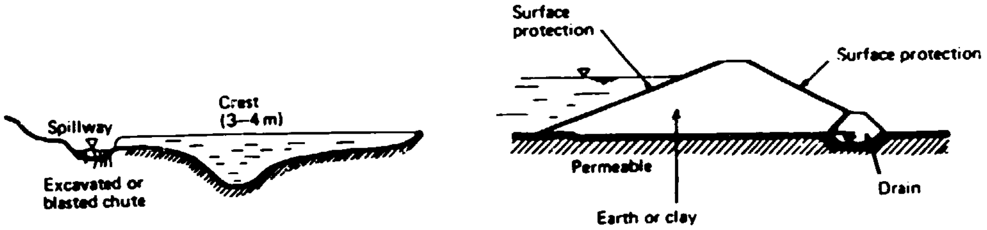
C. Gabion dam

D. Concrete dam



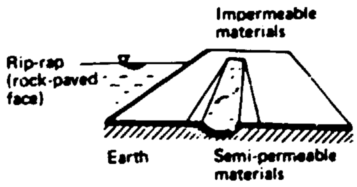
E. Concrete dam

F. Rock-paved wooden dam



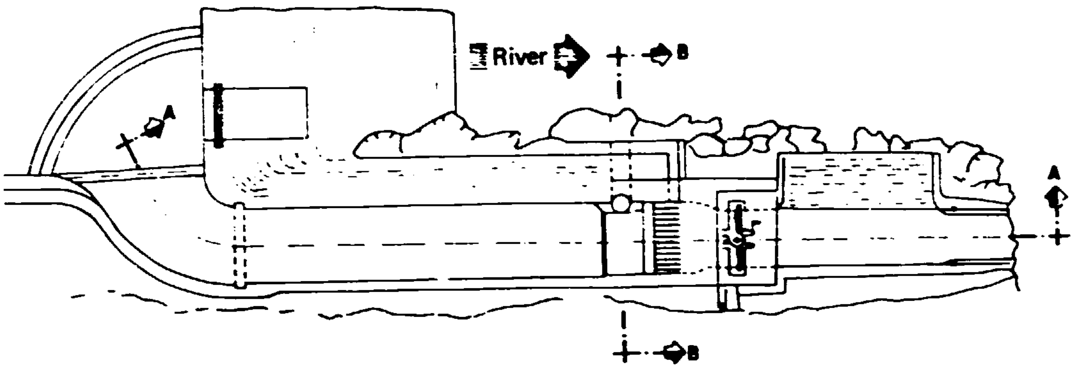
G. Earth dam

H. Homogeneous earth dam

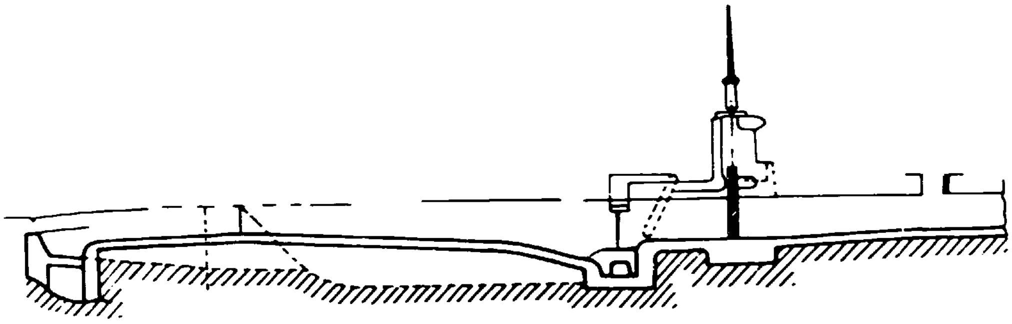


I. Earth dam

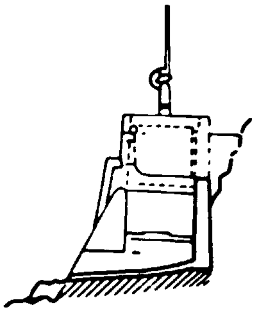
Figure 2. Dams



A. Plan

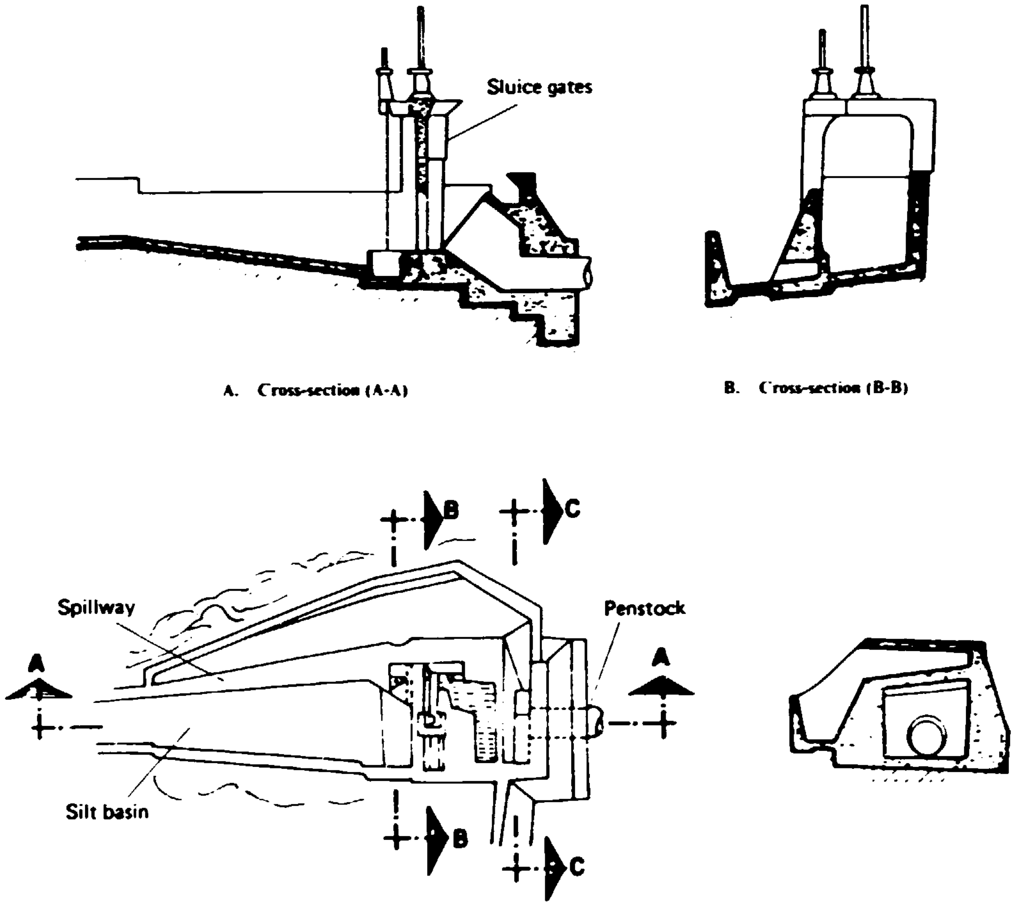


B. Cross-section (A-A)



C. Cross-section (B-B)

Figure 3. General diagram of intake



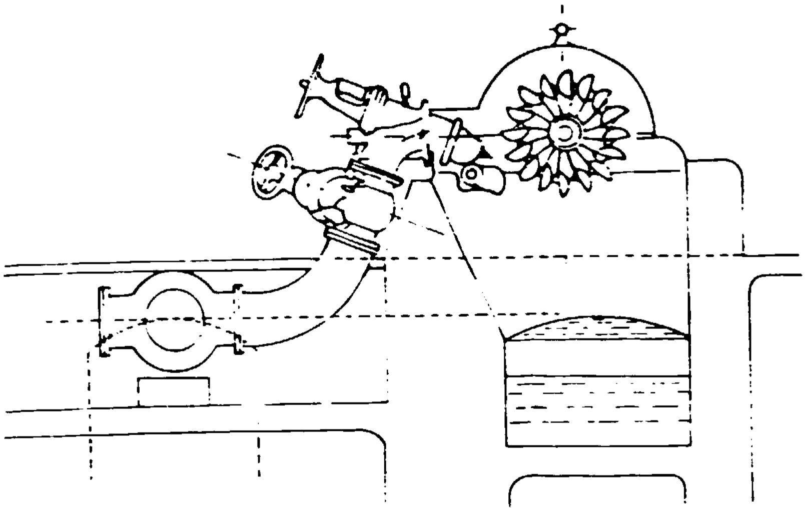
A. Cross-section (A-A)

B. Cross-section (B-B)

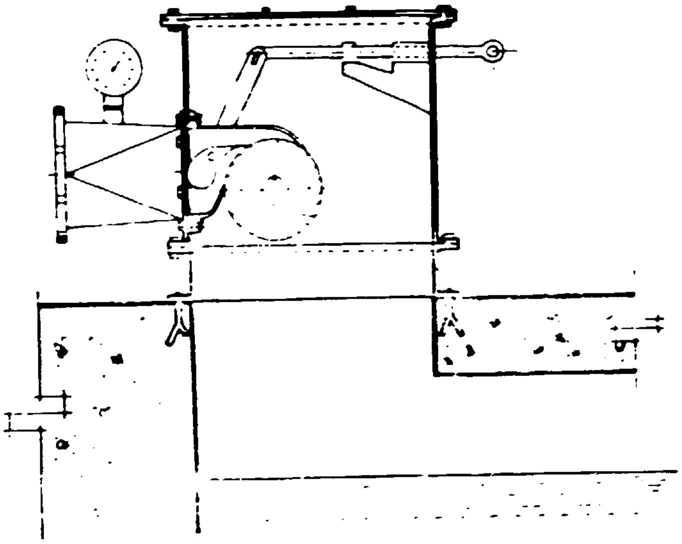
C. Plan

D. Cross-section (C-C)

Figure 4. General diagram of a typical forebay

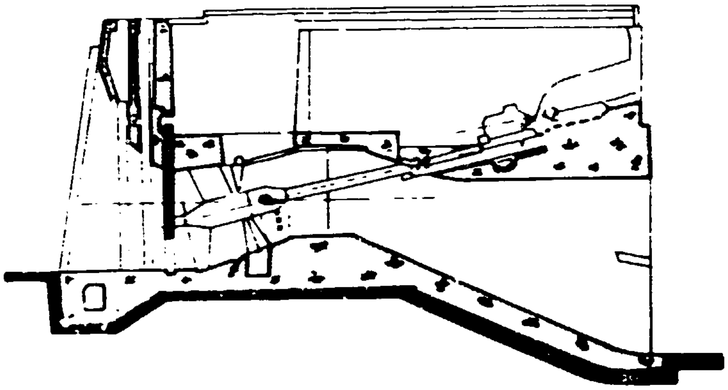


A. **Pelton turbine**

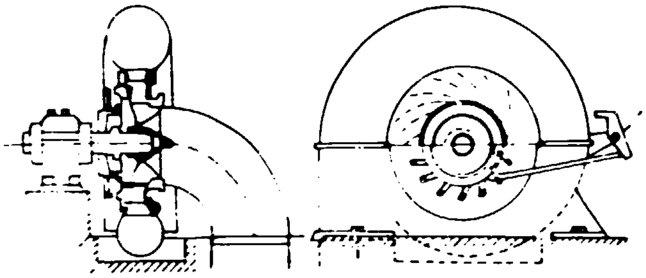


B. **Michell-Banki turbine**

Figure 5. Impulse turbine

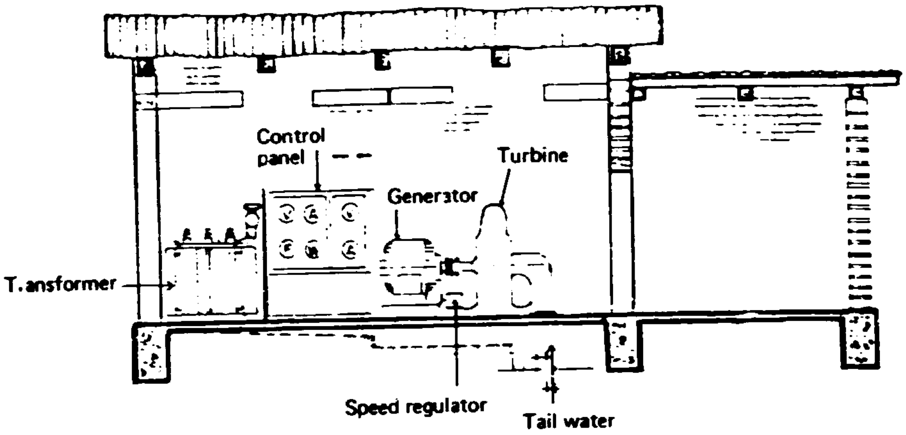


A. Kaplan turbine

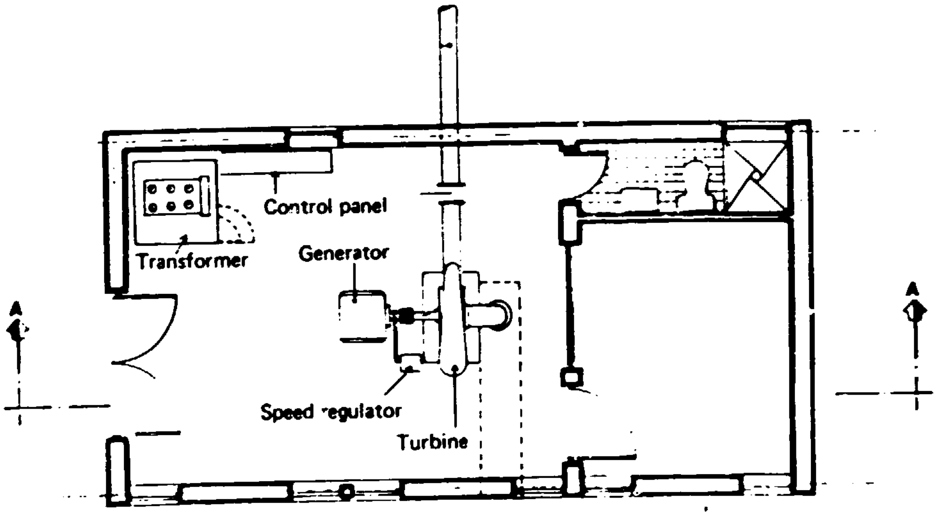


B. Francis turbine

Figure 6. Reaction turbine



A. Cross-section (A-A)



B. Plan

Figure 7. Typical powerhouse

II. Mini-hydropower generation

A. Advantages and limitations

One of the main aims of any policy for developing MHG units as sources of energy is to make the most of their specific advantages and to overcome their limitations. Some of the important points to be borne in mind are given below.

Advantages of MHG

- Solution to problems of growth and difficulties in the supply of fuel, particularly in rural and isolated areas;
- Helps to promote socio-economic and cultural development in the rural environment;
- Technologies available that only require adaptation to specific conditions in order to reduce costs;
- Low operating costs;
- Cheap and simple maintenance;
- Long service life;
- Little or no environmental impact; better control of the hydraulic system;
- Can be compatible with use of the water for other purposes (irrigation, drinking water etc.) thereby improving investment.

Limitations of MHG

- High unit investment cost per installed kW;
- High cost of studies in relation to overall investments;
- Utilization dependent upon the availability of hydraulic resources near the points of demand;
- It is necessary to solve possible contradictions in the priorities of water use, particularly for irrigation;
- Power production may be affected by meteorological and seasonal conditions;
- Continuity of operation depends on the technological characteristics of the installations, on an adequate economic and productive basis for the use of the power generated, and on adequate institutional arrangements for administration, operation and maintenance.

The specific advantages of MHG open up enormous possibilities of application. Their disadvantages may be grouped under two fundamental problems: the investment required per installed kW and the prospects for the continued operation of the plants installed. Figure 8 shows in schematic form the causes of these problems and outlines some of the solutions which may be considered when drawing up development policies.

B. Comparison with alternative systems

The aim of this chapter is not to determine the absolute advantages of one or other power system, but rather to establish in qualitative form, without proposing methodologies for quantitative analysis, the main elements and criteria for comparing the alternatives.

Often, when making comparative analyses of MHG and other alternative systems, certain disadvantages, real or supposed, of the MHG are assumed *a priori* and the economic evaluations of alternatives are frequently distorted by over-conservative indices.

It is not claimed that MHG is the best solution, only that there are appropriate solutions for each case, which are determined by making a comparative analysis of the various alternatives.

Extension of an existing grid

The question of whether to install an MHG or an extension of an existing grid (EEG) is mainly one of economic comparison, particularly as regards the investment required. Some of the elements which must be taken into consideration in such a comparative analysis are presented below.

Mini-hydropower generation

Civil works

Intake, conduction system, forebay, penstock, powerhouse, accessories etc.

Electro-mechanical equipment

Turbine, regulator, generator, switchboard etc.

Transforming

To medium tension; not always necessary (transformer).

Transmission and distribution line

From the machine room to the point of consumption; small distance (low or medium tension, voltage reduction for distribution and consumption).

Extension of an existing grid

Civil works

Substation, switching area.

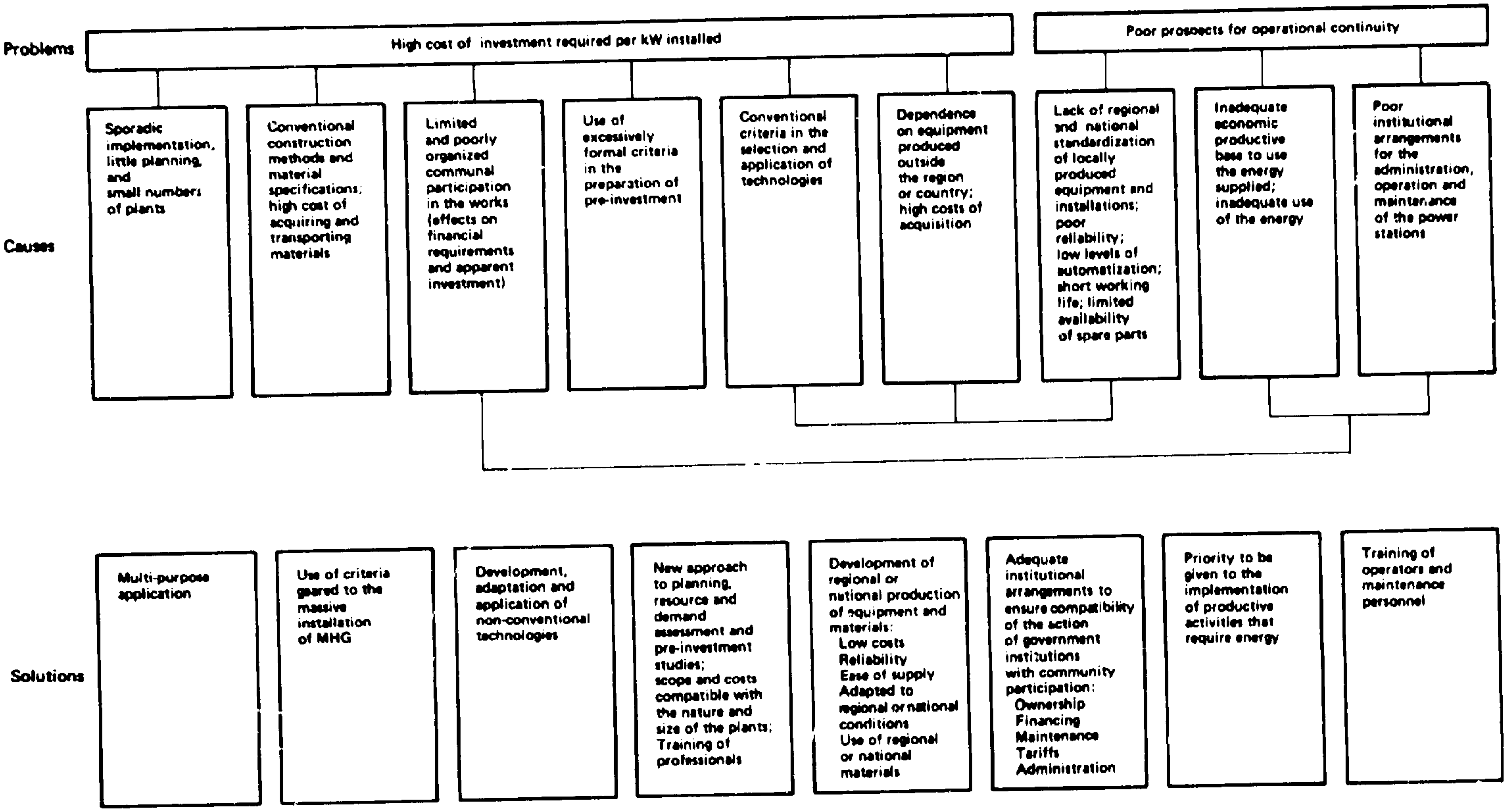


Figure 8. MHG development problems and possible solutions

Transforming

From high to medium tension (transformers, switchboard etc.).

Transmission and distribution line

Medium tension from the substation to the point of consumption, voltage reduction for distribution and consumption.

The greater or lesser importance or magnitude of a given parameter determines the comparative advantages of installing MHG or extending an existing network, as reflected in table 3.

TABLE 3. COMPARATIVE ADVANTAGES OF MHG AND EEG

	Comparative advantage	
Parameter	*Greater importance or magnitude of parameter*	*Lesser importance or magnitude of parameter*
Distance from point of consumption to existing network	MHG	EEG
Distance from point of consumption to site of power station	EEG	MHG
Power capacity required	EEG	MHG
Load factor	MHG	EEG
Reliability of supply	EEG	MHG
Uneven terrain	MHG	EEG
Availability of small-scale economically harnessable hydropower resources	MHG	EEG
Availability of energy	EEG	MHG
Prospects of community participation	MHG	EEG

Combining MHG and EEG

It is possible to combine MHG and EEG in cases such as the following:

(*a*) In countries with abundant small-scale hydraulic resources, densely populated and highly electrified;

(*b*) Possibility of using irrigation and water control dams for power generation if placed near the grid, where demand for electricity is small;

(*c*) In countries over-dependent on imported fossil fuels for generating electricity and with abundant small-scale hydropower resources;

(*d*) Progressive development of electrification in several rural localities, beginning with the installation of an MHG unit and later supplemented by EEG when justified by the growth in demand.

Thermal units

Diesel engines or, for smaller needs, gasoline engines (Otto cycle) are generally used for generating electricity. They were traditionally the main alternative to MHG and their very widespread use was because of the low cost of acquisition and of fuel and lubricants, ease of installation and simplicity of operation.

With the ending of power systems based on the low cost of hydrocarbons, such units in many cases cease to be a valid alternative way of providing power in rural areas. Small-scale steam-power stations operating with the Rankine cycle can be employed to generate electricity, frequently utilizing waste combustible materials or even coal when it is easily available and cheap.

The advantages and disadvantages of thermal units as compared with MHG may be thus summarized:

Advantages	*Disadvantages*
Smaller investments;	High and increasing cost of fuels and lubricants;
Ease of installation;	Expensive to maintain and repair;
Simplicity of operation;	Need more highly skilled maintenance and repair staff;
Fewer studies needed for their installation.	Require imported and difficult-to-obtain spare parts;
	Little prospect of developing local production of motors;
	Short service life (5-8 years);
	Contribute to environmental pollution;
	Help to increase demand for oil.

Economic comparisons of the two alternatives, thermal units or MHG, are frequently distorted by the fact that in some countries the prices of oil and its derivatives are subsidized. In such cases the micro-economic analysis must be corrected by macro-economic factors derived from the true cost of the fuels.

At the present time the main cases in which the employment of small thermal units is appropriate are the following: as emergency or reserve units; and in isolated areas where there are no easily harnessable hydraulic resources and the extension of transmission lines is not justified.

Other renewable sources of energy

The various renewable sources of energy offer valid alternative energy supplies for rural development. However, in most cases they are not substitutes for MHG, either because of the terminal form of the energy supplies (direct mechanical energy or source of heat) or, even if they can produce electric power, economic only for very small power loads.

The advantages of MHG over other renewable sources of energy may be summarized as follows: easy adaptation for producing electric power; lower unit costs of investment per unit of useful energy; and its mature and proven technology.

With regard to the specific characteristics of the main alternative sources of energy, the following points should be noted.

Direct solar energy

The main field of application of direct solar energy in the countries of the third world is heating and drying. Its passive use in environmental heating through appropriate architectural design is also particularly important.

Solar energy can be harnessed for the direct production of electricity through the use of thermal units operating with the Rankine steam cycle, which involve very high initial investment costs and very low efficiency. Photovoltaic cells are also used for the direct conversion of solar radiation into electrical energy, but in the third world their utilization is only justified for the production of energy needed in small quantities and for highly specialized applications, because they are not yet a cheap source of energy.

Wind power

Although wind power is mainly used for pumping water from the sub-soil, it has many other applications as well, and there is even a commercial production of windmills for the generation of electricity. In general they provide an alternative to MHG for the power range under 10 kW.

Bioenergy

Biogas production has great advantages, not only as a source of energy but also because of its capacity for the production of fertilizers and its positive impact on health and the environment. Its main uses as a source of power are in the form of heat for lighting, cooking etc. It can also be used to fuel properly adapted combustion engines, for which it is competitive with MHG in the lower power ranges. The process of pyrolysis and the use of alcohol can also be interesting sources of bioenergy for the operation of small thermal units.

Geothermal energy

Geothermal energy can also be employed to generate electricity. Although it is most frequently applied in medium or large power stations, geothermal energy may also be used for small units.

III. Development of MHG

A. Possibilities of application

Before undertaking specific projects to promote the development of MHG in a given country, it is necessary to determine the nature and magnitude of the problems to be solved by using MHG, to ascertain the existence of small-scale hydraulic resources, and to carry out an overall assessment of national capacities. Compliance with these requirements will involve an analysis of the factors outlined below.

