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INDUSTRY AND ENERGY DEPARTMENT WORKING PAPER
ENERGY SERIES PAPER No. 44

A Methodology for Regional Assessment of Small Scale Hydro Power

Reprinted September 1991
(Originally Published in May 1984)

The World Bank Industry and Energy Department, PRE

A Methodology for Regional Assessment of Small Scale Hydro Power

Prepared for
the World Bank

by

Tudor Engineering Company
San Francisco, California, USA

Reprinted September 1991
(Originally published May 1984)

ABSTRACT

This paper presents a methodology for the regional assessment of small scale hydroelectric potential which covers procedures for both new sites where no developments currently exist and existing sites such as small dams and canal drops which can be retrofitted with hydro generation equipment. The methodology makes use of the principle of representative sampling and analyses of typical projects followed by the extrapolation of the results to the regional area for the overall assessment.

The recommended methodology is for use at the reconnaissance level and covers sampling procedures, study execution, energy planning, regional hydrology development, technical site evaluations, cost and economic analyses, environmental and social considerations, and the final assessment report. The procedures described are intended for use by experienced engineers, hydrologists, economists, and other involved disciplines, and only general principles are therefore covered.

Use of the methodology should result in reasonably accurate estimates in a short period of time of the number, size, and cost of economically justified small-scale hydroelectric projects which could be developed in the particular region or country under study. It is assumed that the methodology will be used primarily to obtain an estimate of the number and cost of small-scale hydroelectric sites so that the likely scope and economic benefits of a long-term development program can be assessed with sufficient reliability to support requests for financing the small hydro programs. However, the technical assessment procedures presented could also be used for reconnaissance-level feasibility assessments in general.

The paper was originally published in May 1984 as Energy Department Paper No. 14 of the former Energy Department. It is being reprinted in the IEN Energy Series as a reference for World Bank energy staff.

METHODOLOGY FOR
REGIONAL ASSESSMENT OF SMALL SCALE HYDROPOWER
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CHAPTER I
INTRODUCTION

REPORT OBJECTIVE

The objective of this report is to present a general methodology for the overall appraisal of small-scale hydroelectric installations for large size regions within developing countries. It is intended that use of the methodology will result in a fairly rapid and accurate estimate of the approximate number, size, cost and economic feasibility of small-scale hydroelectric projects within the region or country under study. It is further intended that this determination be to such a level that the World Bank, or other financing agencies would be able to commit the initial funds for the recommended development program with reasonable confidence that the indicated number of economical small-scale hydroelectric projects can ultimately be identified and constructed within the cost estimate presented in the assessment.

It is not intended that use of the methodology will result in firm recommendations for specific projects other than those relatively few sites studied during the application of the methodology. Such firm recommendations would follow as part of the implementation phase of the project when detailed studies will be conducted after overall economic feasibility has been demonstrated as outlined in this methodology.

METHODOLOGY OVERVIEW

Methodologies for both new sites and existing structures are presented in this report. Both methodologies are based on the principle of representative sampling and extrapolation. The first methodology is for the appraisal of new projects and basically consists of defining the areas where economical hydroelectric projects are likely to be found, analyzing sample portions of this area to determine the number, size and cost of economical sites, and then extrapolating the results to the larger area. The second methodology is for appraisal of existing structures such as canal drops and small dams which may be suitable for the adaptation of hydroelectric generating equipment. This analysis is straightforward and simply consists of compiling an inventory of potential sites, classifying the inventory into representative groups, analyzing of a typical project from each group, and extrapolating the results to the total inventory.

PURPOSE

The recommended methodologies are intended for use by competent and experienced engineers, hydrologists and economists and only general recommendations are therefore presented. Many comprehensive publications exist on the specific engineering, hydrologic and economic approaches necessary to conduct hydroelectric appraisal studies. The references presented with this report provide supplementary information on the necessary specific techniques.

SCOPE OF COVERAGE

The methodology presented in this report is intended to primarily apply to the lower range of hydroelectric sizes. The entire range these sizes can be arbitrarily defined by installed capacity in the following classes:

Classification	Size in kW
Large	>25,000
Intermediate	5,000-25,000
Small	1,000-5,000
Mini	50-2,000
Micro	0-50

These general classifications are based on the size and complexity of the involved structure, the degree of specific site engineering and investigation and custom equipment design that is required, and the end use of the electricity produced. Intermediate and small hydro installations are essentially scaled down versions of large hydro, although some standardized designs of equipment do exist for the small range. They are characterized by relatively large complex structures, including dams, powerhouses and penstocks. These installations would normally be tied to a grid distribution system, either local or national. Mini-hydro on the other hand, can be thought of as pump installations operated in reverse. Small diversion weirs rather than dams are utilized and would be similar to small canal structures. The penstocks are similar to small water transmission or pump discharge lines and the powerhouses similar to pumphouses. Standardized designs (on-the-shelf) exist for all or most equipment items. A typical installation may initially serve one or more isolated small communities, but may later be tied to a larger grid system.

Micro-hydro is similar to mini-hydro except the various features are even smaller and serve individual or several families. The turbines for micro-hydro may even be, in fact, centrifugal pumps operated in reverse.

These definitions are arbitrary and some overlap in the size classifications is necessary because the definitions cannot actually be related to kW size only. For example, an installation of 1000 kW at 3.5 meters (m) of hydraulic head would require a flow of about 34.2 cubic meters per second (cms). This would probably require a propeller turbine with a runner diameter of about 3 m and a large structure to house the turbine generator. This installation would properly be classed as small-hydro rather than mini-hydro. On the other hand, 1000 kW at 100 m of hydraulic head would require only a flow of about 1.2 cms and a small Francis or impulse turbine would be utilized. The turbine generator would be relatively small and would be housed in a much smaller building than the larger propeller turbine. This installation could be considered to fall in the mini-range.

To simplify these classifications, the lower end of these classes, for which this methodology is intended, will be called "small-scale" in this report. The involved capacities will usually be less than 5000 kW, but the actual upper limit will be a matter of judgment by the investigators.

LEVEL OF ANALYSIS

The basic depth of analysis under this proposed methodology would essentially be at the reconnaissance level. This is defined and placed in perspective in the following discussion.

In water resources investigations there are generally four basic levels at which assessments of hydroelectric projects can be conducted. These can be called pre-reconnaissance, reconnaissance, feasibility, and final design. As is explained below, each of these levels is progressively more definitive than the preceding level.

The basic difference between the various levels is the degree of confidence that can be placed in the analysis of costs and benefits. Inasmuch as reasonably accurate determinations of benefits are usually available at a reconnaissance level, the unknowns lie primarily on the cost side of the analysis. Economic justification is determined at all levels of analysis but the certainty of the results increases with the level of effort and the high contingencies provided in the earlier effort for the costs as safety factors can be lowered accordingly as the unknown factors become increasingly defined.

At a pre-reconnaissance level both costs and benefits are very approximate. Generalized information regarding flows, costs and benefits are utilized and contingencies of about 30 percent are utilized. The basic purpose of the pre-reconnaissance analysis is to ascertain if it is prudent to undertake the further expenditures of time, money and materials necessary for more detailed analysis required for the reconnaissance, feasibility and final design level of analysis.

At a reconnaissance level the civil costs are estimated based on general layouts made from map studies which may be supplemented by sketches made on brief site visits. The equipment costs would be estimated based on general curves and tables derived from average manufacturer prices. A contingency of about 20 percent is usually applied to the estimated costs.

At a feasibility level, civil costs would be estimated based on specific site layouts utilizing ground surveys. The equipment costs would be based on specific manufacturer quotes and specific size and projected installation dates. A contingency of 10 percent to 20 percent would be applied to the estimated costs.

At the final design level these civil costs would be based on detailed drawings and known construction data. The equipment costs would be based on committed quotes from manufacturer with guaranteed delivery dates. A contingency of about 10 percent would be applied to the estimated costs.

It should be noted that all levels of analysis would be based on essentially the same hydrologic information. Since adequate hydrologic information underlies all sizing and subsequent analyses, this effort should be initially accomplished to a degree and confidence level sufficient for use at all levels. The particular site under study can then be accurately sized and then related benefits for power and energy fairly assessed.

ECONOMICAL SMALL SCALE HYDROELECTRIC SITE

As used throughout this paper, the term "economical small scale hydroelectric site," usually shortened to "site," will mean one which equals or exceeds the minimum economic criterion that has been established. The concern of this approach is to arrive at an estimate of the number, size, and cost of such sites, and once a site has met the minimum economic requirements, the exact economic ranking for a site will not be of further concern until we later proceed to analyze the overall project economic impact. For instance, if the minimum acceptable economic rate of return is 12 percent, then sites that have a return of less than 12 percent would not be counted, but sites with a return equal to or greater than 12 percent would all be counted the same. The variations in return would, however, be considered in the overall economic conclusions of the assessment.

REPORT FORMAT

The overall Regional assessment methodology is composed of fourteen chapters. The methodology descriptions for new sites and existing structures are followed by recommendations for the general assessment techniques to accompany the methodologies. This includes regional energy evaluation, hydrology, technical evaluation approaches, cost and economic analyses, environmental and social considerations, economic analyses, project implementation, and recommendations for the assessment report. Throughout the report the tables and figures occur as they are first referenced.

CHAPTER II
METHODOLOGY FOR NEW SITES

This chapter outlines the general methodology to be used for the assessment of new sites within the study area. The term "new sites" means that no existing structures would be utilized in the individual project configurations. The detailed technical aspects of the methodology such as conceptual designs, power and energy production, and geology and soils considerations are covered in Chapter VII - "Technical Evaluation of New Sites."

OVERALL APPROACH

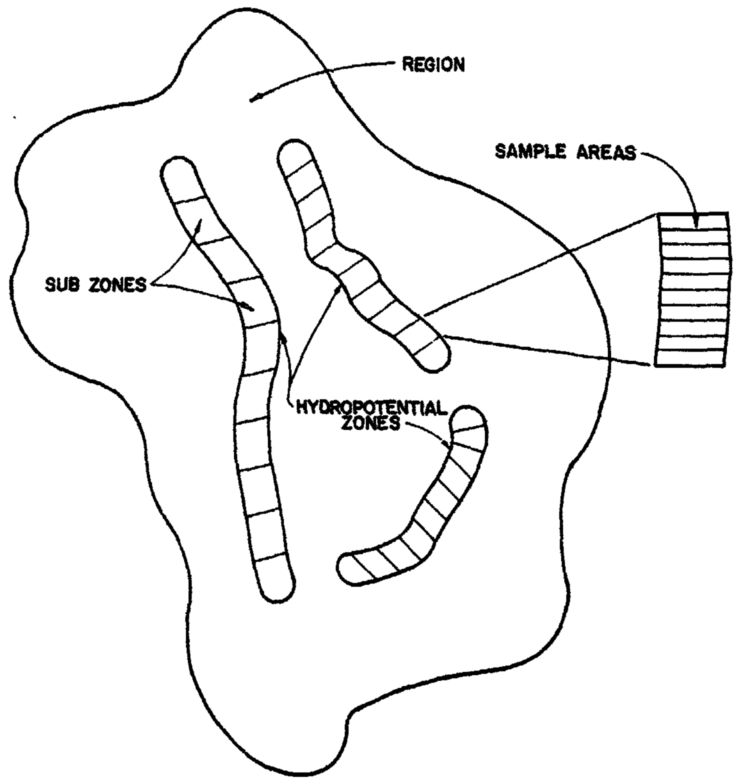
The objective of the methodology is to draw reasonably accurate estimates over large regions of the number size and cost of economical small scale hydro power sites that exist within the region and to accomplish this task with a minimum expenditure of time and effort.

The overall recommended approach to accomplish this objective is to first carefully define the geographic areas where the small scale hydroelectric sites will be located and to then sample a portion of this area to determine the number of economically viable small scale hydroelectric sites contained in the sample area. The results are then extrapolated to the larger area to obtain the overall estimate and statistical sampling theory is used to estimate the margin of error involved.

The geographical areas where the sites are found can be called the "hydropotential zone," which is defined by such parameters as topography, hydrology, accessibility and proximity to power market areas. After using these parameters to delineate overall the hydropotential zone, the next steps in the process are to divide the hydropotential zone into "subzones" of approximately equal area; select smaller "sample areas" from these subzones that are representative or typical of the subzone; study the sample areas in detail to define the number, size and cost of economical small scale hydro sites that are contained therein, and extrapolate the results of the sample area analyses to reach conclusions for the entire region. The following Figure II-1 defines the key physical elements in this approach.

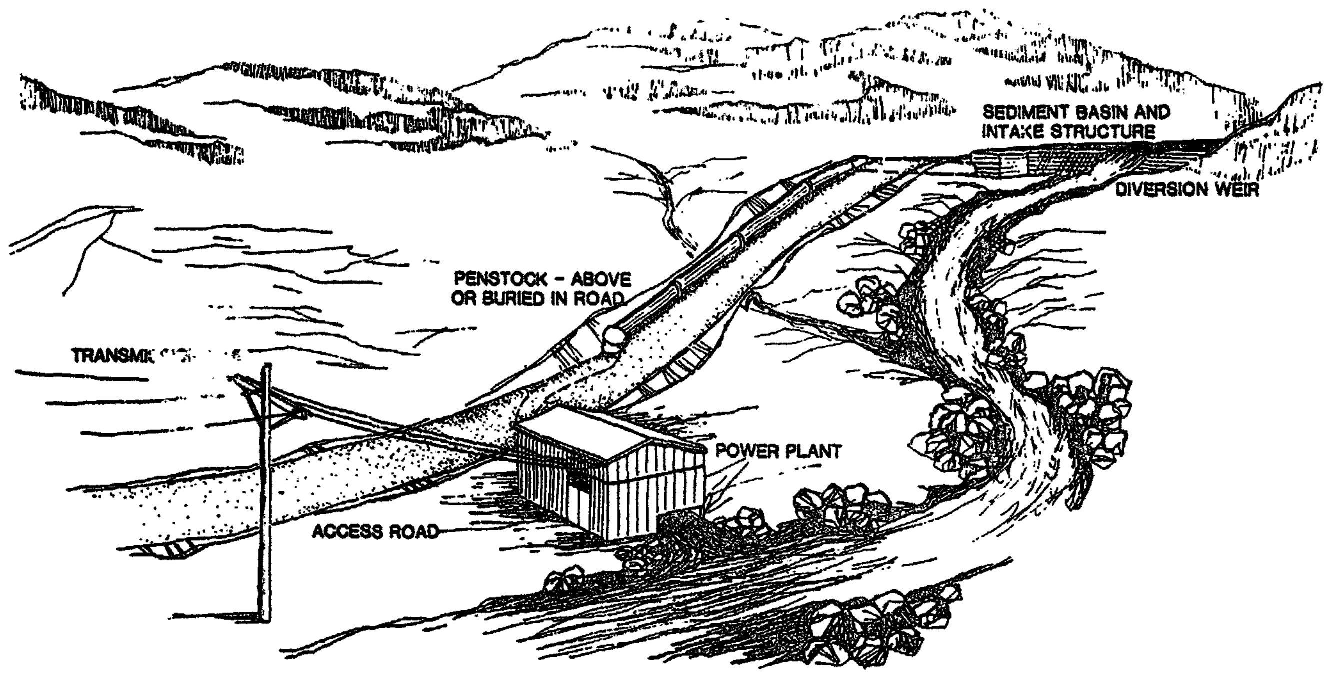
The detailed analysis of the sample areas will consist of reconnaissance level investigations of specific sites together with the related specific economic evaluations. These individual site evaluation procedures are covered in other chapters of this methodology.

The extrapolation process itself is straightforward. The sample area results are extended on a proportional basis to the entire hydropotential zone. Since the sample size can be arbitrarily chosen to be any size such as 5%, 10%, 20%, etc. of the overall hydropotential zone area, the question arises as to what sample size can be used in order to achieve an estimate with the desired degree of accuracy. The proposed methodology therefore utilizes statistical techniques to arrive at the estimated margin of error and the associated probability level that can be assigned to the extrapolated results for various sample sizes. Used in a slightly different manner, the statistical technique can also be applied to arrive at the necessary sample size to obtain a desired margin of error at a given confidence level.

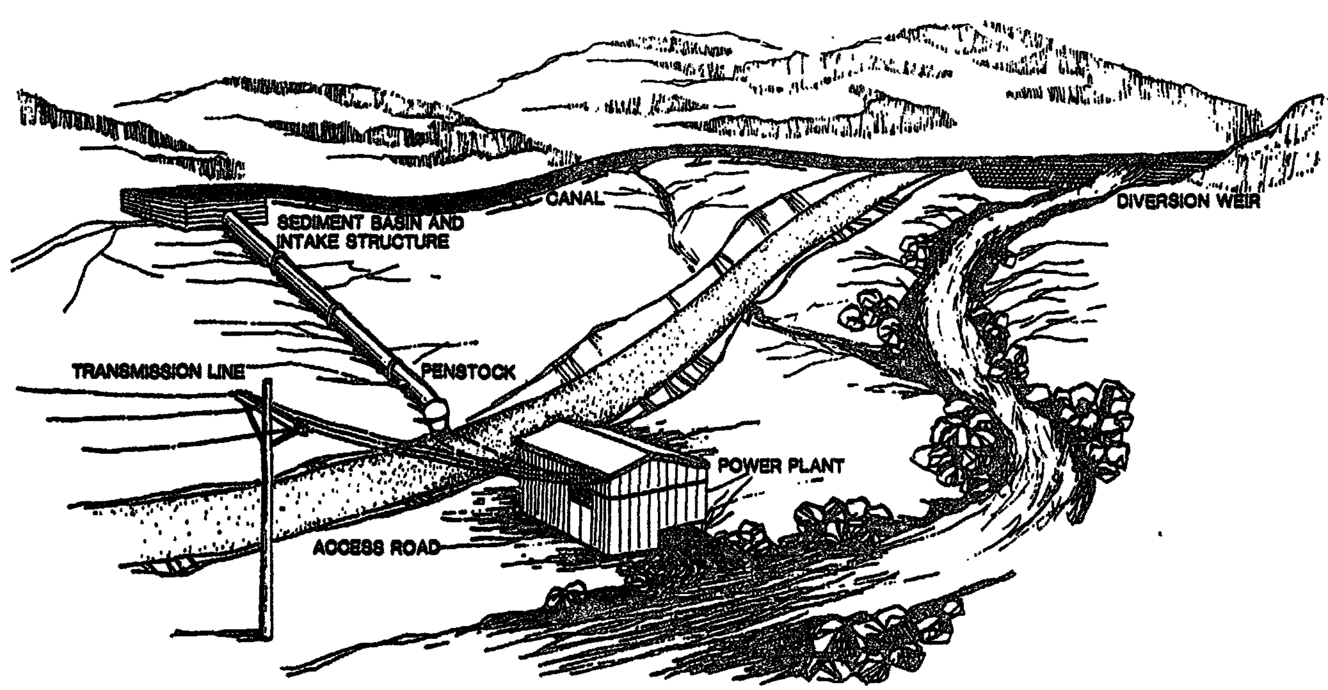


HYDROPOTENTIAL ZONE DEFINITIONS FIGURE II-I

For example, if the analysis of a 10% sample of a given hydropotential zone resulted in the conclusion that 40 sites were present in the sample areas, then the extrapolated results for the entire zone would be 10 times 40 or 400 sites. For purposes of this example, let us assume that use of statistical techniques results in an estimate that the margin of error involved in the extrapolate is plus or minus 27% (i.e. 108 sites) at a 90% confidence level. This indicates that there is a 90% probability that the true number of sites lies between 292 and 508 sites or, stated somewhat differently, that there is a 90% probability that the true number of sites is 292 or greater.



TYPE A – PENSTOCK CONVEYANCE



TYPE B – CANAL AND PENSTOCK CONVEYANCE

TYPICAL NEW SITES FOR HYDRO PROJECTS

FIGURE
II–2

Such a result may well be used by itself. However, if a smaller margin of error is desired, the necessary sample size to achieve this smaller margin of error can be estimated from the initial results. Using the example cited above, let us assume that the desired margin of error is plus or minus 15% rather than 27%. Analysis may indicate that the sample size must be increased from 10% to about 25% of the total hydropotential zone in order to achieve this result. The statistical approach involved in applying these techniques is covered later in this chapter.

It should be kept in mind that the intent of the approach is not to demonstrate detailed feasibility for specific projects but rather to assess regional hydropotential. The exact locations and configurations of various sites that will be developed will be determined during the follow-up implementation phase of the overall program.

TYPICAL PROJECT

The individual projects that will be studied will be small-scale and generally quite simple. A typical project is a simple diversion scheme consisting of a small weir to divert the flow, a conveyance facility consisting of a penstock or a combination canal and penstock to convey the flows and to develop the hydraulic head, a powerhouse containing a small turbine and generator and a transmission line extending to the point of use. In addition, a small sediment removal structure is sometimes included between the diversion weir and penstock. The weir is typically 1.0 m to 2.0 m in height, the penstock 0.30 m to 1.0 meters in diameter, the penstock 100 m to 2,000 m in length and the transmission line 1.0 km to 10.0 km in length. The power plant capacities typically range from 50 kW to 5,000 kW.

Conceptual sketches of two small-scale hydro schemes with alternative conveyance facilities are shown on Figure II-2. Type A illustrates the facilities involved in a typical project using a penstock only, and Type B illustrates the use of a construction canal and penstock. A more detailed description of the various features of small-scale projects is included in Chapter VII - "Technical Evaluation of New Sites."

THE HYDROPOTENTIAL ZONE

As previously mentioned, there are several parameters which determine the areas where small-scale hydroelectric sites can be viably developed. Each of these parameters will define a particular area which, when overlapped with the others, will delineate what can be called the "hydropotential zones." Once these hydropotential zones are defined, other areas of the country or region need not be further investigated for potential sites. As a general rule, the primary parameters which define the hydropotential zones are topography, hydrology, power market area, and site accessibility. In addition, the final defined hydropotential zone should be relaitvely homogenous. These various defining aspects are described below in the following paragraphs.

Topography

Fairly steep topography must exist for a run-of-the-stream diversion type hydroelectric development. In general, a typical project consists of 30 to 100 meters of fall with a conveyance facility length of 500 meters to 5,000 meters. Experience on various projects indicates that the minimum stream slopes for viable hydroelectric sites be at least 5 percent and will range between 5 and 10. Areas having lesser slopes can be disregarded for potential development.

Hydrology

Suitable runoff in conjunction with suitable topography must be available for any hydroelectric development. A detailed development of regional hydrology (as described in Chapter VI) will more precisely define the suitable areas as well as area differences. Since power production is directly proportional to both hydraulic head and flow, no required minimum runoff value can be cited since a considerable level of hydroelectric power can be generated with very small flow if the head is large. However, in a particular region with known topography, a minimum acceptable value of runoff per unit area can be established for use in the hydropotential zone definition process.

Power Market

A power market must exist for each site to be developed and the market must generally be located fairly close to the powerhouse site. The power market area will be the populated areas for isolated sites or the nearest point where the project can be connected to the local or national grid. There is a maximum economic distance for each site over which the energy can be transmitted from the point of generation to the power market area. This maximum distance depends on the size of the project, the local construction costs and the local value of electrical energy. Generally speaking, the maximum economic distance is not likely to exceed about 5 km for a 50-kW site or 10 km to 15 km for a 1000-kW site. The exact allowable distance is an economic decision and will be different for each region under study.

Definition of the power market area for the hydropotential zone will then require a delineation of the populated areas and loadcenters (or grid locations) and a surrounding boundary of economic transmission distances.

A key element to the entire regional assessment will be a thorough power marketability study to establish the areas of potential use, present utilization, potential use, economic benefits and potential alternative sources. This information must be developed in detail for later use in the economic analysis for the study. These elements are discussed more comprehensively in Chapter V - "Energy Planning", and Chapter XI - "Economic Analyses". However, for use in defining the hydropotential zone, the preliminary information developed for the longer term study can be utilized.

Site Accessibility

Access roads or trails must be available within a reasonable distance of the potential sites to facilitate the initial investigation and the following construction activities. This particular parameter is fairly judgmental and depends on the existing access routes as well as the terrain, amount of vegetative cover, and cost of access road construction. Since many rural roads and footpaths remain unmapped in most regions, some field work may be necessary to estimate accessibility.

Homogeneity of Area

The recommended approach is based on sampling areas within a homogeneous region. If the various factors which define the hydropotential zone, especially topography and hydrology, vary enough to cause obvious difference in the expected frequency of occurrence of viable hydroelectric sites per unit area, then different hydropotential zones must be defined and the procedures applied separately to each distinct hydropotential zone. Otherwise, two or more different populations will be mixed and the resulting estimates would not be correct. Complete homogeneity will, of course, never exist due to the many variables involved, along with the geographic dispersion of the sites. However, it is felt that relative homogeneity can be adequately assessed through the use of reasonable judgment by the investigators.

BASIS OF STATISTICAL APPROACH

As previously described, the proposed methodology for regional assessments uses a statistical approach which involves analyzing a portion ("sample") of a hydropotential zone and extrapolating the results to arrive at an estimate of the actual number of sites ("population") that exist within the entire hydropotential zone. This process involves assumptions regarding the type of probability distribution involving the sites and confidence levels and margins of error for the estimated population.