Problems to be solved by MHG	*Elements for analysis*
To provide energy for the rural environment, including small industries development	Orders of magnitude of the problem; Alternatives; For what purpose: To improve living conditions To develop farm industry To develop small industries (fertilizers, sawmills etc.) For mining development To develop handicrafts For irrigation and drainage by pumping Education and culture Health.
Replacing hydrocarbons	Use of thermal power stations and of petroleum derivatives for cooking, lighting or heating; Production and import of hydrocarbons, orders of magnitude, prospects and limitations in replacing them; Transporting hydrocarbons to rural areas; Implications of using thermal equipment (cost, useful life, supplying fuel, maintenance and repairs); Erosion of soil; Hydraulic control; Deforestation; Pollution

Ascertaining the existence of small-scale hydropower potential	*Elements for analysis*
Availability of hydropower resources	Qualitative assessment of: Precipitations and hydrology (flow); Terrain (heads); Geological and qualitative geomorphological characteristics of the territory; Estimate (if possible) of the order of magnitude of the potential; Area or regional conditions.
Location of hydro-resources in relation to demand	It should be borne in mind that for isolated MHG units or those which are a part of small grids, use of hydropower should be close to the location of demand. Potential should be estimated in areas which are close to the demand, except for MHG units which are interconnected with larger grids.
Accessibility of available resources	Communication; Geographic accidents; Climate; Healthiness.
Possibilities of multiple use	Irrigations, use of existing water courses; Use of existing dams; Multiple projects (irrigation and energy).

Maximum utilization of national capacities for developing MHG	*Elements for analysis*
Planning	Organization, experience.
Overall evaluation of resources and demands	Institutions, studies which have been carried out, organization.
Preparation of pre-investment studies	Institutions, advisers able to prepare projects and develop engineering experience.
Financing	Availability, financial institutions, external sources.

Institutional organization	Electrical enterprises and their activities in rural areas; Municipal and co-operative enterprises; Private producers, communal participation.
Construction	Experience, small contractors, contracting firms, enterprises, materials.
Operation and maintenance	Organization of operation and maintenance.
Human resources	Availability at all levels
Technology	Availability, capacities for development and adaptation, information; Experience in acquiring technologies.
Supplying equipment	Existing or potential production, imports, information.

B. Organization of planning and programming

Once it has been decided to develop MHG in a country, it is necessary to define:

(a) The responsible government sector (ministry, government secretariat or institution etc.), which will in general be found within the scope of the ministry or government secretariat responsible for energy affairs;

(b) The body responsible for planning, directing and co-ordinating the development of MHG, which may be the central planning body, the planning office of the competent ministry or government secretariat, or the planning department of an enterprise or institute responsible for energy development.

Within the body responsible for planning, a unit or section should be established which will be specifically in charge of developing MHG separate from the unit or section dealing with larger hydropower sources. The functions of MHG sections or units could include the following:

(a) Proposing development policies and strategy;

(b) Formulating development plans;

(c) Formulating periodic programmes for implementation (studies on civil engineering works and financing);

(d) Co-ordinating and supervising the units responsible for the programmes for evaluating resources and demand, carrying out civil construction works, and plant operations;

(e) Acting as an advisory body for MHG development;

(f) Co-ordination with institutions and enterprises responsible for financing, technological development, production of equipment and training;

(g) Defining tariffs or the criteria for establishing them.

After analysing energy needs, the availability of hydropower resources and the national capacities, a policy decision must be taken as to whether the implementation of MHG should be encouraged or not, in which connection the following should be borne in mind:

(a) The decision should rely on such information as is available and not wait for the preparation of *ad hoc* studies. It should therefore be based on fundamentally qualitative elements and on very approximate quantitative elements. Together with the process of planning the development programme and any possible corrections of the policy which has been adopted;

(b) There may be territorial distinctions within a country concerning the development of MHG, depending on the availability of hydraulic resources and the energy needs which have to be met;

(c) The policy decision should be taken with due regard for the time and context of development priorities in relation to other energy sources;

(d) A policy for the development of MHG is dependent on such factors as the availability of hydraulic resources and energy needs. National capacities are factors which can facilitate or impede the development of MHG in a country, but they are not absolute factors, since they can be changed;

(e) The development of MHG calls for integrated action on various fronts, as reflected in figure 9;

(f) The policy decision to develop MHG should be the basis for the formulation of a strategy of development and specific policies, the elements of which are analysed in the next part of this chapter.

The compulsory or indicative character of the plan will depend on the socio-economic system of the country, its political organization and on whether there is a greater or lesser participation of the public or the private sector in the various parts of the implementation of the plan.

The diagram of relations in figure 10, which is drawn from the overall diagram in figure 9,

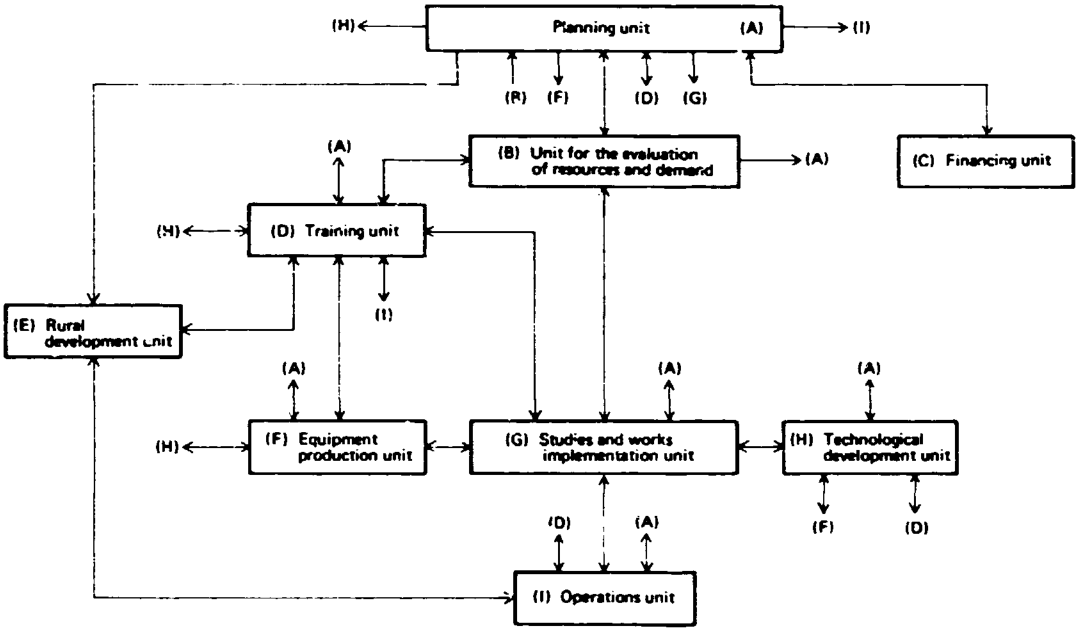
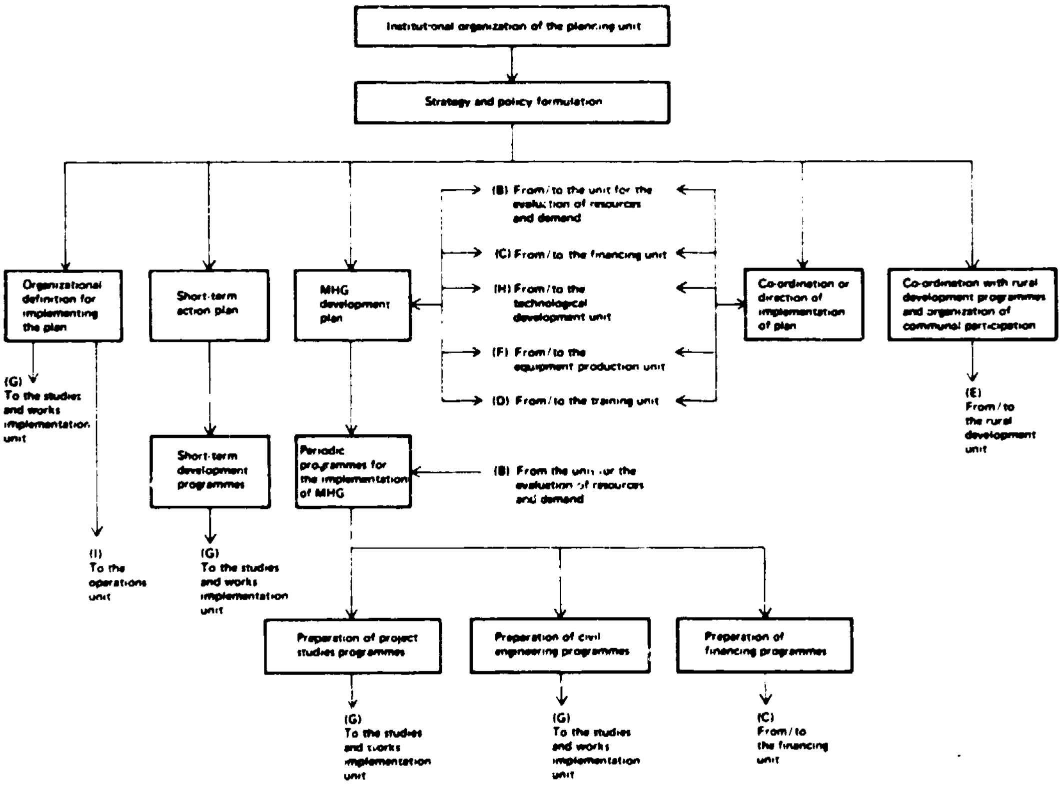


Figure 9. Basic interrelationship of various units required for the development of MHG



Note: Letters within parentheses refer to units covered in figure 9.

Figure 10. Planning unit for the development of MHG

shows the process of planning the development of MHG. The unit in charge of planning should be able to perform the following functions as complementary activities:

(a) Keeping records of localities without electricity and a catalogue of suitable hydraulic resources, prepared by the body responsible for evaluating resources and demand;

(b) Considering requests for financing and actions taken by the local population and deciding whether they can be incorporated in the implementation programmes;

(c) General negotiations concerning the large-scale purchase of equipment;

(d) Co-ordination with communal institutions and organizations which can promote the development of MHG in their localities;

(e) Suggesting needs for technological development to the competent institutions and evaluating the use of non-conventional technologies;

(f) Suggesting institutional schemes for the construction and operation of MHG;

(g) Co-ordinating international technical co-operation.

In a country where systematic projects to develop MHG are being undertaken, the first requirement is to prepare a short-term plan, for carrying out certain concrete projects, and a development plan. The latter will require studies on the evaluation of energy needs, the availability of resources and the establishment of priorities, and should also promote activities in various fields connected with technology, the production of equipment, training and financing.

On the basis of the short-term plan, a one- or two-year implementation programme should be drawn up, taking into account the following factors:

(a) Termination of uncompleted works;

(b) Abandoned works (power stations where civil engineering work has begun, where equipment has been acquired but not yet installed etc.);

(c) Relocation of existing equipment in abandoned plants;

(d) Identified needs (new projects or projects under study);

(e) Existence of civil engineering works which may reduce costs (irrigation canals, dams etc.) and shorten times for implementation;

(f) Intallation of pilot plants to evaluate technological alternatives and capacities for implementation.

The establishment of a short-term plan and its related programmes offers the following advantages:

(a) It makes it possible to initiate MHG development projects without involving any delay because of the need to prepare a coherent, overall plan; on the other hand, it provides sufficient time for drawing up the development plan;

(b) It results in the acquisition of experience which can be used for the development plan;

(c) It creates conditions for the development of mature projects;

(d) It helps to demonstrate the processes of MHG;

(e) It stimulates the development of communal self-help projects.

Simultaneously with the preparation and implementation of the short-term plan and its related programmes, the planning unit should begin to prepare the MHG development plan, which requires the following series of preliminary studies and evaluations to serve as the objective basis of the plan:

(a) Identification of populated and isolated centres and microregions which are in need of energy development, study entrusted to, or contracted with, the unit for the evaluation of resources and demand;

(b) Evaluation of resources in hydrographic basins and watersheds (first approximation) and approximate evaluation of potentially exploitable resources in areas close to isolated population centres and microregions (second approximation), studies entrusted to the unit for the evaluation of resources and demand or to outside contractors;

(c) Inventory of existing MHGs, evaluation of their condition and operational situation;

(d) Estimate of potential financial resources;

(e) Evaluation of available technology and prospects for its development, adaptation or acquisition;

(f) Evaluation of potential for supplying equipment and materials of either national or imported origin, and of potential industrial capacities for equipment manufacturing;

(g) Evaluation of the available experts for studies and engineering;

(h) Summary of investment and operating cost indices;

(i) Evaluation of the institutional situation and of the experts available for the construction and operation of MHG stations; possibilities of communal participation.

The plan must likewise take due account of specific policies which can provide the framework for a development strategy. Various policy suggestions and some of their possible components, which will have to be adapted to the conditions of each country, are presented below. The functioning of the planning unit has been illustrated in figure 10.

Policy of rural energy development	Increase in added value of production by means of establishing rural industries; Development of energy-producing activities; Improving living conditions; Health, culture, recreation; Pumping water; Multi-purpose use of dams; Development of small rural electricity grids; Interconnection of MHG with national networks or development of isolated localities.
Institutional policy	Position in the context of rural development; Participation of electrification bodies or enterprises and communal participation; organizational and entrepreneurial forms; (mixed municipal enterprises, private co-operatives); Distribution of institutional responsibilities among the various activities of MHG development.
Construction policy	Gradual implementation aimed at the future large-scale construction of MHG stations; Intensive use of local materials and labour; Use of non-conventional construction techniques and material.
Financing policy	Basic proportions of resources to be assigned to MHG; Financing criteria: non-recoverable investments and operation financed by tariffs; Evaluation of communal contributions of labour and materials; Ways of obtaining external financing.
Equipment policy	Origin of supplies; priority for national supplies; Promoting the development of domestic production; Adapting project engineering work to national supplies of equipment and materials; Quality and criteria for acceptance; prospects for standardization; Determining equipment components to be obtained from domestic industrial production and to be imported.
Technology policy	Promoting the development and adaptation of technologies relating to equipment and materials; Determining channels for transferring developed technology to industry; Promoting the development of non-conventional construction technologies; Determining channels for distributing construction technologies to project units and communities; Determining what equipment will be developed with local technologies and what will require acquisition of foreign technologies; Determining what conditions are unacceptable for contracts for the acquisition of technology.
Tariff policy	Making energy available to the inhabitants of remote areas with few economic resources; Ensuring the operational continuity of MHG through funds derived from tariffs; Basic proportionality of national tariff systems; subsidies; Promoting the national use of electric energy; Promoting the use of electric energy for production purposes.
Training policy	Training professional and technical cadres for research, project studies and engineering, construction and operation of MHG stations.
Operation and maintenance policy	Selection of equipment technology must take into account its useful life, the need for simplified preventive maintenance and minimum maintenance requirements, ease of maintenance and repairs, domestic manufacturing of components, stocks of spare parts; Organizing regional maintenance squads; Training operators of rural origin in preventive maintenance; Establishing shop facilities for repairs and reconstruction of equipment; Promoting the participation of the local population in the maintenance of infrastructure.

C. Overall evaluation of resources and demand

The overall evaluation of resources and demand is one of the principal elements to consider when promoting the construction of MHG in a country, since it is the main frame of reference for drawing up development plans and implementation programmes. In this connection, the following general considerations should be borne in mind:

(a) The overall evaluations deal with demand and resources for microregions and basins and not with specific projects;

(b) When considering the development of MHG in microregions or isolated localities, it

must not be forgotten that the overall evaluation of demand and resources for energy are closely connected in geographic terms, because of the limitations of the distance over which low- and medium-tension current can be transmitted;

(c) When attempting to connect MHG stations to existing networks, a geographical link should be established between the area where the hydraulic resources are located and the transmission lines to which the stations are to be connected.

It is very important to distinguish between the overall evaluation of resources and demand and evaluations made for specific projects.

Distinctions between overall evaluation and evaluations for specific projects

Overall evaluation	*Specific evaluation*
Needed for the formulation of MHG development plans and programmes;	Needed for studies of individual projects;
Study of the overall energy needs of a microregion or population groups in a specific area;	Study of the energy needs of a locality or population group which may be served by specific projects;
Study of exploitable resources in a basin or dip, with a preliminary list of specific projects;	Study of the resources for a specific project;
General, extensive and multi-disciplinary studies to evaluate resources, including: Hydrology Ecology Geology Geotechnics Availability of aggregates;	Detailed studies of a project, reduced to an absolute minimum in order not to increase pre-investment costs: Flow measurements Geotechnics Topography;
Evaluation of the overall demand in an area must be statistical in nature.	Evaluation of demand must be based on a detailed investigation of the localities connected with the project.

The evaluation needs for specific projects are dealt with in chapter V.

Depending on the local conditions in each country, the overall evaluation of resources and demand should be made by an *ad hoc* technical unit, which should be responsible to the unit in charge of MHG planning. Alternatively, those functions may be entrusted to an institution which specializes in evaluating natural resources in hydrology. Consideration could also be given to having those functions carried out by a specialized unit of a firm engaged in electrical development.

If there are any limitations with respect to the institutional organization for the overall evaluation, consideration might be given to hiring specialized advisers under the supervision of the planning unit.

The unit in charge of the overall evaluations will have the following main functions:

(a) Identifying and evaluating existing MHG;

(b) Assigning priorities to the areas to be evaluated in co-ordination with the Planning Unit;

(c) Carrying out evaluation studies of basins, sub-basins and water sheds by direct methods or mathematical models;

(d) Evaluating energy development needs and potential in rural areas;

(e) Identifying specific MHG projects and suggesting priorities for their development.

A typical flow chart of the process of overall evaluation is presented in figure 11.

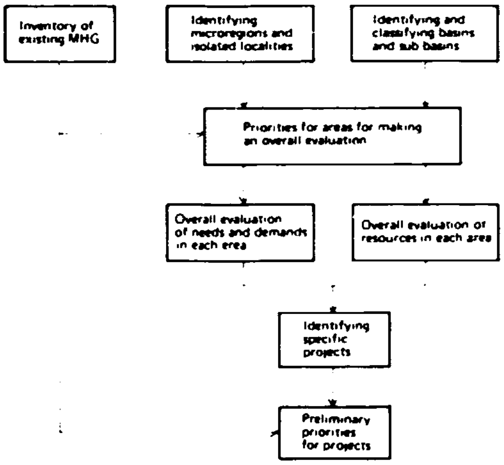


Figure 11. The process of evaluation

The outlines suggested for evaluating resources and demand should not be applied mechanically in all countries, since there are special conditions in each case which call for an individual approach based on the characteristics and distribution of small-scale hydraulic resources, the relative importance of MHG in rural development, and the existence of institutions, statistics, studies and technical cadres for carrying out evaluation activities.

Some of the characteristics required for overall evaluation activities are described below.

Inventory of existing MHG

The establishment of an inventory requires the identification of existing and projected plants. It is recommended that special evaluation forms should be prepared in order to record the following data:

Data concerning the location;

Hydrological data and an appraisal of the basin;

Basic specifications of the power station and its main equipment (capacities, head, flow, type of turbines, penstocks, generators etc.);

State of preservation (for existing plants);

Data concerning service and the population supplied, including characteristics of demand and types of consumption.

The inventory provides a useful tool for organizing plans and programmes when evaluating the state of development of MHG and when determining short-term activities designed to re-adapt, relocate and continue projects. It is also useful for determining the specific reference indices of a country.

The inventory can be used for studying other energy sources, especially with regard to the extension of existing electrical networks and thermal power stations.

An example of possible evaluation forms for recording data on MHG plants is presented below.

Data sheet for MHG plants

Name of the MHG units:

Location:

(1)	(1)	(1)	Location

(1) Define according to the political-administrative division of the country.

Basin	Sub-basin		Watershed	
Capacity	Area (km^2)	Minimum daily flow (m^3/s)	Maximum flood flow (m^3/s)	Multi-year average flow (m^3/s)

Status of the MHG plant (2): Existing ☐ Under construction ☐ Projected ☐
Condition of the MHG plant (2): Good ☐ Bad ☐ Inoperative ☐
Status of the networks: Existing ☐ Under construction ☐ Projected ☐
Condition of the networks: Good ☐ Bad ☐ Inoperative ☐

Power installed or to be installed (kW) (3):

Maximum demand foreseen (kW):

Mean annual energy (kWh):

Kind of turbine:

Design flow (m^3/s):

Gross head (m) (4):

(2) Alternatively indicating basin or sub-basin data.
(3) In generator terminals.
(4) Difference between upper level of water in the forebay and the lower level of head utilization in the turbine.

Population served:
Number of consumers:

Relative use of electric energy (%)

Public Lighting	Household	Commercial	Industrial	Irrigation	Mining	Others

Others (describe):

Productive activities using electric energy (details: carpentry, bakery, brickmaking etc.)

Observations:

Identifying and classifying basins and sub-basins

This is a preliminary approximation based on a study of geographic and topographical maps and on existing hydrographic evaluations. It includes the approximate determination of the hydrographic and physical parameters of the basins and sub-basins of the country, either on the basis of measurements and studies which have been carried out or by inference from mathematical models.

This study may be extended to the systems of watersheds belonging to a sub-basin by establishing correlation parameters when determining runoffs. It will entail the preparation of hydrological studies for specific basins and sub-basins, where the hydrological data call for greater reliability.

It is necessary to draw up criteria for geographic correlation with respect to the identified microregions and isolated localities.

Identifying microregions and isolated localities

The identification of microregions and isolated localities is a preliminary exercise for determining energy needs, based mainly on existing statistical data which can be obtained from censuses and regional studies. Suitably designed files should be prepared in which to record the principal data concerning microregions and rural localities with respect to their population, productive activities and production, communication routes, availability of supplies, approximate energy requirements etc. Data for the preliminary evaluation should be restricted to an absolute minimum.

In the process of grouping localities in microregions, the following factors should be taken into account: physical proximity, communications, political and administrative division of the country, location with respect to sub-basins and hydrographic water shed, and economic and social links.

Considering that the available statistical information will frequently not be up to date and will not contain certain elements of information, it is necessary to prepare mathematical models of population growth or decline and correlation indices for determining quantitative parameters, which should be checked by field sampling. The files should be kept permanently up to date, not only with regard to time, but also with regard to the accuracy of the information.

Priorities assigned to areas or microregions in the overall evaluation

The information obtained during the three previous stages will provide the basic elements for assigning priorities to the areas where the studies for the overall evaluation will be carried out. A simultaneous evaluation of all parts of a country would seem unfeasible for the following reasons: the cost and the limitations of the available financial resources; the minor significance of certain areas for the development of MHG because of their hydroenergy potential or population density; the limitations regarding human resources and institutional experts to carry out the overall evaluation.

This work requires the establishment of priorities among areas in order to prepare a small-scale evaluation of the hydraulic resources in the sub-basins and hydrographic watershed of the areas and an overall evaluation of the needs and energy demand of the localities situated in them. In other words, priorities will be assigned in order to determine those areas which will require more detailed evaluation studies because of their better possibilities for the development of MHG, as shown by the preliminary studies for identifying basins and populations.

An example of the type of form that may be used to collect data on microregions and rural localities is given below.

Data form for the identification of isolated centres and microregions

---

Name of population centre:

Location data:

(1)	(1)	(1)

(1) According to the political-administrative division of the country.

Population		Population density (inhabitants per km^2)	
Number of abandoned potentials			
Domestic	Commercial	Industrial	Others

Watershed to which it belongs

Area (km^2)	Minimum daily flow (m^3/s)	Maximum flood flow (m^3/s)	Annual or multi-year average flow (m^3/s)

Specification alternatives

	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Head utilization for MHG (m) (2)				
Flow utilizable for MHG (m^3/s)				
Installable power for MHG units (kW)				

(2) Measured from the estimated forebay water level to the minimum utilizable level in the discharge.

Status of service

Available electric service: Yes ☐ No ☐
Kind: Hydraulic ☐ Thermal ☐ Transmission from larger electric service ☐
Quality of service: Good ☐ Fair ☐ Bad ☐
Year of installation or interconnection:
Level of subtransmission tension (kW):
Condition of networks: Good ☐ Fair ☐ Bad ☐

Hydraulic generation: Existing ☐ Under construction ☐ Projected ☐
Condition of MHG unit: Good ☐ Bad ☐ Inoperative ☐
Installed capacity (kW): Maximum demand (kW): Total annual energy (kWh):
Available head (m):
Utilizable flow (m^3/s):
Distance from small hydropower station to population centre (km):

Note: In case several units exist, indicate the characteristics of each.

Thermal generation: Existing ☐ Under construction ☐ Projected ☐
Condition: Good ☐ Bad ☐ Inoperative ☐
Installed capacity (kW): Maximum demand (kW): Total anual energy (KWh):
Number of groups: Potential of each: Type of equipment:
Fuel used: Efficiency (kWh per unit of fuel):

Generation from other electric service: Existing ☐ Under construction ☐ Projected ☐
Line capacity (kW): Length (km):
Power of largest electric service (kW): Total annual energy (kWh):
Maximum demand (kW):
Type: Hydraulic ☐
Thermal ☐ Fuel used:
Mixed ☐

Road system

Road: Asphalted ☐ Paved ☐ Unpaved ☐
Passability (months per year):
Distance from other population centres: centre distance (km)

Irrigation

Number: Existing(E): Projected(P):

Irrigation	Status (E or P)	Irrigated Area (km^2)	Flow (m^3/s)

Economic activities

Livestock (head) (pigs, sheep, cattle, others) (details):

Agriculture (area farmed, by types of crop, details):

Mining (type of minerals, reserves, amount exploited):

Agro-industry (types and production capacities):

Other industries and handicrafts (details):

In order to determine the priorities, it is necessary to establish weighted evaluation criteria which must be co-ordinated with the planning unit. The following parameters may be considered; however, their weights and values should be established in connection with the priorities defined by the national development plans and government policies.