Distribution of Sites

The distribution of hydroelectric sites that occur within a region influences the probability confidence level that can be assumed when drawing an inference of overall population based on the extrapolated number of sites from a given sample.

When a large number of objects are randomly distributed over a spatially continuous area, the mathematical distribution theoretically follows a Poisson type. Examples of Poisson distributions are flaws in castings, number of vehicles on a highway passing a point per unit of time, and, theoretically, the number of economical small scale hydroelectric sites found over a homogeneous regional area. Indeed, as will later be discussed, the actual distribution of sites for a large area of peninsular Malaysia was found to closely approximate a Poisson distribution.

Mathematically, the Poisson distribution can be expressed as:

$$P(X) = \frac{\mu^x e^{-\mu}}{X!} \quad \text{and } \sigma = \sqrt{\mu} \tag{1}$$

where X = Number of sites per unit area

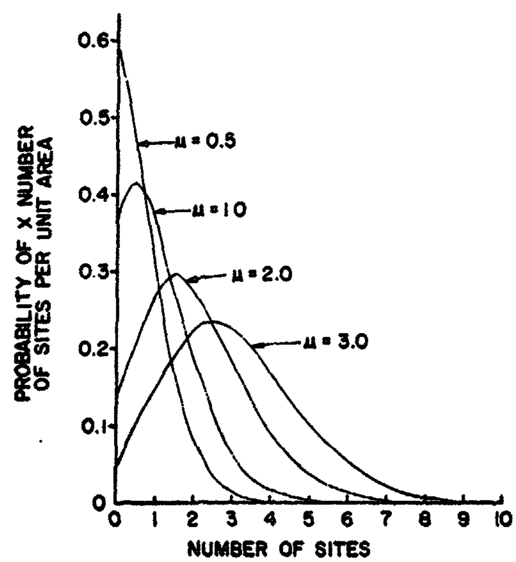
$P(X)$ = Probability of occurrence of X number of sites per unit area;

μ = Mean frequency of sites per unit area for population

e = Napierian logorithem 2.71828.....

σ = Standard deviation for population

The Poisson distribution is characteristically skewed to the right (positive) and, as shown below in Figure II-3, becomes more bell shaped (i.e., normalized) at increasing values of μ.



THEORETICAL POISSON DISTRIBUTION FIGURE II-3

Confidence Levels and Confidence Intervals

In statistics, the probability that is associated with an interval estimate is called the "confidence level." This indicates the probability of how confident we are that the interval estimate contains the true population parameter. A higher probability means more confidence. The "confidence interval" is the range of the estimate we are making. If we report that we are 90 percent confident that the population of sites for a given region will lie between 100 and 160 sites, then the range of 100-160 is the confidence interval. Often, however, we will express the confidence interval in terms of "margin of error" (m) which is the plus or minus values from the estimated population that define the confidence interval. The (m) may be defined as a finite value such as ±12 sites or as a percent of the estimated population such as ±0.10 x 120 sites where 0.10 or 10% is the margin of error.

Since the confidence level attached to the confidence interval indicates the probability that the population will fall within the particular limits, it also therefore defines the probability that the population estimate will fall outside these limits. For example, an estimated population may be given as 120 sites plus or minus 24 sites (120 ± 20%) at a 90% confidence level. This statement indicates that there is a 90% probability that the actual population lies between the confidence interval of 96 sites to 144 sites, and that there is a 10% probability that the population lies outside the confidence interval. Stated alternately, there is a 5% probability that the population mean lies below 96 sites and a 5% probability that the population lies above 144 sites. Therefore, for this estimate, it may also be said that there is a 95% probability that the population is equal to or greater than 96 sites and that there is also a 95% probability that the population is equal to or less than 144 sites.

In establishing the confidence intervals, the Central Limits Theorem can be applied. This theorem states that the distribution of sample means is approximately normal, as the sample size increases, even if the underlying distribution is not normal. However, the more the actual population distribution departs from a normal distribution the larger the samples must be if the distribution of means is to approach normality. If not, a large margin of error will result. For our particular application, this theorem means that even with a Poisson population distribution, the theoretical distribution of samples means for any given sample size will approach normality. Moreover, margins of errors will be smaller when larger site densities per unit area exist and the Poisson distribution itself becomes more bell shaped (see Figure II-3). With this principle in mind, and with the properties of a normal distribution, confidence limits can then be established for various population densities based on various sample sizes.

Margin of Error

To derive the theoretical margin of error for a population estimate, it is first necessary to start with the following formula for the confidence interval for any sample mean ($\bar{x}$):

$$C.I. = \bar{x} \pm t\,\sigma_{\bar{x}} \qquad (2)$$

where C.I. = Confidence Interval

$\bar{\bar{x}}$ = Sample mean

t = Critical Student "t" value associated with a particular confidence level and degree of freedom (equal to sample size minus one.)

$\sigma_{\bar{x}}$ = Standard error of the sampling distribution of means.

Applying the Central Limit Theorem:

$$\sigma_{\bar{x}} = \frac{\sigma}{\sqrt{n}} \frac{\sqrt{N-n}}{\sqrt{N-1}}$$

where σ = Population standard deviation

N = Population sample size (No. of total sample areas)

n = Sample size (No. of sample areas)

For a Poisson distribution:

$$\sigma = \sqrt{\bar{\bar{x}}}$$

$$\text{then } \sigma_{\bar{x}} = \frac{\sqrt{\bar{\bar{x}}}}{\sqrt{n}} \frac{\sqrt{N-n}}{\sqrt{N-1}} \qquad (3)$$

Taking the margin of error (m) as a percentage of the sample mean ($\bar{\bar{x}}$)

$$C.I. = \bar{\bar{x}} \pm m\bar{\bar{x}}$$

Combining this relationship and equation (2), the following identity can be expressed:

$$m\bar{\bar{x}} = t\sigma_{\bar{x}}$$

Substituting the identities expressed above in (3) we have

$$m = \frac{t}{\sqrt{\bar{x}}} \sqrt{\frac{N-n}{n(N-1)}} \qquad (4)$$

This relationship allows us to solve for the ample mean margin of error (m) for any given sample size (n) with a measured sample mean ($\bar{x}$) and a Student "t" value for (n-1) degrees of freedom.

To extend this relationship to the population, we can express the confidence interval for the population as:

$$\text{C.I.} = N\bar{x} \pm mN\bar{x} \qquad (5)$$
$$\text{or C.I.} = X \pm mX$$

where X = estimated population ($N\bar{x}$)
and m = margin of error from (4)

As an example of defining the confidence interval for an estimated population, assume the following results have been obtained from a particular study:

N = 60 (total number of sample areas)
n = 18 (sample areas analysed)
$\bar{x}$ = 1.5 (average number of sites found per sample area)

For the margin of error we have from (4)

$$m = \frac{1.740}{\sqrt{1.5}} \sqrt{\frac{(60-18)}{18(60-1)}}$$

$$m = \pm 0.27$$

For the confidence interval for the population we have from (6)

$$\text{C.I} = 60 \text{ X } 1.5 \pm 0.27 \text{ X } 60 \text{ X } 1.5$$
$$= 90 \pm .27(90)$$
$$= 90 \pm 24$$

There is therefore a 90% probability that the actual number of sites lies between 66 sites and 114 sites.

In applying this approach, it is generally more convenient to express the sample size (n) as a percent of total area (N) using the following identities in the margin of error relationship expressed in (4).

$N = 100$
$n' =$ Sample size (n) expressed as % of N
$\mu =$ unit population mean $\frac{X}{100}$ (Est. No. Sizes ÷ 100)

Substituting in (4) we have:

$$m = \frac{t}{\sqrt{\mu}} \sqrt{\frac{(100-n')}{99n'}} \qquad (6)$$

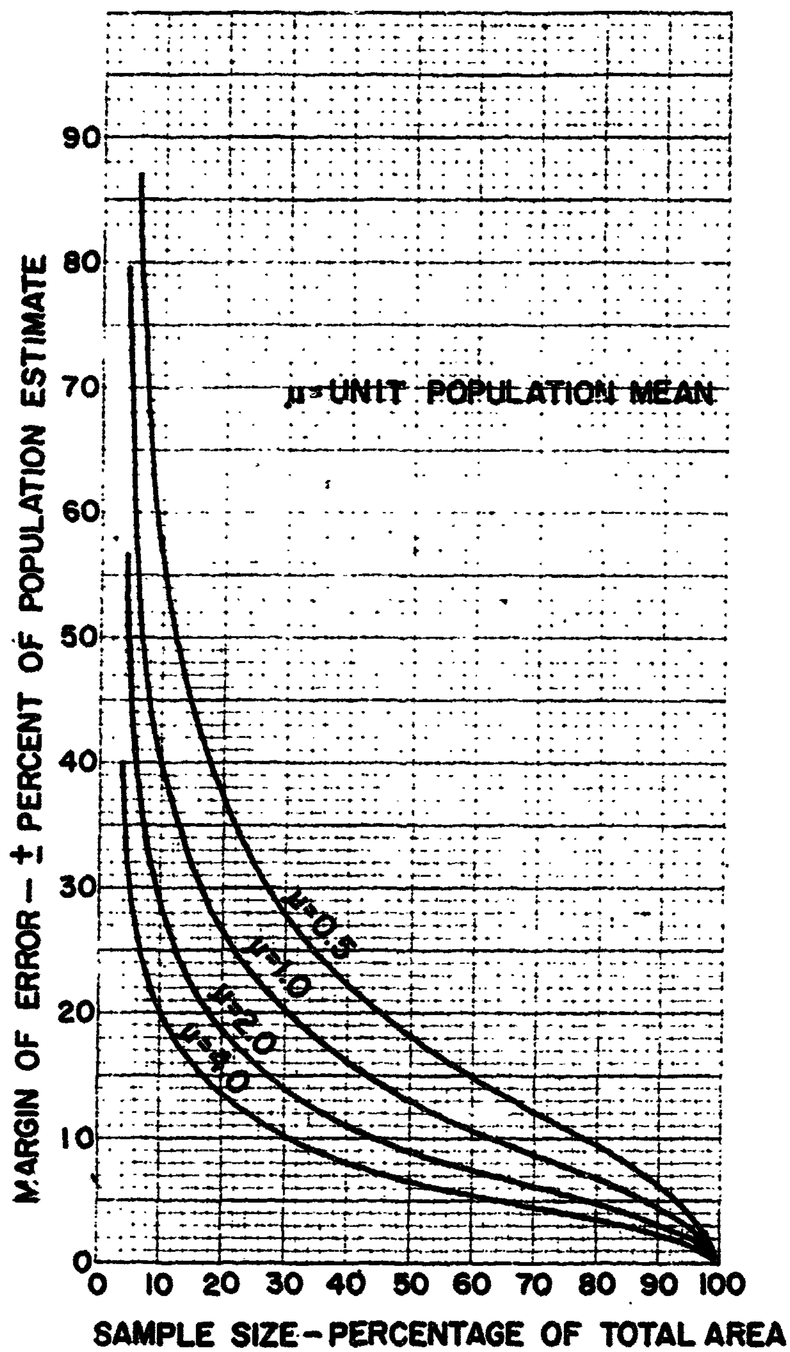
This relationship is very useful in estimating the resulting margin of error for a sample extrapolation for a regional assessment. It may also be used to estimate the required sample size to obtain a desired margin of error. For these purposes, equation (6) has been solved for various values of n' (sample size expressed as a percent of total area) and a range of values of unit population (μ). The results are presented in Figures II-4a, II-4b and II-4c for confidence levels of 80 percent, 90 percent, and 95 percent respectively.

In these figures the margin of error (m) is plotted versus sample size (n') for various values of unit population mean (μ). From these figures we can directly read the probable margin of error for any given sample size and estimated unit population mean (μ). Conversely, for a given margin of error (m) and known unit population mean (μ) we can directly read the required sample size.

In applying this approach to our previous example, where the margin of error was derived as ±27%, we have:

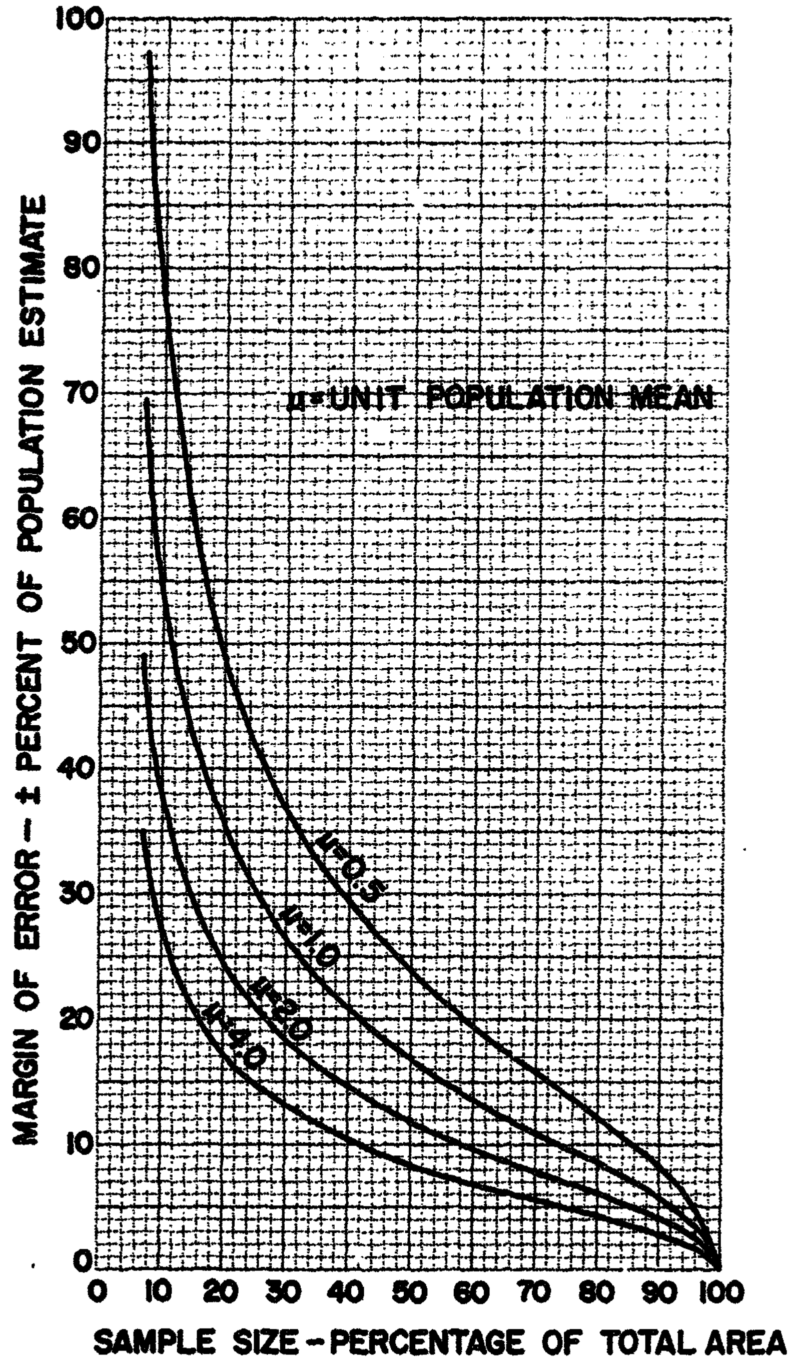
$$n' = \frac{18}{60} \times 100 = 30\% \text{ (percent of total area sampled)}$$
$$\mu = \frac{N\bar{x}}{100} = \frac{60 \times 1.5}{100} = 0.90 \text{ (unit population mean)}$$

Inspection of figure II-4b indicates that for a sample size of 30% and $\mu = 0.90$, the margin of error would indeed be about ±27% and the population estimate at a 90% confidence level would be 94 sites ± 24 sites as before. Further inspection of Figure No. II-4b also indicates that if a smaller margin of error were desired, ±20% for example, the sample size would have to be increased to about 45% of the total hydropotential zone area.



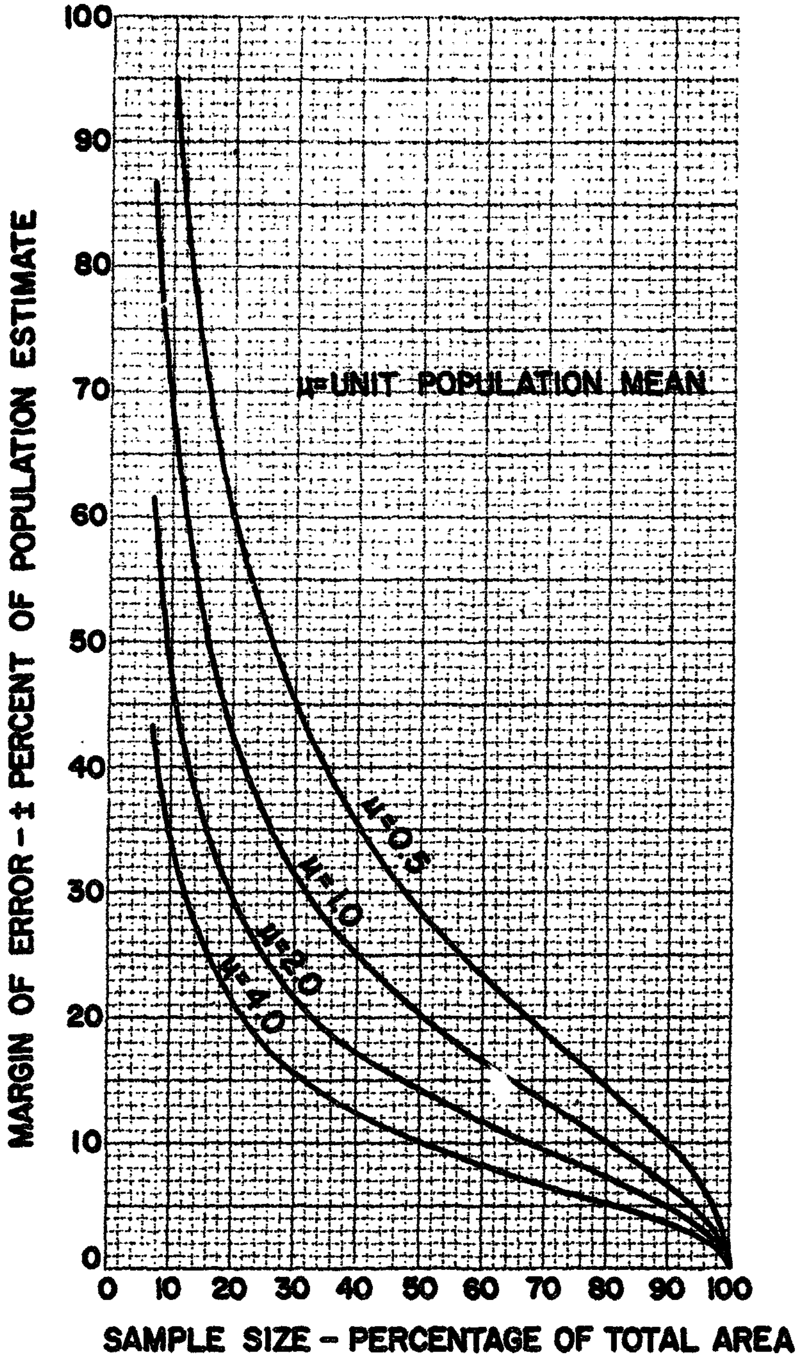
MARGIN OF ERROR vs SAMPLE SIZE
FOR 80 PERCENT CONFIDENCE LEVEL

FIGURE
11-4a



MARGIN OF ERROR vs SAMPLE SIZE
FOR 90 PERCENT CONFIDENCE LEVEL

FIGURE
II-4b



MARGIN OF ERROR vs SAMPLE SIZE
FOR 95 PERCENT CONFIDENCE LEVEL

FIGURE
11-4c

A general analysis of the relationships expressed in Figures II-4a, II-4b and II-4c between sample size, unit population mean and margins of error indicates the following points:

1. As the sample size decreases, the margin of error increases, occurring even more so as the unit population mean decreases.

2. For a given margin of error, the required sample size increases as the unit population mean decreases.

3. The margin of error increases for a given unit population mean and sample size as the confidence level increases. For example, for a 20 percent sample size and unit population mean of $\mu=2.0$, the margin of error would be ±10% for a 80 percent confidence level, ±17% for a 90% confidence level and 21% for a 95% confidence level.

Figures II-4a, II-4b and II-4c have considerable importance for the proposed methodology and will therefore be further discussed when direct application of the methodology is covered.

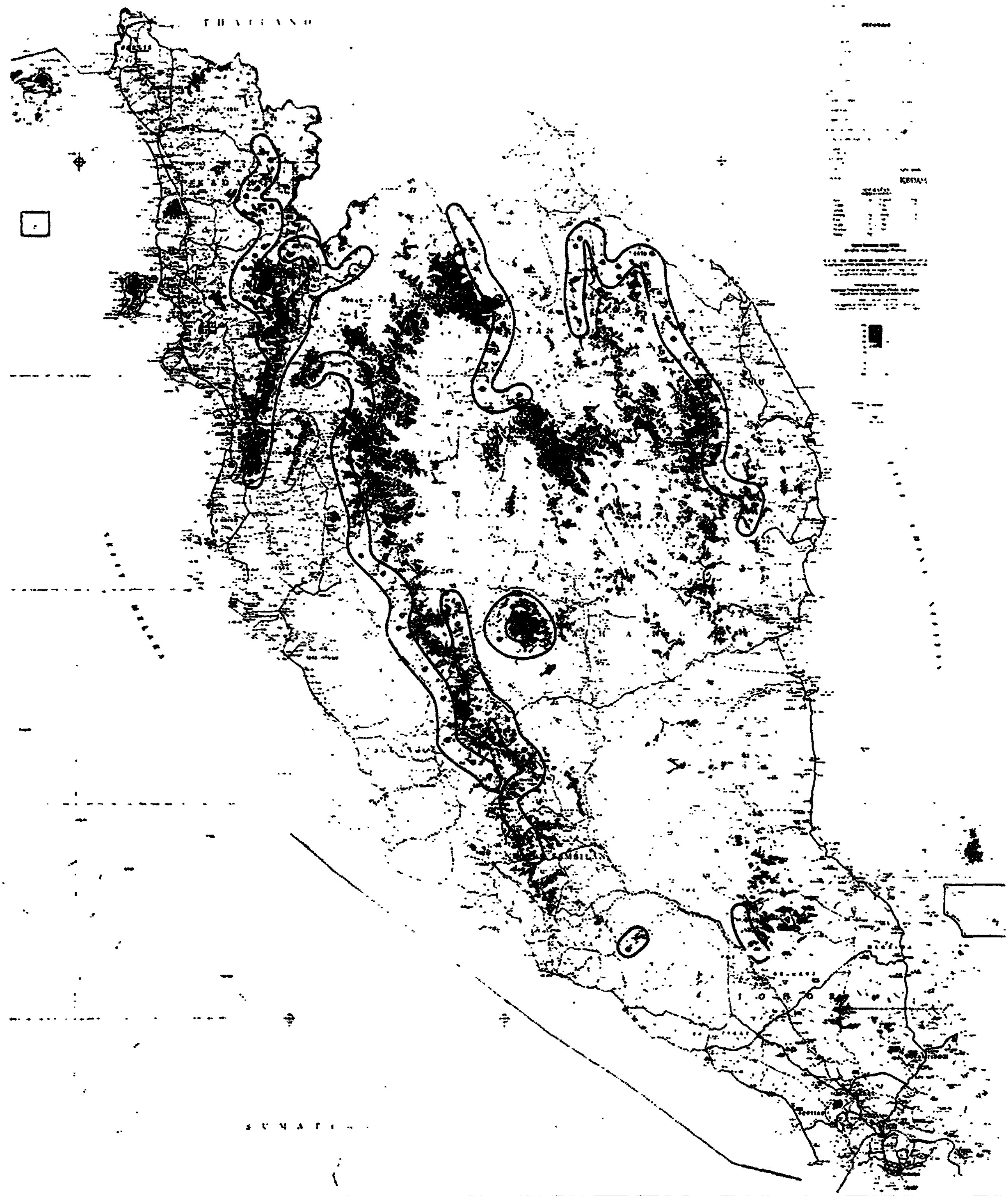
MALAYSIAN EXAMPLE

One large regional area that has recently been extensively studied for small scale hydroelectric sites is peninsular Malaysia where 94 economical sites have recently been identified. While the entire peninsula has not been covered, the areas that have been studied have been fairly extensively investigated, and the results therefore provide a reasonable opportunity to test the proposed methodology.

Description

All identified sites were simple diversion projects with the general configuration as previously described for typical projects. Twenty of the sites were identified by Malaysian government personnel of the National Electricity Board and the remaining seventy four sites by two different consulting engineering companies. While slightly different criteria and approaches were applied by the three entities involved, the general criteria were compatible enough to yield comparable results.

The locations of the sites are shown in Figure II-5. Hydropotential zones have been sketched around the sites and these in turn have been subdivided into nine subzones with 100 sample areas, each comprising approximately one percent of the total hydropotential zone. The hydropotential zones are in accordance with the criteria previously described for defining the zones. Although the resulting zones are not spatially continuous, the key factors which define the zones (i.e., accessibility, topography, hydrology, and market areas) are similar enough that a generally homogeneous area could reasonably be expected.



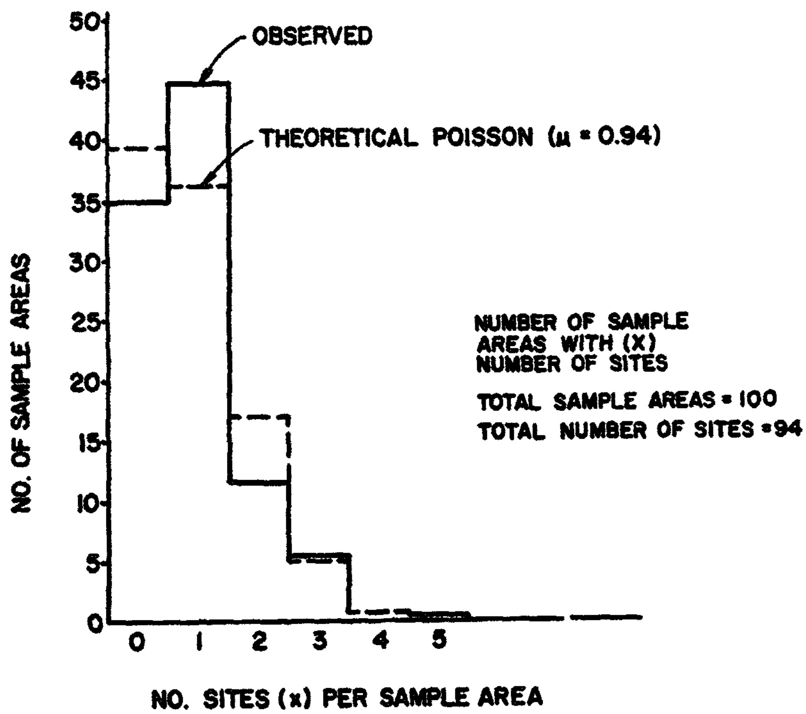
MALAYSIAN EXAMPLE
SITE LOCATIONS AND HYDROPOTENTIAL ZONES

FIGURE
II-5

Analysis of Results

Plotting the average number of sites per analysis unit versus frequency of occurrence results in the observed distribution shown in Figure II-6.

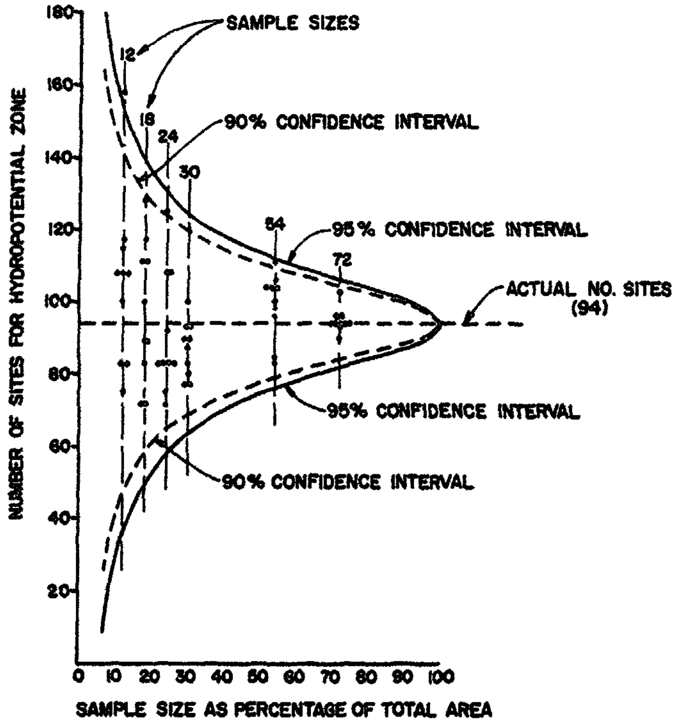
This figure indicates the number of the one percent sample areas wherein various numbers of sites were found. Also shown in Figure II-6 is the theoretical Poisson distribution at the known unit population mean (i.e. $\mu = 94/100 = 0.94$) for the total hydropotential zone. The resulting observed distribution is reasonably close to the theoretically expected Poisson distribution. With an entirely known population and a known distribution, the Malaysian project provides an opportune chance to take hypothetical samples and to check the results that would have resulted had these samples been used to estimate the total population.



THEORETICAL AND OBSERVED DISTRIBUTION OF MALAYSIAN SITES

FIGURE II-6

Proceeding on the assumption that the distribution closely approximates a Poisson with $\mu = 0.94$, theoretical 90 and 95 percent confidence intervals for average number of sites versus size of sample area were derived and are graphically shown on Figure II-8. Ten hypothetical samples were then taken for 12%, 18%, 24%, 30%, 54% and 72% sample sizes. To achieve a reasonable geographic distribution and thus avoid stratified sampling, the same number of one percent sized sample areas were then taken from each subzone. These final sample areas were randomly selected within the subzones for each particular sample. The sample results and extrapolations to the entire hydropotential zone are plotted on Figure II-7 to show the relation between the extrapolated population estimates for the various sample sizes and the confidence intervals.



HYPOTHETICAL POPULATION ESTIMATES FOR MALAYSIAN EXAMPLE

FIGURE II-7

As illustrated, a fairly close agreement resulted between the estimates from the hypothetical sample extrapolations and the expected theoretical limits. For the 6 sets of 10 samples, four values fell out of the 90% confidence interval, very near what would be expected (i.e., 6 X 10x.1 = 6). When only the lower limit of the 90% confidence interval is considered, (i.e. the value above which 95% of the results would equal or exceed) all of the estimates fell above this lower limit.

USE OF METHODOLOGY

The use of the methodology consists of delineating the hydropotential zone or zones, choosing the sample size, selecting the sample areas to comprise the overall sample, analysing the sample areas for viable hydroelectric sites, and extrapolating the results to the entire hydropotential zone to determine the overall population estimate. The associated margin of error and confidence level is then determined. These primary steps are covered in more detail below.

Delineation of Hydropotential Zones, Subzones, and Sample Areas

The hydropotential zones must be as homogeneous as possible for the statistical approach to be effective. Any appreciable variation in the key parameters such as hydrology or topography could very well result in very different unit site densities and would be reason to define separate and distinct hydropotential zones. If the average density of zone A is 0.8 sites per unit area and for zone B is 1.5 sites per unit area, two distinct statistical populations are involved and should be treated separately. Defining the parameters and the hydropotential zones will be a somewhat judgmental process but can be reasonably well quantified on the basis of average stream slope, rainfall intensity, and shape of the flow duration curve.

Any number of distinct hydropotential zones may be delineated, but the larger the region under study, the more likely this possibility will be that several hydropotential zones must be delineated in order to achieve local homogeneity.

In order to avoid stratified sampling and to obtain a reasonable geographic distribution of samples, the hydropotential zones should be further divided into approximately equally sized subzones. The subzones in turn are then further divided into equally sized sample areas. In all, it will be found convenient to subdivide each hydropotential zone into 5 to 10 subzones and 50 to 100 sample areas.

Selection of Initial Sample Size

In applying the proposed methodology, it is desireable to select a sample size that is large enough to yield an acceptable accurate answer without being so large that virtually the entire population is being examined. If large margins of error can be tolerated for the population estimate, sizes as low as 10% of the total hydropotential zone can be used. The sample sizes should not be less than 10% in any case since the statistical approaches used for estimating the margin of error are not valid below this value. If a maximum acceptable margin of error has been established, the required sample size can be derived through a trial and error procedure. After selecting any arbitrary initial sample size equal to or greater than 10%, the necessary analyses are performed and the initial population estimate derived through the extrapolation process. If the margin of error then derived via equation (4) or Figures II-4a, II-4b, or II-4c are in excess of the acceptable maximum, the required sample size can then be modified accordingly and additional analyses performed.

In order to obtain a representative sample and to allow the legitimate application of the statistical methodology to estimate the margin of error, it is extremely important that randomness be strictly observed in selecting the sample area. The number of sample areas should be the same from each subzone. For example, if a 20% sample is desired from a hydropotential zone that has been divided into 10 subzones and each subzone has in turn been divided into 10 sample areas, then two randomly chosen sample areas should be selected from each subzone. This could be objectively accomplished by assigning address numbers to each sample area and using random number tables for sample area selection.

Sample Area Analysis Procedure

The analysis procedure consists of thoroughly investigating the sample areas to determine the number, sizes, configurations, costs, and economic viability of the small scale hydroelectric sites contained therein. Each potential site is identified and individually studied in detail to determine its economic viability. The techniques and considerations involved are covered in the following chapters of this study: Chapter V - "Energy Planning", Chapter VI - "Hydrology for New Sites", Chapter VII - "Technical Evaluation of New Sites", Chapter X - "Cost Analyses", and Chapter XI - "Economic Analyses". Briefly, individual sites would be identified, optimized, and analysed in detail and the results then summarized for the sample areas.

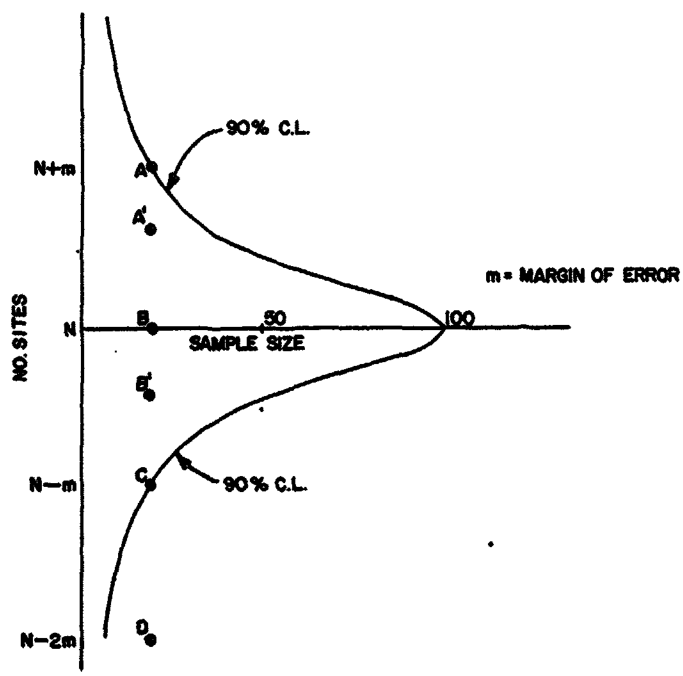
Extrapolation Procedure

Based on the results from the initial sample areas analyses, determine the initial unit population mean (μ) for the hydropotential zone unit site densities and estimate the margin of error from either Figure II-4a, II-4b or II-4c. If the resulting margin of error is in excess of that desired, the sample size must be increased. For example, for a 20% sample size and desired maximum margin of error of ±25% with 90% confidence limits, the unit population mean (μ) has been found to be 1.2 sites per unit area. Figure II-4b indicates, for a 90% confidence level, that the theoretical margin of error for $\mu = 1.2$ is about ±33% and the sample size must be increased from 20% to about 30% so the final population estimate will have the estimate desired margin of error of ±25%.

Margin of Error Adjustment for Population Estimate

If the final estimated number of sites for a given region was equal to or less than the true population, no great problems would result. A program could be established and funded and if more sites in time were found, the program could be extended and additional funds procured. However, if the estimate is larger than the actual population, the resulting program may be over funded and not justified. It would therefore be desirable to be reasonably sure that the final estimate does not exceed the true population, even though we may be considerably underestimating the true population. This can be accomplished by the simple procedure of subtracting the estimated margin of error from the population estimate. The purpose of this adjustment would be to raise the possiblity that the final value would not exceed the actual population.

As shown in Figure II-8, if the original estimate fell at value A the adjustment would bring value A to value B, the actual population value. If it fell at value A′ between value A and value B it would lower the estimate to value B′ between value B and value C (B′). The most conservative result would occur if the estimate was at the low confidence limit of value C, in which case the adjustment would then decrease value C to value D, a value twice the margin of error below the actual population.



MARGIN OF ERROR ADJUSTMENT FIGURE II-8

If the probability was 90% that the original answer was within the specified confidence interval, the application of the margin of error adjustment would result in a population estimate with a probability of 95% of being equal to or less than the actual population:

$$\text{if} \quad P(E-m < X < E+m) = 90$$
$$\text{then} \quad P(E-2m < X < E) = 90$$
$$\text{and} \quad P(X-m < E) = 95$$

where P (.....) = Probability
E = True Population
m = Margin of Error
X = Estimated Population

The results of applying this correction to the extrapolated population values for the 18% sample size for the Malaysia project (94 actual sites) are shown in Table II-1. For the ten 18% samples the original estimated population ranged from 72 to 128 sites. Applying the margin of error adjustment described above yields a final estimated range of 49 to 96 sites.

TABLE II-1
MALAYSIAN EXAMPLE - 18% SAMPLES
DERIVATION OF 95% CONFIDENCE VALUES
USING MARGIN OF ERROR CORRECTIONS

Sample No. (1)	No. Sites From Sample Areas (2)	Total[1] Estimated No. Sites (3)	Unit [2] Population Mean (μ) (4)	Margin[3] of Error (±%) (5)	Margin[4] of Error (±No. Sites) (6)	95%[5] Value (7)
1	13	72	0.72	0.32	23	49
2	15	83	0.83	0.29	24	59
3	20	111	1.11	0.27	30	81
4	23	128	1.28	0.75	32	96[6]
5	18	100	1.00	0.27	27	73
6	16	89	0.89	0.28	20	69
7	20	111	1.11	0.27	30	81
8	21	117	1.17	0.76	30	87
9	13	72	0.72	0.32	23	49
10	16	89	0.89	0.28	25	64

1/ Column (1) x $\frac{100}{18}$

2/ Column (3) ÷ 100

3/ From Figure II-4b

4/ Column (5) x Column (3)

5/ Column (3) - Column (6)

6/ Exceeds actual population of 94 sites

Lest this approach seem too conservative, it should be noted that the application of this margin of error adjustment to a population estimate would have the same net effect of applying a safety factor to the initial population estimate. Such a safety factor adjustment would be a necessary step if a statistical margin of error had not been utilized.

Extrapolation Example

The extrapolation of sample analyses to the population will yield the final assessment recommendations. The estimation of number of sites has been extensively discussed in this chapter. The final assessment would also consider the total installed capacity, the total cost, and the overall internal rate of return (or other economic parameter).

The extrapolation of costs and installed capacity can be accomplished by determining the average values per site and applying these values to the final extrapolated number of sites, (with or without the margin of error adjustment) at the hydropotential zone level. No contingency factor need be applied in this process since it is assumed that a suitable factor will already have been included in the individual site cost estimate. The overall internal rate of return can be derived by using the final estimated number of sites and weighted costs from the sample results. Table II-2 is included as a general example of a regional extrapolation and summary using this general approach. The considerations in deriving this internal rate of return and other benefit/cost parameters are covered in Chapter XI - "Economic Analyses".

AERIAL AND SATTELITE IMAGERY

Aerial and satellite imagery can be very useful in defining the hydropotential zones. Information in varying degrees for all of the parameters used to delineate the zones (i.e. topography, hydrology, power market areas and accessibility) can be derived from overhead imagery.

Data Sources

The primary sources of such images are conventional aerial photographs and Landsat data. Significant developments are currently underway in side-looking airborne radar imagery but widespread applications are not as yet available.

Conventional air photos are widely available for many areas and a check should be made of availability as part of the initial data inventory. To be useful, the photos must be of proper quality and scale and must have been flown quite recently because in many areas it will be found that both power market areas and access roads have increased greatly over a relatively brief period.

Since 1972 the Landsat satellites have taken thousands of images of all portions of the earth's surface. Each area of the globe is currently covered by Landsat sensors every 18 days. Landsat imaging information is available in the form of false color and black and white images from the Multispectral Scanner (MSS) and black and white prints from the Return Beam Vidicon (RBV). Information on hydrology, topography, geology, population density, and accessibility can be readily derived from this source by trained photo-interpreters using available technology.

TABLE II-2
MAP SITE EXTRAPOLATION SUMMARY 1/
(With Margin of Error Adjustment)

Hydropotential Zone	Total No. Sample Areas (N)	Sample Size: No. Sample Areas (n)	Sample Size: % Total Area	Sample Mean ($\bar{x}$)	No. Sites: Sample Area	No. Sites: Total Area (X)	Unit Population Mean (μ) 3/	Margin of Error: ±% 4/	Margin of Error: ± No. Sites 5/	Adjusted No. Sites 6/	Average Cost/Site (C) - $	Total Cost 2/ $	Average Capacity (kW)	Total Capacity (kW)	Average 7/ IRR (R) - %
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
1	33	7	21	3.6	24	119	1.2	36	43	73	1,450,000	105,850,000	726	53,000	12.7
2	27	8	30	2.8	22	73	0.7	33	24	49	1,250,000	61,250,000	605	29,640	13.2
3	20	5	25	3.0	15	60	0.6	42	24	36	700,000	25,200,000	423	15,230	14.5
TOTALS										158		$192,300,000		97,870	

Estimated Number Sites - 158
Total Capacity - 97,870 kW
Total Cost - $192,300,000
Weighted IRR 7/ - 13.1%

1/ This table is presented as a conceptual example only and no significance should be placed on the numerical values used.

2/ In an actual analyses the costs would be broken down into domestic costs in local currency and imported costs in dollars. See Chapter X - "COST ANALYSES."

3/ Col. (7) ÷ 100.

4/ From Fig. II-4b (90% Confidence Level)

5/ Col. (8) times Col. (9).

6/ Col. (7) minus Col. (10). Number of sites that are equal to or less than the true population at a 90% confidence level.

7/ Weighted Internal Rate of Return (IRR) = $\frac{C_1R_1 + C_2R_2 + C_3R_3}{C}$

Use of Data

Photointerpretation of areas without heavy tree cover can be accomplished quickly and accurately on the usual airphotos and satellite images. Roads, villages, farms, buildings and factories can be counted and evaluated. Such areas are more difficult to evaluate in areas of heavy tree cover. Considerable information can, however, be obtained with airphotos by a trained photointerpreter. Power markets can be recognized by the effects of humans on the forest or jungle: the itinerant farmer must pierce — or thin considerably — the vegetative canopy for his plot; the permanent farmer or the plantation manager disturbs the forest either by removing the trees or by replacing them with domesticated varieties; miners dump mack piles or tailings; lumbermen fell the trees and ship them to semipermanent log mills. Most villages are relatively open. Roads can be located because all but the smallest disturb the forest canopy somewhat and can be intermittently discerned from point to point along their route; farms develop along ensuing roads; fords and bridges mark roads at streams and rivers.

The ordinary steps in defining the hydropotential zones would be to first define the area where the sites could be physically located (i.e. areas with suitable topography, hydrology, accessibility) and to then investigate the power market area that would utilize the power product from the site.

Inasmuch as significant other sources of data exist to define the topographic and hydrological parameters, probably the most significant use of overhead imagery would be for the power market and accessibility parameter definitions, although some application for hydrological aspects may also prove useful.

False color images from MSS Landsat data for the infrared spectrum will probably be the most cost efficient approach for large scale definition of the power market areas. Such imagery will allow the populated areas to be defined and population densities to be relatively quantified. This data, together with selected on-site investigations to achieve some correlation between population and energy use, should prove to be a very useful tool in power market definition.

Landsat imagery will be less applicable for access road definition to the available resolution level. Each image covers about 185 km by 185 km and the resolution cells were about 80 m, and more recent images use 35 m. This is sufficient for some applications but low level aerial photos will be much more useful due to the small size of the trails and roads involved and the intermittent visual evidence that will exist, especially in areas of dense vegetative cover.

For hydrologic applications satellite imagery is most useful in glaciated areas and to a lesser extent in areas with a seasonal snowpack. In Peru, for example, the hydrologic regions with good base flow (desirable for small isolated hydro plants) are those with glaciers. During the summer most of the precipitation on the glaciers is stored. During the winter, skies are clear and ice and snowmelt maintain the river flows very high compared to regions with no glaciers. Neither glaciers nor other regions receive much precipitation in the winter. Only two satellite images are needed to show all the glaciers in Peru. Other countries in which the small scale hydropotential is large in part due to glaciers, include Nepal, India, Kashmir, Afghanistan, Chile and Argentina.

In general, models relating satellite imagery and hydrologic data needed for the regional assessment of small scale hydro will prove to be more complex and time-consuming than water balance models. Such imagery, however, may well be useful in extrapolating hydrologic data from regions with known data to regions with no data using similar vegetative cover, elevations, topography and exposure directions.

A final advisory note is that if extensive use of overhead imagery is planned in defining the various hydropotential zone parameters, a trained photo interpreter should be involved. This is a specialized field which is rapidly evolving and which can be technologically complex. A good general reference for personnel not specializing in the field is "Remote Sensing and Image Interpretation", Lillesand and Kiefer, Wiley; 1979.

APPLICATION CONSIDERATIONS

There are various ways in which the results of a regional assessment may be used and these end uses may influence consideration of such aspects as the acceptable margins of error and confidence levels. For instance, if the results will be used to fund the development a project consisting of a specific number of sites over a relative short time period, then a highly accurate answer may be desired, unless the number of sites to be developed is well below the population estimate. If, however, a longer term program approach is to be established when a number of sites, say 25% of the initial estimates, are to be funded and developed per year, results with larger margins of error could well be utilized. Such a "project" and "program" approach is discussed in more detail in Chapter XIII - "PROJECT IMPLEMENTATION".

It is to be emphasized that a reasonable amount of judgment is necessary when applying the techniques outlined in this section. This will be especially true when defining the hydropotential zones. Each investigation will be unique and the various suggestions contained herein should accordingly be taken as guidelines rather than rules and should be modified to fit the situations encountered as the investigator's best judgment dictates. In applying the suggested methodology, as in many other types of planning studies, there are no "right" or "wrong" answers. Rather, there are only reasonable estimates based on reasonable assumptions and judgments.

Some other related observations regarding the application of the proposed methodology are:

1. If a highly accurate estimate is desired, large samples must generally be used. This will be especially true if the unit population mean is low. (See Figures II-4a, II-4b and II-4c.)

2. If a conservative answer is desired, the approach using the margin of error adjustment will result in an estimate that, with a high probability, will be equal to or less than the actual population. The estimate may, however, be below the true population by as much as two times the margin of error.

3. If an approximate answer is allowable, the estimate may be used with no adjustments but with the realization that a margin of error is involved and the estimate may well be above the actual population by a factor of one margin of error. However, this approximate estimate may well be allowable for a long term program approach.

4. High margins of error are possible at low sample sizes, especially as the unit population mean decreases.

5. It is possible to use confidence levels of 80%, 90% or 95% or any other value desired. In this analyses 90% confidence levels have generally been adopted for use in examples since it would seem to be a reasonable value upon which to make investment decisions and since use of the lower 90% confidence interval limits allows the use of a 95% one sided probability. If 90% one sided probabilities are acceptable, use may be made of the 80% confidence level present in Figure II-4a. Although larger confidence levels such as 95% (with 97.5% one sided probabilities) could be adopted, and Figure II-4c is furnished for this purpose, the results may be somewhat misleading, since it is questionable whether or not such high probabilities could actually be realized due to the nature of the basic data utilized. The margins of error are also considerably larger for 95% confidence limits than for 90% confidence limits for the same sample size.

6. The statistical sampling approach discussed in this chapter is applicable over any sized region as long as approximate homogeneity is maintained. However, if the unit population mean for a particular study proves to be very low (i.e. $\mu < 0.5$) the required sample size may well exceed 50% of the hydropotential zone. Under these conditions, the incremental effort to analyse the entire area may be relatively low and the statistical sampling techniques may not be applicable. Other approaches covered herein such as the hydropotential zone concept and the technical assessment methods would, however, still apply.

CHAPTER III
METHODOLOGY FOR EXISTING SITES

This section presents the general methodology procedures to assess sites at existing structures such as canal drops, diversion weirs, and small dams for the addition of hydropower generating facilities. The use of such existing structures may constitute a large amount of the developable hydrologic resources in a given region and an assessment of these sources should certainly be part of any regional appraisal of small hydroelectric potential.

OVERALL APPROACH

Just as for the new site approach, the general methodology relies on the principle of representative sampling and extrapolation although similar statistical techniques are not utilized. The overall approach will be to first inventory the available existing structures, separate the inventory into representative groups, select a typical project from each representative group, evaluate the typical project, and extrapolate the typical project evaluation to obtain the overall evaluation.

The evaluation of each individual site is very straightforward and can probably be accomplished to a higher degree of confidence than can be obtained from the new sites. However, more judgment may be involved in the initial groupings, selection of typical projects, and the extrapolation process. Just as for the new site evaluations, it should be kept in mind that the final goal in the evaluation process is to estimate to a reasonable degree of certainty the number, size, and overall cost of the economically viable projects that can be developed at existing sites in a given region. Judgment factors should be qualified as much as possible, and where this is not always possible, a higher contingency factor should be applied.