Parameters for assigning priorities to areas for the overall evaluation of resources and needs

- The population which can be served;
- The existence of hydraulic resources;
- The existence of favourable conditions for constructing MHG, insofar as it can be determined from the preliminary studies;
- The possibilities of the area for economic development and for the use of energy for productive purposes;
- The physical interconnection between localities in the area and with other regions (road network);
- Possibilities of interconnection with larger systems;
- Other energy alternatives;
- Possibilities of multiple-purpose development.

Some of the above-mentioned criteria would hardly come under consideration in determining priorities, because of the limited information provided by the preliminary identification studies and inventories.

This stage still does not provide an adequate basis for the development plan and the MHG implementation programmes derived from it, but it is certainly useful for formulating the short-term plan, especially in those cases where possibilities for projects with special advantages have been specifically identified.

Overall evaluation of resources in each area

The overall evaluation will focus on the sub-basins and watersheds which offer the best possibilities and are closely connected with the localities which are potential users. It should therefore be carried out together with the evaluation study of demand and needs referred to below.

As previously mentioned, the overall evaluation studies of the resources of each area and sub-basin may include studies of hydrology, ecology, geology, geomorphology, geotechnics and the availability of aggregates, the possible scope of which is described in the following paragraphs. However, although the evaluations will make it possible to identify specific projects, they should not be made for every project, in order to avoid excessive pre-investment costs. Moreover, the depth and scope of the evaluation will depend on the hydroenergy potential and energy requirements of the project.

Hydrology

The purpose of hydrological studies is to estimate the flows which can be used for mini-power stations by generally determining the minimum flows for which there is an 85-95 per cent probability that they will be exceeded on a monthly basis. With regard to the methodological aspects, the minimum flow is generally ascertained on the basis of flow-duration curves, although they are often hard to determine by direct methods, since in many cases no hydrometric records are available. In such cases, indirect methods involving the determination and application of index values must be used.

Criteria of constant similitude between the sub-basins and the main basins may be established to help generalize the information available for the larger basins, especially with regard to the precipitation-duration and flow-duration curves.

The available pluviometric information (precipitation measurements) should be supplemented by preparing regression equations of existing data. Moreover, the hydrometric information which is generally available should be used by applying interpolation criteria to supplement the flow records. Hydrological models can also be used when there are no representative hydrological series in the sub-basins by simulating run-off series for the drainage area in question. One interesting model which would require some adaptation for practical use is the Norwegian SNFS system in which the transfer through each sub-basin is simulated by a system of tanks.

In the final analysis, the monthly minimum flow, or that which is exceeded 95 per cent of the time, assuming the predominant use of run-of-river mini-hydropower stations, can be defined as a percentage of the average multi-annual flow. Equations may be formulated by which a relationship is established between the annual average flow or the annual average hydraulic capacity $(m^3s^{-1}km^{-2})$ (also known as discharge modulus) and the corresponding drainage area of the basin, which, together with the duration curves, makes it possible to define linear expressions for calculating the minimum monthly flows.

Daily flows may vary considerably, since daily minimum values are generally lower than monthly values. However, the fact that they cannot be very accurately predicted could lead to an apparently insoluble problem, since there is practically no storage in the case of run-of-river mini-hydrostations. In spite of this difficulty, the problem may be irrelevant, since the occurrence of daily minimum flows which are less than the monthly ones would affect the operation of the plants only temporarily.

Ideally, it would be desirable to have estimates for a minimum period of three years concerning the watercourse from which water would be obtained, although this is only practical for groups of projects in a given basin and not for a specific mini-hydropower station.

Relevant information supplied by the local population, if properly interpreted, may also help to evaluate historical flows, specially with regard to floods. Maximum flows supply a useful reference point for planning civil engineering works, especially as regards their protection.

Ecology

The ecology studies are designed to describe the environment in which flora and fauna will develop in order to determine its effect on project characteristics, building types, materials, equipment to be used and prospects for conservation and, on the other hand, the effect of establishing mini-hydropower stations on the ecology of the basin or sub-basin. From the methodological point of view, such a study is suitable for evaluating basins but not for evaluating specific projects. In the latter case, only general comments are needed on the ecological aspects, which involve the following: climate, biological zones, soils (from the point of view of human use), vegetation, fauna, bodies of water and aquatic biology.

Geology

The purpose of geology studies is to determine the basic characteristics and composition of the soil and subsoil of the basin in order to establish general guidelines for construction, mainly concerning its structural and seismic aspects. With regard to methodology, it is advisable to undertake studies which apply to basins and sub-basins rather than to specific projects. The most relevant aspects of such studies are the following: lithology (paralysing geological formations by stratigraphical methods), structural geology (examining faults and determining directions of volcanic activity), and seismology (considering records, the probability of earthquakes and their magnitude).

Geomorphology

In the field of geomorphology, the aim is to study the conformation of the surface of the terrain and evaluate it with a view to determining, in particular, the accumulation and deposit of sediment in the watercourses, considering its eroding effects on equipment and the consequent need for suitable planning for silt basins and the selection of appropriate materials for the turbines, mainly rotors and injection systems. It is also helpful in making a final selection of the site in order to avoid possible landslides and erosion. The methodological aspects involve the identification of structures on the basis of geomorphological maps, mainly with respect to scarps, slopes and valley bottoms (river beds), and may be applied to the overall study of basins and sub-basins.

Geotechnics

The study of geotechnics will involve an analysis of soils with respect to their characteristics, mechanical properties, stability and water-table, mainly in order to help plan the construction of hydraulic works. As regards methodology, the application of geotechnical studies to basins and sub-basins is limited, because of the great diversity of individual variations. In this case, therefore, it will be limited to descriptive aspects based on geological studies.

A geotechnical study is particularly relevant for the study of soils in possible specific locations for civil engineering works, in order to help select final locations and to define design requirements. The extent of its use depends on the size of the individual project, both with respect to study costs and the risks inherent in the construction work itself. In the case of mini-hydropower stations, geotechnical studies should generally be reduced to a minimum, depending on qualitative judgements, mainly by excavations and drillings, an estimate of the bearing capacity of the soil, and an estimate of safety factors both for designing the intake, forebay and supports for the piping, and for anchoring the main equipment.

Availability of aggregates

The availability of suitable materials for aggregates (stone, gravel, sand etc.) is investigated because it represents an important factor in reducing construction costs. The methodology adopted involves a differentiated study of the existence and characteristics of the principal kinds of material needed (granular, rip-rap and quarried material, sand, gravel etc.).

Overall evaluation of energy needs and demand in each area

This study should be combined with an evaluation of the hydropower resources of the area in question in order to determine the feasibility, and facilitate the subsequent formulation, of specific MHG projects.

Such an approach requires a detailed study of the data obtained from a preliminary identification of microregions and isolated areas through field evaluation surveys describing the characteristics of each locality.

It is necessary to keep an extensive data file for each locality and to prepare card indexes for microregions or groups of localities which can be integrated into a small grid.

A socio-economic analysis of each locality may cover the points described below. However, it should be borne in mind that this analysis could be more limited and some elements left for consideration in studies of specific projects or simply disregarded.

Scope of the socio-economic analysis of localities

Population	Number, size of families, breakdown by activities, income, cultural levels etc. Typification of the possible levels of satisfying energy needs. Historical information about growth (or stagnation); migrations. Forecasts (estimates) of growth and of the rise in the indices of energy needs.
Economic activities	Description of existing productive and supporting activities; economic impact. Potential of the area. Identifying projects in energy-consuming activities. Requirements for project implementation; time limits.
Transport and communications	Transport systems (personnel and goods); highways, postal system, telecommunications etc.
Services	Drinking water, drainage, energy supplies; trade.
Education	Schools and cultural activities; educational needs and their specific energy requirements.
Physical description of the locality	Geographic location, distance, physical description (streets, distances, types of construction etc.).

The socio-economic analysis should provide the basic data for each locality, so that the requirements and potential for electricity consumption and the required installed capacity may be determined by using indices.

In this stage of overall evaluation, only approximate requirements of installed capacity may be determined on the basis of indices. In addition, preliminary evaluations of energy consumption may be carried out for various kinds of consumption, including households, public lighting, economically productive activities and miscellaneous consumption (health, education, culture; social, political and religious activities etc.).

Approximate periods of daily use may also be estimated for each category and its seasonal variations. The proposed additional analysis provides the necessary data to determine required installed capacity and demand at the pre-feasibility level for studies of specific projects.

Identifying specific projects

Because of the interaction between alternative MHG projects which can be defined from the overall evaluation of resources, together with the evaluation of needs and demand in all the localities of an area, it is possible to determine and define in approximate terms those projects which can meet the basic energy needs of the population at minimum cost. For that purpose, the following factors and recommendations must be considered:

(a) To what extent is it economically justifiable to organize groups of localities to form small interconnected medium-tension grids, depending on their extension and the topographic characteristics of the area?

(b) Projects of relatively greater capacity, which can economically replace several smaller ones, should be selected;

(c) The topography and characteristics of the site determine the head type of the power station. High heads are more convenient, since they involve smaller investments and ensure greater economy of water, although they are subject to more wear and tear and the greater water-level losses decrease the availability of water for other purposes at higher levels;

(d) Account should be taken of increased requirements of installed capacity, either by overdesigning the installations or allowing for future enlargement;

(e) Construction problems should be anticipated when defining projects;

(f) Alternative solutions and projects should be assessed;

(g) The above guidelines should be supported by field evaluation.

It should be pointed out that the objective at this stage is to try to define projects which could meet the basic energy needs of the area in question by trying to optimize combinations, but not to establish priorities for implementation, which is a part of the next stage.

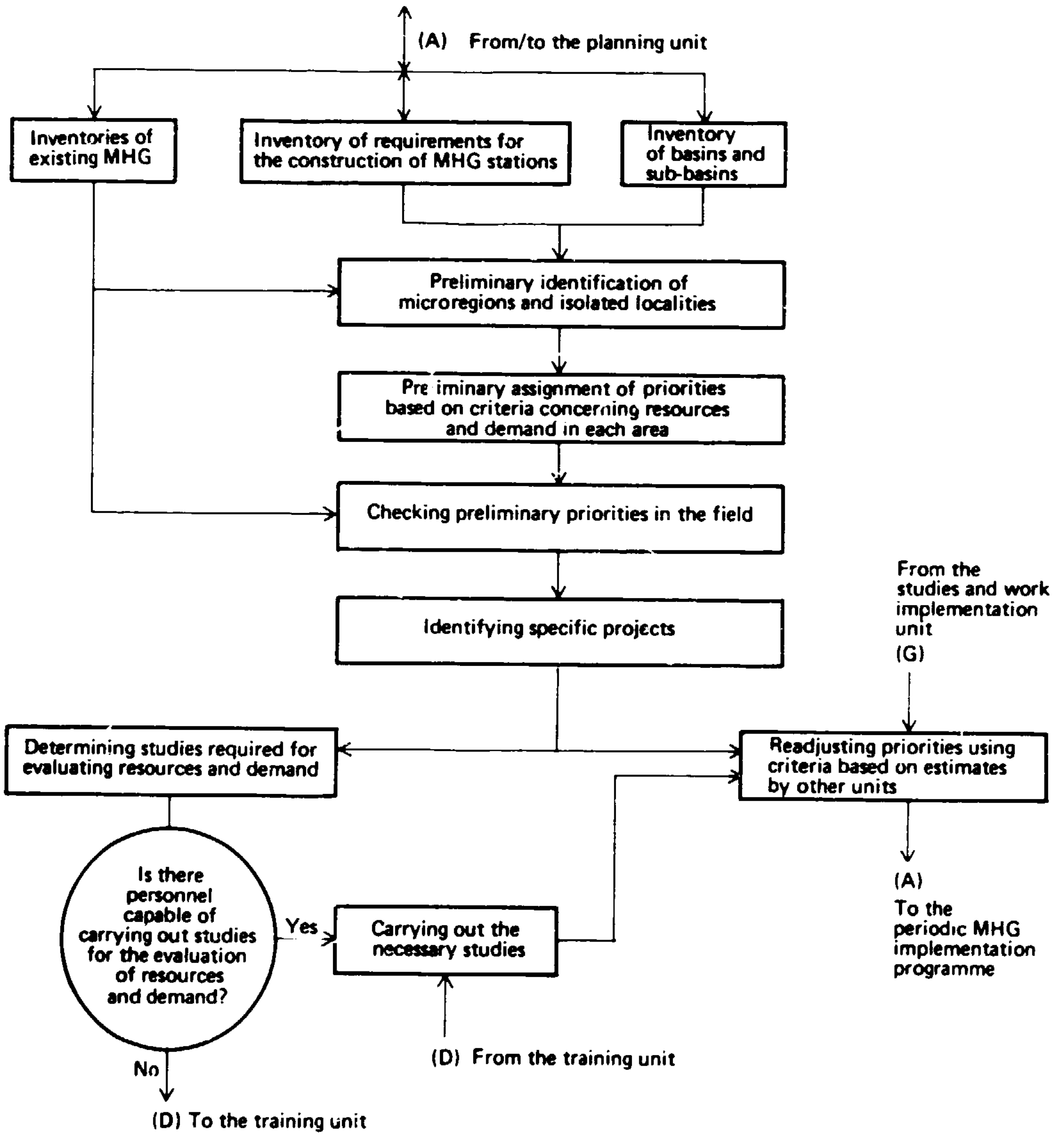


Figure 12. Unit for the evaluation of resources and demand

Assigning preliminary priorities to projects

The assignment of preliminary priorities to projects forms the basis for defining the development plan and its implementation programmes, which is the responsibility of the Planning Unit. Weighted evaluation criteria must be established in order to determine the priorities, while taking due account of economic, technical and social factors. The following general factors should be considered.

Factors for establishing priorities for the implementation of projects

Size and cost, including cost of transmission lines;

Population to be serviced, load factors;

Energy used in productive activities, including industrial production in relation to energy produced;

Availability and permanence of the hydraulic resource;

Possibilities of mutually complementary use in the case of multiple projects or possibilities of interference with the use of water for other purposes;

Possibilities of using local labour and materials for construction;

Possibilities of organized participation on the part of the community by contributing labour and materials;

Availability of access roads and road connections;

Possibilities of creating local employment;

Possibilities of continuity of service, self-financing of operation and community support;

Possibilities of supplying equipment, preferably of national origin;

Engineering requirements and problems involved in the project;

Various productive activities which may be developed in isolated localities and the approximate requirements of installed capacities are shown in table 4.

TABLE 4. INSTALLED CAPACITY REQUIRED FOR PRODUCTIVE ACTIVITIES IN ISOLATED AREAS

Activity	*Installed capacity required (kW)*
Carpentry shops	5-15
Bakeries	2-5
Handicraft activities	1-2
Small sawmills	15-30
Small sugar-cane mills	10-20
Grain mill	3-20
Weaving	0.5-6
Coffee beneficiaries	5-30
Quarries	6-30
Ice-making	6-60
Irrigation pump	2-100
Brick-making	1-5
Lodging (20 guests)	2-5
Restaurant	1-2
Vegetable canning	5-20
Dairy products (butter, cheese)	2-10
Milk-processors (cooling and pre-evaporation)	5-20
Silos	3-5
Electrical and mechanical workshops (repairs)	5-15
Petrol pumps	0.5-5

By applying the above guidelines it will be possible to prepare lists of projects in order of priority for use in planning and programming activities, although this will not automatically ensure the inclusion of those projects in the programmes, since the planning unit will have to establish other priorities with respect to questions of regional development, rural industrial development and sectoral policies.

The functioning of the unit for the evaluation of resources and demand is reflected in figure 12.

D. Pre-investment studies

This section is concerned mainly with pre-investment studies for specific projects, studies relating to the overall analysis of resources and demand having been dealt with in the preceding section. The dividing line between the two types of study is not always easy to draw, since studies for specific projects may be related to the process of identifying projects and establishing priorities.

Specific project studies serve two basic purposes: technical and economic justification, and the provision of guidelines for project execution.

Pre-investment studies represent one of the basic differences between MHG and larger-size plants. The preparation of studies therefore often poses the following problems:

(a) High study costs, often amounting to between 30 and 50 per cent of total investments;

(b) Formal terms of reference not always adequate to the needs of the project;

(c) Over-abundant information, processing of data of little significance, lack of relevant facts and failure to establish a correlation between the study and the realities of the project;

(d) Limited practical value for determining investments required or for guiding plant construction.

The above-mentioned drawbacks may be attributed to the following causes:

(a) Uncritical transfer of terms of reference commonly used for large hydroelectric projects;

(b) Routing division of studies into successive phases (pre-feasibility, feasibility and detailed engineering) without taking into account the aim of the particular study;

(c) Formalistic demands and excessive data requirements made by financing institutions;

(d) Lack of definition of targets enabling proportions to be established between study costs and total project investment;

(e) Lack of comprehensive studies on resources and demand by basins and microregions respectively;

(f) Limited amount of direct information and excessive processing of inferred or estimated data;

(g) Lack of technical and economic manuals on project development;

(h) Limitations in consultancy systems and in the capacity of public institutions to carry out studies;

(i) Little consideration of technical alternatives;

(i) Little consideration given to the prospects for participation by the local population in the project.

It is important that targets be set at the Planning Unit stage regarding the maximum cost of studies as a percentage of the total investment and according to the size of the power station. Targets should obviously be set for each country as part of an approximate calculation of the cost of the components of the studies and the establishment of their scope. It should not be forgotten that the studies are a rough guide for future operations and a means of protecting the total project investment. They should therefore be kept within reasonable limits to prevent their becoming a high-risk investment themselves, which could lead to a significant increase in total investment or even to the absurd situation where their cost could seriously affect the feasibility of the project.

Definite targets must be set by each country for the maximum cost of pre-investment studies with respect to total investment in an MHG project, which will in turn define the scope of the studies. Chapter V, section F, deals with costs and includes a reference curve based on the data in table 5, which show that the percentage cost of studies for smaller power values ought to increase within reasonable limits.

TABLE 5. COSTS OF PRE-INVESTMENT STUDIES AS A PERCENTAGE OF TOTAL COSTS

Power (kW)	*Maximum percentage of total costs allocated to studies*
10	15
100	11
1 000	8

The scope of the studies is closely related to the proportion desired between their costs and total investment and to where the project stands in MHG development planning; in other words, whether or not comprehensive information on basins and areas for groups of projects is available, which depends on the thoroughness of the project studies carried out as part of the overall evaluations referred to in chapter III of this Manual.

In the light of the above-mentioned considerations, some general guidelines are presented below for preparing pre-investment studies for the three conventional phases of pre-feasibility, feasibility and detailed engineering.

Pre-feasibility or reconnaissance study

In the case of MHG, it is desirable to establish minimum requirements at the level of the pre-feasibility study, which could be replaced by the concept of a reconnaissance study, implying something of more restricted scope. On the other hand, it is useful in this phase to ensure that the data needed to settle the investment question are available so that, if possible, the preparation of a feasibility study will not be essential.

The degree of approximation to a pre-feasibility study will differ, depending on whether or not the project in question is beyond the scope of the planning and overall evaluation process, as shown below.

Characteristics of pre-feasibility studies according to their relationship to planning and overall evaluation

Projects which form part of the plan and overall evaluation of resources and demand	*Independent projects outside the context of overall evaluations and plans*
The decision to carry out studies is taken at the planning stage on the basis of the overall evaluations made. It remains for the pre-feasibility study to analyse alternatives, define plant specifications, determine the scope of project engineering and assess its feasibility prospects.	If the project looks promising in a preliminary survey, the pre-feasibility study can have the scope of the planned projects. If not, it should provide alternatives and approximations as to their specifications and investment requirements, and assess the desirability of going on with the studies.
The overall evaluation may contain adequate data on hydrology, the assessment of resources, energy demand and installed capacity requirements, so that it only remains to assess the data in a field study, to make flow measurements and to provide additional details.	Evaluation of resources and analysis of demand fall within the scope of the study.

Also of importance will be the size of the project, which will determine the scope of the pre-feasibility study in proportion to the estimated requirements, and other factors relating to the size of the project, as outlined below for power stations tentatively separated into two power ranges.

Characteristics of pre-feasibility studies according to size of MHG plant

Lower power values (less than 100 kW)	*Higher power values (at least 100 kW)*
Checking water flows using indirect methods during short periods and generalizing by means of qualitative assessments.	Checking flows through measurements taken over long periods or the use of similarity models.

Very limited topographical surveys, or their elimination; the use of artisan methods for levelling falls.	Detailed topographical surveys of the most relevant areas (intake, channel, forebay, fall, powerhouse, tailrace); careful determining of the head and layout of a penstock.
Visual assessment of the structure of the terrain for construction purposes.	Applying geotechnical methods to check the characteristics of the terrain in areas where the main construction work is to take place.
Overdimensioning and larger safety margins taking into account greater uncertainty factors.	Less overdimensioning and reduced safety margins in view of more complete studies and the greater investment involved.
More consideration of the use of non-conventional technologies tending to reduce costs, even if given margins of reliability and service life must be sacrificed.	Less consideration of non-conventional technologies even though in many cases they will be relevant in this power range.

The foregoing should be regarded as guidelines, for the scope of each individual project must be decided in the light of the objective characteristics of the project. The items covered by MHG pre-feasibility studies are included in the following check-list.

Checklist for MHG pre-feasibility studies

1. Summary review of all the essential findings.
2. Project background and history:
   - *(a)* Project sponsor(s);
   - *(b)* Project history;
   - *(c)* Cost of studies and investigations already performed.
3. Market and plant capacity:
   - *(a)* Load demand and market
     Its past growth, estimated future growth, and connection with the grid;
   - *(b)* Sales forecast and marketing
     Competition with other energy sources
     Estimated annual sales revenues from power supply;
   - *(c)* Power estimates
     Hydrologic study
     Firm power
     Secondary power
     Waste water;
   - *(d)* Determination of installed capacity.
4. Location and site (including, if appropriate, the geological study and estimates of the cost of land and of storage reimbursement).
5. Project engineering:
   - *(a)* Preliminary determination of scope of MHG project;
   - *(b)* Technology and equipment
     Rough estimate of costs of local and foreign technology
     Rough layout of proposed equipment and powerhouse
     Turbine, generator, gate and valve, auxiliary equipment etc.
     Rough estimate of investment in equipment;
   - *(c)* Civil engineering works
     Rough layout of intake, conveyance structure and powerhouse
     Rough estimate of investment cost of civil engineering works (local and foreign).
6. Plant organization and overhead cost.
7. Manpower:
   - *(a)* Estimated manpower requirement broken down into major skill categories;
   - *(b)* Estimated manpower costs.
8. Implementation scheduling:
   - *(a)* Main construction method and implementation time schedule;
   - *(b)* Estimate of implementation costs.
9. Financial and economic evaluation:
   - *(a)* Total investment costs;
   - *(b)* Project financing
     Proposed capital structure and proposed financing (local and foreign)
     Interest;
   - *(c)* Production cost;
   - *(d)* Financial evaluation based on above estimates
     Pay-off period
     Simple rate of return
     Break-even point
     Internal rate of return
     Comparative cost of alternative sources of energy;
   - *(e)* National economic evaluation
     Preliminary tests
     Approximate cost-benefit analysis, using estimated weights and shadow price (foreign exchange, labour, capital)
     Economic and industrial diversification
     Estimate of employment-creation effect
     Estimate of foreign exchange savings.

Feasibility

The pre-feasibility or reconnaissance studies for MHG should cover the elements needed to take a decision on investments, with a view to cutting out feasibility studies and proceeding directly to project engineering studies. However, feasibility studies are desirable for projects which raise problems on technical and economic grounds, or when alternatives must be compared, provided such studies are justified by the scale of the project.

Detail engineering

Detail engineering studies should include the following:

Supplementary topographic details;

Supplementary geotechnical study (when justified by the scale of the project);

Final specifications for the project;

Detailed design of each civil engineering item and specifications of materials;

Final specifications of electromechanical and auxiliary equipment; quotations, evaluation of alternatives and proposed purchases;

Electrical design of transmission lines and installations;

Recommendations for construction, installation and start-up;

Implementation schedules and work programme;

In the absence of feasibility studies, the engineering study should include a supplementary financial and economic analysis dealing with the following points:

Investment and financing;

Schedule of payments;

Personnel requirements;

Operating and amortization costs;

Consideration of tariff schemes;

Analysis of sensitivity of investments;

Organizational aspects of construction and operation;

The scope and depth of the engineering studies will also depend on the scale of the proposed investments. The main features may be classified as follows:

Characteristics of engineering studies according to size of MHG plant

Lower power ranges (less than 100 kW)	*Higher power ranges (greater than 100 kW)*
Less study of detail in design, details to be supplemented as work proceeds.	More study of detail in design.
Larger safety factors for design.	Smaller safety factors for design.
Proportionately greater use of local materials.	Proportionately lesser use of local materials.
Drawings commensurate with capabilities of a construction foreman.	Drawings commensurate with capabilities of a civil engineer.
Considerations of price and simplicity will be major items in the final selection of equipment.	Considerations of reliability and service life will be major items in the final selection of equipment.
More extended use of non-conventional technologies.	More extended use of conventional technologies.
More use of semi-standard designs.	More use of "tailor-made" designs.