TYPICAL PROJECTS

A typical project will consist of retrofitting existing structures such as low dams and canal drops with hydrogeneration equipment. The installation will generally fall into the low head range, (i.e. 20 meters or less) and propeller type and crossflow turbines would be most often utilized, although Francis type turbines may have some limited applications.

Some projects may well be found that would have higher heads, but it is doubtful whether or not a sufficient number are available for such a project to be considered typical. In such a case the project may be quite feasible, but a considerable amount of site specific study or "custom engineering" would be necessary to demonstrate feasibility, and for this reason it is doubtful whether such a site can be included to be studied in detail at this level of analysis. The presence of such sites could be noted and a general estimate of feasibility made after other detailed studies are completed. The projects could then be studied in detail when the development of the other projects begin. It will therefore be assumed that the typical project to be studied will be in the low head range, and the remainder of this chapter will be in this direction.

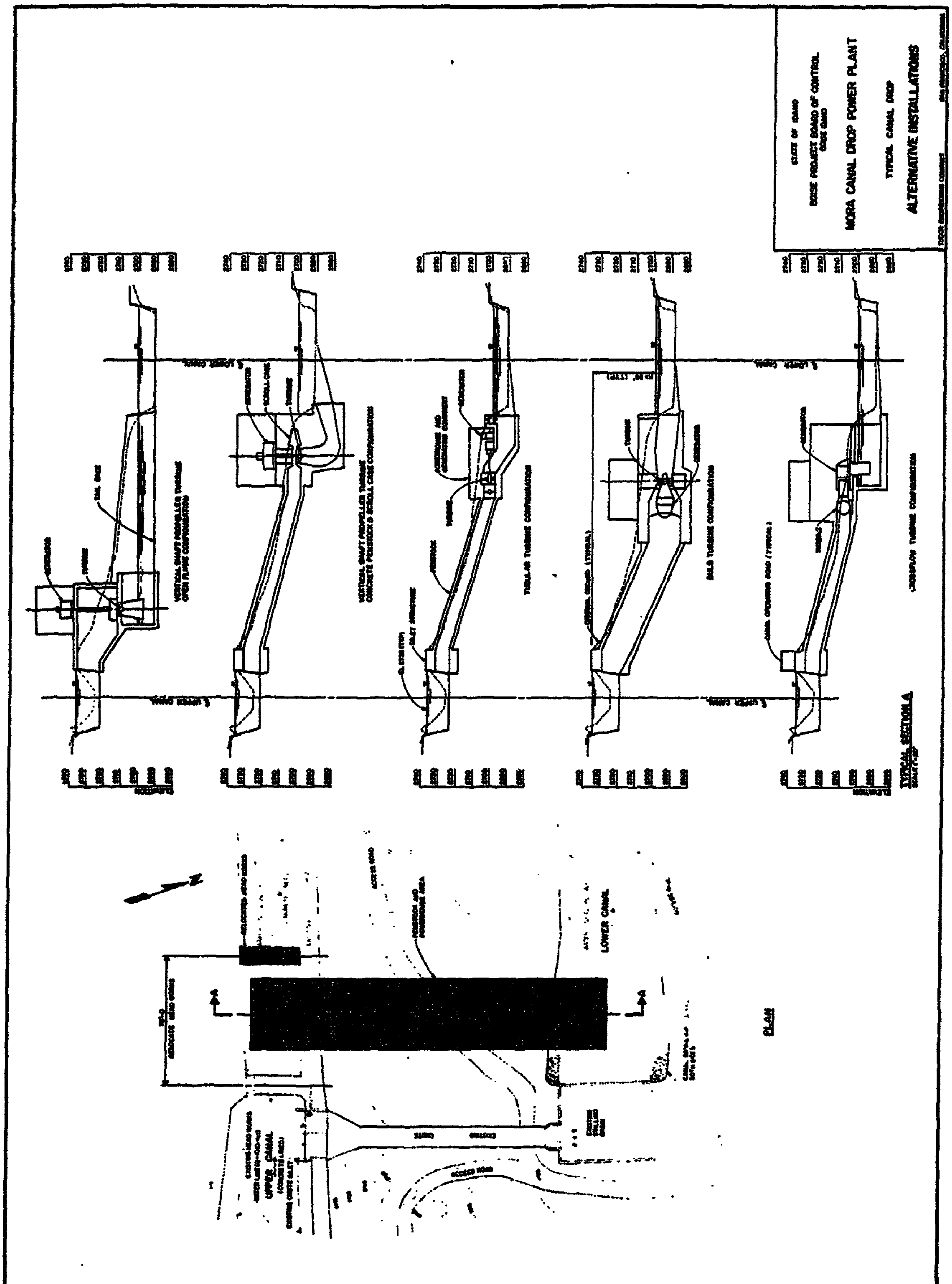

STATE OF IDAHO
BOISE PROJECT BOARD OF CONTROL
BOISE IDAHO
MORA CANAL DROP POWER PLANT
TYPICAL CANAL DROP
ALTERNATIVE INSTALLATIONS
TYPICAL SECTION A-A
PLAN
LOWER CANAL
UPPER CANAL

FIG. III-1

There are many configurations of low head turbines and no one can be cited as typical. Figure III-1 is included to illustrate the possibilities that can exist at any particular location. This Figure illustrates a number of alternative installations at a canal drop near Boise, Idaho, U.S.A. As shown, while the configurations vary considerably, most low head retrofits will have the following features:

1. An intake structure or connection to the existing structure.

2. A short penstock or open channel conveyance facility.

3. A powerhouse.

4. Hydrogeneration and control equipment in the powerhouse.

5. A by-pass facility to pass the flows around the power plant in the event of a sudden outage or when the plant is shut down for maintenance.

METHODOLOGY PROCEDURE

The following six-step procedure describes the implementation of the recommended methodology.

1. An inventory would be conducted of all known existing sites. This would primarily include canal drop structures, diversion dams, and small irrigation and water supply dams. As part of the inventory process general hydrology information would be collected for each site for classification purposes. Those sites that were not relatively near power market areas (i.e. local villages or elements of the national grid) would be screened out and not included in this inventory.

2. The inventory is separated into representative groups with similar characteristics. This would be based on head, flow, release patterns and configurations. The number of such groups would depend on the diversity of the inventoried sites. Hydraulic head would be one of the primary parameters since the cost per installed kW is very sensitive to head in the low head range of installation.

3. A typical project would be selected from each representative group for detailed analysis.

4. Detailed hydrology data would be developed for each typical site.

5. Conceptual design, cost estimates, benefit evaluations and economic analyses would then be conducted for each site studied to analyse final site feasibility.

6. The results from the typical projects would then be extrapolated to arrive at the overall appraisal for the total inventory of sites. The suggested general procedure for the extrapolation is covered in the following discussion.

EXTRAPOLATION OF RESULTS

The extrapolation of the results of the typical project to the entire inventory would be accomplished by first extrapolating to the representative group and summing those results to obtain the overall appraisal. Unlike the new site methodology where the number of sites was extrapolated, a more appropriate procedure for existing sites where the total number of sites is known would be to compute the total potential installed capacity of all inventoried projects and to arrive at the total group cost by applying a cost per installed kW derived from the pilot projects. Table III-1 is presented as an example and the suggested procedure for the extrapolation is outlined below.

Installed Capacity

The total installed capacity of each group would be arrived at by computing the capacity of each site with the simple formula:

$$P = 9.8QHe$$

in which
- P = Power in kW
- Q = Flow in cubic meters per second (cms)
- H = Head in meters
- e = Turbine/generator efficiency

and summing the results. The values used should be readily available and the calculation can be rapidly accomplished. A safety factor (SF) should be applied to the results since not all sites may prove developable. The SF will vary from group to group and would be a somewhat judgmental value based on the unknowns involved and the group homogeneity. A value of 0.75 is suggested as a starting value to be increased or decreased as applicable. The SF would also be applied to the number of sites.

Extrapolation of Costs

The extrapolation of costs can be accomplished by determining the cost per kW of the typical project and applying this value to the estimated total installed capacity. No safety factor need be applied in this process since the SF has already been applied to the capacity and it is assumed that contingencies for quantity and price unknowns will already have been applied in the cost estimating process.

TABLE III-1

EXISTING SITE EXTRAPOLATION SUMMARY 1/

	TYPICAL PROJECT			GROUP			EXTRAPOLATION			
Group	Capacity (kW)	Cost ($)	Cost 2/ Per/kW ($)	Total No. Sites	Total Capacity (kW)	Safety Factor	Total 3/ Capacity (kW)	Total 4/ No. Sites	Total 5/ Cost (C) ($)	IRR (R) (%)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	
1	675	2,025,000	3,000	10	6,750	0.80	5,400	8	15,186,000	15.2
2	825	1,856,250	2,250	5	4,125	0.75	3,094	4	6,962,000	12.3
3	250	450,000	1,800	14	3,500	0.60	2,100	8	3,780,000	13.9
4	150	246,000	1,640	6	900	0.50	450	3	738,000	14.5
							10,706	21	26,666,000	

Estimated Number Sites	21
Total Capacity	10,706 kW
Total Cost	$26,666,000
Weighted IRR	14.0%

1/ This table is presented as a conceptual example only and no significance should be placed on the numerical values used.

2/ In an actual analyses the costs would be broken down into domestic costs in local currency and imported costs in dollars. See Chapter X - "COST ANALYSES."

3/ Col. (5) times Col. (6).

4/ Col. (4) times Col. (6).

5/ Col. (3) times Col. (7).

6/ Weighted Internal Rate of Return (IRR) $= \dfrac{C_1R_1 + C_2R_2 + C_3R_3 + C_4R_4}{\Sigma C}$

CHAPTER IV
STUDY EXECUTION

This section describes the consideration that should be given to organization and personnel, logistics, the study schedule, preparation steps for the study and collection of the necessary basic data.

ORGANIZATION AND PERSONNEL

In many countries, due to the lack of local experience, the first small hydro planning studies will often be staffed by expatriate personnel initially. However, the initial study or studies will often include training and technology transfer as primary goals and the basic site study skills and techniques involved should be easily transferable. The size of the team to conduct the studies will depend on the scope of the study and the extent of the region involved, but the minimum team composition consists of a team leader, one hydrologist, one economist and one or two project engineers with broad civil and design layout backgrounds. Some expertise in environmental subject and sociology is desirable, but the necessary appraisals at this particular study level can be generally evaluated by other members of the study team or conducted by local personnel.

If the initial team consists of expatriate personnel, it is highly desirable to conduct the study in conjunction with a local counterpart staff with similar disciplines from either the government or private sector. In addition to overcoming any language barrier which may exist, working with a counterpart staff multiplies the effectiveness of the expatriate team and greatly expedites the gathering of local data. Local knowledge of environmental, cultural, hydrologic, economic factors, and such technical factors as soils and geology are essential to successful completion of the program.

SCHEDULE AND STUDY TIMING

The length of time necessary to conduct the study using the methodology presented in this report is intended to be between three and five months. The exact time necessary depends primarily on the size and homogeneity of the area to be covered. Such aspects as the availability of data affects more the accuracy of the results than the project timing since assumptions and approximations are necessitated rather than additional study time.

The team leader should arrive in advance of the rest of the project team to line up the necessary study logistics. The rest of the team then begins to arrive for various lengths of stay depending on the discipline. The hydrology studies usually take a minimum of four weeks to accomplish and the hydrologist may well arrive with the team leader since his work must be completed as early as possible. The economist is involved in the power market analyses, the determination of marginal costs, the cost estimating process and establishment of the benefit cost analyses methodology. This work takes a minimum of two to four weeks on site and perhaps some later home office work. The project engineers are involved in the general study execution, including data collection, site analyses, both office and field, cost and economic analyses and report writing. They remain until the end of the project.

PREPARATION

Prior to proceeding to the area to be studied, estimated prices and delivery times for later cost estimating use are obtained of items that will be imported for the projects. These usually include most mechanical, electrical, and control equipment. Obtaining a number of typical layouts of equipment and civil features of small projects similar to those contemplated also expedites the conceptual design processes. If local draftsmen are utilized, example formats of the proposed layouts and graphs save considerable time.

LOGISTICS

The required local logistical support for a regional study are office space and desks, local transportation, and all locally available data and maps. The available mapping varies widely from place to place but, at a minimum, military maps at a scale of about 1:50,000 are generally available in most counties. Geologic maps at about the same scale are widely available and may greatly aid the hydropotential zone definition process.

Demographic data regarding village locations, sizes, economic levels and population projections are generally available from the central planning organization which exists in various forms in most countries. Current and projected electrification data for the country will be available through the national power organization. Land use and settlement data can usually be obtained through forestry and agricultural organizations. This may also be a worthwhile source of access roads information if such uses as old or planned logging areas are on record.

Early contact should be made with the central economic planning organization to gather data on discount rates, local inflation and price escalation and, if applicable, the estimated "shadow" prices of labor and materials.

For field work, cameras, stream flow meters, hand levels, tapes and sometimes altimeters are invaluable. These may not be available locally and should be brought with the project team.

CHAPTER V
ENERGY PLANNING

This chapter discusses various aspects of energy planning as they relate to the individual hydroelectric sites to be constructed. This includes the present and planned national or regional energy pictures, the type of market that the project will supply, the present and projected energy demand, and the types of small-scale hydroelectric projects that could be considered in the planning and evaluation process.

NATIONAL ENERGY PICTURE

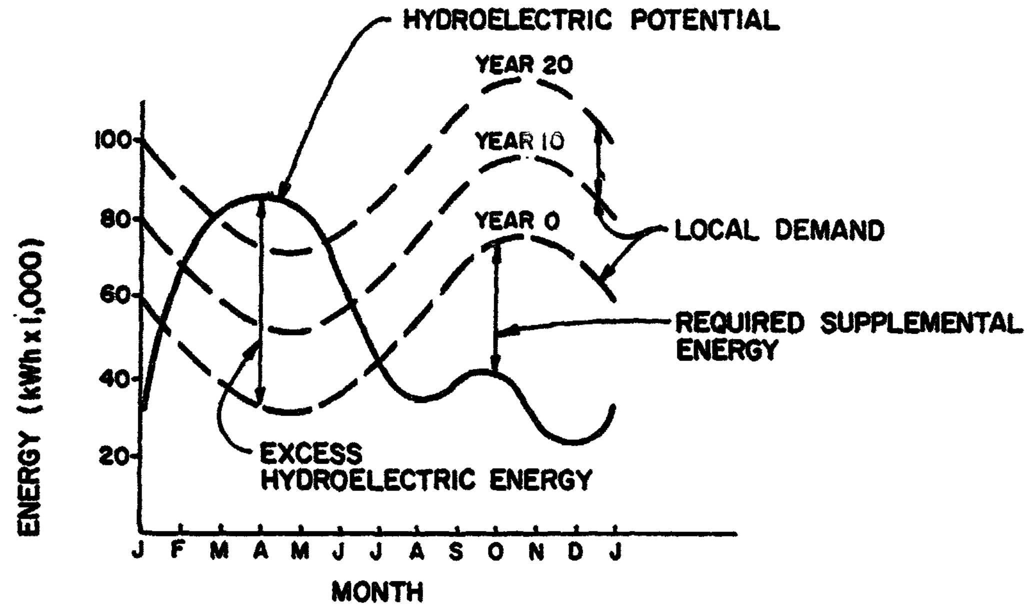
The national, regional and local energy picture should be generally assessed in order to perceive the overall context of the proposed new small-scale hydroelectric installations, and to establish the basis of the hydro benefit evaluation. Forecasts of demand, and present and planned locations and capacities of electrical generating equipment and distribution systems should be noted. This will indicate the need for the proposed hydroelectric installations, and, together with later economic analyses, will establish whether or not the projects will be initially tied to a grid. These aspects have a significant impact in assessing the project benefits.

MARKET TYPES

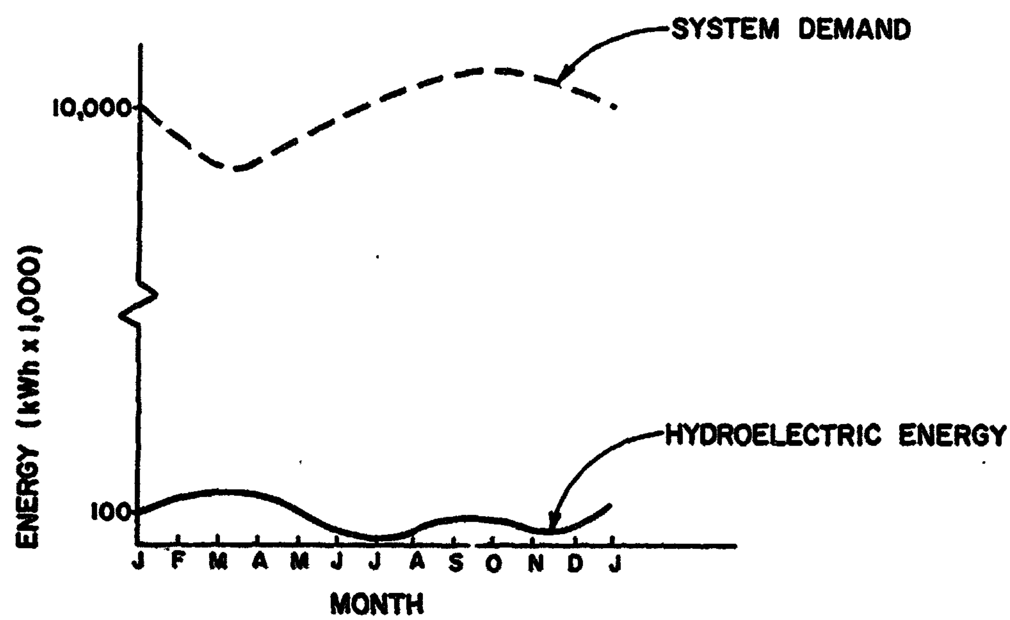
The two basic types of power markets that the small-scale hydro installations serve are grid ties and isolated sites. In some instances it is found that a location will be an isolated site for the initial portion of the project life and later will be tied to a grid system as the national or regional distribution systems are expanded. This is subsequently referred to as the "delayed grid-tie site." The characteristics of these types of markets are discussed below.

Isolated Sites

For isolated sites, the hydro energy is supplied to a small local area which is not tied to a national grid but which may be part of a mini-grid utilizing local small diesel generators. Even with a connection to a fairly large mini-grid, the installation is considered to be an isolated site if the hydro generation constitutes a major part of the total generation. The hydro energy produced at the site varies with the hydrologic cycle and the normal pattern of energy production does not generally match the pattern of local demand. This is illustrated in the conceptual graph shown on Figure V-1a. As shown, when the demand exceeds the hydro energy supply, either a shortage occurs or supplemental power must be supplied. When the theoretical supply exceeds the demand either a supplemental use for the energy (such as heating) must be found or the hydro project will spill the excess water and generate less than capacity. Those differences also change from year to year as the demand increases with time.



ISOLATED SYSTEM FIG. V-1a



GRID TIE SYSTEM FIG. V-1b

ENERGY SUPPLY AND DEMAND

FIGURE V-1

Grid Ties

For a grid tie type of market, all of the small-scale hydroelectric energy produced is fed into the national or larger local grid where, compared to the size of the small-scale hydro unit, a relatively unlimited demand exists. This is illustrated in a conceptual graph in Figure V-1b of annual energy supply and demand for a typical grid tie. The value of the hydro energy in this case is the cost of the avoided energy that would have been produced in the system had the small-scale project not been utilized.

Delayed Grid Tie Sites

This type of site reflects a changing market condition where the project is initially an isolated site but is later tied to a national or local grid. The major problem encountered here is to avoid undersizing the small-scale hydro installation in order to economically maximize its dual purpose use in its transition from local to system use.

ENERGY DEMAND PROJECTIONS

To estimate the size of the proposed small-scale hydro project, establish its operating characteristics, and to assess the project benefits, an energy demand forecast is necessary. It is assumed that such information is available on a large countrywide or regional grid but that it will be necessary to assess locally for the isolated sites. Various approaches are used to prepare demand forecasts and they can be strongly influenced by national goals for rural and village electrification, economic and social objectives of the program, and pricing policy. This subject is well covered in various publications available from the World Bank. 1/

For this level of appraisal study, establishing typical loads and demand forecasts for the isolated projects not currently electrified is the most difficult task. Inasmuch as the small-scale hydro plant normally represents an insignificant proportion of a national or regional network, projection of future demands for the grid-tie type of project is less important. For delayed grid-tie projects, the greatest concern is in those cases where the hydro generation potential of the site exceeds the local market demands in the short-run, thus requiring tradeoff studies between initial and ultimate sizing of the hydro plant, and necessity for staged development.

Demand forecasts for the isolated project are normally based on country data for comparable villages and usually keyed to estimates of per capita use and number of households or consuming units. Recognition is given to growth in the number of consumers, consumption per consumer, and types of consumers - i.e. commercial, agricultural, small agro - industrial, as well as levels of

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1/ See especially Chapter 7, Electricity Economics, Essays and Case Studies, R. Turvey and D. Anderson, World Bank, 1977.

household use. If information is not available within the country, available data from neighboring countries may prove useful. Establishing comparability (especially with regards to levels and source of income) and projecting growth within the country rural electrification policy framework for the type of electric service to be provided requires consultation with government and electric utility officials. A considerable amount of experienced judgment is also necessary.

An initial attempt should be made to forecast demands regardless of the electric generation source, whether it be diesel or hydro or some other alternative, as the avoided costs when comparing conditions with and without hydro forms the basis for the later economic evaluation. However, it must also be recognized that the availability of relatively less expensive hydro could of itself influence the demand forecast. As discussed subsequently in the economics chapter, appropriate adjustments are needed to acknowledge credits occuring to the hydro plant for making more energy available than may be expected under the diesel alternative. On the other hand, reductions may be in order in the case of those hydro projects where the pattern of generation leaves a shortfall in meeting demands during particular times of the day or seasons, as indicated in the subsequent discussion on variable-load type hydro projects.

To adequately credit the long life of the hydro project (which under good conditions could be up to 50 years or longer) and to recognize the high initial capital intensity involved, it is desirable to extend the demand forecast over the project life. Some escalation in use over the project life should also be anticipated. This may be limited to the foreseeable future of say 20 years, or extended beyond. It is advisable to formulate several alternative projections as part of a sensitivity analysis in conjunction with the economic studies. This is especially true where there is surplus small-scale hydro generation available over and above local village needs but well within regional demands.

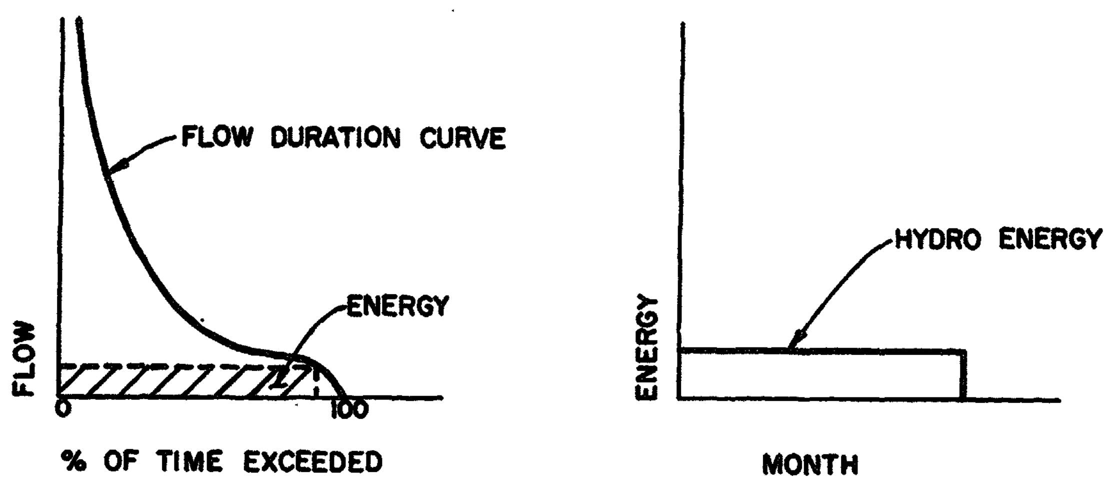
Energy projections (like any projections) beyond the reasonably foreseeable future of 10 years or so, are very problematical. However, when discounting rates are of the order of 10% or more, as is likely, the discounting factors that apply to values beyond the 10th year are of the order of 0.35 or less. In these circumstances errors in estimation of values beyond the 10th year contribute progressively less to the uncertainty of the total present worth figure and are of lesser significance than the values for the first 10 years in which conditions and demands can be more precisely predicted.

HYDROELECTRIC PROJECT TYPES

To meet the energy demand patterns formulated above it is necessary to establish the type of hydroelectric project to be considered. The three primary types are called Base Load, Variable Load and Integrated Installations. The type of project to be ultimately installed depends on local governmental policy and economics. The differences between the types depends on the generation pattern of the hydroplant and the degree of supplemental power by small diesel units (or other alternative source) that is assumed. The three primary types are described below.

Base Generation Type

A "Base Generation" type of small hydro installation is designed to be available on a basis comparable to thermal generation or about 90 to 95 percent of the time. This means that the plant is designed to operate at the 90 to 95 percent exceedence level on the flow duration curve. No supplemental sources of power are installed with this type. The annual energy generated and the generation pattern for the Base Load Type are illustrated in Figure V-2a.

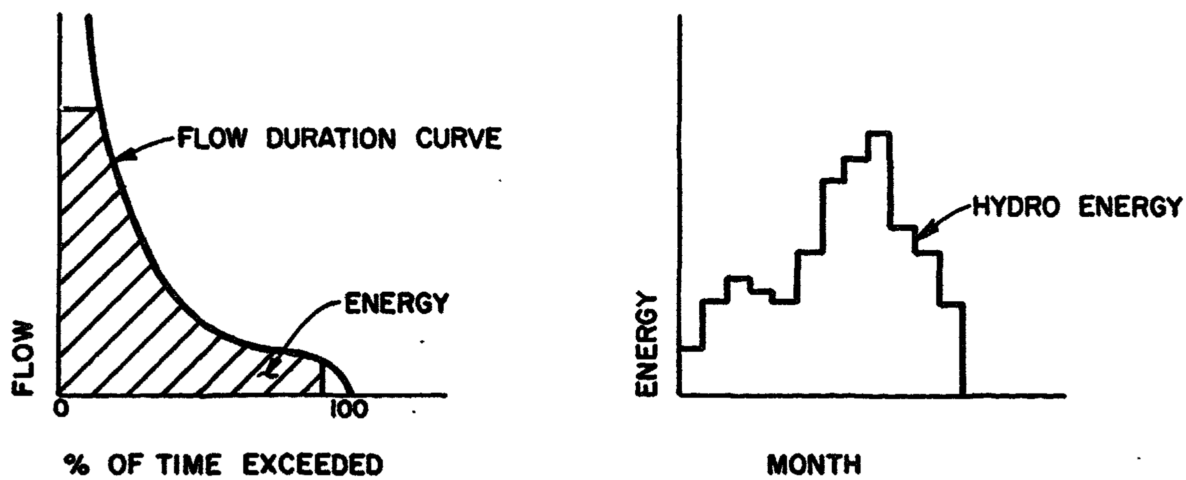


BASE GENERATION FIG. V-2a

This type of installation has the advantage of being extremely self sufficient with no other energy sources needed. This type, however, has the disadvantage of foregoing potential energy production from spills which will occur 90 to 95 percent of the time.

Variable Generation Type

A "Variable Generation" type of small hydro installation is designed to either serve alone or as part of a larger system. The output varies with the amount and pattern of water available. The installation is designed for a much lower exceedence value on the flow duration curve and has a larger installation capacity for the same hydrology than the base generation type. The maximum flow is at the 10 to 25 percent exceedence point and the minimum between 70 to 90 percent. The annual energy and the generation pattern for a Variable Load Type are illustrated in Figure V-2b.

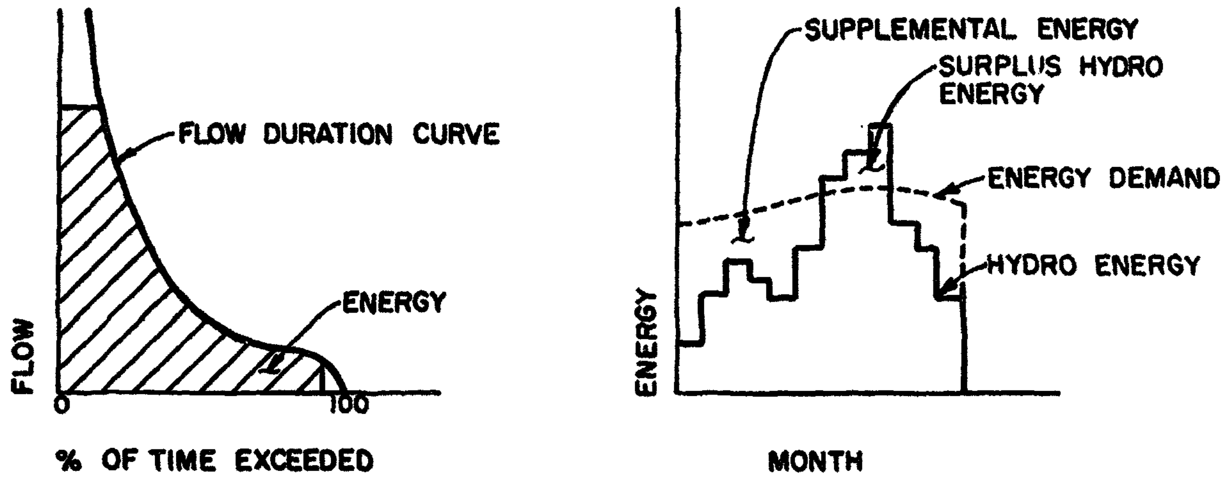


VARIABLE GENERATION FIG. V-2b

This type of installation is most efficient when it is tied into a larger grid but is much less so when it serves as the sole generation source for an isolated area.

Combined Generation Type

A "Combined Generation" type of installation is similar to the variable generation type except that supplemental energy sources, usually small diesel units, are available when the hydro energy supply is insufficient to meet the energy demand. A hypothetical annual energy and monthly generation pattern are shown in Figure V-2c.



COMBINED GENERATION FIG. V-2c

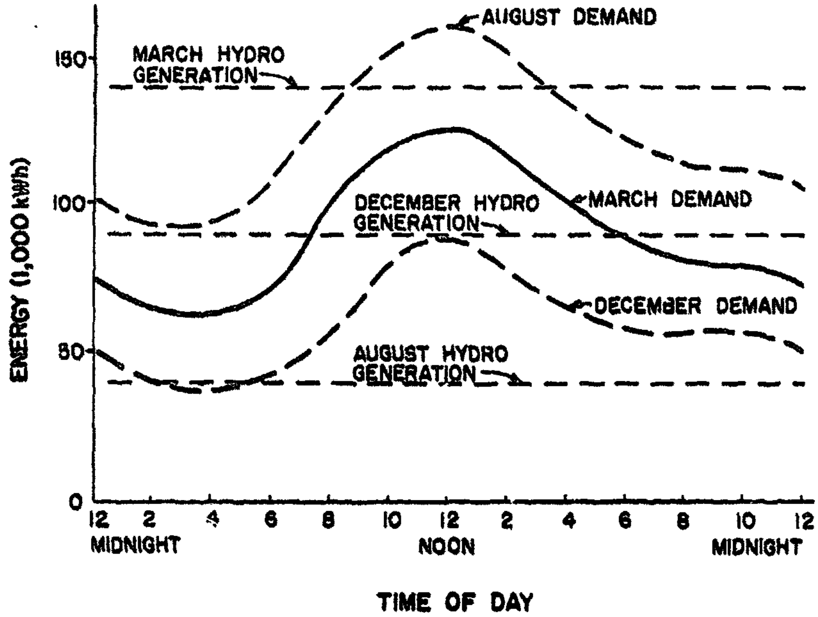
This type of installation is utilized as an integrated system to meet the total energy demands of an isolated area.

DAILY ENERGY SUPPLY AND DEMAND

With small-scale hydroelectric projects the question often arises as to the possibility or advisability of providing additional water storage to facilitate higher daytime and lower nighttime production of energy to match the daily demand pattern and to thus minimize the use of supplemental energy sources such as diesel generation. In theory, the idea is very simple. When the electrical demand is less than the available flow provides, the excess flow is stored in a reservoir and used when the demand is greater than the available flow would provide.

In practice, this idea is harder to implement since the required demand varies from month to month and year to year, as does the stream flow and the resulting generating pattern. This is illustrated in Figure V-3.

A small-scale hydroelectric project with daily storage is more self-sufficient than a simple run-of-the-river scheme, but a considerably larger diversion dam must be constructed to provide the required water storage. For example, instead of a run-of-the-river type of generation utilizing 0.3 cms for 24 hours to produce 600 kW, it is desired to provide daily storage regulation so that the same daily average flow will produce 400 kW for 16 hours and 1000 kW for 8 hours. For purposes of the example, assume a condition where the stream



DAILY SUPPLY AND DEMAND FIGURE V-3

slope is 0.05 and a cross section of the channel is of a trapezoidal shape with a 10.0 meter bottom width, with side slopes of one horizontal to two vertical. The additional dam height to furnish the required storage can now be computed. If the height of the diversion weir for a run-of-the-river scheme is 1.5 m, the storage behind the weir would be 240 cubic meters. The additional storage required for the daily peaking operation would be 6,050 cubic meters and the required dam to yield this storage would be 6.7 m.

Storage provided for off-peak storage may also be subject to rapid depletion, depending on the rate of sediment buildup that occurs behind the diversion dam. In addition, the large daily variation in flows that result may have significant environmental impacts.

Detailed analyses of a given site may well show that such an installation would prove to be economically and engineeringly feasible. However, it is questionable whether such effort can be expended at a reconnaissance level, especially with an approach utilizing a considerable amount of extrapolation to reach final results and conclusions. It is therefore suggested that daily storage not be incorporated in the study at this level of analysis and that the diversion project be limited to the more conservative approach of run-of-the-river only, with no provisions for daily storage. At any rate this does not preclude such an approach being used later in the development process when more detailed analysis of each individual site is more justified.

CHAPTER VI
HYDROLOGY FOR NEW SITES

The determination of the available flows is the most critical factor in evaluating the potential of a small-scale hydropower site. From these flows, estimates are made of the power and energy which can be generated at the site. This is the foundation information upon which all other studies for the hydroelectric project ultimately depend.

Some generalized methods of deriving information defining these site flows in the form of flow-duration curves, hydrographs and flood estimates for new hydropower sites on ungaged streams are described in this chapter. As it is presumed that experienced hydrologists will conduct the regional assessment studies, details of the methods are not described in great detail.

OVERVIEW

On large-scale projects, sequences of hypothetical streamflows are generated to represent the expected future flows at the site. Power production for all options is computed on a detailed level by sequential power plant operation simulation using daily or monthly flow records and a detailed mathematical representation of the hydropower facility. In the regional assessment for small-scale hydropower, however, such elaborate simulations are not warranted.

The instantaneous discharge hydrograph at a site derived from data representing a long period of years is the best indication of the amount of water available for hydropower generation. However, at new sites such a hydrograph will seldom if ever be available, and there is usually insufficient time to measure the flow at the site for more than a very short period.

For a regional assessment of small-scale hydropower, the recommended approach is to derive flow-duration curves and average weekly or monthly hydrographs for the site based on a regional hydrologic study using all available information for the major hydrologic parameters such as precipitation, runoff and evaporation. Watershed models to accomplish this task do exist, but they require numerous elaborate input data and calibrations and the use of a computer which may or may not be available along with the necessary trained personnel. However, such models may very well be worthwhile on large extensive investigations.

In addition to the flow-duration curve and hydrograph, an estimate of flood levels at the hydroelectric site is needed to set the elevation of the generator floor and to assess the integrity of the intake structures during the passage of large floods. Again, a regional flood study using all available flood data is generally the best method to obtain this estimate for the regional assessment.

It is the hydrologist's evaluation of the site hydrology that determines if the hydropower project will perform as conceived. Therefore, the hydrologist must convey to the planner any doubts concerning the validity of his final derived data so that the project can be designed appropriately. If there are grave uncertainties about the amount of flow available for generation, it is advisable to design the project assuming flows smaller than expected in order to avoid oversizing the unit. Provision can be made in the design of the plant to add capacity if it is later found, in fact, that more flow is actually available over a longer period of time.

TIMING AND DEGREE OF EFFORT

The hydrology must be determined before any other deterministic studies are undertaken for the various sites. The regional investigations must therefore be initiated as soon as possible after the overall assessment study has begun. The depth of the hydrology investigation for a given region is quite judgmental, since this task could be completed in anywhere from two weeks to one year or more. It is suggested that the hydrology effort should be planned for completion in a four-to-six-week period in order to be compatible with the timing and level of effort for the other study activities.

A final advisory note is in order. Often, there will be no additional funding or time available to upgrade the regional hydrologic assessment studies and the hydrologic studies performed during the regional assessment will be the only studies available at the initial design stage. Therefore, it is recommended that the field verification of hydrologic information be accomplished to the highest degree possible during the regional assessment. As discussed in the following Chapter XIII - "PROJECT IMPLEMENTATION CONSIDERATIONS," a gaging program should be established for long-term development use, but the information will only be useful at a later date.

REGIONAL HYDROLOGY CONCEPT

To study a large area for hydroelectric resources it is necessary to use a regional approach. The objectives of the type of appraisal covered in this document, i.e. fairly rapid assessment of the overall regional small-scale hydroelectric potential, do not allow time for a site-by-site hydrology study. Nor, for that matter, does the available data justify such a detailed approach. The small ungaged catchments that are of interest are actually best covered by a regional approach.

Historic records alone are of limited value in hydrologic studies for ungaged catchments or catchments with only a few years of record. In many areas, the streamflow records are not 100 percent reliable and may also contain gaps and errors which cannot be removed without numerous long hours of diligent detective work. A regional hydrologic approach, however, can overcome these deficiencies. Hydrologic records from a number of streams and catchments in a region are assembled along with geologic, topographic, soil, vegetation and land use maps, and meteorological data. The assemblage is then studied as a unit.

The first step in the analysis is to select a representative period of years for the study. The period should contain wet and dry, as well as normal years. As rain gage records are commonly much longer than streamflow records, judgments on the cyclic nature (wet and dry) of the streamflow should be confirmed by studying the time series for rainfall. Thereafter, relations are sought among the assembled data from which are made the estimation of streamflow and floods at any hydropower site within the region.

The regional relation among mean annual precipitation, catchment area and mean annual runoff is usually first assessed. If this simple relation does not coherently organize the streamflow data for the region, the effects of other parameters such as percent of lakes and wetlands, type of soil, land use, and basin slope are then added to the relation.

For the flood analyses, the magnitude of the average annual peak floods within a region are usually closely correlated with the size of the catchments, provided there are no lakes, wet lands or reservoirs included in the studied area. The coefficient of variation of the flood peaks is also related to the catchment size, larger areas usually having lower coefficients of variation.

In summary, the regional hydrologic analyses is one way of quickly bringing all significant data to bear on predicting streamflow and floods at an individual hydropower site within the region.

FLOW-DURATION CURVES AND HYDROGRAPHS

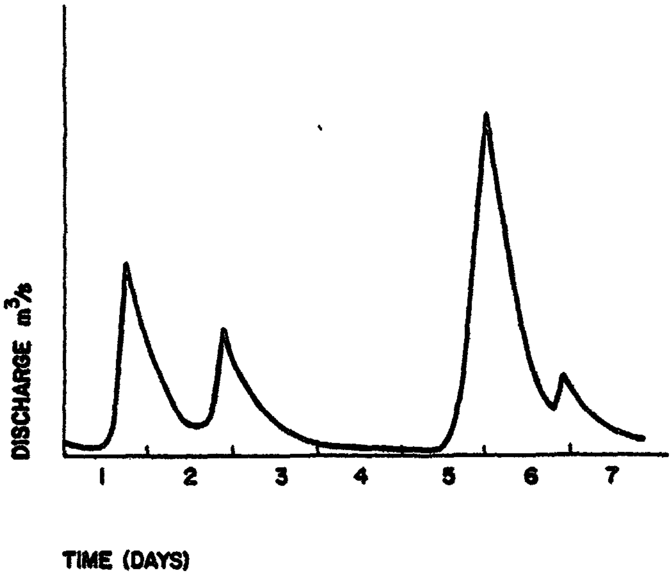
Flow Duration Curves

The flow-duration curve for a given site is a cumulative frequency curve showing the percent of time a specified discharge is exceeded during a given period, usually a year.

When a flow-duration curve is prepared from many years of data, the area under the curve represents the average annual quantity of water available at the site. The curve is therefore very useful in determining the installed capacity and the average annual energy production. These lrocedures are described in the following Chapter VI, "Project Engineering For New Sites."

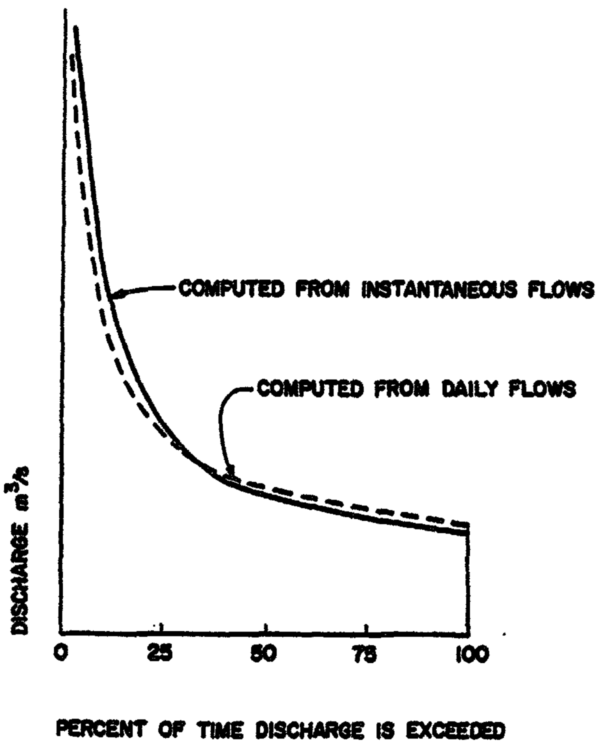
For the regional assessment of small-scale hydropower, the flow-duration curve is commonly prepared using mean daily streamflow values. The differences between flow duration curves constructed from mean daily values and those derived from instantaneous flows (usually approximated by semi-hourly or hourly flows) should be determined to check that the mean daily curves are suitable approximations.

In the tropics where afternoon or evening storms occur in as many as 20 days per month during the rainy season, the weekly streamflow at a gaging site may be similiar to that shown in Figure VI-1.



TYPICAL HYDROGRAPHS IN THE TROPICS FIGURE VI-1

The instantaneous flow duration curve prepared for these types of hydrographs is shaped as shown in Figure VI-2. If the mean daily flows are employed, the shape of the flow duration curve changes somewhat, mostly in the region where the flow is exceeded a smaller percent of the time. This difference between flow duration curves based on instantaneous and daily flows is also illustrated in Figure VI-2.



TYPICAL FLOW DURATION CURVE FIGURE VI-2

If the proposed hydropower station is to be operated as an isolated site, it may be desirable to design the plant for a lower flow but higher availability (i.e., a base generation type - see Chapter V, "Energy Planning"). In such situations, great care must be taken to define the low-flow end of the flow duration curve where the higher exceedence values are of primary interest. Sites supplied by catchments with lakes, wet lands, glaciers or large aquifers are the most suitable for firm power and isolated loads.

If the proposed hydropower station is to be connected to a regional electric distribution system, the annual amount of energy generated at the site is a prime consideration. In these situations it is the central portion of the flow-duration curve which must be adequately defined.

Large flows which occur during floods cannot be utilized economically for small-scale hydropower generation without storage for the flood water. Thus, the flood end of the flow duration curve with very low exceedence values is relatively unimportant.

Hydrographs

The hydrograph at a given site is a temporal pattern of the historical flows, on an instantaneous, daily, weekly, or monthly basis. The longer the interval used (i.e. daily, weekly, or monthly) the more averaging that takes place.

This averaging of flows, which is inherent in hydrographs, usually precludes the use of weekly or monthly hydrographs to compute power and energy generation at a run-of-the-river type of installation. Turbines have both high and low operating limits and the use of averaged streamflow values for power and energy calculations usually yields erroneous answers, since the higher and lower flows which occur are averaged out. For example, a Francis turbine has a general operating range of 105 percent to 30 percent of design flow. If the streamflow for the first half of a month is 150 percent of design flow and the streamflow for the rest of the month is 25 percent of design flow, the average monthly flow would appear as 87.5 percent of design flow, indicating continuous generation at this discharge throughout the month. Actually, the turbine would generate with 105 percent of design flow for the first half of the month and would generate nothing for the remainder of the month. In this case only about 60 percent of the energy that would be indicated using the average monthly flow could actually be generated.

The use of instantaneous flow duration curves for power and energy computations overcomes this disadvantage of hydrographs since all flows are involved in the makeup of the curve. However, while the amount and installed capacity can be derived from an instantaneous flow duration curve, the monthly (or weekly) pattern of this production cannot, and this is the chief use of hydrographs for a run-of-the-river type of installation. The use of the derived hydrograph to accomplish this and to thus estimate the need for supplemental diesel generation is described in Chapter VII - "Technical Evaluation of New Sites."

DATA SOURCES

The prime data required for regional hydrologic analyses of streamflow and floods are:

1. Catchment areas
2. Annual streamflows and flood peaks
3. Annual basin precipitation
4. Meterological records including at least air temperature, relative humidity, wind speed and pan evaporation.

Catchment areas are easily obtained from topographic maps. Recent aerial photographs are helpful if the map scales are small or if there is any doubt about the accuracy of the maps.

Streamflow records are usually published by the government agencies which collect and process the streamflow data. Recently, most agencies can supply daily streamflow records at gaging stations from files stored in computers. Other sources are: publications on national and regional hydrology; reconnaissance, feasibility and design reports on large-scale hydroelectric projects in the region; and water supply study reports for industrial and municipal water. Perhaps the country had commissioned a study for a "National Water Resources Development Plan." This document will contain numerous valuable pieces of hydrologic and meteorologic data. The government department in charge of water resources planning will usually have all these and other useful documents in their offices.

Annual basin precipitation can be obtained by locating the catchment on the annual precipitation map for the region. Usually such precipitation maps have been prepared by the government agencies using all but the latest raingage data. Such documents and other climatic data can usually be found in libraries or at the National Weather Service Agency.

The potential evapotranspiration can be computed quickly from Class A pan evaporation measurements. If no pan data are available, the potential evapotranspiration must be computed using available weather station data. In agricultural areas with irrigation, these calculations will have been done as a part of the crop irrigation requirements.

Maps of the World Water Balance (Baum Gartner and Reichel, 1975) show global precipitation, evaporation and runoff. However, the scales are too small and the information is too general for use in the regional assessment of small scale hydro power. UNESCO and WMO (1977) discuss and give examples of the development of hydrologic maps in their series of studies and reports in hydrology. UNESCO (1974) has provided (very helpful) methods for water balance computations.

In general, the data published by UNESCO and WMO are good bases from which to start the hydrologic studies. For example, one can obtain estimates of annual precipitation in peninsular Malaysia in any good library in the United States. Maps of these data form a skeleton which must be fleshed out by adding updated data from all hydrologic stations in the area.

Often International Agencies have hydrologic experts working in developing countries. These people may have at their finger tips much of the regional hydrologic data needed for the assessment of small hydro potential.

Secondary data needed for regional hydrology analyses of streamflow and floods include information on the following:

1. Geology
2. Topography
3. Soils
4. Land use
5. Vegetation
6. Monsoons
7. Catchment slopes
8. River profiles

The sources of these data may be widespread. When obtaining the prime data, it may be advantageous to ask the people in the offices visited where the best place is to obtain the secondary data.

HYDROLOGIC METHODOLOGIES

It is necessary to derive a flow duration curve and an average monthly hydrograph for each specific site to be studied. As previously covered, the flow duration curve is used to determine the power and energy potential of the site and the hydrograph is used to determine the pattern of the power and energy production. The general steps necessary to derive the flow duration curve and hydrograph are:

1. Perform a regional study to derive the regional dimensionless flow duration curve parameters and hydrograph pattern.

2. Determine the catchment area of the desired site.

3. Using the data from the regional study, derive a local dimensionless flow duration curve.

4. Determine the local annual runoff.

5. Using the data from steps 3 and 4, derive a local flow duration curve.

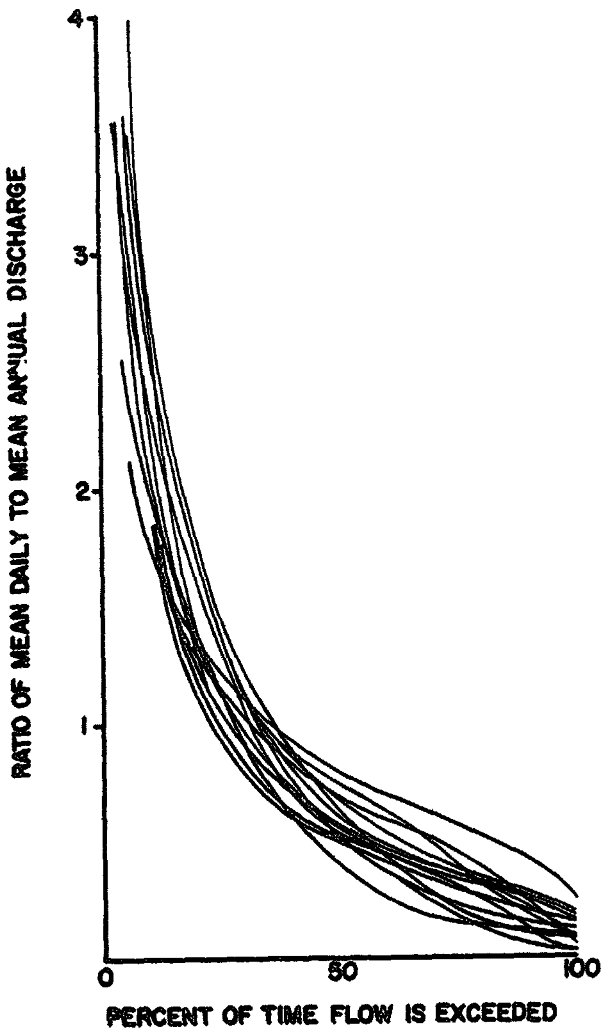
6. Using the data from steps 1 and 4, derive a local average monthly hydrograph.