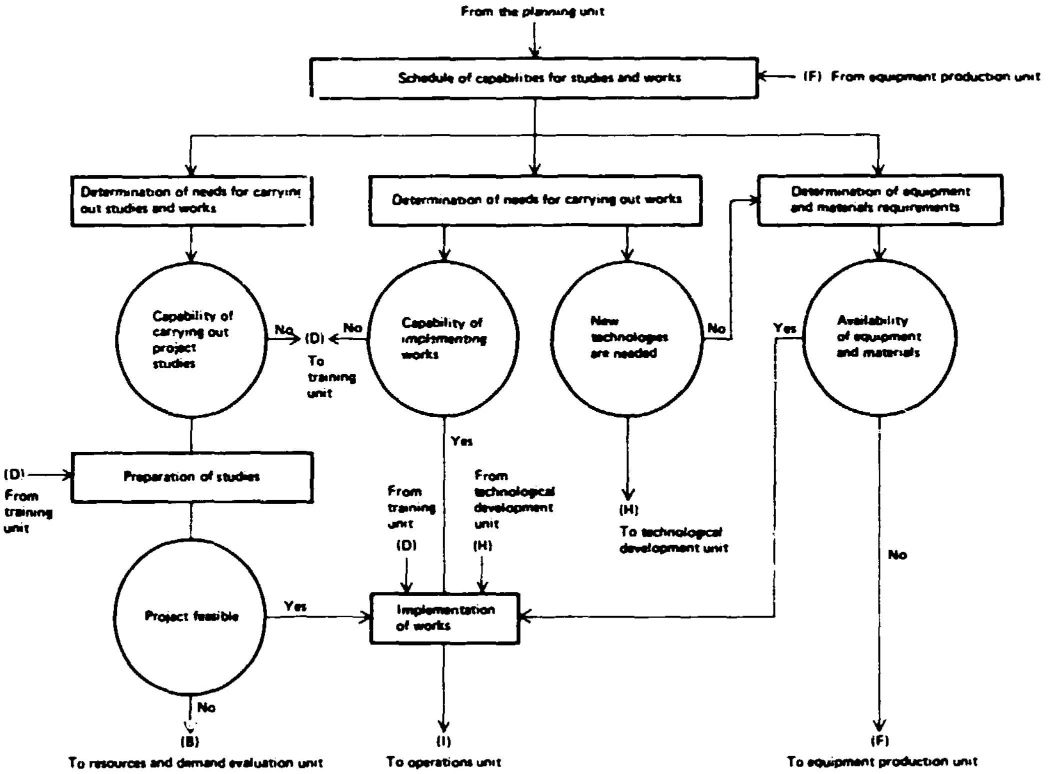
Standard equipment, including turbines, should be specified and selected for all MHG stations.

Pre-investment project studies may be entrusted to various bodies or individuals, such as the projects and engineering section of an electricity board or undertaking responsible for implementing MHG, a specialized hydroproject institution or agency, and independent consultants and experts. The choice will depend on the policies, social and economic system, and technical capabilities of the country.

It is useful if the electricity board or enterprise acting as executive agent for the MHG programme has a projects and engineering section capable of making the necessary pre-investment studies and of subcontracting and overseeing studies when its own project development capabilities are overloaded.

Contracting good consultants is often difficult, and the supervising agency needs a high level of technical capability in order to be able to define the scope of the studies clearly, evaluate costs and check on the quality of the studies. The common mistake of carrying out studies which contain little substance and a mass of irrelevant information should be avoided. Another matter for concern is the tendency of financial institutions to establish such requirements regarding the qualifications of consultants and the scope of studies that pre-investment costs tend to be very high and the studies contain formal elements which for the most part are useless for project evaluation and implementation.

Guidelines on the functioning of the unit for the implementation of works and studies are presented in figure 13.



Note: Letters within parentheses refer to units covered in figure 9.

Figure 13. Unit for the implementation of studies and works

E. Financing

The financing section will deal with the general problems of financing investments for MHG, with the emphasis on aspects likely to reduce investment or its financial and foreign currency requirements. Common problems in MHG financing are the following:

Heavy investment per installed kW;

Substantial foreign currency requirements;

High study costs and irrelevancy of studies to project operation and implementation;

Individual projects are on too small a scale to be financially interesting and are expensive to administer and to evaluate;

Little experience of systems for financing groups of projects;

Difficulties of including national engineering in pre-investment studies;

Unsatisfactory schemes for financing national supplies;

Underestimating potential community contributions of manpower and materials;

Lack of MHG financing policies;

Inadequate economic capability of communities;

Misconceptions of rural electrification based on spontaneous development of productive activities requiring energy.

To deal with the above-mentioned problems, the recommendations given below should be borne in mind when drawing up financing schemes. Many of the recommendations are given detailed consideration later in this section.

General guidelines for improving financing prospects of MHG

1. Reduce investment and foreign currency requirements by means of non-conventional technologies, standardization, national production of equipment and local materials, and community participation in construction works.

2. Increase the relevance and reduce the cost of pre-investment studies by overall assessments of resources and demand by zones and basins, preparation of guidelines for project formulation and design handbooks etc.

3. Finance groups of related projects.

4. Increase community participation in the building and operation of plants.

5. Increase the share of national engineering in projects by strengthening the engineering capabilities of the institutions responsible for implementing MHG projects and giving preference to suitable domestic consultants over foreign consultants.

6. Develop systems for financing national supplies.

7. Stimulate community participation in project implementation by emphasizing such participation in the study of priorities and developing appropriate systems for the financial evaluation of community contributions and technical assistance requirements.

8. Determine a national MHG financing policy.

9. Promote the parallel development of energy-intensive productive activities.

10. Develop guidelines on the rational use of energy.

Special attention should be paid to reducing investment needs, including pre-investment studies, and foreign currency requirements.

General guidelines for reducing investment costs and foreign currency requirements

1. Overall evaluation of demand and resources should be broken down by zones and basins, thus reducing the costs of individual studies and achieving economies of scale in the multi-disciplinary study of areas possibly involving a number of projects.

2. Wherever possible, proceed directly from pre-feasibility studies to deal with engineering studies.

3. Simplify terms of reference of studies and prepare guidelines for their elaboration.

4. Prepare design manuals and handbooks.

5. Consider using non-conventional technologies and the intensive use of local materials from the pre-investment study phases.

6. Use domestically produced equipment and materials and, if possible, nationally developed or adapted technologies not subject to royalty payments or large numbers of imported parts.

7. Use standard items of equipment and consider cheaper and shorter-life alternatives for low-power installations.

8. A semi-standardization of civil engineering works would be useful.

9. The use of national engineering in projects helps to save foreign currency, reduce relative costs and improve adaptation to actual conditions in the country.

10. Community participation helps to reduce apparent investment and therefore requires less domestic financing.

To promote the development of MHG projects, appropriate policies must be defined, such as setting up an MHG development fund which can be administered by a government-financed agency or by the electricity board or institution concerned. Possible sources of financing made available through the fund are illustrated in figure 14.

Various methods of MHG financing are described below.

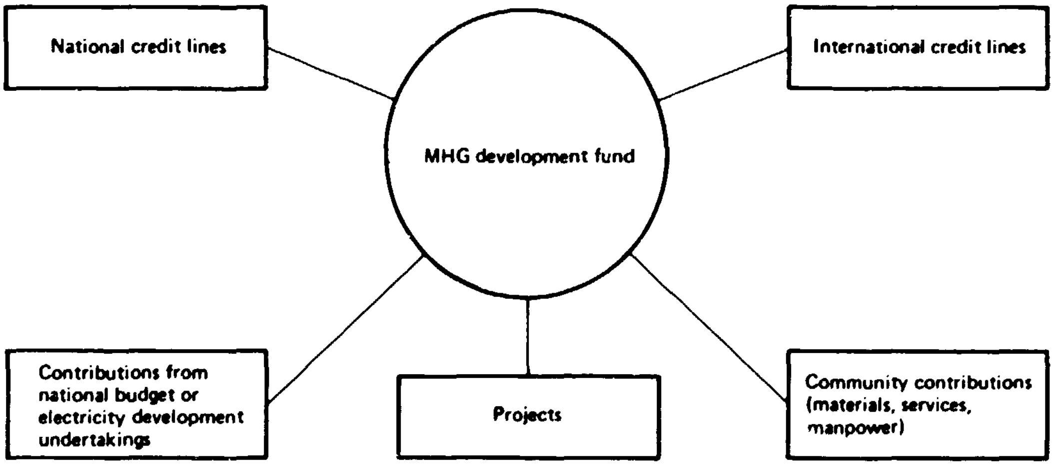


Figure 14. Project financing through an MHG development fund

International credit lines

A clear distinction is necessary between untied credit lines, such as some international finance agencies can provide, and tied credit lines from financial institutions in countries wishing to promote their equipment and engineering sales through financial promotion.

Tied credits are satisfactory provided that the elements concerned are not produced domestically, and after analysis of their technical characteristics, pricing and financial conditions has shown them to be the best option. The temptations of soft financing often lead to the purchase of equipment which is too expensive or inadequate.

Specific credit lines defining various financing conditions should be arranged in order that the financing of groups of projects may be subsequently negoiated. The criteria and terms of reference for studies should be realistic, and preferably made known by the publication of guidelines for project preparation and assessment.

National credit lines

National credit lines should be used mainly to finance domestically produced supplies of equipment and materials. They can be arranged with agencies concerned with financing the promotion of industry. Credit lines for site development and works can be arranged with agencies concerned with financing land development.

Contributions from national budgets or electricity development undertakings

In the light of the development plans and their annual MHG implementation programmes, resources could be allocated in proportion to the credits obtainable. Some of the investment finance could take the form of a grant or be established as a percentage of the profits of the power companies.

Contributions from the community

Community contributions should be determined during the studies phase. They should be regarded as part of the total investment and therefore need to be properly assessed. Community contributions usually consist of unskilled building labour, materials (mainly aggregates for the civil engineering works) and services (local and carting and transport, storage, security etc.).

Where investments are financed on a basis of partial repayments, financing would take place through a revolving fund. However, irrespective of the scheme of investment repayment and even in the case of outright grants, projects must earn at least enough to cover operation and maintenance costs, otherwise the plant may be brought to a standstill by the first operational problem to arise or its installations may be threatened by eventual damage. Moreover, it would be difficult to devise a scheme in which permanently non-recoverable contributions were closely associated with sustained growth of MHG.

The proportions of financing to come from credits, budget contributions and community contributions should be defined in general terms. Some countries have adopted a method by which the investment is divided into three roughly equal parts, the first to be financed by credits, the second by budget contributions and the third by community contributions.

Investment recovery criteria must also be considered in finance policy in the light of tariff possibilities and the aims of rural electricity development. Three typical cases will now be given, but intermediate solutions are possible.

Outright grants

With outright grants there is no question of recovering investments. Budget contributions and financing are a matter for government or the electricity development board, and the tariff system merely cover operation and maintenance costs.

The system can be used to develop MHG in areas where incomes are very low, but because of its limited financial capabilities, only relatively few MHG plants could be built.

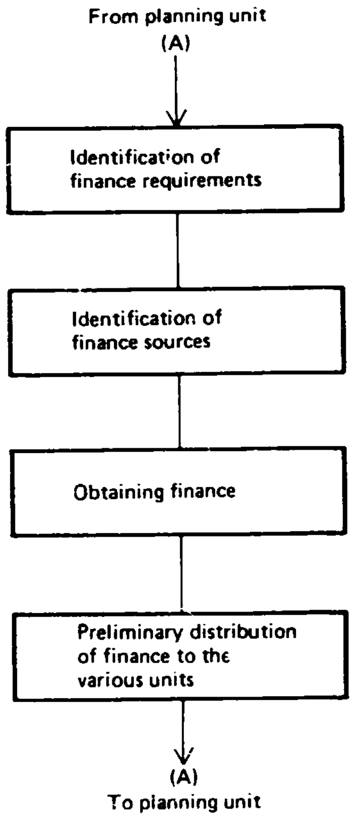
Partial grants

In the case of partial grants, the budget and community contributions are often regarded as part of the grant, and the loans obtained are to be paid through appropriate tariff arrangements.

Total recovery of investment

Though ideal financially, the total recovery of investment usually proves to be impossible for a rural electricity development, since implementation is greatly hampered by restricting it to cases in which the likely income from supplying electricity will cover capital amortization and loan service charges over a given period. Schemes of this type can be used for MHG installed mainly to serve profitable productive activities, such as mining, agro-industry etc.

The financing unit functions along the lines indicated in figure 15.



Note: Letters within parentheses refer to units covered in figure 9

Figure 15. Financing unit

F. Construction and start-up

This section will deal mainly with the problems and methods of construction as they relate to such matters as excavation work, civil engineering, the installation of electromechanical systems and equipment, and the actual starting-up of the plant.

Of all the various types of alternative sources of energy, MHG poses the most exacting construction requirements because of the relatively large scale of the building operations and the considerable size of the installations.

The construction processes will vary according to the following factors:

Planned installed power;
Nature of the terrain;
Location of the site;
Mode in which the plant is to be used (independently or with interconnections);
Availability of skilled labour;
Construction technology;
Ease of access and transport;
Technological sophistication of the equipment;
Climate;
Particular factors in the case of multi-purpose projects.

The construction process is schematically represented by the flow chart in figure 16.

The stages of the construction process are analysed below.

Revision of studies and inspection

The office responsible for carrying out the project, which may be a part of the electricity board, must first of all define the areas of responsibility for the management and supervision of the project. The next step will be a revision of the studies and a site inspection concentrating on characteristics, specifications, and construction guidelines. The task of revision may be entrusted to independent professionals or consultants if sufficient trained personnel of this kind are not available, or when a project is designed for direct implementation under the auspices of a municipal government or private firm.

Acquisition of basic equipment

Considering the possibility of problems with delivery schedules, arrangements should be made for the acquisition of the equipment as soon as the revision of the studies has been concluded. In some cases, these arrangements may be begun as early as the engineering study stage.

The heading "basic equipment" normally covers such items as the turbines, speed regulators, generators, main valves, electrical control panels and transformers. It may also include electrical materials and pressure tubing for penstocks, together with the related accessories.

Co-ordination with the financing unit

Co-ordination with the financing unit is required in order to determine the modalities and timetables of the release of funds for the various stages scheduled in the project construction programme. At the community level, this co-ordination may also be tied in with co-ordination of disbursements and community contributions. In addition, the procurement of the equipment must be co-ordinated with the financing unit.

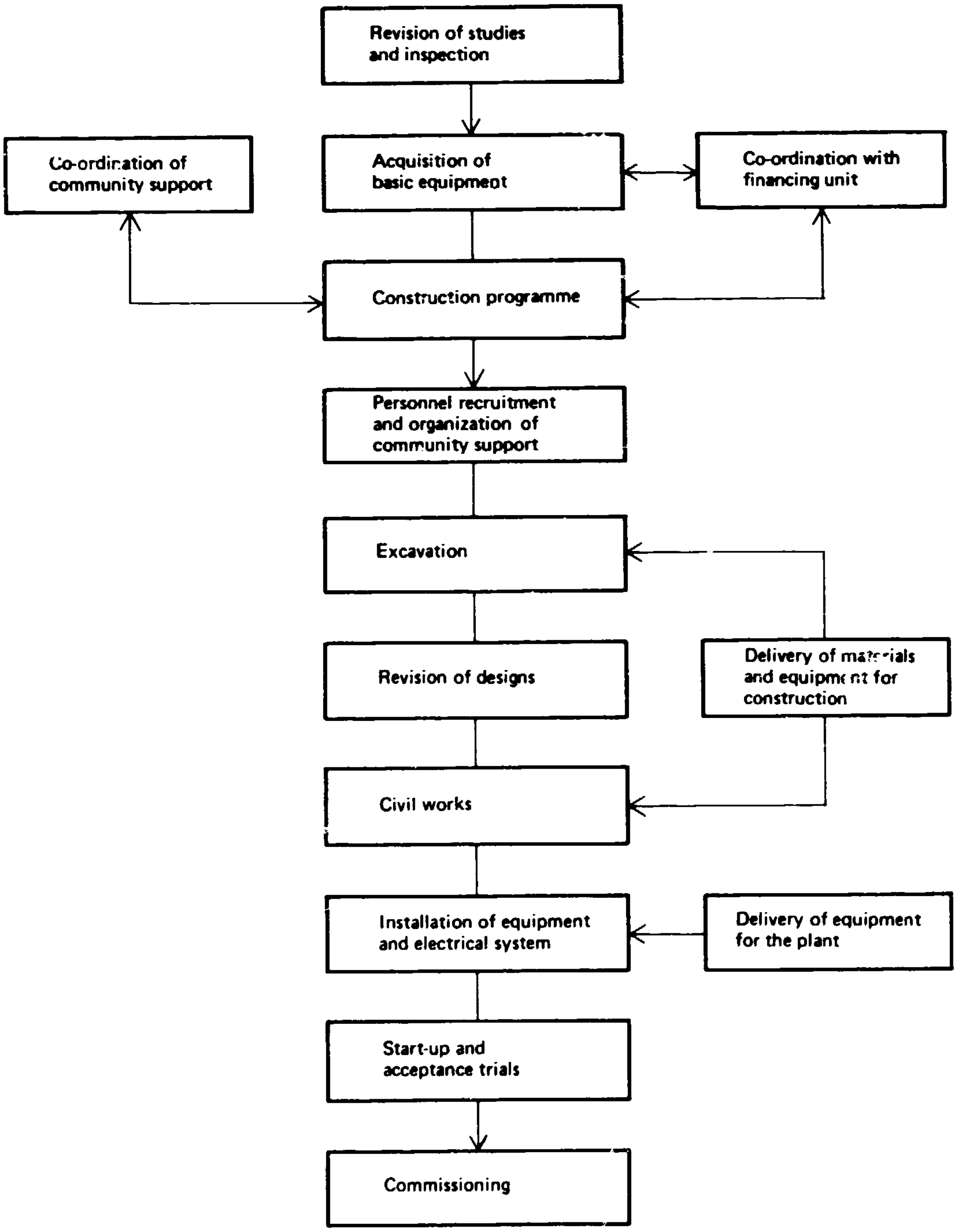


Figure 16. Flow chart of the construction process

Co-ordination of community support

Specific areas of possible co-operation must be identified as early as the study and implementation-decision stage. Co-ordination is required prior to the commencement of construction in order to produce some sort of formal agreement with the community covering, among other things, the following points:

Manpower: types and number of man-hours for each phase of construction; supervisory responsibilities;

Materials: generally aggregates for civil engineering works, such as stone and sand, wood for formwork etc.; quantities, location etc.;

Services: transport, storage and warehousing of materials, personnel transport facilities, provision for security etc.; definition of responsibilities;

Monetary resources.

Depending on the type of social organization and the traditions of the country, such agreements will be concluded with the most representative authorities capable of mobilizing the support required. Those authorities may be community leaders, the senior officials of co-operative organizations, or the members of the municipal government. It is also essential to make certain that the agreements are brought to the attention of the local citizens and supported by them.

Construction programme

The construction programme must be drawn up in harmony with the actions referred to in the preceding sections. The characteristics of the construction programme are determined by the nature of the project. In the specific case of MHG, allowance must be made for considerable margins of uncertainty in the various phases of execution, this uncertainty being the result principally of the exploratory nature of the studies, the logistic problems inherent in any project which involves only a minimum of administrative apparatus, and the difficulties that frequently arise, with respect to organization and adherence to progress schedules, in activities in which there is an element of relatively voluntary community participation.

The following questions should be considered in project construction programmes:

(a) Excessively detailed programmes should be avoided, and programmes should be limited to a discussion of the principal elements only;

(b) The planning should include sufficient latitude for unforeseen developments, particularly with regard to design modifications, supplies, and work to be performed by the community;

(c) Preference should be given to the use of logical systems for the progress timetables as a means of clearly defining the critical paths, but with only the principal events considered;

(d) In programming the work to be performed by the local community, consideration should be given to the possibility of interference with other activities requiring the attention of the inhabitants, particularly during the planting and harvest seasons;

(e) Arrangements should be made for technical support to meet requirements arising from unforeseen design changes, particularly with respect to civil engineering;

(f) In planning for the transport of materials and equipment from outside the area, consideration should be given to possible problems of access, especially during the rainy season;

(g) The modes by which materials are to be hauled should be the subject of advance planning, particularly when draught animals are to be used;

(h) All work-related responsibilities must be set forth in the programme.

Personnel recruitment and organization of community support

The basic construction team may include the following members: one supervisor (generally an engineer, who may be in charge of more than one project), one site construction foreman, skilled workers (masons, carpenters etc.) and unskilled workers. The supervising engineer normally reports to the office responsible for the implementation of the project. The construction foreman is frequently a contractor in charge of his own crew of skilled workers; the unskilled work-force may be provided by the local community. In situations of this kind, provision must be made for the prevention of any conflicts of responsibility between the contractor and the community. In organizing community support, specific personnel should be assigned to the construction manager.

The equipment installation phase will require a supervisory engineer (mechanical or electrical) at the head of a team which might consist of one mechanic or fitter, one installation electrician and assistants. The equipment installation team will, in many cases, be provided by the project implementation office. The assistants may be drawn from the potential local operators of the plant.

The above recommendations regarding the composition of the construction crews are intended as guidelines only and are subject to considerable modification depending on the size and particular features of the project. The general aim should be to keep the technical team to the indispensable minimum, since it is a major cost factor, particularly in the case of small plants of less than 50 kW output.

It is essential to remember that the presence in the community, during the execution of the project, of skilled technicians and workers may give rise to unusual socio-economic situations. The effect of such situations may be beneficial, by providing an opportunity for social and cultural exchanges, but it may also be negative if the outside personnel fail to adapt themselves to local customs or if, by their behaviour, they create problems.

In order to facilitate the participation of local communities in the project, consideration should be given to the formation of work groups or brigades to fulfil assigned plan objectives.

Excavation

Higher or lower levels of mechanization will be employed, depending on the structure and socio-economic development of the country and on the size and characteristics of the project. In the case of MHG, frequent intensive use of local manpower with low levels of mechanization is preferred. On the other hand, it is important to avoid underestimating the value of the community effort simply because it is not included in the cash budget, since a frequent error is to fail to provide for a minimum of mechanization capable of economizing on a large number of man-hours.

The excavation of the channel is the major task at this stage, after which come the intake and the surge chamber with the silt basin, and finally the powerhouse and the penstock support structure.

Construction

The civil engineering works pose greater requirements with respect to skilled labour, which may be supplemented through community efforts in the form of assistants and personnel engaged in hauling the materials. As a means of broadening community participation, consideration should be given to the possibility of training local personnel, particularly as masons.

The timely transport of materials is one of the most important factors in avoiding excessive costs and delays in scheduling. Depending on conditions in the country and the nature of the terrain, the use of locally available draught animals may be of great importance. In instances when such animals are used, it is necessary to arrange for the preparation of appropriate paths and to plan carefully the movement of the loads so as to avoid interference.

The safety of the personnel requires that consideration be given to their skill levels and experience, and that suitable provision be made for the full use of the materials and equipment needed to ensure their safety.

Since the engineering plans are to be supplemented or corrected during the actual work on the project, the experience of the construction foreman is a critical factor. In the case of modifications which depend mainly on the terrain or on existing structures, the views of the local inhabitants may be very useful.

Installation of equipment and electrical systems

The installation of the equipment normally requires skilled and trained personnel. Nevertheless, an effort should be made to involve in such work any local inhabitants who appear potentially capable of being trained as operators, in order that they may become familiar with the equipment and the installation.

The safety and security of the electrical systems is a matter of major importance for the continuing good operation of the plant and the protection of its operating personnel. It must be assumed that the plant itself will not be inspected or repaired with any great frequency.

Start-up and acceptance trials

In the stage of plant start-up and acceptance trials, which marks the transition to normal plant operation, the following points must be kept in mind:

(a) The acceptance trials must be standardized according to the guidelines established for each plant type and size;

(b) The actual start-up of the plant must be carefully planned, with duties and responsibilities clearly assigned and safety aspects provided for. The emergency procedures must be clear and well understood by all those taking part in the trials;

(c) As part of the start-up operation, the indigenous operators designated to be responsible for plant operation must be evaluated and their competence certified;

(d) It is desirable that the suppliers of the main equipment be present at the start-up of the plant.

G. Operation and maintenance

In the four preceding sections, our analysis has been chiefly concerned with MHG implementation from the points of view of the comprehensive evaluation of resources and demand, pre-investment studies, financing, construction and start-up, and indirectly with operation and maintenance.

In this section, various points are considered in connection with the next phase in the establishment of MHG, namely its use and daily operation. This phase is of decisive importance, since even projects which have been efficiently managed throughout their implementation may fail unless organizational schemes and operating procedures are established which guarantee the optimal utilization of invested capital.

Frequent problems in MHG plant operation and maintenance are:

Unsuitable administrative, organizational and financial arrangements;

Insufficient liaison between the plant management and the local community and its organizations;

Limited capabilities for plant management and operation in rural communities;

Operating and maintenance costs disproportionately high in relation to the energy produced;

Excessive bureaucracy in the centralized management of small plants;

The high cost and problems of social adaptation associated with operators brought in from outside the community;

The frequently inadequate skill levels of locally recruited operators;

Excessively high tariff rates, inhibiting development in rural areas;

Rates too low to cover the costs of operation and maintenance;

Absence of technical support for maintenance and repair;

Inadequate component standardization and lack of spare parts.

The problems of MHG operation and maintenance are basically simple, as described in greater detail in chapter V. The chief difficulties are institutional in nature and have to do with the running and management of the plants as well as with the origin and technical background of the operators and maintenance personnel. Among the various administrative arrangements that may be adopted for MHG management, three typical ones are discussed below.

Direct subordination to a government or regional electric power authority

The advantages and disadvantages of an MHG administrative system directly subordinated to a government or regional electric power authority are described below.

Advantages

The possibility of centralizing actions of greater technical complexity and of taking advantage of the economies of scale inherent in the overall management of groups of plants;

High skill levels on the part of the personnel;

Solid financial and technical backing.

Disadvantages

Each plant is by itself too small in the context of a large organization, with the result that, of the extended decision-making channels, it may be neglected;

High operating costs as a consequence of high general expenses (overheads) and operator and maintenance costs;

The remoteness of the authority, and thus of the plant, from the local community and its problems;

Problems in reconciling water needs for irrigation and generation;

Difficulties in mobilizing community support for maintenance work at the site.