The suggested procedures to derive the regional and local flow duration curves, the average annual runoff and the average monthly hydrograph are covered below.

Derivation of Flow-Duration-Curves

Flow-duration curves can be regionalized. For each streamgaging station, a normalized or dimensionless flow-duration curve is prepared by dividing the ordinate (discharge) by the mean annual flow for the site. Comparison of all annual flow duration curves for the region usually shows that the shape of the nondimensional curves is somewhat related to catchment area provided there are no lakes and wetlands and the precipitation regime has not changed.

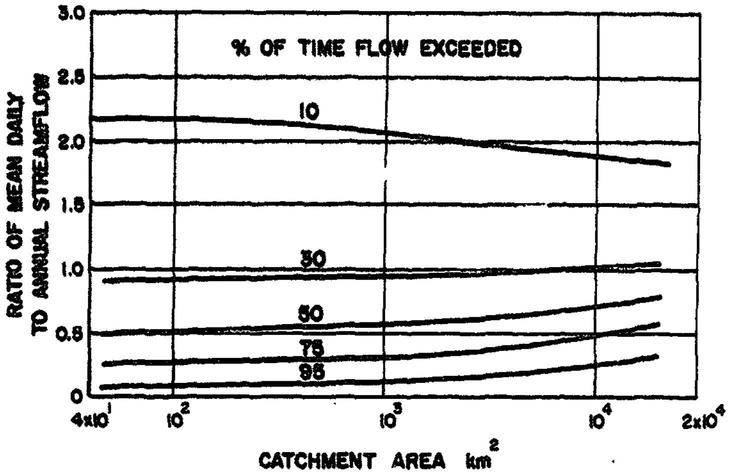
As an example, the dimensionless flow-duration curves for streamgaging stations in eastern peninsular Malaysia are shown in Figure VI-3. These are for catchments ranging in size from 48 square kilometers to 19,000 square kilometers. The lengths of record vary from 3 years to 25 years.



FLOW DURATION CURVE FOR STREAMGAGES IN EASTERN PENINSULAR MALAYSIA

FIGURE VI-3

Analyzing these non-dimensional flow-duration curves with respect to catchment area for various exceedence values results in the relation shown in Figure VI-4. Clearly, there is a pattern of changing shape for each exceedence value with size of catchment. For this particular example, the shape of the diemnsionless flow-duration curve which would be constructed from the parameters given in Figure V1-4 would remain fairly constant for areas from 40 square kilometers to about 1,000 square kilometers and then begins to become somewhat flatter.



REGIONAL FLOW DURATION CURVE PARAMETERS FIGURE VI-4

A relationship similar to that presented in Figure VI-5 can generally be derived for any particular region under study. After such derivation, a non-dimensional flow duration curve for any particular site can be generated by simply determining the catchment area of the site and selecting the pertinent exceedence values of a flow duration curve.To derive a site specific flow duration curve it then remains necessary only to multiply the ordinates of the non-dimensionless curve by the mean annual flow at the site to obtain the desired site-specific flow duration curve.

Determination of Annual Runoff

There are many hydrologic techniques utilized to derive the annual runoff of a specific site. The following discussion presents some very general observations and suggestions pertaining to how this can be accomplished.

As there are probably no flow data available at any of the new hydropower sites in a region, the best estimate of the flow at the site is usually that made from the streamflow records available in the region around the site. The streamflow at the site is related to that at nearby stream gages; the two principal correlating factors are basin precipitation and catchment area.

Consider first a site located on a stream having a gaging station either downstream or upstream from the site. If there is no groundwater flow to or from adjacent catchments, one can assume that, on an annual basis, the discharge at the hydropower site is proportional to the catchment area and the gross annual precipitation less evapotranspiration:

$$Q_1 = \frac{A_1}{A_2} \times \frac{(P_1 - E_t)}{(P_2 - E_t)} \times Q_2 \tag{1}$$

Here
Q_1 = annual runoff at the hydropower site
A_1 = catchment area at the hydropower site
A_2 = catchment area at the streamgage
P_1 = catchment precipitation for the hydropower site
P_2 = catchment precipitation for the streamgage
E_t = annual evapotranspiration for the catchment, here taken to be the same for both catchments
Q_2 = annual runoff at the streamgage.

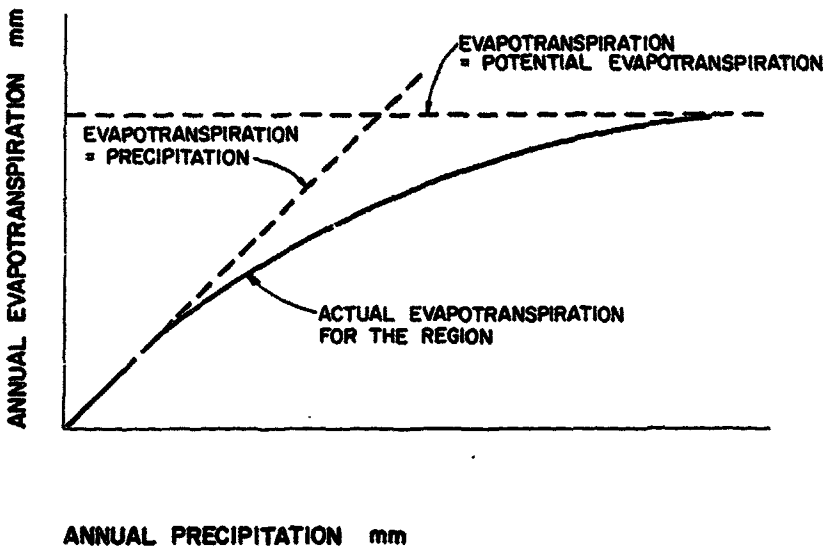
When there are "n" streamgages available on the stream, the "n" estimates of the annual runoff at the hydropower sites should be made. Inevitably, these estimates are not equal. The question is whether the deviations of the estimate from the mean can be correlated with any other hydrologic variable such as lithology, basin relief, basin aspect, soil type, or land use. The deviation is:

$$D_m = \overline{Q}_1 - \frac{A_1}{A_m} \times \frac{(P_1 - E_{t1})}{(P_m - E_{tm})} \times Q_m \tag{2}$$

in which the subscripts "1" and "m" refer to the hydropower site and the "m-th" gaging station respectively and $\overline{Q}_1$ is the average of all estimates of streamflow at the hydropower site. Statistical methods should be used to determine the relation (or lack of) among the magnitude of the deviations and the other hydrologic variables. Often the deviation is related to groundwater.

The same mathematical model (which is really a ratio of annual water balances for two catchments) can be used for catchments adjacent to the hydropower site. Catchments from the region can be added to the correlation as long as homogeneity remains between the involved hydrologic parameters.

The annual evapotranspiration from a catchment can also be estimated from a regional analysis. In areas where the rainfall is very low, the annual evapotranspiration is often almost as much as the annual precipitation. Conversely, where annual precipitation is extremely large and distributed somewhat uniformly with respect to seasons, the annual evapotranspiration approaches the potential evapotranspiration. It follows then that the shape of the evapotranspiration versus precipitation curve is as shown in Figure VI 5. The potential evapotranspiration can be calculated from the pan evaporation and meteological data available for the region.



REGIONAL EVAPOTRANSPIRATION FIGURE VI-5

In areas where rainfall intensity or soil type and land use varies greatly, annual evapotranspiration depends not only on annual precipitation but upon these other variables. An analysis of the deviations of the actual values of evapotranspiration from the mean curve should be accomplished to establish the correlation.

Catchments with lakes and wetlands have a higher annual evapotranspiration rate than other catchments with the same annual precipitation. This increase in evapotranspiration can be estimated using a water balance for the catchment. Care must be taken with these catchments because such aquatic areas may be fed with groundwater, the source of which may be outside the catchment.

In contrast to deriving the annual streamflow from a deterministic water balance methodology described above, hydrologists often use the following correlation model:

$$Q = RA^a P^b S^c \ldots \qquad (3)$$

in which Q = annual streamflow at the site
A = catchment area
P = annual precipitation
S = slope of the catchment

The coefficients R, a, b . . . are numbers obtained by a multiple regression and correlation analysis. Linear regression analysis is also sometimes employed to determine these constants.

Derivation of Hydrograph

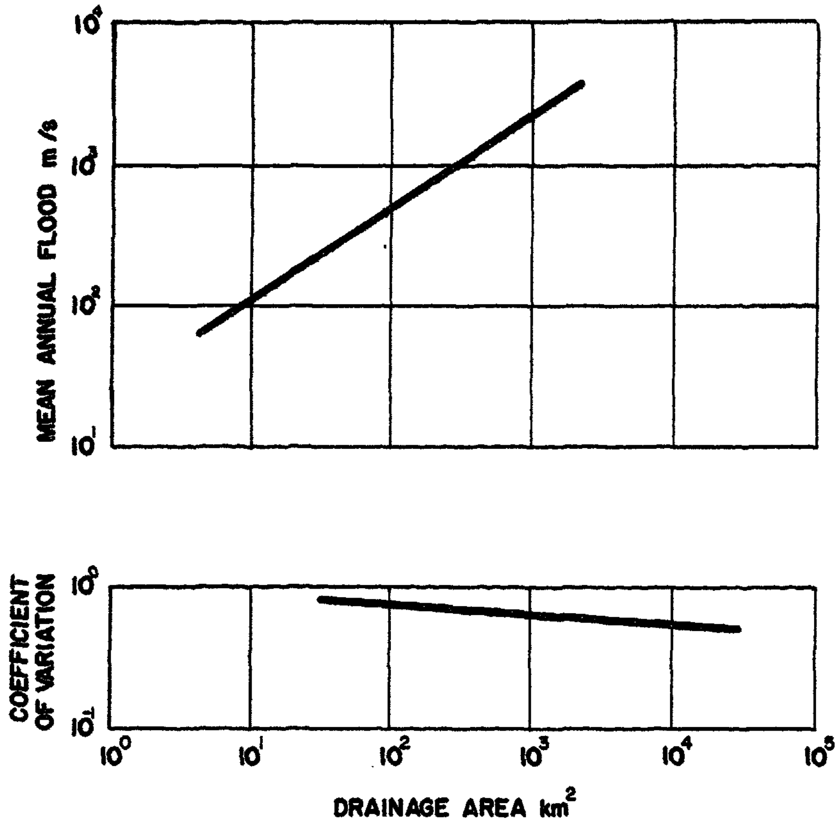
The derivation of a local site-specific hydrograph can be accomplished by simply scaling down the monthly (or weekly) magnitude of the hydrographs from which the regional flow duration curves have been derived. The resulting annual total volume of runoff should be compatible with the average annual runoff as determined above for the site. Since the hydrograph is used only to establish the daily, weekly or monthly variation in power and energy production for the site, great effort is not justified in derivation of the hydrograph.

FLOOD HYDROLOGY

Flood Discharge

The feasibility investigator needs an estimate of flood water height at the power plant location so the site can be selected with some confidence that frequent flooding will not occur. The regional flood study provides this information.

The annual instantaneous peak discharge records for each streamgaging station in the region is first assembled. The mean annual flood and the coefficient of variation for each flood record are then computed. The catchment area is chosen as the independent variable and the results are plotted as in Figure VI-6.



REGIONAL FLOOD FREQUENCY CURVES FIGURE VI-6

If the correlation of mean annual flood and coefficient of variation with catchment area is adequate, the floods for ungaged sites can be adequately estimated. Two types of flood frequency distribution functions commonly used are the Gumbel and the log-normal. Either requires only the mean and coefficient of variation to define the entire distribution. For example, using the Gumbel distribution, the 50-year flood is:

$$Q(50) = \overline{Q}\,(1 + 2.59\,C_v)$$

in which $\overline{Q}$ = mean annual flood

C_v = coefficient of variation

If the correlations are initially poor, then additional variables can be added to the regressions until a suitable correlation is obtained. Some variables commonly employed to improve the correlation are: slope of catchment; annual basin precipitation; land-use; and elevation of basin.

In areas where the streams are alluvial and the geology is homogeneous with respect to rock types, an estimate of the mean annual flood can be made by measuring the channel dimensions that were shaped primarily by floods. Flood data at streamgages are required to determine the relation between mean annual flood and channel width. The relation is then used for ungaged sites in the same region. This fluvial morphological method requires careful selection of channel sections by hydrologists familiar with the technique.

Flood Stage

The flood stage for the design flood discharge is computed assuming either uniform or nonuniform flow in the stream. Manning's equation or a form of the backwater equation are applicable. The required river geometry is obtained from the surveyor's map of the site.

The main problem with determining the flood level is choosing a value of Manning's roughness coefficient. There are usually no field data from which estimates of the roughness can be calculated. At sites suitable for small-scale hydropower development, the streams are often choked with large boulders, fallen trees and overhanging branches. The banks are very low and lined with thick vegetation and the width-to-depth ratio is small. There is no catalogue of roughness coefficients for such streams as there has been very little use for this type of information in the past.

FIELD INVESTIGATIONS

The field investigation of the proposed sites is important to assess the degree of confidence that can be placed in the derived hydrology. There are three main parts to the field investigation: (1) inspection of the site and catchment; (2) interviews with people who live in the area; and (3) inspection of the primary stream gaging sites upon which the derived hydrology is based.

The inspection of the site and catchment is needed to establish if the land-use has changed (recent extensive logging or land clearing operations, for example) and to estimate the roughness coefficient of the stream. A dry-season visit is most useful as one can estimate the low flow in the stream at that time, and it is also a good time to look for springs.

Interviews with local residents are necessary to confirm that the stream does not dry up at times. These people may remember some of the higher flood levels along the stream. Such information is valuable in confirming that the generator floor is set at an appropriate level. Also, they will know if there are any upstream diversions of water for irrigation or other uses.

Inspection of as many primary gaging stations as possible is advisable in order to assess the degree of credibility that can be placed in the data from the sites. Perhaps an obsolete rating curve is being used, or the stream has shifted somewhat since the gage was established, or the data are obtained by a local resident who lives several kilometers away and visits the site only infrequently. Many special circumstances can surround the data gathering process and on-site visits are always very worthwhile.

CHAPTER VII
TECHNICAL EVALUATION OF NEW SITES

This chapter describes the technical aspects of the site evaluation process. This includes the conceptual design formulation, with observations on accuracy and degree of effort, the estimation of power and energy production, site selection and evaluation procedures, geology soils considerations, and field verification activities.

CONCEPTUAL DESIGN PROCESS

Conceptual design refers to the initial design formulation - the visualization of the configuration and location of the basic project features and the subsequent preparation of the layout or project plan of the site. For small-scale hydro sites, the visualization process is often carried out in the field where initial site layout sketches are made and the locations of the project features are determined.

The project layout is then made in the office and is based on site sketches, photographs and sometimes field surveys. This is an important process since the project cost estimates are based on these conceptual designs. The layouts should be as accurate as possible within the limitations of time and budget.

PROJECT FEATURES

The features of a typical small-scale hydro site consist of the headworks facilities, which include a diversion weir, an intake structure, and a sediment basin (included as necessary); a penstock or other conveyance facility; a powerhouse; hydro generating equipment, a transmission line; and access roads or trails as necessary for initial construction and later operation and maintenance. There are many possible designs and configurations for each of these features. To serve as some conceptual design examples, included with this Chapter as Figures VII-1a to VII-1c and Figures VII-2a to VII-2c are drawings showing the headworks facilities, plans and profiles and powerhouse layouts for one small-scale hydropower site in Malaysia and one in Alaska.

These included drawings were prepared for detailed feasibility studies and are somewhat more elaborate than are required for the recommended regional assessment approach. In practice only one drawing per site is necessary, but it should include all pertinent information such as a plan and profile and a general layout of the headworks and powerhouse facilities. The basic purpose of such project layouts at the reconnaissance level is to document the conceptual design and to allow accurate cost estimates for the project facilities to be prepared.

Some general comments and functional descriptions of the various project features illustrated on the sample drawings and normally included with small scale diversion projects are listed below.

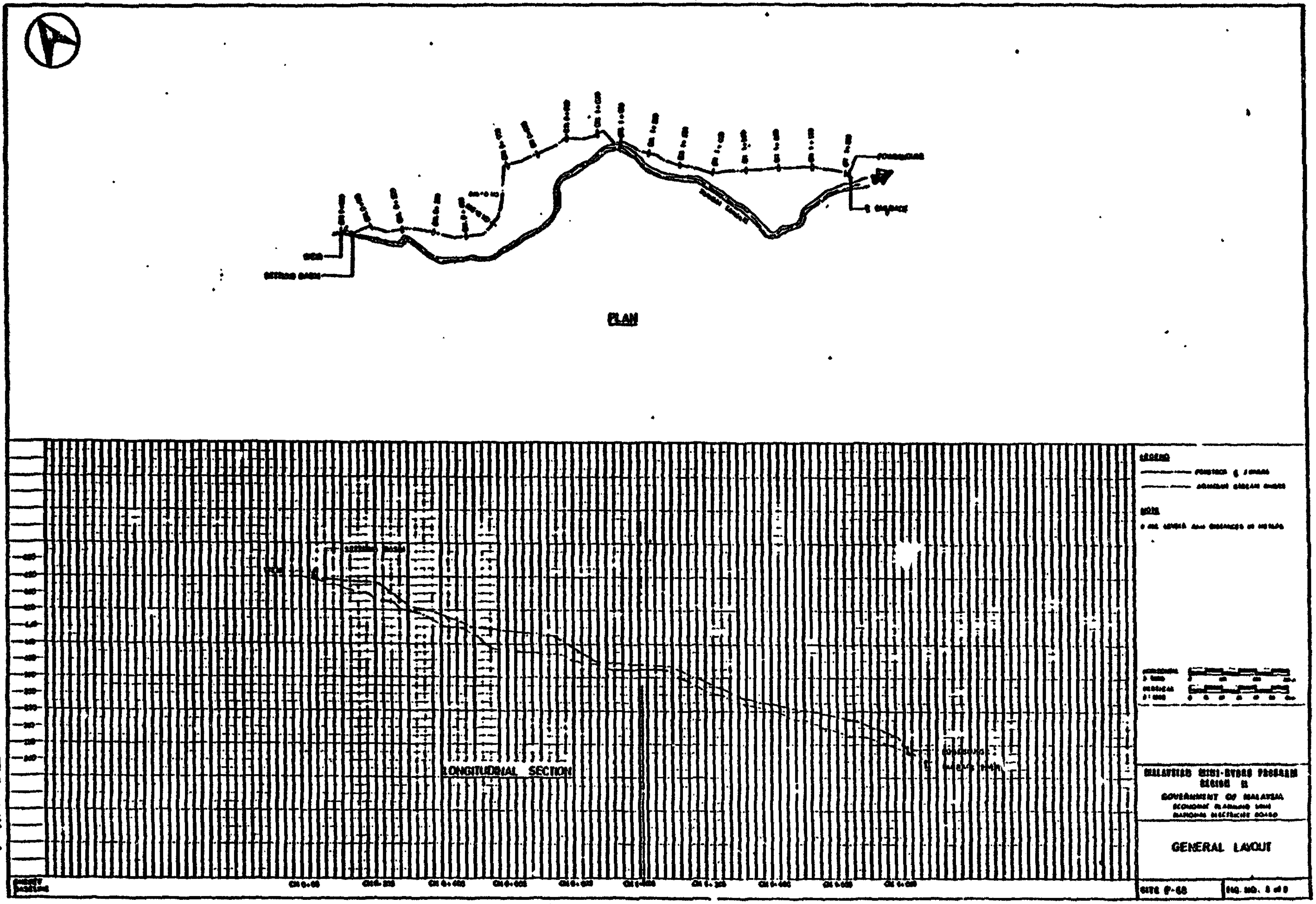

PLAN
LONGITUDINAL SECTION
GOVERNMENT OF MALAYSIA
GENERAL LAYOUT

FIG. VII-1a

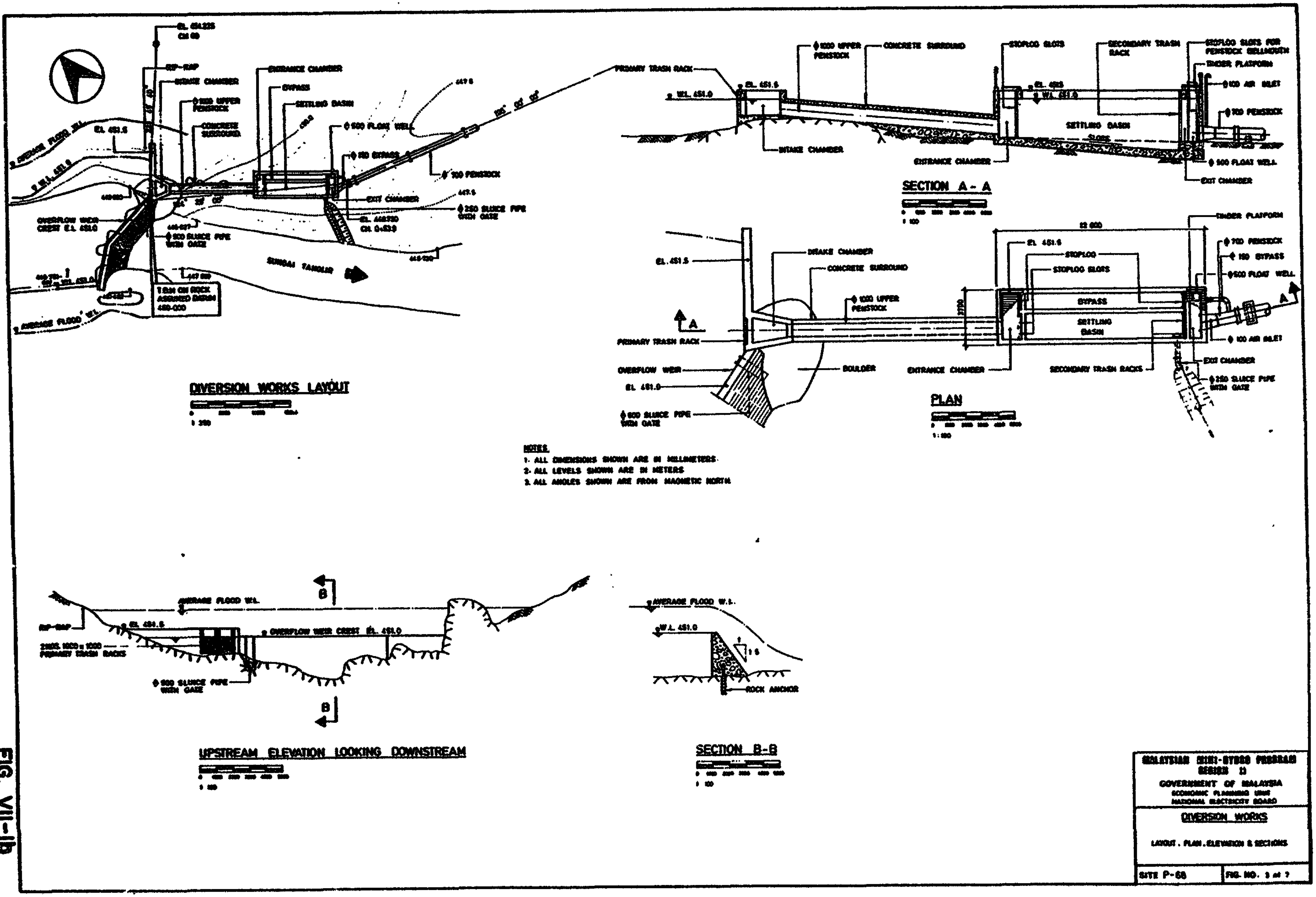

DIVERSION WORKS LAYOUT
SECTION A - A
PLAN
UPSTREAM ELEVATION LOOKING DOWNSTREAM
SECTION B-B
SUNGAI TANGLIR
ENTRANCE CHAMBER
BYPASS
SETTLING BASIN
INTAKE CHAMBER
CONCRETE SURROUND
PRIMARY TRASH RACK
SECONDARY TRASH RACKS
EXIT CHAMBER
OVERFLOW WEIR
BOULDER
TIMBER PLATFORM
ROCK ANCHOR
AVERAGE FLOOD W.L.
W.L. 451.0
EL. 451.5
NOTES.
1. ALL DIMENSIONS SHOWN ARE IN MILLIMETERS.
2. ALL LEVELS SHOWN ARE IN METERS
3. ALL ANGLES SHOWN ARE FROM MAGNETIC NORTH
GOVERNMENT OF MALAYSIA
DIVERSION WORKS
SITE P-68