Establishment of a community energy enterprise, possibly in the form of a municipal enterprise, co-operative or other type of association

The advantages and disadvantages of establishing a community energy enterprise for MHG management are outlined below.

Advantages

Activities centralized at a level facilitating service-related decision-making.

Greater ease in mobilizing community support for maintenance work;

The resolution, within the community, of conflicts of interest regarding the use of the water;

Lower operating costs.

Disadvantages

Little experience and know-how in business management;

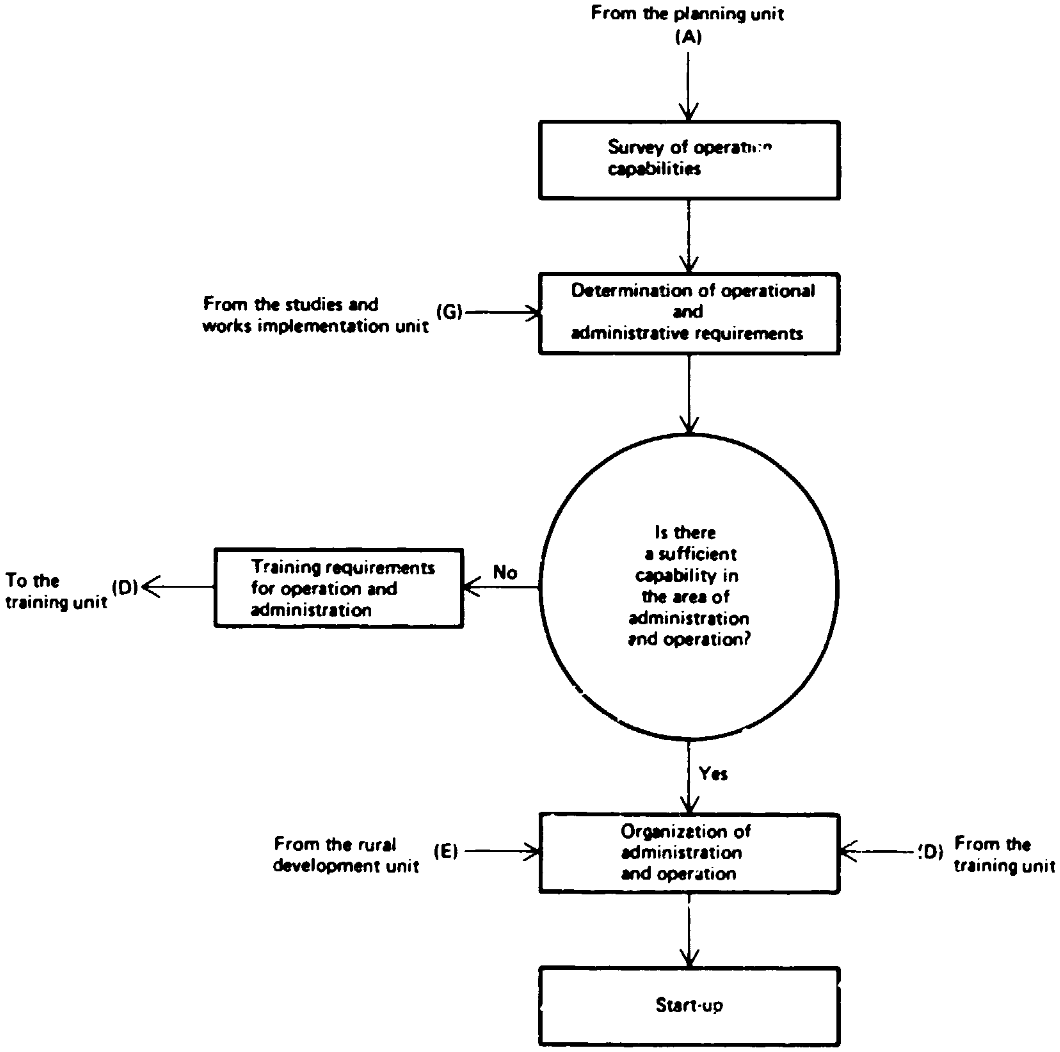
Problems in collecting electricity bills and in the use of financial reserves (which might occasionally be improperly diverted to other purposes) for replacement and maintenance;

The possibility of faulty maintenance;

Poor opportunities for economies of scale.

Private power enterprise

A private power enterprise, even in countries with a market economy, raises problems when applied to public-service MHG in rural areas, since such plants are not generally regarded as investment opportunities offering an adequate profit margin, but as tools for the promotion of development. Normally, the best prospects for such an alternative are provided by independent producers who require energy for their production activities (agro-industries, sawmills, mines etc.) and can sell any surplus power to nearby communities. The selection of the appropriate administrative arrangement will depend on the socio-economic structure of the country, the extent to which such plants have been developed there, the capacity and nature of the electric power enterprises, the size and remoteness of the plants, and finally the traditions, work experience, and managerial skills of the community.



Note: Letters within parentheses refer to units covered in figure 9.

Figure 17. Operations unit

Without advocating any one particular scheme, it is often possible to adopt a combined model involving a communal, municipal, or co-operative enterprise in association with the government electric power authority.

General guidelines for a scheme involving a communal enterprise in association with an electric power authority are presented below:

(a) The enterprise is set up in accordance with the contributions made to its establishment, the value of the manpower, materials, and services employed being regarded as the contribution of the community;

(b) The enterprise has a board of directors consisting of a representative of the electric power authority and of the representative organizations or associated bodies of the local community and local municipal authorities;

(c) The enterprise will employ the minimum number of personnel required for its operation with a view to covering four basic requirements: the administration of funds, the collection of bills, the operation of the plant and preventive maintenance, for which the number of employees may vary according to the size of the plant and the extent to which its equipment is automated. At small plants, with an output of less than 100 kW, the total staff may consist of one or two operators to be also responsible for administrative tasks and the collection of bills in addition to their duties in the area of operation and preventive maintenance. At larger plants which service a small system, there may in addition be an administrator and a bill collector;

(d) As far as possible, all the personnel of the enterprise should be recruited from the local community and trained by the government or regional electric power authority;

(e) The electric power authority will train the operating personnel of the plant in preventive maintenance, and will provide technical support, in the event there is a need for repairs, in the form of flying maintenance brigades set up to service groups of plants at the regional level;

(f) The community enterprise will collect and administer the funds raised through billing, and will maintain a reserve to finance repairs and replacements and, if possible, the physical expansion of the plant, in addition to covering normal operating costs and staff salaries and wages;

(g) The community enterprise will be responsible for ensuring that the funds are used only for the purposes established in relation to the development of the local power system. The government or regional electric power authority will be responsible for supervising and auditing the management of the funds;

(h) The community enterprise and the government or regional electric power authority will define the terms of their co-operation in an agreement or contract;

(i) Direct investment contributions by the electric power authority and the community will not be returned nor will they earn profit. The financing received in the form of loans may be either assumed by the electric power authority or returned in whole or in part by the community enterprise.

The functioning of the operations unit is reflected in figure 17.

H. Requirements in the area of human resources and training

The successful implementation of MHG plans, programmes and projects requires the promotion of training courses, including aspects relating to non-conventional technologies, civil engineering design and construction, electromechanical equipment and its repair and maintenance. The following steps should be taken in organizing the courses:

(a) Infrastructure survey of training establishments;

(b) Securing of funds for financing the courses;

(c) Establishment of a pilot training programme on the subject of the development of water resources, with particular reference to rural areas;

(d) Establishment of programmes to provide specialized training in MHG.

It would be advisable to carry out a survey of the capabilities of the country with respect to centres of higher education, research institutes and special schools for the training of intermediate-level technicians. As an initial step, a pilot-technology programme on the development of water resources in rural areas should be established. On the basis of the experience gained with such a programme, a decision could be reached as to the possibility of organizing a specialized course in MHG. It would be best if developing countries began by organizing exchanges of experience among themselves before seeking to supplement their information from outside sources.

The various types of MHG engineering training courses include the following: training courses, undergraduate regular courses in the field of non-conventional technology, and specialized postgraduate courses. The training courses, which are of short duration, are designed to provide current information on all phases of MHG design and installation for engineers whose activities are related to MHG development in their various phases of execution. A very important factor is the need to improve the standard curricula of the engineering departments of universities and institutes of technology by including courses on MHG and applicable non-conventional technologies. Post-graduate courses as such will be conducted at a more advanced theoretical level and may, in principle, extend over an entire academic year.

The following recommended guidelines should be borne in mind in planning the engineering courses:

(a) The courses should be designed to consolidate the advances already achieved in the country;

(b) The courses should be organized for all areas of specialization and graded differently according to area. The emphasis should be on the preparation of monograph studies by interdisciplinary groups;

(c) The courses should cover the areas of civil, electrical, mechanical and industrial engineering, economic administration and operations research.

The following recommended criteria should be applied in preparing courses for intermediate-level technical personnel:

(a) Theoretical aspects should be considered within the same programme for engineers and as a part of in-plant training;

(b) An MHG plant for training should be established for the training of technical personnel and skilled workers. Experimentation in the use of non-conventional technologies might also be conducted at such MHG plants;

(c) The courses should cover civil construction, electro-mechanical equipment and administration, all primarily from a technical point of view;

(d) The training of mechanics and maintenance electricians should be undertaken through the establishment of training units in the major repair shops.

The basic objective of the course is to help narrow the existing gap between the number of people with higher education, where there has been a relative advance, and the shortage of intermediate-level technicians, which is a general phenomenon in developing countries. With respect to the training of MHG operators, preference should be given to institutionalized arrangements designed to train operators from rural areas. It has been concluded, on the basis of a certain amount of experience, that the first part of the courses should be carried out at the school plant and continued at existing MHG plants. The first part should be of a theoretical and practical nature, in keeping with the educational level of the operators. In the case of rural operators, it should be expected that they will have completed at least their primary education. The course would run three months and cover the following subjects:

Basic sciences (fundamentals of mathematics, physics and chemistry);
Basic operating principles of an MHG plant and its equipment;
MHG plant operation and the interpretation of operating manuals;
Preventive maintenance principles and methods for MHG;
Maintenance and repair of building structures and installations;
Maintenance and minor repairs of mechanical and electrical equipment;
Mechanical and electrical trouble-shooting;
Identification of mechanical and electrical malfunctions;
Fundamentals of technical drawings and diagram reading;
Fundamentals of electrical installations;
Reading of instruments;
Bench-work mechanics (fitting);
Safety in operation;
Fundamentals of administration and book-keeping;

The second part would be essentially of a practical nature and would consist of a two-month period of operator training at an existing MHG station under the supervision and instruction of a skilled operator.

The manpower requirements at each stage of an MHG project are as follows:

1. *Planning and programming*
   Engineers
   Economists and social scientists
2. *Global evaluations of resources and demands*
   Civil engineers
   Hydrologists
   Geological engineers
   Geomorphologists
   Ecologists
   Electrical engineers
   Mechanical engineers
   Energy economists
   Social scientists
   Topographers
   Hydrometry specialists
   Draughtsmen
   Engineering assistants

3. *Studies of specific projects*

   Civil engineers (mainly structural engineers, supported by specialists in hydraulic engineering)
   Mechanical engineers
   Electrical engineers
   Topographers
   Technical draughtsmen
   Engineering assistants
   Test inspectors

4. *Construction*

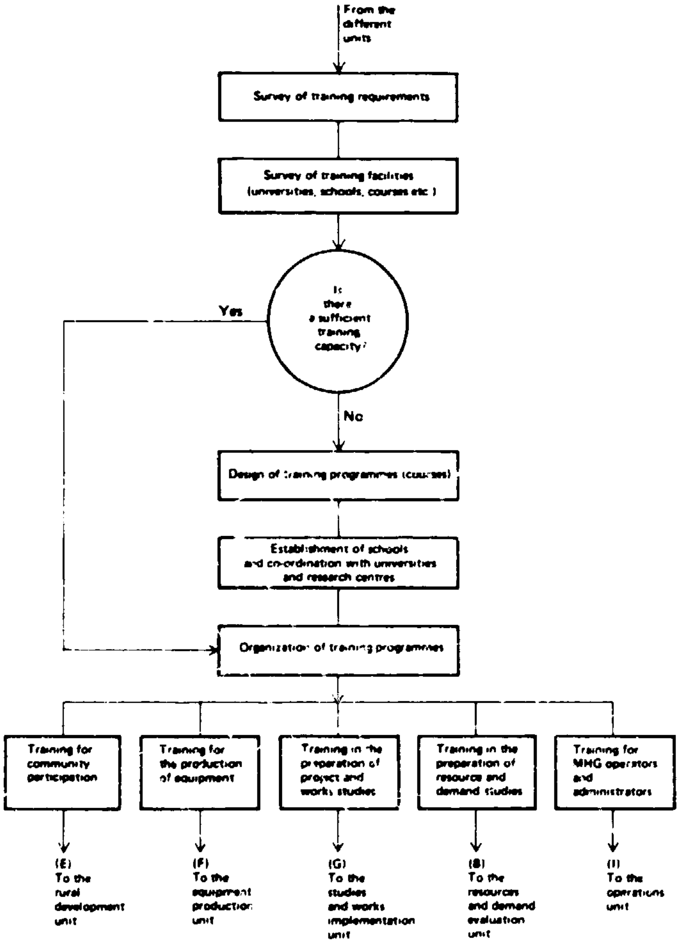
   Civil engineers
   Electrical engineers
   Mechanical engineers
   Topographers
   Draughtsmen
   Building inspectors
   Electrical technicians

5. *Operation and maintenance*

   Electromechanical engineers
   Mechanics and electricians

Each country must determine its manpower requirements for technology development and production of equipment and materials in accordance with the nature of the programmes and activities it intends to implement. The above list represents an ideal situation. In actual practice, countries may begin their programmes with fewer human resources, since it may be expected that as the work proceeds they will be able to find solutions to their temporary lack of qualified personnel.

A flow chart for the training unit is presented in figure 18.



Note: Letters within parentheses refer to units covered in figure 9.

Figure 18. Training unit

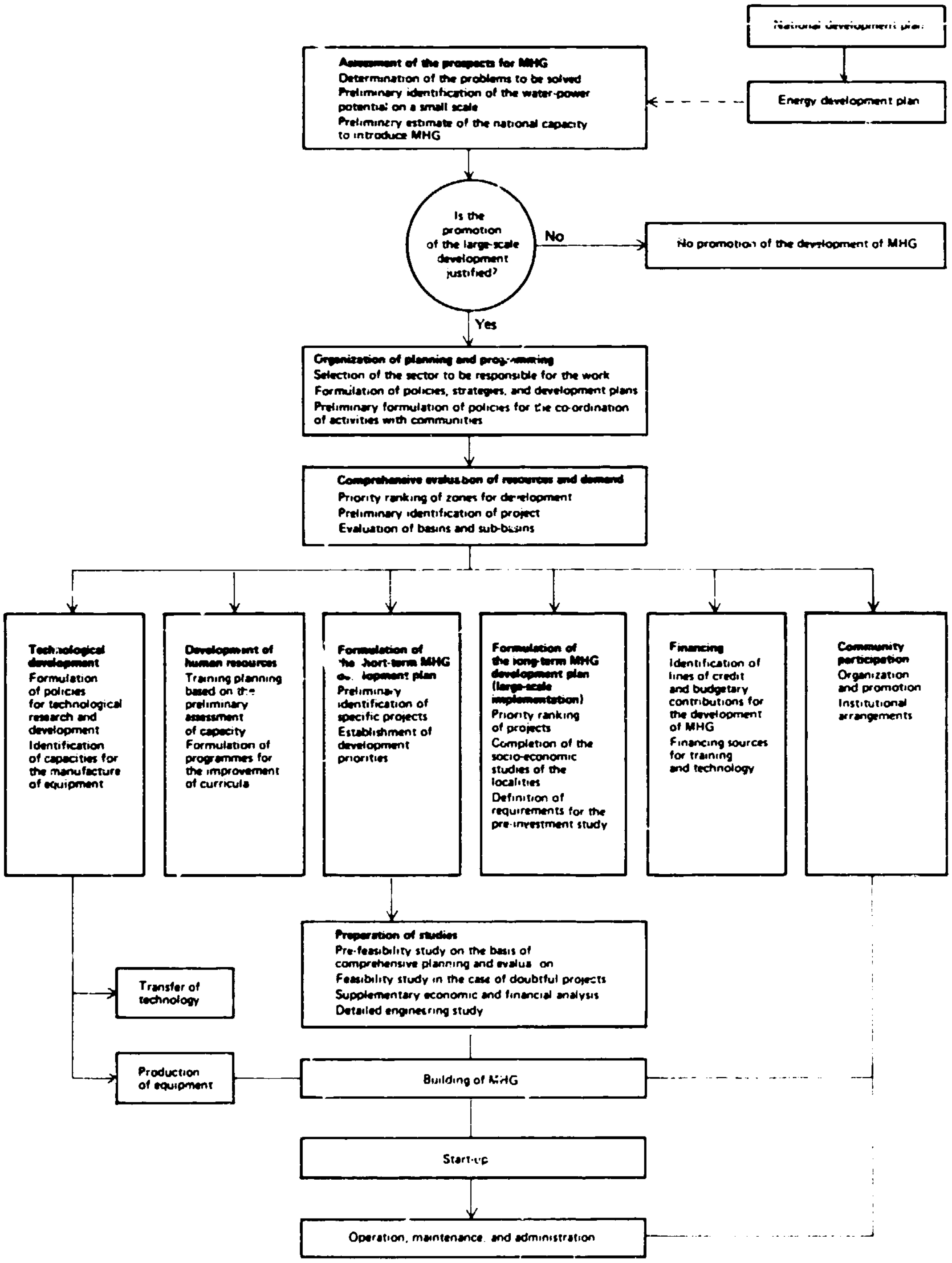


Figure 19. Flow chart of action required for building MHG stations on a large scale

I. Synthesis of the MHG building process (from planning to completion)

As indicated in the preceding sections, the decision-making process involved in the building of MHG must be of a comprehensive nature, because a number of different factors need to be considered. It may be seen from figure 19 that the process begins with a preliminary assessment of the prospects for the stations. This phase must include a study of the problems to be solved, the available water resources and the capacity of the country to undertake MHG projects within the context of its national development planning, specifically in the area of energy development. Following the completion of the preliminary study, a political decision must be made as to whether to mount the necessary effort to build the facilities.

If it is decided to move forward in this direction as part of the national development policy, the next step is to establish an organizational framework for planning and programming and to devise procedures for the evaluation of resources and demand at the basin and sub-basin level. The proposed framework and procedures would serve as a basis for the formulation both of a short-term development plan permitting the immediate implementation of specific projects and of a more long-range plan envisaging the building of MHG on a large scale. At the same time, policies must be defined and actions taken in the areas of financing, the development of human resources (training), community participation, and technological development. This final aspect is critical to the determination of guidelines regarding the transfer of technology and the promotion of domestic equipment production.

It is within the context of such plans and policies that the undertaking of specific projects should be initiated. The first stage in this connection consists in the preparation of a pre-feasibility (reconnaissance) study, if necessary. A feasibility study should be considered only in doubtful situations when such a preliminary analysis is required. In many cases it may be eliminated altogether and the detailed engineering study, including a supplementary economic and financial analysis, begun immediately.

The next phase of the project is concerned with the actual building of the plant and the installation of its equipment, followed by the start-up of the facility (for details see chapter III, section F, and chapter V, section D).

Finally, there is the task of establishing operating procedures for the plant, which also include the areas of maintenance and administration. The essential work of this stage is described in chapter III, section G, and chapter V, section E.

IV. Development of technological capabilities

A. Assessment of technological capabilities

The technological development of a country should start with an inventory of its human resources and industrial potential. In the case of technological development for the construction and equipment of MHG stations, the inventory should focus on the identification of human resources and the production of equipment and materials.

With regard to materials and equipment not produced in the country, the possibility of developing technology for their production or acquiring foreign technology, if justified by the national or regional market, should be considered. The alternative would be to import the materials or equipment components.

The production required to meet the needs of MHG and the industries involved in such production includes the following:

Materials for civil engineering works

Granular materials, clay and silt
Cement
Steel construction bars
Pressure pipes for penstocks (steel, PVC, polyethylene, asbestos-cement)
Gate and butterfly valves
Grates and gates
Wood
Steel cables
Bricks
Tiles
Nails
Explosives
Galvanized wire mesh
Bolts, nuts, washers and screws of various types

Equipment and tools for civil engineering works

Pickaxes
Spades
Wheelbarrows
Motor pumps
Concrete mixers

Electromechanical materials

Copper and alloys
Structural steel
Stainless steel
Shafts
Bearings
Electrical conductors
Posts and accessories
Electrical materials

Electromechanical equipment

Hydraulic turbines
Speed regulators
Electricity generators and voltage regulators
Measuring instruments (voltmeters, ammeters, power factor meters, frequency meters, kilowatt meters and energy meters, manometers)
Mechanical transmission systems (gears, belts and couplings)
Measurement and high-tension power transformers

Industries involved

Casting
Metalworking and engineering
Precision engineering
Electrical engineering and allied industries

B. Equipment

Manufacturing capacity

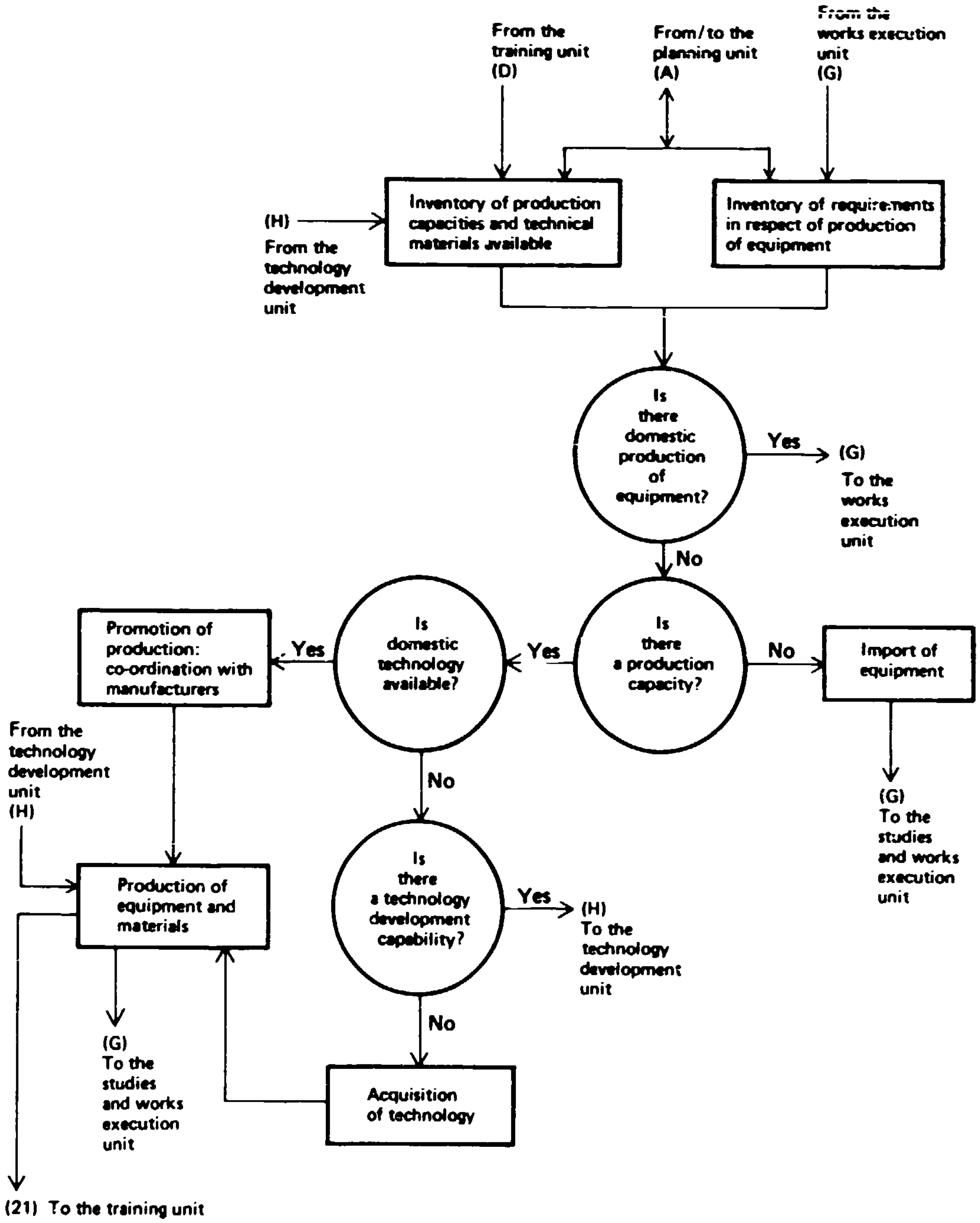
Once the materials and equipment for MHG in a particular country have been identified, an analysis must be carried out to determine the advisability of the local production of imported equipment (figure 20). Some of the requirements which should be taken into account for the production of MHG equipment are given below:

(a) Adequate technical information on production is essential. Alternative sources of technology are as follows: applied research by the manufacturer himself; applied research by centres and institutes within the country; and purchase of technology from foreign manufacturers and research centres;

(b) Emphasis should be placed on items which are of a size and type making them appropriate to the productive infrastructure of the individual country;

(c) The use and adaptation of materials of domestic or regional origin should be maximized;

(d) The equipment produced should be standardized;



Note: Letters within parentheses refer to units covered in figure 9.

Figure 20. Equipment production unit

(e) Production lines associated with those producing related equipment should be set up, because the exclusive production of equipment for MHG is not justified by the small size of the market;

(f) The production of spare parts, mainly those subject to wear, should be contemplated, and a permanent stock of such parts maintained.

Various allied industries are involved in the production of MHG equipment and materials.