FIG. VII-Ib

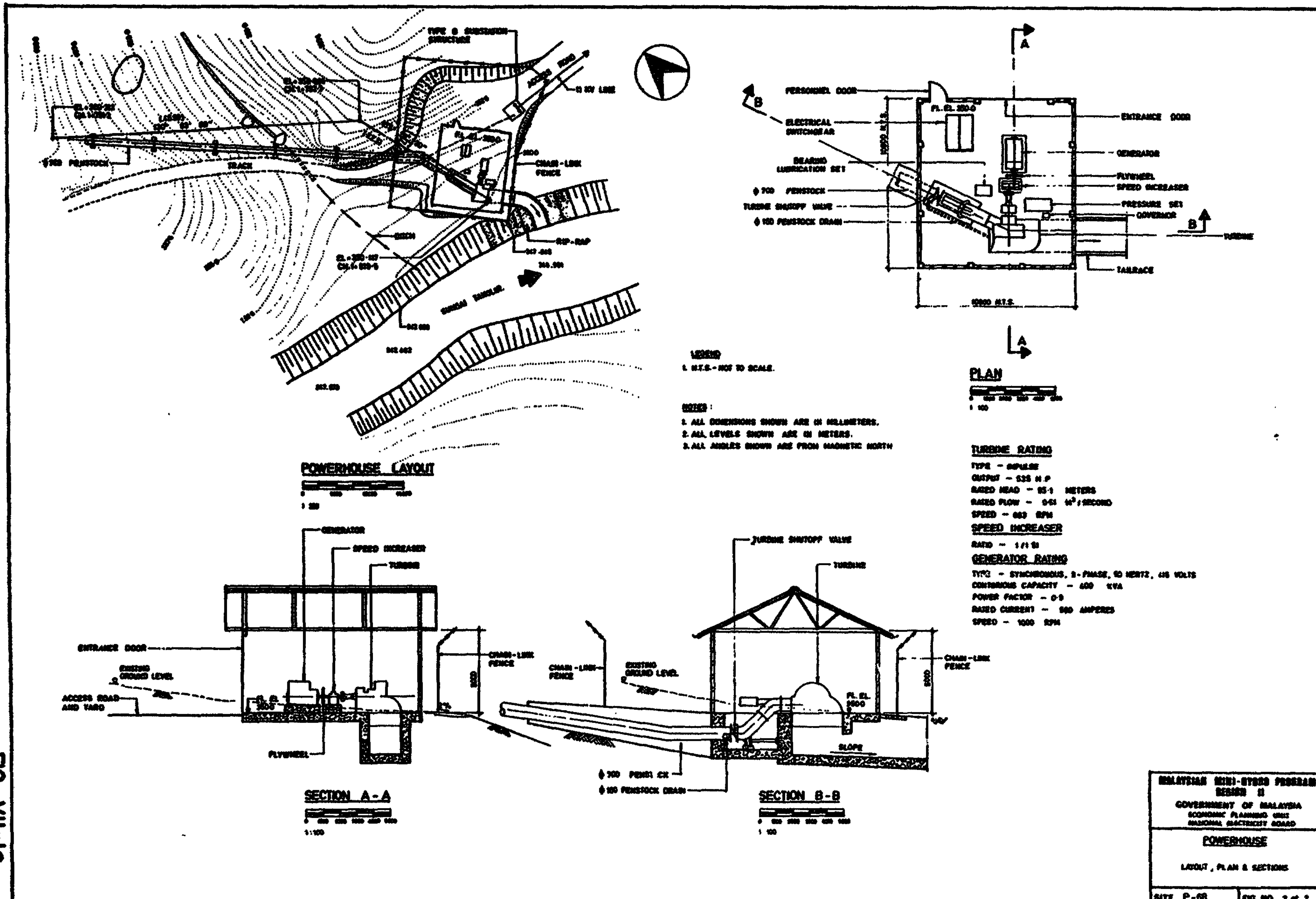
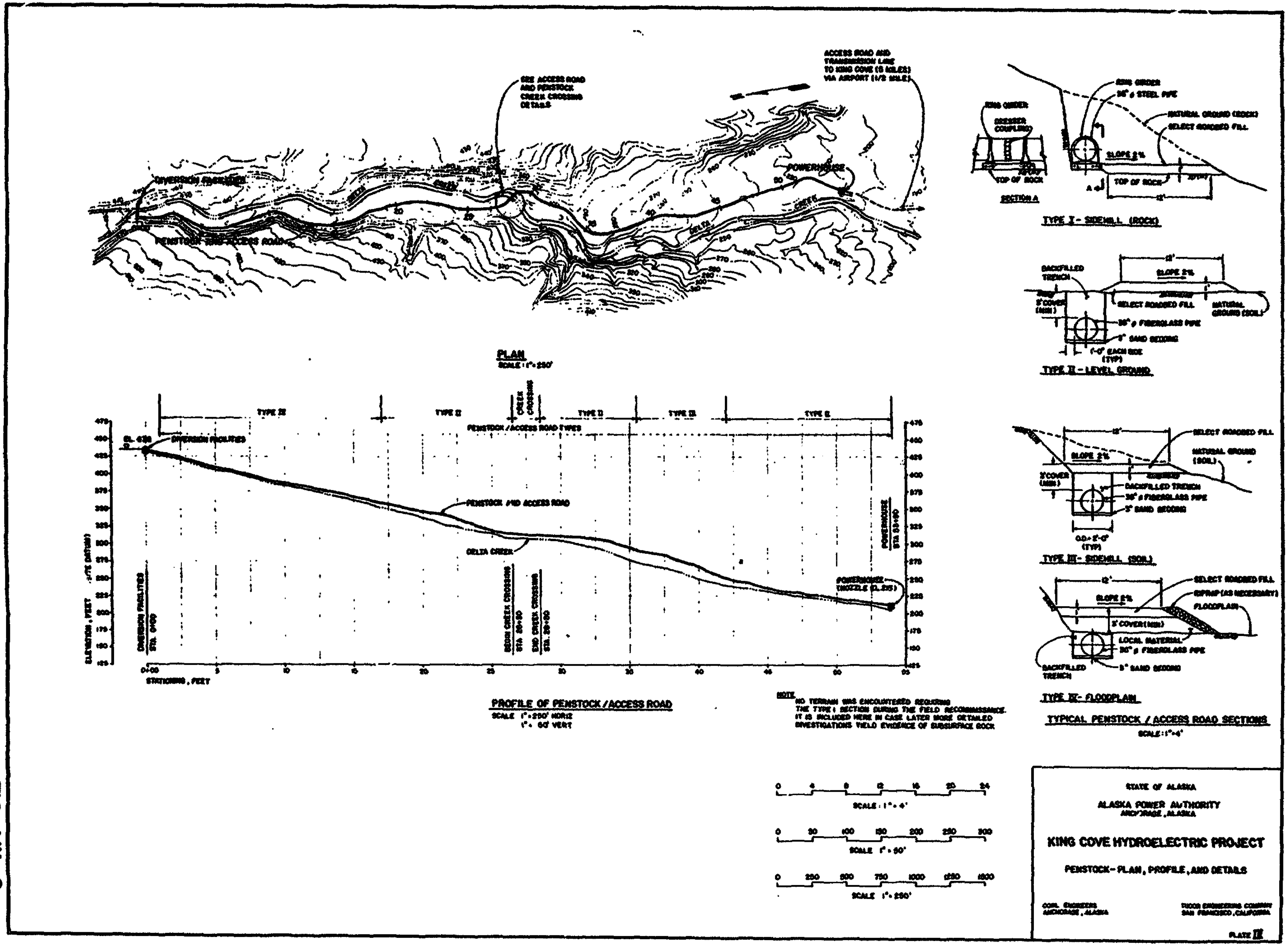
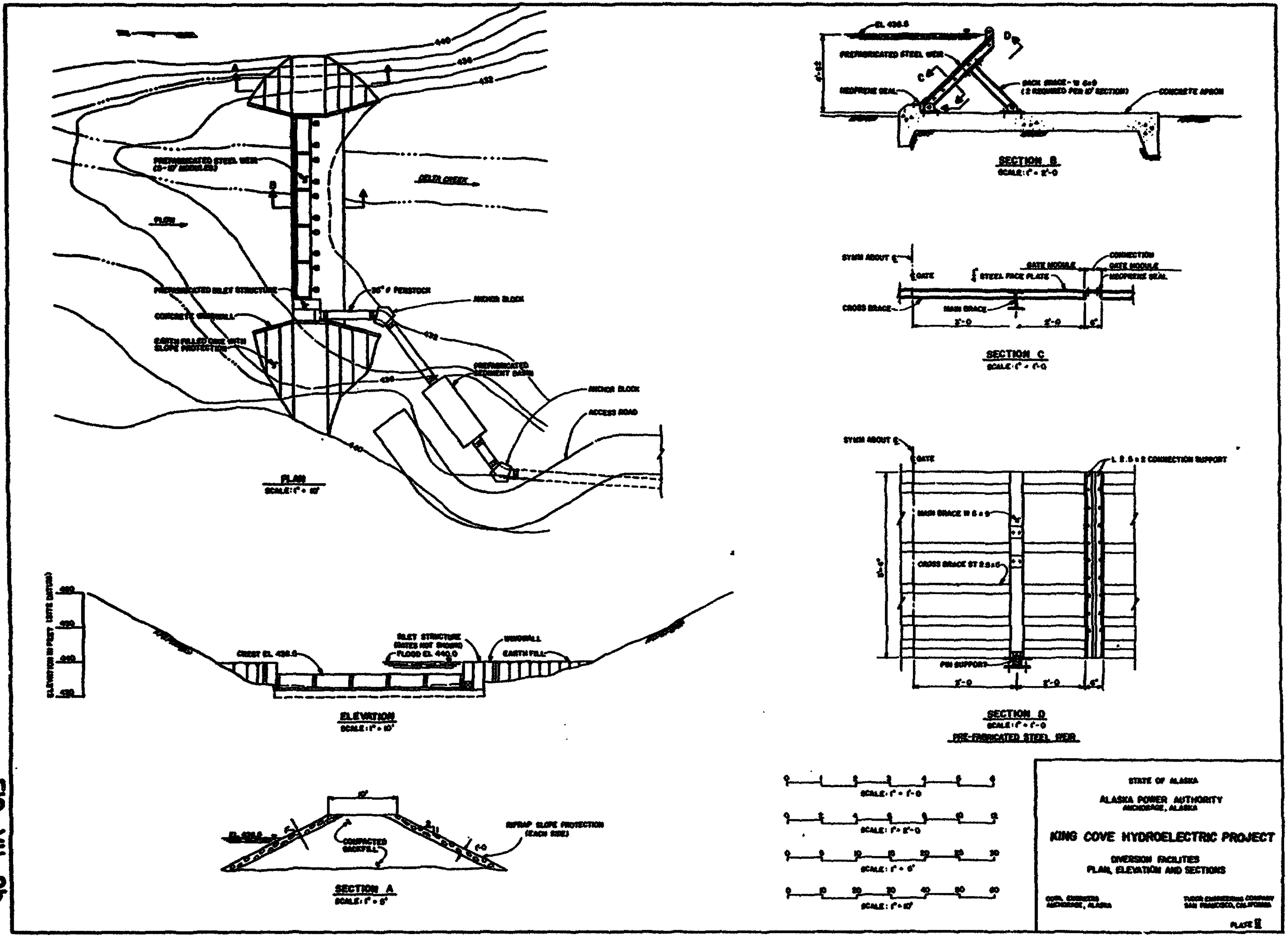

POWERHOUSE LAYOUT
1:200
PLAN
1:100
SECTION A-A
1:100
SECTION B-B
1:100
LEGEND
1. N.T.S. - NOT TO SCALE.
NOTES:
1. ALL DIMENSIONS SHOWN ARE IN MILLIMETERS.
2. ALL LEVELS SHOWN ARE IN METERS.
3. ALL ANGLES SHOWN ARE FROM MAGNETIC NORTH
TURBINE RATING
TYPE - IMPULSE
SPEED INCREASER
GENERATOR RATING
PERSONNEL DOOR
ELECTRICAL SWITCHGEAR
BEARING LUBRICATION SET
TURBINE SHUTOFF VALVE
ENTRANCE DOOR
GENERATOR
FLYWHEEL
SPEED INCREASER
PRESSURE SET
GOVERNOR
TURBINE
TAILRACE
CHAIN-LINK FENCE
EXISTING GROUND LEVEL
ACCESS ROAD AND YARD
SLOPE
RIP-RAP
DITCH
TRACK
PENSTOCK
11 KV LINE
ACCESS ROAD
GOVERNMENT OF MALAYSIA
POWERHOUSE
LAYOUT, PLAN & SECTIONS
SITE P-68

FIG. VII-1C



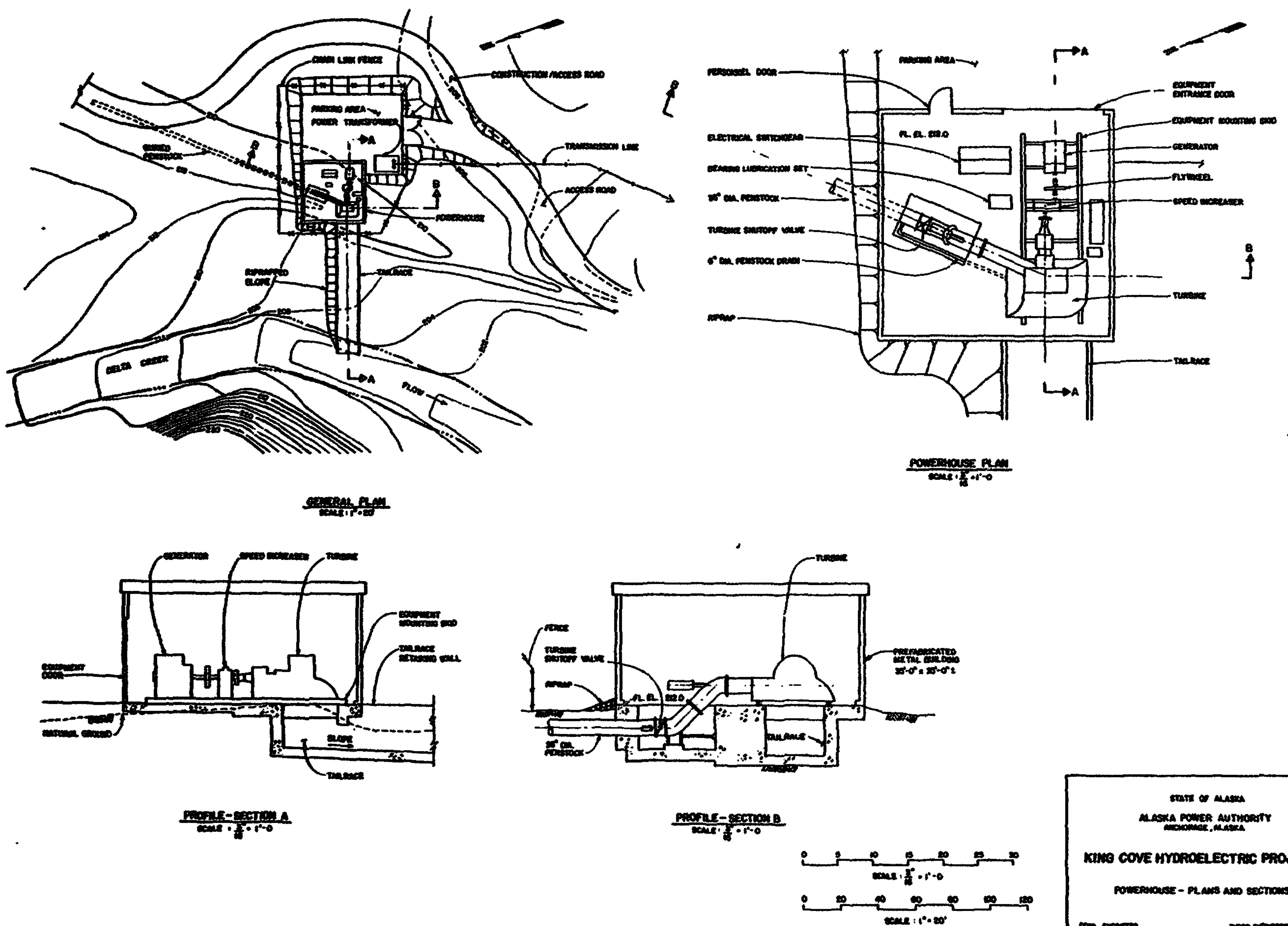
PLAN
SCALE: 1"=250'
PENSTOCK AND ACCESS ROAD
DIVERSION FACILITIES
POWERHOUSE
DELTA CREEK
SEE ACCESS ROAD AND PENSTOCK CREEK CROSSING DETAILS
ACCESS ROAD AND TRANSMISSION LINE TO KING COVE (5 MILES) VIA AIRPORT (1/2 MILE)
PROFILE OF PENSTOCK / ACCESS ROAD
SCALE 1"=250' HORIZ
1"= 60' VERT
PENSTOCK / ACCESS ROAD TYPES
TYPE II
TYPE III
CREEK CROSSING
ELEVATION, FEET
STATIONING, FEET
EL. 438
DIVERSION FACILITIES STA. 0+00
BEGIN CREEK CROSSING STA 26+50
END CREEK CROSSING STA. 28+50
PENSTOCK AND ACCESS ROAD
DELTA CREEK
POWERHOUSE NOZZLE (EL.215)
POWERHOUSE STA 53+90
NOTE
NO TERRAIN WAS ENCOUNTERED REQUIRING THE TYPE I SECTION DURING THE FIELD RECONNAISSANCE. IT IS INCLUDED HERE IN CASE LATER MORE DETAILED INVESTIGATIONS YIELD EVIDENCE OF SUBSURFACE ROCK
TYPE I - SIDEHILL (ROCK)
RING GIRDER
30" ø STEEL PIPE
NATURAL GROUND (ROCK)
SELECT ROADBED FILL
SLOPE 2%
TOP OF ROCK
DRESSER COUPLING
SECTION A
TYPE II - LEVEL GROUND
BACKFILLED TRENCH
3' COVER (MIN)
SELECT ROADBED FILL
NATURAL GROUND (SOIL)
30" ø FIBERGLASS PIPE
3" SAND BEDDING
1'-0" EACH SIDE (TYP)
TYPE III - SIDEHILL (SOIL)
SELECT ROADBED FILL
NATURAL GROUND (SOIL)
BACKFILLED TRENCH
O.D.+2'-0" (TYP)
TYPE IV - FLOODPLAIN
RIPRAP (AS NECESSARY)
FLOODPLAIN
LOCAL MATERIAL
TYPICAL PENSTOCK / ACCESS ROAD SECTIONS
SCALE: 1"=4'
SCALE: 1"=4'
SCALE 1"=50'
SCALE 1"=250'
STATE OF ALASKA
ALASKA POWER AUTHORITY
ANCHORAGE, ALASKA
KING COVE HYDROELECTRIC PROJECT
PENSTOCK - PLAN, PROFILE, AND DETAILS
CORL ENGINEERS ANCHORAGE, ALASKA
TUDOR ENGINEERING COMPANY SAN FRANCISCO, CALIFORNIA
PLATE IX

FIG. VII-2a



PREFABRICATED STEEL WEIR
DELTA CREEK
FLOW
PREFABRICATED INLET STRUCTURE
CONCRETE WINGWALL
ANCHOR BLOCK
ACCESS ROAD
PLAN
ELEVATION
INLET STRUCTURE
WINGWALL
EARTH FILL
SECTION A
RIPRAP SLOPE PROTECTION (EACH SIDE)
COMPACTED BACKFILL
SECTION B
PREFABRICATED STEEL WEIR
NEOPRENE SEAL
CONCRETE APRON
SECTION C
GATE MODULE
NEOPRENE SEAL
CROSS BRACE
MAIN BRACE
SECTION D
PIN SUPPORT
PRE-FABRICATED STEEL WEIR
STATE OF ALASKA
ALASKA POWER AUTHORITY
ANCHORAGE, ALASKA
KING COVE HYDROELECTRIC PROJECT
DIVERSION FACILITIES
PLAN, ELEVATION AND SECTIONS
SAN FRANCISCO, CALIFORNIA

FIG. VII-2b



STATE OF ALASKA

ALASKA POWER AUTHORITY
ANCHORAGE, ALASKA

KING COVE HYDROELECTRIC PROJECT

POWERHOUSE - PLANS AND SECTIONS

PLATE VI

FIG. VII-2c

Diversion Weir

The basic function of a diversion weir is to divert water out of the stream and into the penstock via the offtake structure. The term "diversion weir" is used here rather than "diversion dam" since the word "dam" brings to most people an image of the massive concrete and fill structures typical of large hydro and irrigation projects. The term "weir" is more descriptive than "dam" of both the function, (simple diversion rather than storage) and size, (one to two meters in height). Many designs and materials are used for weirs but a very simple visualization is a trapezoidal concrete or rubble masonry section one to two meters in height with a slanting upstream face, a short crest about 30 centimeters in width, and a vertical downstream face. A rock foundation is desirable, but due to the small sizes involved, not always necessary.

Offtake Structure

The offtake structure generally incorporates a trashrack to exclude floating debris and the larger sediment sizes. A sluice gate is sometimes included to remove and to keep sediment clear of the intake to the canal or penstock.

Sediment Basin

A sediment basin should be included if evidence indicates that the stream sometimes carries sizes of sediment that would damage the penstock and turbine. A typical sediment basin is fairly simple and inexpensive and should be included if any doubt as to need exists since it is usually a small part of the overall project cost.

The sediment basin can either be incorporated into the offtake structure or placed immediately downstream. The downstream location is sometimes preferred as it can then be placed out of the floodplain. The structure can be visualized as a simple open basin with internal weirs, baffles and cleanouts to facilitate the sediment deposition and removal.

Conveyance Facility

The conveyance facility transports the water from the diversion weir area to the powerhouse and can be a penstock or a combination of canal and penstock. At the early conceptual design stage it is sometimes easier to assume the continuous penstock configuration since it is usually to be buildable and will be a conservative approach. Determination that a less costly canal can be constructed may entail more effort than is available at this stage of design. The penstock itself can be constructed from a variety of materials, depending on the hydraulic head involved. However, basing the conceptual design and cost estimates on the materials and construction methods used for similarly sized local water transmission and distribution facilities is probably be the best practical approach.

It is sometimes convenient to include an access road from the power plant to the headworks facilities and to construct the penstock along this roadway. Minimal use of anchor blocks results from burying the pipe where soil conditions permit and supporting the pipe above ground where rock is encountered.

Powerhouse

The powerhouse shelters the turbine/generating equipment and is designed and constructed in accordance with local practice for small one story structures. The base of the structure is a continuous concrete slab which serves as a monolithic foundation for the generating equipment. The resulting unit pressures are very low on the underlying soil and the foundation pressures are not usually a design or siting constraint.

Turbine/Generating Equipment

The selection of the size and type of generating equipment depends on the flow, hydraulic head, and other factors. The selection process and available options are amply covered in the included report references. For the higher heads usually involved in the diversion type of project described above, the turbines are usually impulse or Francis type units. Where a fairly long penstock is involved the impulse type unit is often found to be preferable since water hammer stresses are minimized. This is due to the use of jet deflectors and the slower allowable valve closing times when outages occur and rapid shutdowns are necessary. Impulse units also suffer less damage from sediment than do Francis units.

The generators will be either induction or the more expensive synchronous type. Induction generators are generally used when the site will be tied to a large existing grid. Synchronous generators are used for isolated sites and sometimes for grid tie sites which have the likelihood of becoming isolated due to failure or interruption of the primary transmission line supplying the area grid. The frequency, probability and impact of such interruptions are judgment factors for generator selection.

Transmission Line

The transmission line is a low-voltage facility constructed in accordance with local practices and extends from the powerhouse to the center of the planned market area from which point the distribution facilities start. While the transmission line cost is always included as a project economic cost, the distribution system is not necessarily so included since a comparable distribution system would also be part of any alternative system considered and is thus a common cost to both. Of course, it is necessary to include the distribution system as a project development cost if no distribution system currently exists.

Cost Reducing Options

There are many cost reducing options that can be used for each of the features described above. The diversion weir may be comprised of wooden logs or boulders that are replaced annually. The conveyance facilities may be unlined canals and/or penstocks consisting of plastic, fiber glass, asbestos cement, or used gas or petroleum pipe. A turbine/generator specification may be a simple functional specification several pages long rather than a detailed specification of more than a hundred pages. Such options may well reduce both initial and long-term costs, but the investigator should keep in mind that lower inital costs do not necessarily mean lower long-term costs. If such lower initial costs are obtained at the risk of incurring higher long-term costs due to increased maintenance, lowered project reliability, and a shortened project life, the lower initial cost may prove to be illusory.

This is not meant to discourage or disparage innovative cost saving design options which should certainly be investigated for small-scale hydro designs. Too often such designs are a version of scaled down large hydro facilities and over design and lack of imagination is common. Rather, it is intended as a reminder that the long-term aspects should be thoroughly considered during the initial design process.