Equipment and material	*Allied industry*
Pressure pipes for penstocks	Factories manufacturing pipes with markets determined by domestic industry rather than MHG.
Hydraulic turbines and speed regulators	Metalworking and engineering enterprises, factories manufacturing centrifugal pumps, valves, vacuum equipment, fans, mixers and foundry shops.
Electricity generators	Factories producing alternators for thermal electricity generation units and factories producing electric motors.
Transformers, electrical materials and accessories	Electromechanical machinery industries.

Development and adaptation of technology

Technological research and development can be one of the basic tools for promoting and sustaining programmes for the construction of MHG in individual countries, since the technologies involved are mature, and only adaptation and innovation processes of a non-conventional nature, permitting adjustment to the specific conditions of the individual country, are required.

Owing to the great diversity of existing situations with regard to research activities, MHG construction programmes and industrial development, it is not possible to establish a single organizational pattern for the development and adaptation of technologies which would be applicable in all third world countries. Therefore, only a few general recommendations and alternative organizational patterns are presented below for the guidance of countries interested in promoting programmes for the development and adaptation of MHG technology.

In the MHG national development plans of each country, the development and adaptation of equipment technologies will have to be regarded as part of planning. It will therefore be necessary to determine specific policies, general objectives and the resources to be allocated. The following recommendations should be considered in organizing programmes for the development and adaptation of MHG technology.

(a) There must be a well-defined financing prospect from the stage of programme determination so as to avoid the loss of research projects owing to shortage of funds;

(b) In order to achieve correct administration of the programme, there must be operational follow-up as regards results, the time required for execution and utilization of funds;

(c) From the initial stage of the programme, the form and characteristics of results, which may involve dissemination and transfer of technology, must be clearly defined (see figure 21);

(d) A variety of institutional criteria may be adopted for programme implementation, which may take place through universities, research institutes, industrial enterprises and electrification boards;

(e) Normally, the programme will be executed through research lines or interrelated groups of projects. Each requires a brief but clear specific formulation prior to initiation;

(f) The programme may be divided into two types of activity: aspects relating to civil engineering works and installations, and aspects relating to design and production of equipment and materials;

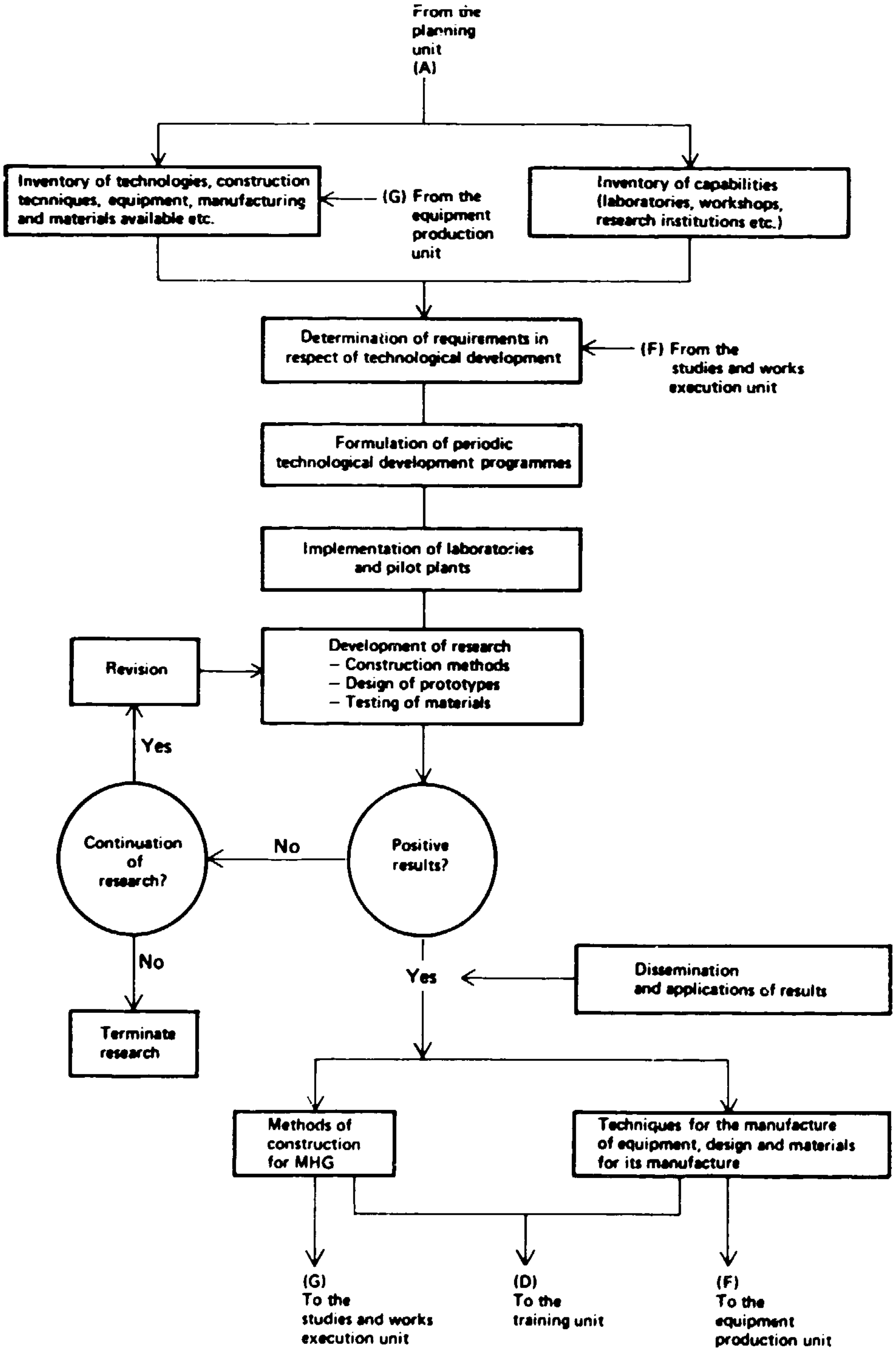
(g) Each project should have a well-defined execution sequence. Figure 22 shows a typical methodology;

(h) The programme execution team need not necessarily consist of experts. Only one or two experienced professionals are required, and the remainder may be young professionals with a good academic background;

(i) Guidelines should be established for the preparation, at each stage of the project, of documents and reports, which should reflect positive and negative aspects and failures, so as to ensure continuity and the accumulation of knowledge useful for the programme, thus avoiding a situation of dependency on the presence of each individual executor;

(j) During programme execution, the executing agency must maintain close contact between the industry and the enterprise responsible for electrification, in order to achieve results with practical application;

(k) Dissemination of results may take place through manuals and brochures in the case of installation and construction of civil engineering works;



Note. Letters within parentheses refer to units covered in figure 9.

Figure 21. Technology development unit

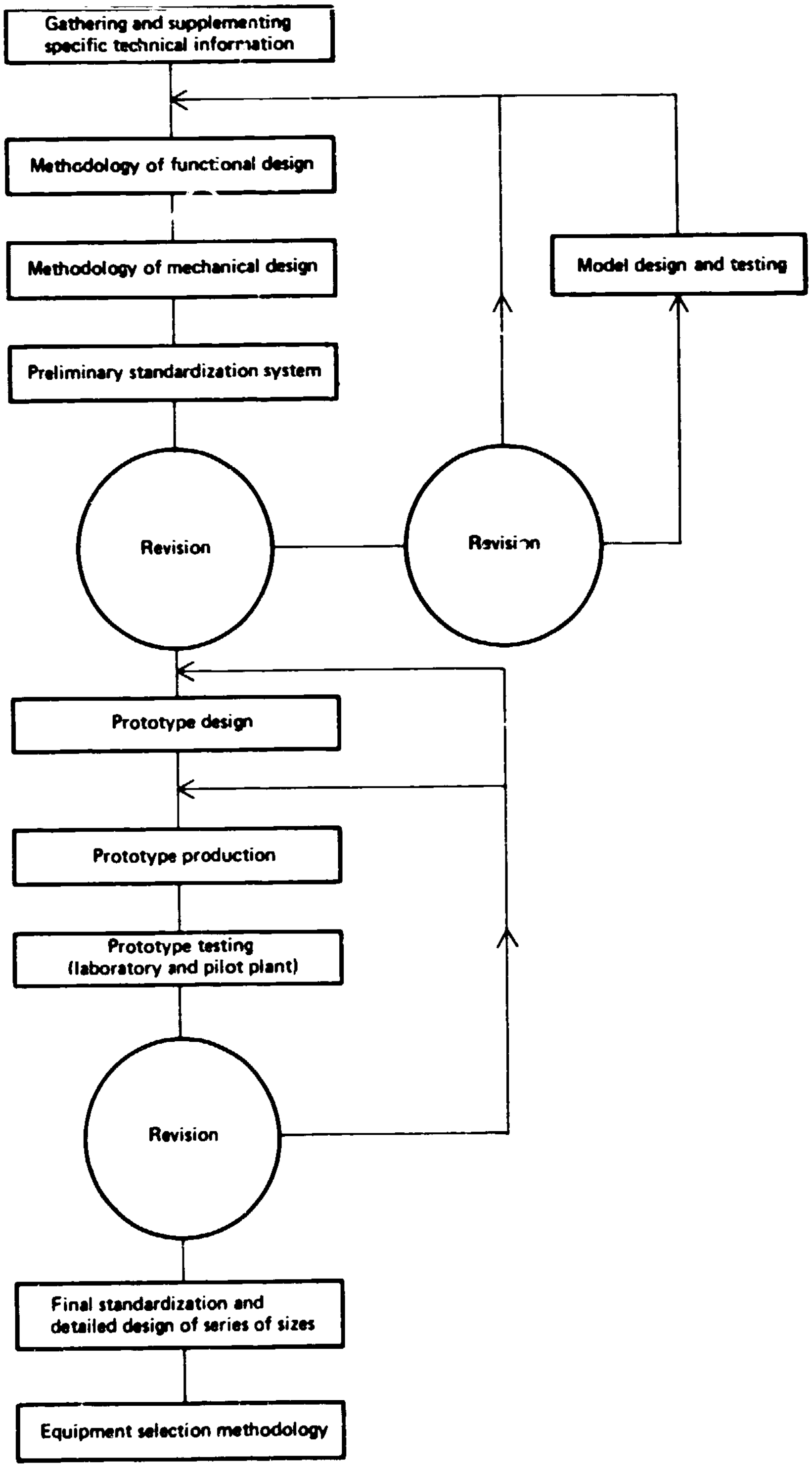


Figure 22. Typical sequence in the execution of a specific technological research project for MHG equipment

(l) In the case of equipment, results may be transferred to industry in order to promote the industrial production of such equipment, the enterprise being provided with all technical information required;

(m) The development and adaptation of equipment technology should be focused on development of non-conventional technologies, taking as a point of reference the industrial capacity of each country.

The flow chart of a technology development unit and the stages in the formulation and execution of MHG technological research projects are reflected in figures 21-23.

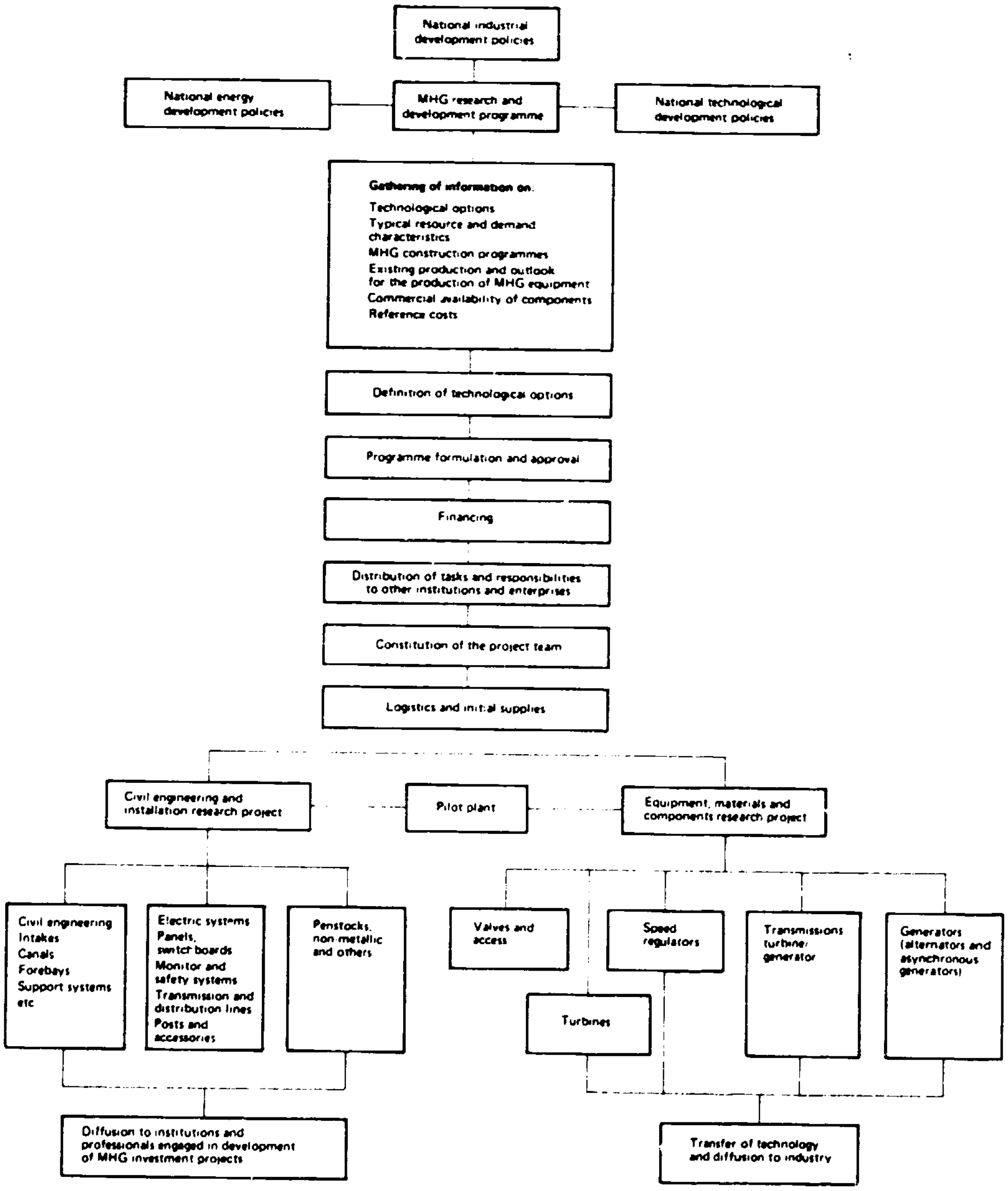


Figure 23. Stages in the formulation of an MHG technological research project

The technological development of MHG equipment could proceed along the following lines:

Technological alternatives in the production of MHG equipment

Equipment	*Type*	*Recommendations for technological development*
Hydraulic turbines	Pelton, Michell-Banki, Francis, Kaplan or axial flow	Selection of two or three types of turbine in the light of the characteristics of resources and demand in the country Development of hydraulic and mechanical designs Study of aspects relating to construction and materials for each part, in the light of the characteristics of the industrial production of the country Establishment of methods for the selection of turbines Establishment of methods for assembly and disassembly of equipment Establishment of recommendations for operation and maintenance
Speed regulators	Oleo-mechanical, electric/electronic, energy dispersion	Selection of the type of regulator most suitable in the light of the characteristics of operation, industrial capability in the country and technological experience Functional, electrical and mechanical design Standardization as appropriate for standardized turbines Preparation of manufacturing manuals Studies on matters relating to construction and materials Establishment of methods of selection Establishment of recommendations for operation and maintenance
Electricity generators	Alternators for MHG, induction motors as generators	Study for the adaptation of the alternators for thermal electricity generation units, mainly as regards runaway speed protection, so that they may be used with hydraulic turbines Adaptation of electric motors to operate as autonomous generators Establishment of recommendations for operation and maintenance General design of generators and most suitable manufacturing process
Electricity transformers	High-tension power, measuring	Studies of designs and forms of construction, taking into account the industrial capability of the country Standardization Establishment of recommendations for operation and maintenance
Miscellaneous electrical equipment and materials	Control panels, conductors, insulators, lightning arresters	Study for the production of this equipment after standardization Establishment of methods of selection Establishment of recommendations for installation and maintenance

Acquisition of technology

Depending on the level of development of each country as regards capacity to generate usable technologies, project execution possibilities and prospects for the production of equipment, it will be necessary to acquire a greater or lesser amount of technology from other countries. The various means of acquiring knowledge which can be used in production, ranging from technical assistance and the provision of information to the purchase of technological packages to set up production lines, including detailed plans and instructions for manufacturing, assembly and technical services, can be looked upon as purchases of technology.

Most countries have their own legislation regulating the acquisition of technology, and it is therefore impossible to lay down specific guidelines on the matter, but general recommendations can be made regarding the acquisition of technology for manufacturing MHG equipment. With regard to MHG, the acquisition of technology relates primarily to the electromechanical equipment and accessories.

Various considerations and recommendations which should be borne in mind in connection with the acquisition of technology are given below:

(a) With a view to achieving technological development in keeping with the characteristics and industrial capacity of a country, it is advisable to limit the acquisition of technology to cases in which the development of technology is not considered to be of interest;

(b) The acquisition of technologies should take place through a process of selection of alternatives and should be limited to those parts in respect of which the level of technological development attained makes possible full production, in keeping with the priorities laid down for national technological development. The acquisition of technology should be organized in such a way that it makes a real contribution to such development by permitting the assimilation of knowledge by national technicians. Disguised commercial elements of acquisition of technology and technical assistance, aimed only at the granting of exclusive licenses under the appearance of bilateral assistance programmes, must also be avoided;

(c) The acquisition of technology will be justified when the complexity of the equipment or of some of its parts surpasses the development capacity of the country. Acquisition should be confined to those elements which are necessary and cannot be designed or manufactured in the country without foreign assistance. Restrictions making it necessary to import parts which could be locally produced should be avoided, while, on the other hand, the local manufacture of components and use of materials available in the country should be promoted;

(d) The fullest and most careful analysis possible should be made of alternatives prior to any process of technology transfer. Inclusion of the largest possible number of alternatives under the same terms of reference should be ensured, and evaluation criteria should be laid down prior to the analysis. Technologies appropriate to the industrial and technological level of development of the country, using mainly local raw materials and labour, should be given favourable consideration;

(e) Contracts for the purchase of technology should be concluded with fixed periods of duration, at the end of which the obligation to pay royalties ceases, and the royalties should be fixed only on the basis of a percentage of sales, avoiding the inclusion of minimum payment obligations. Restrictions with regard to the scope of the market for products should also be avoided, and obligations to purchase raw materials from a given supplier should not be accepted, thus preserving the freedom to purchase on the market if more favourable terms can be obtained;

(f) In order to improve the negotiating capacity of national enterprises in respect of the acquisition of technology, it is important that clear policies should be defined and that legislation should tend to limit the imposition of restrictive clauses by suppliers and technology.

Import of equipment

If the specific characteristics of a country as regards its industrial policies or production capability are such that the local manufacture of certain types or sizes of equipment is not justified, those items must be imported. In such cases, personnel trained in the analysis and selection of alternatives and the technical equipment required for carrying out acceptance testing are necessary. The support which can be extended in this field by institutions engaging in technological research is important.

In purchasing equipment, the following technical considerations must be taken into account: the capability for the manufacture and repair of components and spare parts in the country; characteristics of maintenance and operation appropriate to the conditions of use; ability to withstand situations arising out of errors of operation; and ease of assembly and disassembly of parts and accessories.

In addition to the requirements in respect of fulfilment of technical specifications, guarantees, costs and delivery date for equipment, suppliers should be asked to provide the following: general assembly drawing of equipment; detailed drawings and information on the materials used in the main components of the equipment which are subject to repair; lists of spare parts; instructions for assembly, disassembly and repair; and technical assistance for the training of local personnel responsible for the maintenance and repair of equipment.

For bidding or tendering for the acquisition of electromechanical equipment for MHG projects, it is important that the following technical data should be provided: usable head, maximum generating power at the contacts of the generator; generating frequency; generating voltage; and environmental conditions under which the equipment operates.

The suppliers of the main pieces of equipment should also be asked to provide the following technical data: type of turbine and its specifications; efficiency curves of the turbine and generator operating under different load conditions; type of speed regulator and its specifications; characteristic curves of operation of the regulator; type of mechanical transmission or direct coupling between turbine and generator; and specifications of the control panel or switchboard, including ranges and accuracy of the instruments integrated into it.

When bidding or tendering is carried out, it is recommended that a list of possible suppliers should have been identified in advance. They should be asked to provide information on: reliability and efficiency of their equipment; cost indexes; credit facilities; expected life term of equipment; fulfilment of delivery dates; and ease of adaptation of equipment to local industry for the manufacture of spare parts.

C. Development and adaptation of technologies for construction

With regard to the development and adaptation of technologies for construction, it is essential to stress the need for research both on methods of construction and on the use of non-conventional materials. The research must be linked with investment projects by means of pilot plants.

Although the design and construction of civil engineering works are largely determined by the nature of the site, the possibility of preparing manuals envisaging standardization or semi-standardization of civil engineering works must be investigated. It is also very important to organize research relating to the production of prefabricated elements for civil engineering works.

The institutions carrying out research on materials and various elements for MHG should co-ordinate their activities with the units which are engaged in engineering activities in the field, and which may be carrying out research in the context of investment programmes during and after construction. The research concerning materials should be oriented towards establishment of their hydraulic and mechanical properties.

In general, there are two technological alternatives as regards civil engineering works. One, the conventional alternative, is based on the use of concrete, reinforcing steel and structural steel, considering separately the structures required for MHG. The other involves a minimum utilization of those materials and endeavours to integrate structures, such as the silt basin and forebay, and utilize existing infrastructure, such as irrigation canals. As regards methods of construction, mention can be made of those based mainly on intensive use of labour, in the optimum case with community participation, those based on intensive use of machinery, and mixed cases.

It would be highly advisable to promote or support surveys to increase knowledge of existing production capacities of materials so as to be able to develop their supply. Construction technologies should be disseminated by means of manuals for the design and execution of works.

D. Check-list of technological alternatives

The technological alternatives most suitable for each country cannot be rigidly stated because the conditions governing the development and adaptation of technology for MHG will vary, as will conditions relating to geography, hydraulics, labour, availability of skilled manpower, appropriate financing etc., all of which have a bearing on the determination of technological alternatives.

Taking into account the above-mentioned factors, a selection of possible areas of interest for technological development is presented below.

Construction

The various materials which can be used in the civil engineering works for MHG are analysed below. It is important to stress that, in the context of non-conventional technologies, the following is taken into account: use and improvement of existing intakes and irrigation canals; forebay installed "in-line" with the canal and including the silt basin; penstock conduit in non-metallic materials, dams of artisanal construction, reduction to a minimum of the use of costly materials such as concrete, and use of non-conventional materials such as ferrocement, soil cement etc.

It is advisable to specify materials taking into consideration the applicable national standards, and when these are not available, to use appropriate foreign standards and norms. It is important to promote the development of national standards for the main materials employed in MHG, in order to ensure the drafting of adequate specifications and good quality control.

The technological alternatives arising from the characteristics of various materials are presented in table 6.

TABLE 6. TECHNOLOGICAL ALTERNATIVES IN THE USE OF MATERIALS

Material	*Use*	*Advantages*	*Disadvantages*
Clay and silt	Dams or core walls	High degree of impermeability	Possibility of fracturing
Granular materials	Dams or core walls	Low degree of impermeability	Better performance under external loads
Wood	Dams, penstocks, powerhouse, gates	Low price	Short life
Gabions	Dams, canals, protection of slopes	Low cost, easily adapted to the site	Permeable during the initial period

TABLE 6 *(continued)*

Material	*Use*	*Advantages*	*Disadvantages*
Concrete	Dams, canals and anchorages, core walls, forebay, powerhouse	Durability, resistance to high compression	High cost, poor performance in torrent works
Ferrocement	Linings, silt basin, forebay	Low cost, high general resistance	Low resistance to concentrated and piercing loads, exacting construction
Soil cement	Linings, dams	Low cost	Poor durability, low resistance
Polyvinyl chloride (PVC)	Penstock	Low cost, light weight, rapid installation, easy adaptation to profile, low head losses	Relative fragility; should be buried, low resistance to solar radiation
Polyethylene	Penstock	Continuous lengths, withstands considerable deformation, ease of transport and installation, good resistance to impact and solar radiation	Joints require special steel couplings which are exacting to install, high head losses
Asbestos-cement	Penstock	Lower cost than in the case of PVC, good adaptation to the profile of the fall, no expansion joints required, reduced head losses	Relatively heavy and fragile, so that it is advisable to bury them

Equipment

The list below describes the principal items of equipment used for MHG, together with a number of recommendations for the development of technology research projects.

Hydraulic turbines

Type	*General characteristics*
Pelton	This is a tangential-flow action turbine consisting of one or more nozzles and a runner carrying a certain number of buckets. The range of application of Pelton turbines is limited to low specific speeds. Operating with high heads and reduced flows, this turbine can give an efficiency of approximately 85 per cent. Its manufacture requires an industrial plant equipped to perform operations of casting, welding, cutting and basic machining (turning, planing, and drilling). The runner and nozzles are normally produced by casting.
Michell-Banki	This is a partial-admission, cross-flow, action turbine with radial intake, and consists of an injector and a runner having a certain number of curved blades. The range of application lies between that of the double-nozzle Pelton and the high-speed Francis turbine, in situations involving medium heads and moderate flows. This turbine can operate with efficiencies in the order of 80 per cent and generate up to 1,000 kW of power. Because of its particular geometry, the Michell-Banki can be easily produced and is regarded as a low-cost turbine. Its manufacture requires an industrial plant equipped to perform welding, cutting, and basic machining operations (turning, planing and drilling). It can be produced using welded parts.
Francis	The use of this turbine is restricted to medium specific speeds and, like the Michell-Banki type, to medium heads and moderate flows. Its efficiency lies between 83 and 90 per cent. Its manufacture requires an industrial plant with the necessary equipment for casting, welding, cutting and machining.
Axial	This is an axial-flow reaction turbine, with a speed control system incorporated in the runner in the particular case of Kaplan turbines. Its area of application is limited to fairly high specific speeds. Operating with very low heads and large flows, it is capable of achieving efficiencies of about 90 per cent. Its manufacture requires an industrial plant set up for casting, welding and cutting, and equipped with the usual basic machine tools.

Speed regulators for hydraulic turbines

Type	*General characteristics*
Electrical-electronic (with flow control)	This regulator consists of an electronic device designed to detect variations in the speed of the turbine on the basis of the variations in generating frequency that accompany a change in load, and an electric motor which drives a mechanism opening or closing the flow regulation valve of the turbine in either direction. As the electronic unit is the same in all cases and does not depend on the power, this regulator is inexpensive to manufacture, the electric motor or the hydraulic servomechanism being the principal variable cost factor. Its manufacture requires an industrial plant specializing in electrical and mechanical work and with its own electronics shop.
Energy-dissipation (electrical-electronic)	This regulator consists of an electronic device designed to detect variations in the speed of the turbine on the basis of the variations in generating frequency that accompany a change in load and a system of electrical resistances that increase or reduce fictitious loads to maintain constant load on the turbine. The electronic device is similar to the one required for the electric-electronic regulator with positive water control Its manufacture requires an industrial plant with an electronics shop.
Oleo-mechanical	This kind of regulator consists of a speed sensitive element, usually in the form of a centrifugal pendulum, a force distribution element incorporating a pressurized oil distribution valve and a servo-motor, a compensation and reversing system designed to stabilize the velocity of the group, a gear or sliding vane pump, and a number of actuating devices to control the flow-regulation valve of the turbine. The cost of manufacturing this regulator is, comparatively speaking, higher than the cost of the electro-electronic regulator, and its production requires an industrial plant equipped to perform welding, cutting and precision machine-tool operations.

Electrical generators

Type	*General characteristics*
Alternators	These are generators with a design incorporating a voltage regulator and reinforced coils capable of withstanding turbine runaway speeds. For economic reasons, the use of two- or four-pole alternators is recommended for MHG. Manufacture requires an electro-mechanical plant with basic machine tools and equipment for the winding of coils, welding and cutting.
Induction generators	These are induction motors operating as generators either independently or in parallel with an alternator. Their manufacture requires no more than the adaptation of existing electrical motors and can be undertaken at the manufacturing plant itself.

V. Approaches to specific projects

A. Specific assessment of demand and resources

Demand

An important point to remember is that the demand estimated in the planning phase will be used for the specific projects phase. Demand is assessed in the light of local and regional conditions. The potential electricity demand is calculated and a global estimate of future growth in demand is prepared by establishing a planning target to be achieved in a time equal to the estimated time required for a grid supply. The analyses require field investigations and processing of the data discovered. The following activities are required for specific demand assessment: identification of the major development complex of the zone; identification of the area of influence of the development complex; inventory of socio-economic activities; identification of possible future growth factors in the zone; and analysis of data yielded by field work and other sources.

The possible sequence of phases in demand estimation is reflected in figure 24.

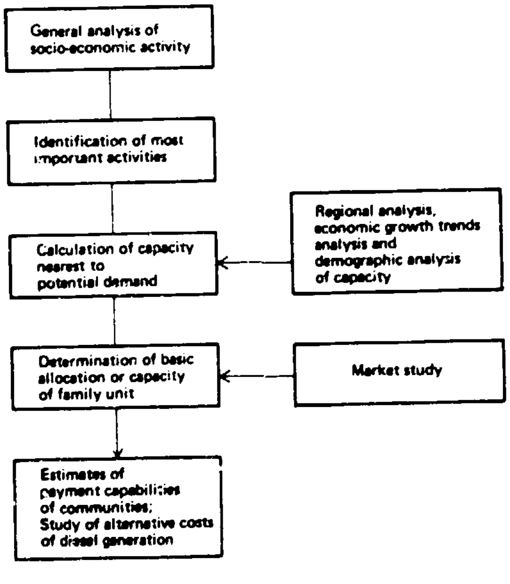


Figure 24. The process of demand estimation

Resources

Resources are estimated on the basis of analysing existing cartographic, geological, geomorphological, hydrological and ecological data, supplemented by field surveys, headwater surveys and topographic surveys. Possible headwaters are identified from information supplied by the local population. Headwaters located near, that is within approximately 15 km of, settlements in the basins under study are researched and their discharges surveyed.

The available head is determined by simple topographic methods. A pocket altimeter is satisfactory for high falls, and a precision altimeter should be used for low falls. In both cases a spirit level can also be used.

B. Selection of technology for the development and design of MHG systems

The general design criteria for the selection of technology for MHG systems concern the characteristics of the region, such as access facilities for possible future use of building equipment, and the availability of local building materials. Specific MHG design criteria are presented below.

Criteria for siting intake works

1. The maximum narrowing of the stream channel should be determined in order to minimize spillway length and, therefore, excavations and structural work.

2. A site should be found corresponding to the sediment conditions.

3. The best foundation for the structure preferably on rock out-croppings, should be found in order to ensure stability.

4. The minimum length of conduit in contact with maximum waters should be chosen in order to reduce the amounts of reinforced concrete

Design criteria for conduit systems

1. The plan should be suitably designed to minimize excavations.

2. There should be a minimum water flow rate of 1 m/s to avoid sedimentation.

3. The duct cross-section should be close to the optimum hydraulic value.

4. A check on seepage should be made to determine whether the duct walls and base need lining. As a general rule, lined ducts cost twice as much as unlined.

Criteria for designing silt basins and surge chambers

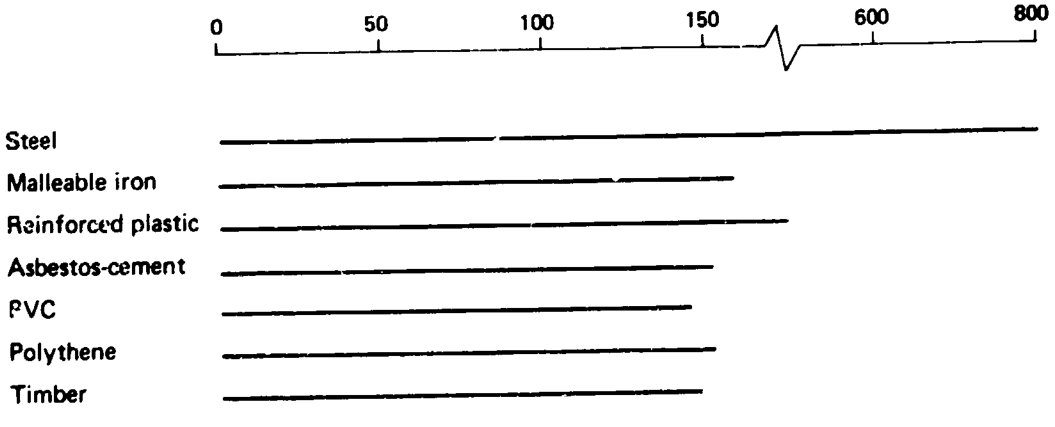
1. The capacity should be checked to ensure the following: appropriate supply to penstock; absorption and damping of oscillations arising from opening and closing of inlet valves due to variations in turbine loading; and control of water level at penstock inlet.

2. The design dimensions of the silt basin should be determined in the light of the permissible size of the particles that can be allowed to enter the turbine and the characteristics of the solids in the water.

3. The depth of the silt basin should be such as to preclude disturbances due to rising and descending flows caused by temperature changes.

Criteria for penstock design

1. Various materials are suitable and various types and sizes may be used in combination to achieve optimum solutions. The figure below shows the various materials which may be used under different heads (in metres):



In order to withstand the maximum permissible water hammer for power stations, the rated pressure of the tubing should be approximately 30 per cent more than the gross drop. Water hammer surging can be controlled by appropriate timing of the closing of the controller.

2. Building costs, which increase with diameter as well as with ground conditions, should be balanced against tubing pressure drop, which reduces output. This comparison will help to determine the optimum diameter.

3. Anchorages should be designed for safety factors based on overturning, sliding and bearing capacity. The tubing should also be studied for three different kinds of load: dynamic pressure load on tubing, static pressure load on tubing and load on empty tubing. It is also advisable to design a filter to extend along the whole length of the penstock to drain possible seepages.

Design criteria for powerhouses

1. The area to be built on depends upon plant requirements, head, water flow and the number of units. If enough funds are available, a residential area can be found for the operator. A water supply system with filter bed purification and a sewage system with septic tank would then be available.

2. Drains or some other system should be provided around the powerhouse perimeter to intercept surface water and keep down the level of the water-table.

Design criteria for transmission lines

The design of transmission lines is governed by the following variables: line voltage, capacity, power factor, length, height above sea level, average, maximum and minimum outside temperatures, and wind speed.

C. Building methods

The various methods of building the elements involved in MHG are considered below.

Dam

Gabions are easy to install and cheap. Possible early seepage can be prevented by concrete or timber bulkheads. Conditions may become critical with very low flows in cases in which significant losses are unacceptable.

If appropriate materials are available in the region, it is worth considering the alternatives of massive concrete or of brick. Massive concrete has the advantage of using appropriate rock coming from excavation works. This is the best solution for sites with high water heads over dams, but foundation problems are much easier with heads of below two metres. The main difficulty is that since the structure is rigid, cracking may occur due to differential settlements. If there are facilities for transporting materials and equipment, alternative combined structures for the dam and intake of reinforced concrete can be considered, provided that the structure is of small dimensions.

Intake

There are various possibilities. If there are old stream beds, they can be enlarged by excavation and the water diverted through them, so that the construction of the intake system can proceed in almost completely dry conditions.

Another possibility is to use sheet piling. The intake, lock and conduit are constructed first, then the spillway is constructed while the water flows through the lock and intake. This alternative calls for sheet piling of appreciable length and reduces the space available for working during construction. The maximum permissible discharge of the lock increases the risk of flood damage.

The first alternative may be better if excavation costs are justified by the reduction in risks and inconveniences as compared with the sheet piling alternative.

Silt basin

This can be positioned immediately after the intake works, in which case the nearness of the flow is used economically for sediment cleanliness. The water should also be free of sediment along the construction conduit, although sediment may occur in its open run.

Another alternative is to use a combined sand trap and forebay. This option is certainly cheap but requires a faster flow rate through the conduit system to prevent sedimentation. It is usually associated with the use of earth conduits and is useful for MHGs.

Penstock

Steel pipes are very expensive from the points of view of both materials and installation. Cement asbestos pipes are cheaper and easier to obtain, although in some cases there may be limitations due to the maximum commercially available diameters.

Powerhouse

Here more than in any other part of the civil engineering works, the use of pre-fabricated elements may be regarded as a means of cutting costs. It is very important to bear in mind local materials, not only for reasons of cost but also of appearance, taking into account their behaviour under seismic conditions.

D. Selection of equipment

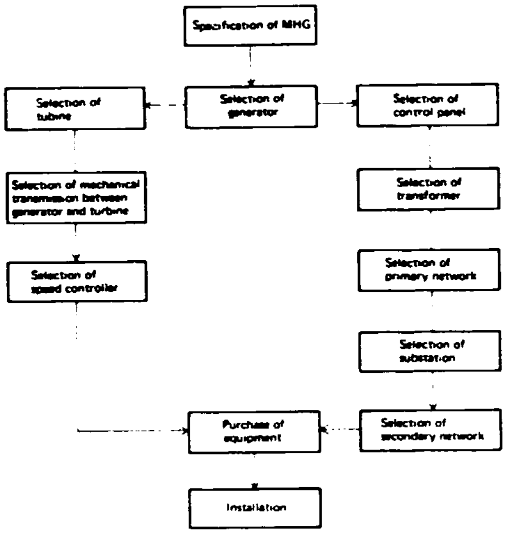
MHG equipment should be selected from the commercial catalogues of national and international makers of standard equipment. The main selection criteria should be reliability and cheapness.

Details of the procedure for selecting the various items of MHG equipment are given below.

Equipment	*Selection parameter*	*Selection procedure*
Trash rack	Allowable particle size	According to the specification of turbine materials, minimum flow selection and head. This can be for automatic or manual cleaning.
Valve	Pipe size, pressure	Mainly gate, butterfly, and spherical valves, according to pipe size, turbine intake, water head and closing time.
Turbine	Head, discharge, power	Once the characteristics of the turbines as explained in chapter IV, and the generator speed are known, a turbine speed can be decided on and the best kind of turbine can be selected using the methodology given in the annex. It should be remembered that turbine cost is inversely proportional to turbine speed. Once the kind of turbine has been decided on, a standard model suitable for the head, discharge and power is selected from commercial catalogues. These parameters will determine turbine speed, which will not differ greatly from the planned value.

Speed controller	Capacity, frequency	Selection of the speed controller is automatic once the turbine has been selected. The controller can be oleo-mechanical or electro-electronic.
Turbine and generator transmission	RPM, load	The mechanical transmission between the turbine and the generator should be selected in the light of the speeds of each and bearing in mind that belt transmission is used for high speeds and gearing for low speeds. If the turbine and generator both run at the same speed, a direct coupling is used.
Generator	Capacity	The generation voltage and frequency are selected with reference to electrical standards for generation in each country. The most appropriate kind of generator should be selected accordingly, as indicated in chapter IV. A generator of the required capacity and generation frequency and voltage should be identified in the commercial catalogues. Bear in mind that generator cost is inversely proportional to its speed.
Control panel for power-house	Capacity, voltage, frequency	A control panel should be selected to suit the maximum capacity, voltage and frequency of the generator. The aim should be to use the least possible amount of instrumentation compatible with effective control.
Power trans-formers	Capacity, voltage	Transmission voltage is selected in accordance with each country's standards for transformers and the transformer to be used may be selected from commercial catalogues on the basis of capacity. Remember that short-circuit currents may be five or six times the rated current.
Transmission or primary network	Capacity, transmission voltage	The optimum cable cross-section is selected in accordance with each country's standards for electrical conductors and to give minimum voltage drop and power loss.
Substation	Capacity	The distribution voltage is determined in accordance with each country's standards. The transformation ratio can then be found and the corresponding substations selected from the catalogues.
Distribution or secondary network (consumer connections)	Distribution voltage	The same criteria and standards used to select the primary network are used to select the secondary network.

The selection process is illustrated in figure 25.



Note: The selection process may also start with the turbine.

Figure 25. Process of equipment selection for MHG

E. Operation, maintenance and repair

Operational characteristics depend mainly on the size of the plant, the type of service, the level of control automation, the reliability of the equipment and the institutional structure of the electric power system.

Assuming an MHG with a low level of automation, limited to the velocity and voltage regulators and the safety systems, and designed to operate only a certain number of hours a day, a single operator might be all that is required. For a continuously operating MHG, on the other hand, two operators working in shifts would be needed. The operators must be able to perform their duties with competence and to handle tasks involving preventive maintenance and minor emergency repairs.

An MHG operator must have at least basic knowledge in the following areas: fundamentals of industrial electrical systems, bench machining, welding, administration and operational sequences.

Maintenance and repair operations may be distributed as follows:

Activity	*Responsibility*
Preventive maintenance of equipment	Operator
Preventive maintenance and general repairs to the civil engineering structures	Operator with community support
General equipment repairs	"Flying maintenance squads" of the electric utility or the operator
Major equipment repairs	Specialized workshops or the manufacturers

Recommendations concerning civil works

1. The channels, diversion dams, spillways, control sluice gates, piping, and conduits should be regularly inspected. The frequency of the inspections, which are extremely important, varies according to climatic conditions.

2. During flood periods, daily inspections should be carried out with a view to detecting threatening conditions caused by rising waters or slides. Such threatening situations may include: erosion of supporting pillars, unusual loads on the ducts at or along the river bed, the accumulation of waste material at the grids or gates of the diversion dams, unacceptable erosion below the diversion dams, or abnormal down-channel water levels. Flooding may be more of a problem at low-head installations than at high-head plants because it may damage the dam and the generating units. Slides may damage the canals and ducts, in some instances filling them with debris and causing overflows and abnormally high sediment loads on the turbines.

3. The inspections made during periods of emergency should be carried out by experienced personnel who are familiar with the operation of the facility.

4. The dam should be inspected annually in order to make certain of the integrity of the dam itself and of its abutments.

5. Any structural fissues or leakage through the dam or its abutments should be the subject of frequent and careful inspection for the purpose of detecting possible changes.

6. Permanent bench-marks should be made on the dam during construction for use in performing measurements designed to record the beginnings of any possible slippage or movement.

7. Piezometers should be installed in the foundation of the dam and their readings checked at least once a month for the purpose of detecting any sudden changes in pressure below the dam.

Recommendations concerning electromechanical equipment

1. The machinery and valves should be regularly serviced so as to ensure that they will operate properly and reliably when required.

2. All gates and valves should be operated through their full range of travel at least once a month. In the case of small plants, defective valves and gates may be replaced and the defective parts taken to a central workshop for repair. The same may be done in the case of turbines, regulators, generators, and transformers when they are small enough.

3. In both high- and low-head projects, the valves and gates should be test-operated at least once a month to ensure that they will perform reliably when required. If there are a number of gates, they should preferably be of identical design, and consideration should be given to the acquisition of a replacement gate to be used in the event of damage caused by floating debris or wear.

4. Generators should be inspected every six months and disconnected once a year for preventive maintenance.

5. The turbines should be disconnected and inspected each year for faults.

6. The control panels should be inspected every four months and disconnected every year for preventive maintenance.

7. The busbars, especially their connections, should be inspected every four months.

8. The transformers must be inspected every six months and disconnected every year for preventive maintenance.

9. The circuits must be inspected every six months and checked for faults at the time of the annual maintenance.

10. The substations must be periodically (every three months) checked for short circuits.

F. Costs

This section deals with a number of quantitative guidelines which may be used to estimate the costs of an MHG for purposes of planning and rough calculation. The fact is that reliable cost predictions for specific projects on the basis of overall indicators are not possible, since each individual case requires a detailed cost analysis taking into account the particular features of the project.

Figures 26-31 show unit costs for total MHG investment and for the three principal investment components: pre-investment studies, equipment and civil engineering. As the figures are based on information relating to various Latin American

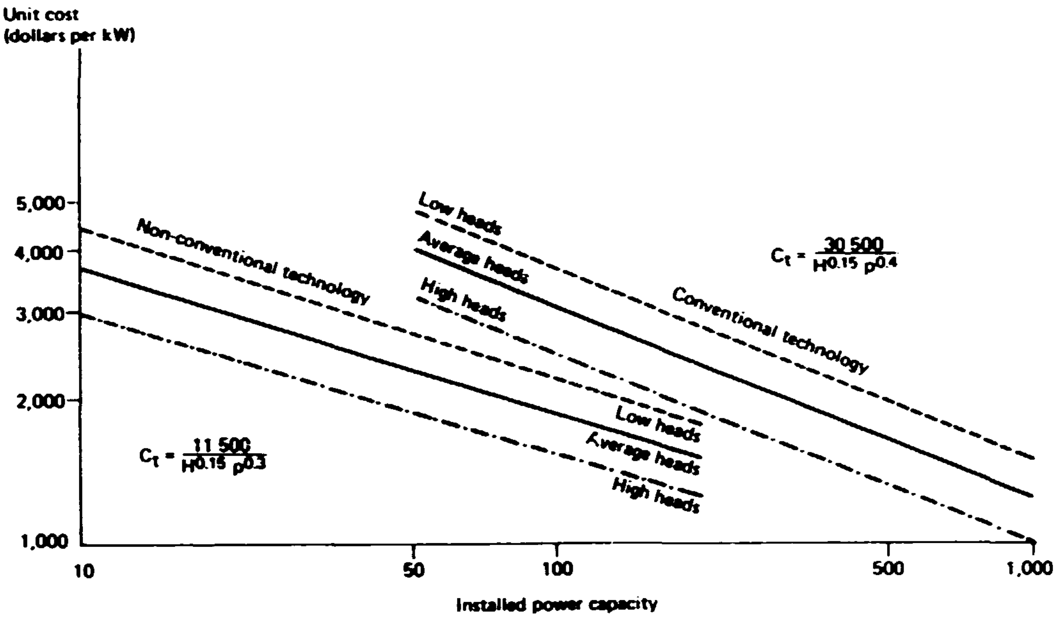


Figure 26. Reference indicators for unit investment costs

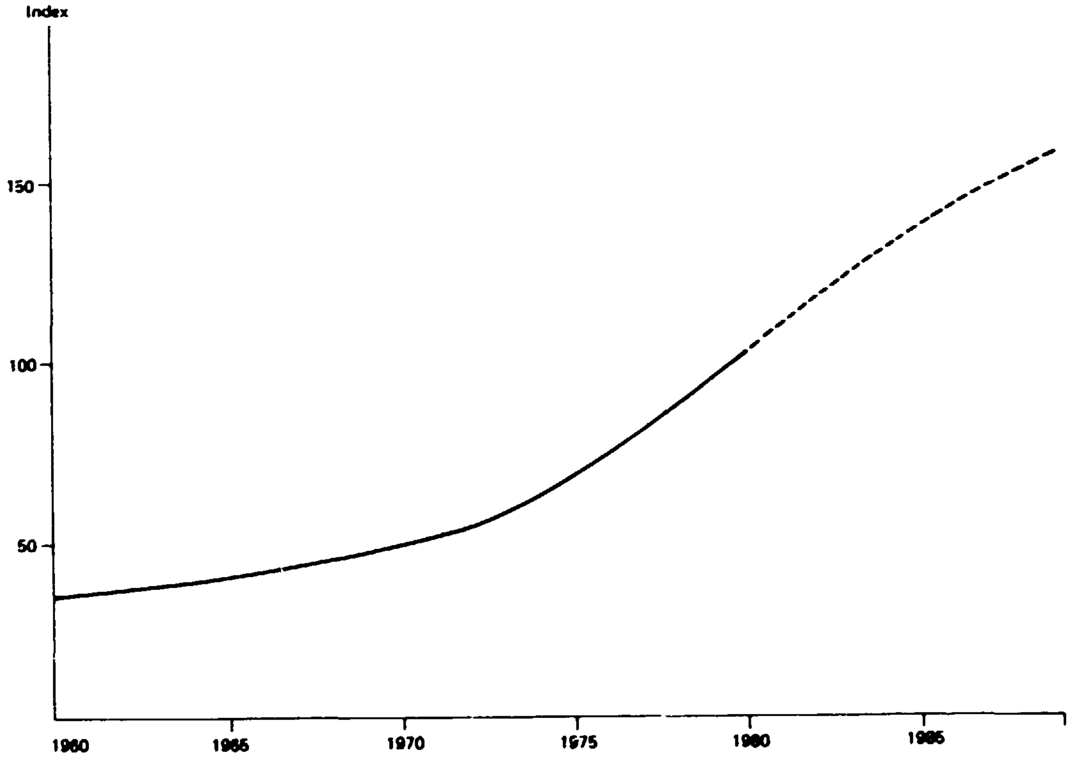


Figure 27. Approximate index for the variation of MHG investment costs in time

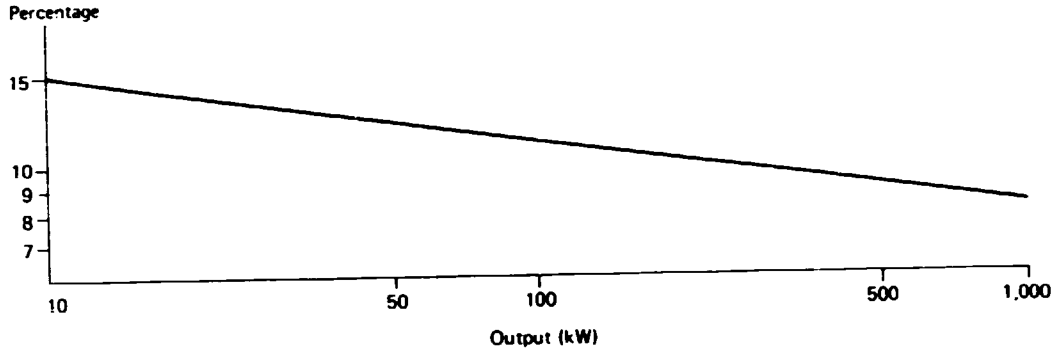


Figure 28. Study costs as a maximum recommended percentage of total project cost measured in terms of MHG output

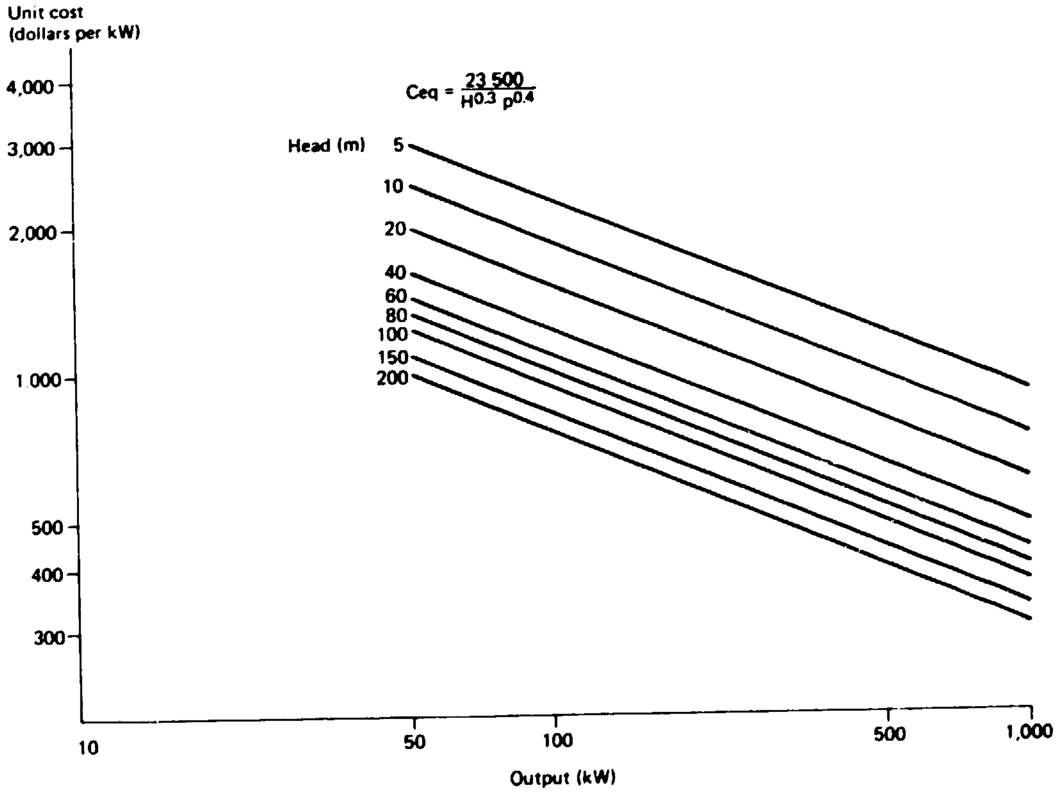


Figure 29. Unit cost of imported electromechanical equipment

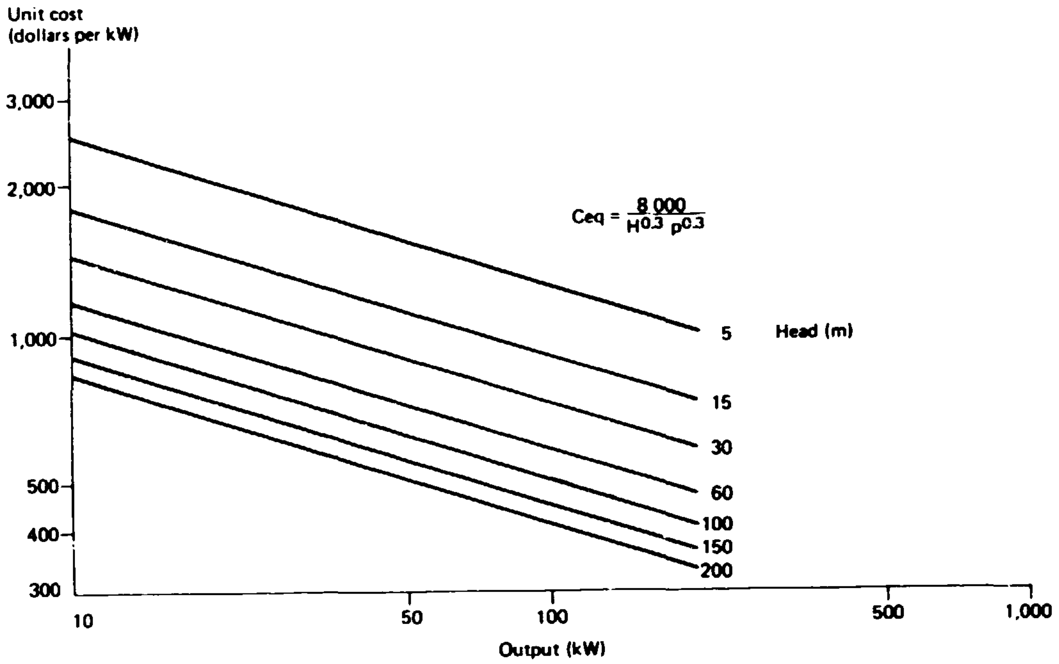


Figure 30. Unit cost of domestically manufactured equipment and technology

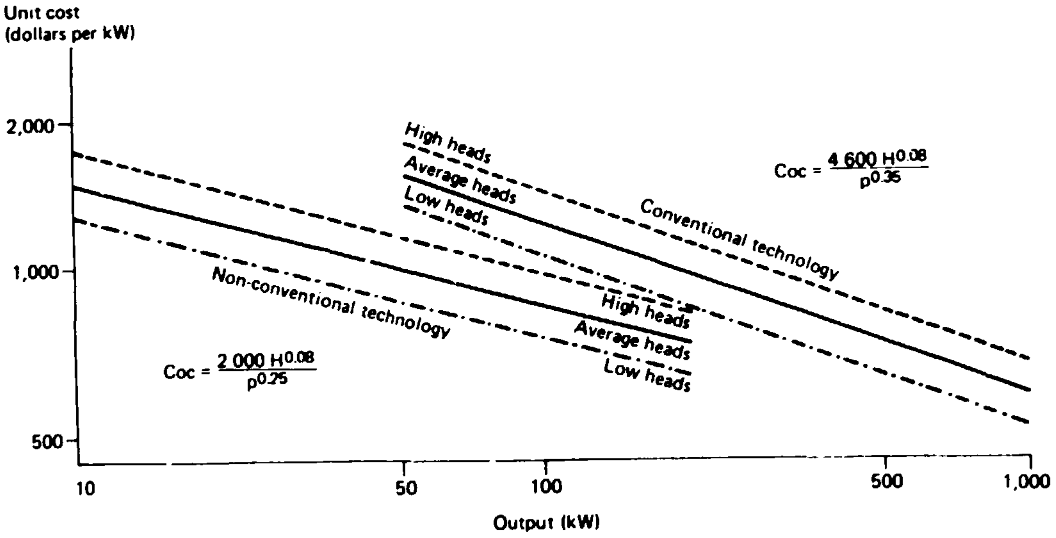


Figure 31. Unit cost of MHG civil construction

countries, it is recommended that offices responsible for MHG planning should adapt them to conditions existing in their own countries. That can be done in at least an approximate way by experimentally determining certain correction factors for use with the graphs presented in the figures.

Unit costs of total MHG investment

Figure 26 shows the total unit costs for an MHG plant in dollars per kilowatt of installed power for different power ratings (output) and heads. The elements and hypotheses considered in the preparation of the graph are outlined below.

The following conclusions may be drawn from the total investment cost curves:

1. MHG costs may vary between $1,000 and $5,000 per installed kilowatt;

2. Unit costs rise rapidly as power ratings decrease;

3. Plants operating with low heads are more costly than those with high heads;

4. The use of non-conventional technology for the civil construction and of domestically produced equipment and technology makes for lower unit costs than conventional technology and imported equipment. This advantage tends to become less significant as the power rises.

Factors considered in the preparation of figure 26

1. The data processed were drawn from 35 projects in three Latin American countries, the correlation factors with respect to the graph being in the order of 70 per cent.

2. The lower curves, for the non-conventional technology option, were plotted by adding the costs of the studies to those of the equipment and the civil engineering works, assuming domestically manufactured equipment.

3. The costs are based on 1980 prices, and the data used were adjusted according to the indices given in figure 27, which is a very rough indicator of the time variations in MHG investment costs described in this Manual. For specific cases, it is advisable to study the variations for each equipment component and the civil work costs according to the particular conditions given for each country.

4. The curves presented are of only relative statistical value, since in the case of specific projects one must expect significant variations from one country to another.

5. The variations from country to country may be due to the following factors: availability and cost of labour and materials; equipment purchases and freight costs; engineering costs; geographical conditions and problems of access; dollar exchange rates; currency market conditions and controls; and variations in cost indicators over time.

6. Variations with respect to each specific project are due to: distances and access conditions; physical conditions (geology, hydrology, geomorphology, soil mechanics, ecology etc.); and significant differences in the scale of the civil construction.

7. The graph in figure 26 refers to stations having only one electromechanical unit.

8. The definition of high, medium, and low heads is taken from the power and head classification of OLADE presented in chapter I.

Unit costs of pre-investment studies

As pointed out in chapter III, section D, study costs are frequently disproportionately high in terms of the total investment. It is therefore advisable to set limits to study costs as a percentage of the total cost of the project.

For purposes of guidance, figure 28 shows a proposed graph of maximum desirable study costs as a function of plant output. In actual practice, it is recommended that each country plan such costs as part of its MHG policy and in accordance with the minimum depth and coverage of the studies themselves.

Unit costs of electromechanical equipment

Figures 29 and 30 indicate the unit costs of electromechanical equipment in the cases of respective equipment imported from manufacturers in developed countries and equipment manufactured domestically using technologies developed or adapted in the country and not subject to the payment of royalties. The electromechanical equipment includes the following items: turbines, velocity regulators, generators, electrical control panels and instrumentation, and installations (excluding anchoring systems).

The following points should be noted in connection with figures 29 and 30.

(a) The data used in preparing figure 29 were based on 25 cases, the curves having a correlation factor of 97 per cent;

(b) The data used in preparing figure 30 were based on 10 cases, with the equipment manufactured in a single Latin American country. The curves were plotted on the basis of figure 29, the correlation factor being lower than in that figure;

(c) The costs are given in 1980 dollars and are based on an adjustment of the values given in figure 27;

(d) Variations from country to country may be due to: freight and insurance, import duties, taxes, local transport, laws designed to promote industrial development, exchange rates, currency market conditions and controls, and variations in cost indicators over time;

(e) Variations from one particular project to another may be the result of conditions of access and local freight charges, and of installation costs;

(*f*) Implicit in the equipment costs is the selection of the optimum turbine type according to the head and power of the station.

A number of general conclusions, including those listed below, may be drawn from figures 29 and 30 for guidance in the selection of equipment.

1. The unit costs of the electromechanical equipment for an MHG plant may vary between $300 and $3,000 per installed kW of power.

2. Unit costs rise rapidly for the lower power ratings.

3. Unit costs increase sharply as the head decreases (in the proportion of 3:1 for heads of 5 m and 200 m, respectively).

4. Generally speaking, domestically manufactured equipment and domestic technology may be priced at one-half the cost of equivalent imported equipment and technology.

Unit costs of civil construction

Figure 31 shows the unit cost indicators for the civil works associated with an MHG project. The diagram is intended for reference use only. The following items are included under civil works: dams and intakes, canals, forebays, silt basins, penstocks and anchorings, accessories (gates, grids etc.), machine rooms (powerhouse) and equipment support systems, and run-off canals.

It should be noted that the above-mentioned cost elements do not include the power transmission and distribution systems. Some of the factors involved in plotting the civil construction cost curves are outlined below.

1. The curves, which are based on data for 25 simulated projects having a correlation factor of about 60 per cent, reflect the approximate correlation projects of the difference in total unit costs less the costs of studies and equipment.

2. The variations from one specific case to another are very wide.

3. The correlations for conventional technologies rest on the assumption that the technological conditions of the project are as described in chapter I (guideline 5).

4. The correlations for non-conventional technologies rest on the assumption that the technological conditions of the project are as described in the preceding section.

5. The costs are given in 1980 dollars.

6. Variations from country to country may be due to: costs and availability of construction materials; labour costs; and geographical conditions and problems of access.

7. Variations from project to project may be due to: the physical characteristics of the project (geology, geomorphology, hydrology, soil mechanics, canal length, topography, aggregate materials etc.); building methods; depth of the engineering studies; and experience in design engineering.

Figure 31 suggests a number of general conclusions, in particular those listed below, concerning the limits of application of the graph itself and the trends revealed in it.

1. The curves are designed to provide only an approximate estimate, for use during the planning stage. For each individual project, a satisfactory approximation requires physical surveys at the actual work site.

2. The unit costs of civil works may vary between $450 and $1,800 per installed kilowatt.

3. Unit costs increase as the power decreases, but not as rapidly as for the electromechanical equipment.

4. The unit costs of civil works increase as the head increases, in a relationship that is thus the inverse of, and also less marked than, that which exists between unit equipment costs and head.

5. All other factors being equal, the use of non-conventional technologies is less costly than the use of conventional technologies, this advantage being greater for the lower power ratings.

VI. International Co-operation[1]

The principal possibilities for international co-operation in the MHG field lie in the areas of technology, training, studies and construction. Co-operative projects may be undertaken at the world, regional, subregional, or simply the bilateral level.

The term "international co-operation" extends to all types of international relations which are designed to pursue the mutual advantages of the co-operating parties and which are the subject of international agreements. It is based on the following principles: respect for the sovereignty of the parties; equality of rights for all parties; the voluntary participation of all parties; mutual assistance; and reciprocal benefits.

A. International organizations operating at the world level

The following are some fo the organizations that are in a position to provide support in the development of MHG.

Organization	*Area of activity*
International Bank for Reconstruction and Developmen. (IBRD); World Bank	Financing of development projects; grants short- or medium-term loans at interest to both the Governments of the member countries and to public and private institutions, provided they have the backing of the Government of the country in question
International Labour Organisation (ILO)	Co-operation in training programmes for middle-level technicians and skilled workers
Organization of Petroleum Exporting Countries (OPEC); OPEC Fund for International Development	Financial assistance for development projects, particularly in the area of alternative energy sources and on behalf of the countries most seriously affected by the petroleum price structure; currently financing an MHG programme
United Nations Development Programme (UNDP)	Financing of development plans, programmes and projects
United Nations Educational, Scientific and Cultural Organization (UNESCO)	Co-operation in scientific and educational development programmes
United Nations Industrial Development Organization (UNIDO)	Co-operation in industrial development programmes; currently engaged in promotion of MHG programmes and implementing a number of projects in developing countries
World Meteorological Organization (WMO)	Co-operation in meteorological and hydrological programmes on behalf of development projects

Some of the problems which arise in relations with international organizations and the methods for overcoming them are outlined below.

Problems	*Remedial action*
Poor selection of experts	Request, by the national organizations, of a more extensive list of experts; provision of adequate and sufficiently detailed information to the international organization
Failure to take full advantage of the expert's skills	Formulation of a detailed plan specifying, sufficiently in advance of the expert's arrival, the activities the institution wishes to have carried out; assignment of government co-operation personnel sufficiently qualified to work with the expert

As part of their effort to promote the use of MHG, the international organizations must lend their support to the establishment of local infrastructure in such areas as planning, studies, design, operation and maintenance, administration, financing and technological development. As

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[1] This chapter is intended to be updated and expanded in the next edition, subject to the collection of more detailed information on activities of the organizations mentioned in this Manual.

a general rule, contacts with international organizations should be handled through their resident representatives in the individual countries.

Among the international banking institutions with world-wide operations, mention should be made, in addition to the IBRD, of the Export-Import Bank (EXIMBANK) and the International Finance Corporation.

B. Regional and subregional co-operation

Regional and subregional co-operation may involve studies and construction activities, and may be undertaken by a group of three or more countries. In principle the term "regional" refers to organizations operating on a continental or subcontinental basis, while "subregional" refers to groups of countries within a less extensive geographical zone.

Organization	*Area of activity*
Afro-Asian Organization for Rural Reconstruction	
Common African and Mauritian Organization	
East African Common Services Organization	Trade, financing, and studies of social problems
Latin American Energy Organization (OLADE)	Is conducting a regional-level MHG programme
Organization of African Unity	Has a Commission for Scientific and Technical Research
Organization of American States	Advisory services, consultation, and support for economic development projects
Organization of Central American States	Seeks solution to common problems and promotes economic, social and cultural development through concerted co-operative action

Special mention should be made of OLADE work in promoting, co-ordinating, and advising on MHG projects and programmes, and of its activities in other energy areas.

It is extremely important that all the supporting organizations carry out their work within a framework of co-ordination, promotion and consultation, so that they may contribute to the strengthening or establishment of the necessary infrastructure in the various countries.

Among the regional banks, the following in particular could be mentioned:

Bank	*Purposes*
African Development Bank	Its purpose is to contribute to the economic development and social progress of its members. It has established an African Development Fund
Asian Development Bank	Unlike the African Development Bank, this bank has extra-regional subscribers in addition to those from within the Asian region. It grants loans for infrastructure investments
Central American Bank for Economic Integration	It is the principal financing institution for the Central American Integration Programme and the main lending institution for regional economic development
Inter-American Development Bank (IDB)	The purpose of IDB is to promote the development of the member countries, individually and collectively, through the financing of development and technical assistance projects. It is currently studying the financing of MHG projects in several countries

C. Bilateral co-operation

In the case of bilateral technical co-operation, particular care and attention must be given to how the objectives and scope of the programme are defined, in order to avoid hidden forms of technology sales governed by commercial objectives. Where this is unavoidable, the negotiating terms with respect to the purchase of the technology must be explicit and clear. Moreover, the conditions of the agreement must be favourable and not involve, under the guise of an assistance programme, the granting of any exclusive rights. Similarly, in all cases of international technical assistance, the means by which the know-how in question is to be effectively assimilated by the recipient party must be clearly set forth. It is of vital importance that the government co-operating personnel receiving the assistance be perfectly clear as to the obejctives and that a work programme be prepared in advance. Their qualifications must be sufficient to enable them to assimilate effectively the knowledge being transferred.

Developing countries may request bilateral assistance through their diplomatic missions or commercial attachés. As a general rule, it is to be recommended that, in order to deal both with MHG projects and with other matters of technology and co-operation, the developing countries should create a government office for foreign technical assistance to be responsible for co-ordinating international co-operation in the country and advising the organizations affected on how to make the best possible use of such assistance.

D. Non-governmental organizations

According to the definition used by the United Nations, non-governmental organizations are international organizations which have not been established on the basis of agreements between Governments. The United Nations Economic and Social Council has devised procedures governing consultative co-operation for a number of non-governmental organizations of interest to the Council.

In 1975 there were 2,500 non-governmental organizations, a number of which were active in the area of science and technology. The Non-Governmental Organizations Section of the Department of Public Information of the United Nations Secretariat is responsible for co-operation with those bodies. It also convenes the Conference of Non-Governmental Organizations, which has its headquarters at Geneva and functions as the permanent organ of the non-governmental consultative organizations.

For the purpose of ascertaining which of the organizations are engaged in MHG programmes, they may also be contacted through the information services of the various countries in their diplomatic or consular missions or their information centres abroad.

Non-governmental organizations may suffer from limitations in the following areas: financing, constitutional or policy restrictions on activities, lack of acceptance by certain Governments etc.

Annex

BASIC CALCULATIONS

This annex describes the steps involved in preparing a mini-hydroelectric power plant project, using as an example the 16-kW pilot plant project at Obrajillo, Peru. It should be noted that the project was carried out for research purposes and that an existing irrigation channel was used in the design of the plant.

The typical stages involved in project execution are reflected in figure 32.

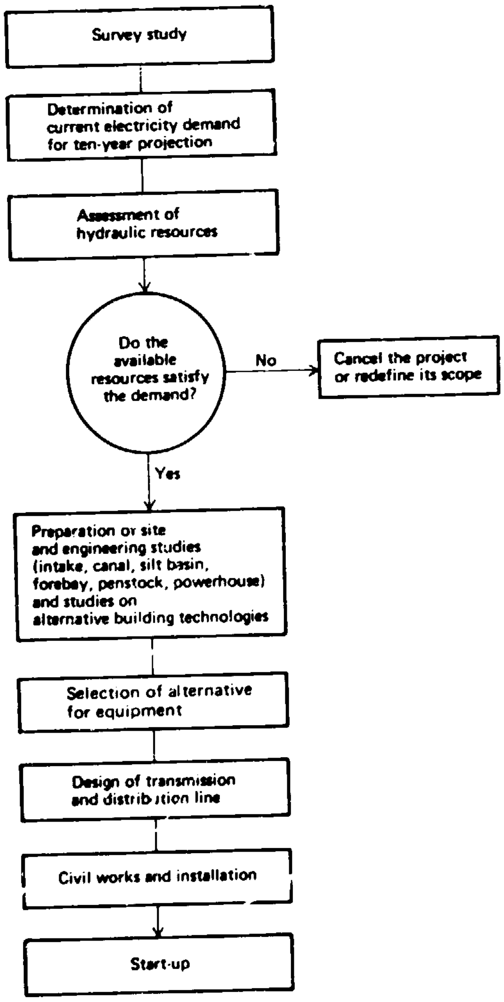

Figure 32. Sequence flow chart for a specific project

The procedure described below was followed in designing the project.

A. Demand study

The community to be supplied with electric power had a population of 595 inhabitants and a growth rate that could be considered zero, since according to statistics there had been no population increase in recent years as a result of migration to the city. The town had a bakery which obtained its required electric power from a head-engine-powered generating unit. There was also a small dairy plant which had its own similar power supply. It should be noted that the town in question lacked any street or house lighting.

In order to determine what kind of power would be required from the future hydraulic power plant, the following factors were considered:

(a) Power consumption by the bakery occurred between 3 a.m. and 7 a.m.;

(b) Power consumption by the dairy enterprise occurred between 8 a.m. and 6 p.m.;

(c) House lighting was to be provided only during the period from 6 p.m. to 10 p.m.;

(d) Street lighting was to be provided only between 6 p.m. and 10 p.m.

On the basis of the above-mentioned factors it was ascertained that the maximum load of the generating plant would be determined by the street and house lighting. Consumption was calculated using a figure of 25 W per inhabitant, yielding an approximate required power of 16 kW. Provision was made for the possibility of further expansion to permit a higher installed capacity per inhabitant.

B. Resources study

In the case of this project a canal which followed a course near the town and was used for irrigation was already available. The canal draws its water from the Chillón River, the minimum annual discharge of which is 1.2 m^3/s. The water for the canal is obtained through an intake which is cleared and otherwise maintained every year, after the high water, by the town residents as a community activity.

The first step was to locate a fall, which was subsequently levelled using topographic techniques. On the basis of the head determination (56.5 m) and the required generator power (16 kW), the water flow was established and simultaneously the optimum diameter for the penstock was selected. With the 20-cm (8-in)

PVC pipe selected, the result was a net head of 55.3 m and a maximum discharge of 0.048 m³/s, derived from the following formula:

$$\text{Maximum discharge} = \frac{P}{9.807\ \eta\ H_n}$$

where: P is the generating power (16 kW)
H_n is the net head (55.3 m)
η is the total efficiency of the plant (62 per cent), selected from table 7 below.

TABLE 7. TOTAL EFFICIENCY OF MINI-HYDROPOWER PLANTS

Power (kW)	*Turbine type*			
	Pelton	*Michell-Banki*	*Francis*	*Axial*
Up to 50	58-65	54-62	59-65	58-66
50-500	65-69	62-65	66-70	66-70
500-5 000	69-73	65[a]	70-74	70-74

[a] The Michell-Banki turbine operates to a maximum power of 1,000 kW.

Once the discharge had been determined, a hydraulic analysis was carried out in order to determine whether the capacity of the canal was sufficient to supply the plant and provide for irrigation at the same time. The study made it possible to identify certain critical zones where the canal had to be widened.

The figures in the table take into account generator efficiency, which is low for the lower power ratings.

C. Site selection and design of civil structures

The existing intake had to be improved so as to make it possible to regulate the admission of water into the irrigation canal. The critical zones of the canal were reinforced and widened in order to provide the necessary capacity. A forebay was built, which simultaneously functioned as a silt basin and provided a way of returning the overflow to the irrigation canal. An appropriately anchored PVC penstock was designed. Although the recommended procedure is to bury a line of this kind, the pipe in question was installed above ground so as to make it possible to test it for performance and weather-resistance, and also to test a number of protective coating materials.

D. Selection of equipment

Selection of the generator

The guiding assumption was the need for 16 kW generation output. On that basis, the specifications called for a 20 kVA alternator with a power factor of 0.8, generation voltage of 220 V, and generation frequency of 60 Hz. The generator satisfied the maximum power requirement. The rotation speed of the alternator was 1,800 rev/min. As a research alternative, an asynchronous generator was also installed, with a bank of condensors to permit independent operation.

Selection of turbines

Since it was designed to operate as a pilot plant, one of the aims of the Obrajillo project was to study and develop a technology for turbines of low specific speed. The specific speeds of various turbine types are shown in table 8.

TABLE 8. SELECTION OF TURBINES ACCORDING TO SPECIFIC SPEEDS

Turbine type	N_s	N_q	H_{max}
Single-nozzle Pelton	10-29	3-9	1 800-400
Two or multi-nozzle Pelton	29-59	9-18	400-350
Michell-Banki	29-220	9-68	200-80
Slow Francis	59-124	18-38	350-150
Normal Francis	124-220	38-68	150-80
Fast Francis	220-440	68-135	80-20
Propeller and Kaplan turbines	342-980	105-300	35-5

Note: N_s and N_q are defined in the text.

There are two expressions for the calculation of the specific speed. The first depends on the efficiency of the turbine and is written in the form:

$$N_s = \frac{N \times \sqrt{P}}{H_n^{5/4}}$$

where P is the net power in hp (1 hp = 750 W), H_n is the net head in m, and N is the speed in rev/min.

The second expression for specific speed makes it possible to arrive at efficiency-independent similitude criteria and is written as:

$$N_q = \frac{N \times \sqrt{Q}}{H_n^{3/4}}$$

where Q is the flow in m³/s.

With a view to low specific speed, it was decided for this project to use Pelton and Michell-Banki turbines, which were to operate under the same head and flow conditions. In order to ensure that the turbines would perform within their customary specific r.p.m. range while operating under these conditions, it was necessary to determine suitable runner diameters to make possible an optimal rotating speed for the turbine.

In the case of the Michell-Banki turbine:

$$N = \frac{39.85\sqrt{H_n}}{D_{ext}}$$

where D_{ext} is the external diameter of the runner in m.

For the Pelton turbine:

$$N = \frac{38.00\sqrt{H_n}}{D_p}$$

where D_p is the diameter of the Pelton runner in m.

Runner diameters of 200 mm for the Michell-Banki and 600 mm for the Pelton turbine were adopted, making it necessary to use a mechanical belt transmission system between the turbine and the alternator.

E. Design of the powerhouse

For this project, an existing mill large enough to accommodate the equipment and carry out research was used as the powerhouse.