ACCURACY AND DEGREE OF EFFORT

The suggested site selection and site evaluation procedures are covered in the following sections of this chapter. However, the question first arises as to how accurate the conceptual design process can be using the available data and small-scale mapping and what degree or expenditure of effort is justified on the conceptual design of the various project features.

These questions can be addressed in part using the following examples from 41 small-scale hydroelectric projects in Malaysia. Table VII-1 lists the percent of total construction cost per site or the primary project features. The data is from a detailed feasibility study completed in 1981.

TABLE VII-I
RELATIVE COST OF MALAYSIAN PROJECT FEATURES

Feature	Percent of Total Project Construction Cost: Low	High	Average
Headworks	4	15	8
Penstock	5	30	20
Powerhouse	3	20	9
Turbine Generator	24	77	47
Transmission Line	3	42	16
			100

The projects ranged from 15 kW to 1000 kW and were all diversion projects as generally described in Chapter IV. The Headworks category in this case includes a low concrete diversion weir, an offtake structure and a sediment basin. The Penstock includes an access road from the powerhouse to the headworks and the Turbine Generator includes all control and substation equipment.

The lengths and sizes of the features varied widely from one small project to another. This was especially true of the penstocks and transmission line lengths, where even for two projects with the same installed capacity, these items varied considerably and thus change the respective feature percent of total project costs.

However, using the average values, some general observations regarding accuracy and degree of effort can be made. Quite accurate estimates for penstock (20%) and transmission line (16%) quantities and lengths are possible using 1:50,000 scale mapping. The powerhouse (9%) is a small building using local practices and accurate costs should be obtainable. Siting problems and foundation pressures for the powerhouse are generally not a problem so the unknown involved should be minimal. The turbine/generating equipment (47%) is usually based on imported prices which the appraisal team will have pre-prepared for rapid access. For installation, the use of local labor is assumed, using the manufacturer's recommended labor effort, and the resulting estimate can be quite accurate.

The headworks features (8%), i.e. the diversion weir, the offtake structure, and the sediment basin (if included), constitutes the largest unknown quantity, and detailed topographic mapping is necessary to prepare accurate layouts. However, at this level of analysis, a site visit with sketches and photographs should provide adequate information to accurately estimate the involved quantities.

In summary, on a similar study approximately 92% of the costs for each site studied (the penstock at 20%, the powerhouse at 9%, the turbine/generator equipment at 8% and the transmission line at 16%) could be fairly accurately estimated using small-scale (1:50,000) maps and available data in the project office. The remaining 8% can be quantified to a fairly accurate degree with a brief site visit. It is judgmental just how much effort should be expended on the headworks features which constitute an average of only 8% of total project costs and the investigators may well find that the use of higher contingencies and only sample visits may well suffice, especially after the general geologic conditions of the project areas are established.

POWER AND ENERGY PRODUCTION

In analysing the power and energy production at any given site, it is necessary to derive both the estimated amount and pattern of the production. For this analysis, it is first necessary to derive a flow duration curve and a hydrograph for the site as has been generally covered in the preceding Chapter V.

It is suggested that the installed capacity and the amount of energy production be based on the flow duration curve and the approximate pattern of production be based on the hydrograph. This process is explained below.

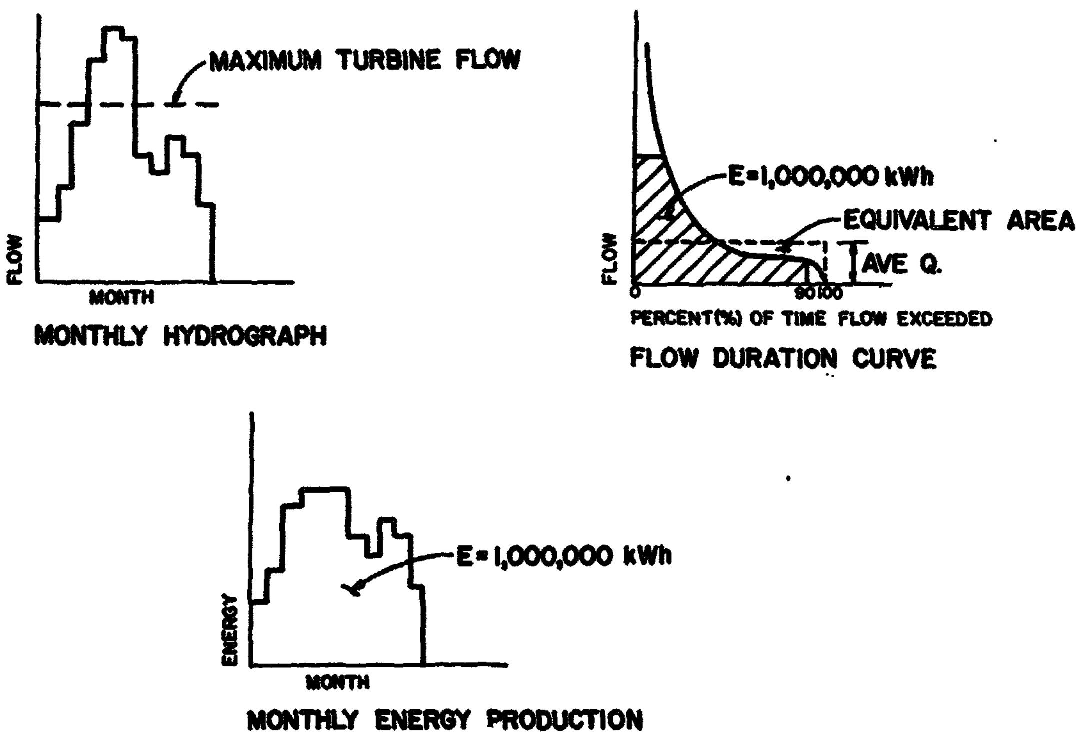
Amount of Power and Energy

The installed capacity at a given site depends on the local conditions and includes the market type, the desired hydroelectric project type (see Chapter III - Energy Planning), the hydrologic conditions at the site and the local demand. These factors have been covered elsewhere and for purposes of this section it is assumed that the installed capacity has already been chosen. With this as a factor and since all turbines have effective operating ranges, the amount of annual energy production can easily be calculated from the flow duration curve using the principle that the area under the curve within the turbine operating range is proportional to the average flow through the turbine.

Another value for energy production can be derived using average monthly or weekly hydrograph values, but the average values used tend to dampen out the highs and lows, which for some regions - especially tropical areas of intense intermittent rainfall - may be extreme, resulting in erroneous values. On an instantaneous flow duration curve all flow values are accounted for, and the resulting answer is therefore more accurate. The hydrograph method is suitable for situations such as canals or reservoirs where controlled and predictable releases are involved, but is not generally suitable for run-of-the-river diversion type installations.

Patterns of Energy Production

With the total amount of average annual energy production determined, it is necessary to estimate the pattern of this production on a monthly (or weekly) basis for use in the energy planning and economic evaluation phase of this overall analysis. It is suggested that this can be accomplished using the monthly hydrograph flow values on a proportional basis. The resulting energy pattern is approximate but should usually be accurate enough for planning purposes. A general example of this derivation is presented in Figure VII-3.



POWER AND ENERGY PRODUCTION

FIGURE VII-3

SITE SELECTION PROCESS

The site selection process involves the selection of viable sites within the defined hydropotential zone for more detailed analysis. This process is greatly facilitated by using various approaches involving pre-analysed configurations, general unit runoff values, and analysing streamflow and topographic constraints. These suggested approaches are as follows:

1. A general analysis is conducted to determine the composition of typical economical small projects. For example, this would include a determination of the maximum allowable lengths and sizes of penstocks and transmission line for various sizes of projects. A 50 kW project would possibly be limited to a 1000 m penstock and a 5 km transmission line while a 500 kW project could possibly support a 5000 m penstock and a 10 km transmission line. This step entails a general analysis of project costs, benefits and economics. The net result of this process is a generally defined envelope of the configuration of economical projects of various sizes.

2. In a similar vein, "general rules of thumb" are developed for unit runoff and thus the minimum size of catchment area necessary to yield a desired flow can be quickly determined. Small catchment areas can be rapidly delineated on topographic maps and those with less area than required are eliminated from further consideration.

3. The available stream features often dictate the weir location. For instance the weir location is frequently fixed by the inflow of a major stream branch. If a location upstream of the junction is considered, the flow from the major branch must be disregarded.

4. The stream profile frequently dictates the project head and length of penstock. If a particular reach of stream is fairly flat, then steep, then flat, it is often found that the optimal project encompasses only the steep portions since only diminishing returns are realized by further extending the project either upstream or downstream.

EVALUATION PROCEDURE

The detailed evaluation procedure for each site selected to be studied in detail can be accomplished by the following general step by step procedure:

1. The site specific flow duration curve and average monthly hydrograph are developed from the regional hydrology (see Chapter VI - "Hydrology for New Sites").

2. The project features are sized and a preliminary layout is made. A field inspection may be included as part of this activity.

3. The project power and energy production is determined (see the previous section of this chapter, which covered this subject).

4. The project costs are determined. This includes direct construction costs, indirect costs and annual operation, maintenance and replacement costs (see Chapter X - "Cost Analyses").

5. An economic anlaysis is conducted for the project. This includes a determination of the project benefits and economic internal rate of return (IER) for the project (see Chapter XI - "Economic Analyses").

GEOLOGY AND SOILS CONSIDERATIONS

Due to the small sizes and weights of the project features normally involved in new small diversion projects, geology and soils considerations are ordinarily not the governing criteria for feature siting to the extent they are for larger hydro facilities. In other words, the importance of these considerations are in direct proportion to the size of the involved features.

Surface observations by the field investigators and reliance on their judgment in siting the various features involved is normally sufficient for small scale hydro projects at this level of appraisal and more detailed investigations entailing borings and laboratory testing will seldom be necessary. With this in mind, the general suggested geology and soils considerations for various project features are as follows:

Diversion Weir and Offtake Structure

The average diversion weir is approximately 1.0 to 2.0 meters in height. The preferred foundation material is monolithic rock, but this ideal condition is seldom available. Next in preference is large boulders into which the dam can be dowelled. However, even alluvium is sufficient with such low heads, and a flat slab preceding the weir with shallow cutoff walls should minimize seepage.

Sediment Basin

If a sediment basin is two meters in depth with a 0.30 m base slab, the unit weight or the foundation is 0.56 kg/cm, a very low bearing pressure and any firm ground is adequate for the foundation.

Penstock and Access Road

The penstock is often constructed in conjunction with an access road from the power plant to the headworks facilities. The access road is three to four meters in width and the penstock can be buried in the roadway section or placed above ground on the roadway section. Shallow cuts are often necessary. Cut slopes are 1:1 and flatter, depending on the stability of the material. Observation of surface conditions and of the stability of previously constructed roads in the general vicinity are the best guide to allowable cut slope.

Power Plant

While the turbine/generating equipment is fairly heavy, the resulting unit foundation weights are quite small when it is installed with the entire base of the power plant as the foundation, and, like the sediment basin cited above, virtually any solid ground is sufficient. Soft clays and swampy areas should, of course, be avoided. Often the powerhouse is placed on firm ground out of the floodplain where the foundation cannot be undermined or the equipment flooded.

FIELD VERIFICATIONS

It is highly desirable to visit as many sites as possible as part of the site evaluation process, especially early in the evaluation. Such visits serve the following purposes:

1. Confirm that the project features can be placed in the planned locations.

2. Confirm that the planned hydraulic head is available (an altimeter is very useful for a rapid check of elevations).

3. Observe the geologic and soil conditions.

4. Observe highwater evidence at the planned headworks and power plant locations.

5. Provide for a better estimate of project quantities, especially headwork features.

6. Judge whether or not a sediment basin should be included.

7. Confirm or observe the power market conditions.

The terrain at the project location may sometimes have features such as incised rocky gorge and outcrops that are not readily apparent on the large scale maps used for siting purposes. Also, the side slopes of the stream where the penstock or other conveyance facilities are planned may prove to be very unstable. Both of these conditions would make the penstock construction difficult or impossible, but general observation of surface conditions would supply adequate information for the study purposes.

After a number of visits have been made and general knowledge developed by the investigators of the regional hydrology, geology and soil conditions, it may often be possible to extrapolate this knowledge and to make only intermittent visits to the remaining sites studied with little or no loss of accuracy.

CHAPTER VIII
HYDROLOGY FOR EXISTING SITES

Existing sites which have the potential for the addition of small-scale hydropower generating facilities include outlet works or spill sections at existing dams, elevation drops in canals, and drops in water supply lines. In each case there is usually human control over the flow of water at the site. Also, floods are not a factor in canals and water supply lines.

As the flow at sites at existing structures is usually intermittent but with a regular pattern, and records are available, it is more convenient and feasible to accomplish the power studies using the historical hydrograph for the site rather than utilizing flow duration curves as are used for new sites. When flows are regular and follow regular repeating patterns such as releases from large dams, and on large irrigation systems, monthly hydrographs are adequate, otherwise instantaneous or mean daily flows should be used.

HYDROGRAPHS

At outlet works at existing dams, the flow releases depend on the demand for the water and how much water is stored in the dam. During long droughts, most reservoirs are severely depleted so there is very little release even though the demand is high. If the dam supplies irrigation water, there may be no releases during the period when no irrigation water is needed.

At most existing dams sites it will generally be found that the existing or historical release pattern must be maintained due to established downstream needs. Even if an analysis demonstrates that total economic benefits can be increased by modifying the release pattern, it may be very difficult to achieve such modifications in practice. At any rate, reservoir operation studies to analyse the effect of modified releases may prove to be very time consuming and for the reconnaissance level of analysis involved in a regional assessment study it is recommended that the studies be conducted using historical releases. This approach will yield conservative results and does not preclude more detailed studies utilizing modified releases during the later final design studies.

When using the historical releases, two hydrographic records should be gathered and analysed. The hydrograph of the actual releases through the outlet should be compared with the simulated outlet releases originally used to design the project. Any difference should be resolved before one of the hydrographs is chosen to estimate the hydropower potential at the site.

The situation at pressure dropping stations in water supply lines is similar to that at outlet works; the flow is dependent on the demand for water and, in dry periods, on how much is stored upstream. In most cases the demand for municipal and industrial water grows continuously until the limit of the water supply system is reached. That is, in the first years after the completion of the water supply line, the discharge in the line is smaller than the design value. In later years the design value is reached. Generally, flow in water lines is continuous but not constant throughout the year.

At existing weirs on rivers, the flow over the weir is the upstream flow minus the flow diverted by the weir. The hydrology studies performed to design the weir and canal which offtakes from the weir generally supply the necessary data needed to derive the hydrograph for spills over the weir. In some cases, the weirs are very old and the design reports are found to be drastically out of date. In this case, the hydrology should be updated in the most economical manner.

At canal drop sites, the hydrograph is usually intermittent but fairly constant when flowing. The best sites are on canals supplied with sediment-free water. Canals with large sediment loads may decrease in carrying capacity due to the deposition of sediment over time if maintenance is sporadic and allowance should be made of this condition when using the historical flow records.

FLOODS

Floods do not occur at sites at canal or pipeline drops.

Floods at existing weirs can be determined from a regional flood study. The methodology for such a study is presented in Chapter V. At many old weirs, the higher flood levels are marked on the abutments of the weir. These marks can be used to construct and extrapolate the flood frequency curve for the site at the weir.

Flood frequency downstream of existing dams is more difficult to obtain. The magnitude of the flood peak immediately downstream of the dam depends on the peak and volume of the flood coming into the reservoir, the amount of storage available when the flood arrives, and on the stage-discharge characteristics of the spillway. A routing study considering the joint probabilities of flood magnitude, flood volume and reservoir level are beyond the scope of the regional assessment study. Instead, the flood level at the site downstream from the dam can be taken as some fraction of the level before the dam was built. Of course, if the dam serves a multipurpose role including flood control, the feasibility and design reports contain data on floods with and without the dam.

CHAPTER IX
TECHNICAL EVALUATION OF EXISTING SITES

This chapter describes the technical aspects of the site evaluation process. This includes the conceptual design process, power and energy production, site evaluation procedures, and geology and soil considerations.

CONCEPTUAL DESIGN PROCESS

The initial conceptual design process involves visiting the project site and visualizing the configuration of the project features. A project layout is then prepared based either on existing as-built plans (if available) or new site sketches prepared on the basis of photographs and site measurements.

The investigator should be familiar with the various available equipment options and configurations, which vary widely. Fortunately, this process can be aided by the extensive handbooks and manuals available which deal with retrofitting existing structures with hydrogeneration equipment. Several of those publications are listed with the included references. For equipment configurations, the most extensive coverage is probably reference No. 7, "Reconnaissance Evaluation of small, Low-Head Hydroelectric Installations," published by the United States Bureau of Reclamation.

As a general format example of a conceptual design format and layout, Figure IX-1 is included with this chapter. This particular drawing is of a small canal drop in the Philippines utilizing a tubular type turbine.

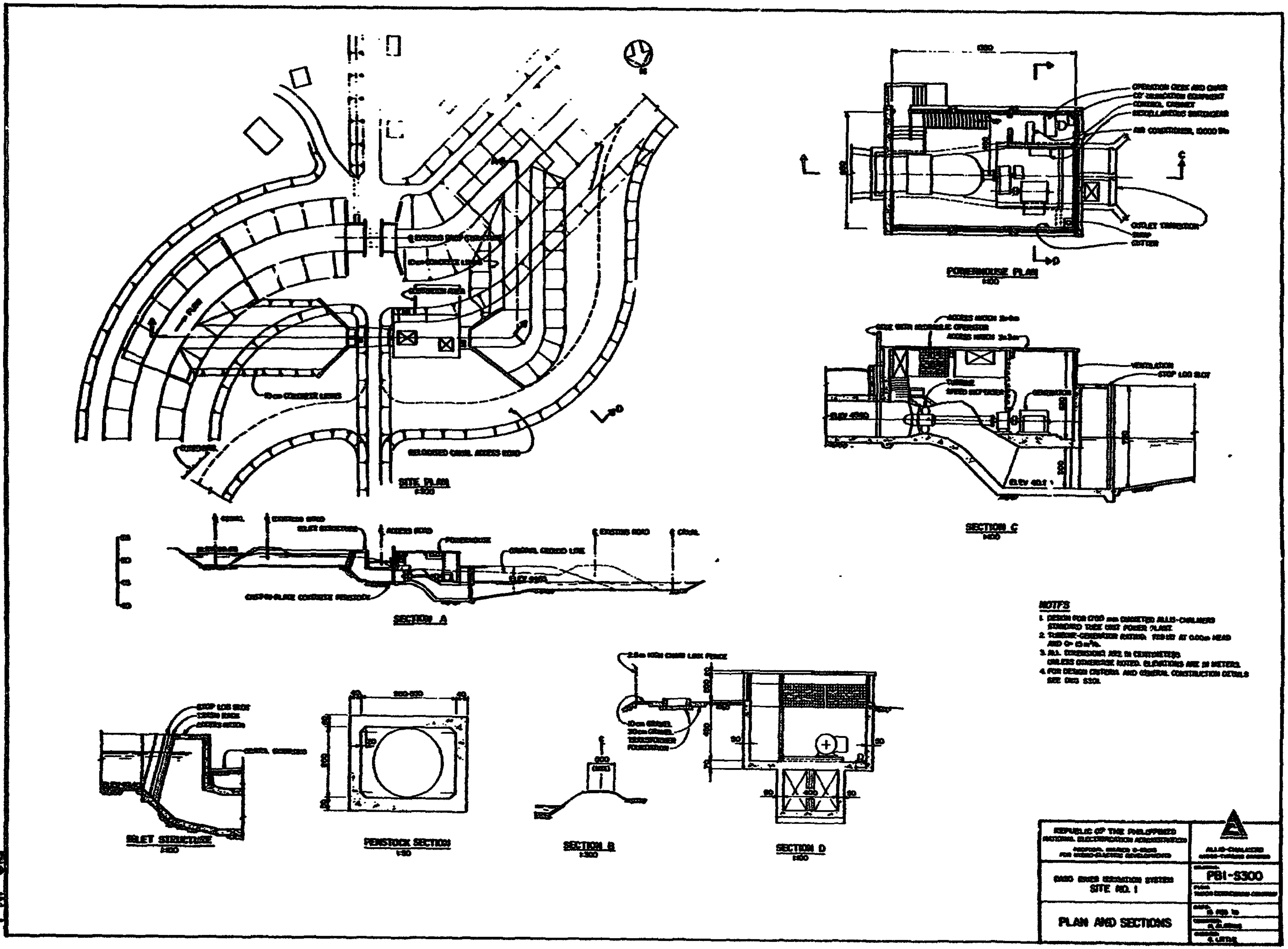
POWER AND ENERGY PRODUCTION

Power and energy calculations for existing structures can best be accomplished using average monthly or weekly historical hydrographs. Generally the flows in canals and from reservoirs are more predictable than run-of-the river schemes, and the hydrograph should usually give accurate results for generation using the hydrograph has the added advantage that an accurate generation pattern can be developed at the same time.

An exception to these statements would be those installations at existing diversion dams or other low dams where run of the river flows will be encountered. In this case a flow duration curve should be utilized as previously described in Chapter VII - "Technical Evaluation of New Sites."

SITE SELECTION

The individual sites selected for detailed study from each representative group should be as typical as possible in order that the results can be used with reasonable confidence for the rest of the group. Just as for the separation of the inventoried sites into representative groups, the selection of typical projects will be judgmental and no criteria other than being reasonably typical can be recommended.



SITE PLAN
POWERHOUSE PLAN
SECTION C
SECTION A
NOTES
INLET STRUCTURE
PENSTOCK SECTION
SECTION B
SECTION D
REPUBLIC OF THE PHILIPPINES
ALLIS-CHALMERS
PBI-S300
SITE NO. 1
PLAN AND SECTIONS

FIG. IX-1

EVALUATION PROCEDURE

The detailed evaluation procedure for the typical sites will be similar to that recommended for new sites:

1. The site specific monthly hydrograph is developed from existing flow records (see Chapter VIII - "Hydrology for Existing Sites").

2. A site inspection is made and the initial conceptual design is formulated. Foundation conditions are observed and any significant environmental effects are noted. Photographs are taken, field measurements are made and any existing plans are obtained.

3. In the project office the project features are sized and a preliminary layout is made. (See Fig. IX-1 as an example.)

4. The project power and energy production is determined (see previous section of this chapter).

5. The project costs are determined. This includes direct construction costs, indirect costs and annual operation and maintenance costs (see Chapter X - "Cost Analyses").

6. An economic analysis is conducted for the site. This includes a determination of the benefits and the net present value or other measure of economic worth for the site (see Chapter XI - "Economic Analyses").

GEOLOGY AND SOILS CONSIDERATIONS

The structures involved in retrofitting existing sites for hydro generation facilities are larger and heavier than those used for the new sites and geologic and soil conditions are therefore of more concern. It will generally be found, however, that the unit bearing pressures are still quite low and are considerably less than for the more massive structures used for medium and large hydroelectric installations.

The existing structure being utilized for the hydroelectric installation will often be found to have equal or higher unit bearing pressures than the new installation and the site will therefore in all likelihood present no geologic problems for the new construction. In many cases it will be found that the site was originally chosen because adequate foundation conditions existed for the existing structure.

Ordinarily, surface observations of site conditions at this level of investigation will suffice for the preliminary layout and subsequent cost estimates. However, hand auger borings with borehole loggings using the universal soil classification system can be easily, rapidly, and inexpensively accomplished. General soil bearing capacities can then be obtained from this data and the resulting information, together with site observations and reasonable judgment, should enable experienced personnel to accomplish the conceptual design and preliminary layouts needed. More complete soils investigations may well be necessary late for design purposes but these can be obtained as part of the project implementation process.

Rather than being concerned with adequate bearing pressures, a common problem encountered at low head installations where the turbine setting is low with respect to the tailwater is the existence of net uplift pressures. In this case additional weight must often be added to the power plant in the form of thicker walls and foundations.

FIELD VERIFICATIONS

All existing sites to be studied in detail should be visited as part of the evaluation process. Such visits will serve the following purposes:

1. Enable the investigator to judge whether or not the site can be considered typical for that particular group category of which it is a part.

2. Allow the on-site conceptual design to be accomplished.

3. Provide opportunity for obtaining site photographs and measurements to make the necessary preliminary layouts.

4. Allow observation of the geologic and soil conditions.

5. Allow observation of the conditions and adequacy of the existing structures.

6. Confirm or provide opportunity for observation of the power market conditions.

In a larger sense, as much as time permits, as many of the inventoried structures as possible should be visited in order to assist and confirm the original group classifications. This will also more accurately enable the late capacity and cost extrapolations to be accomplished and to thus better ensure the accuracy of the overall appraisal results.

CHAPTER X
COST ANALYSES

This chapter concerns the cost aspects of project development. Included are the assumptions and sources of the costs to be used, and derivation of the various components of the cost estimates including direct construction costs, development (or indirect) costs, and operation and maintenance costs.

BASIS OF COST ESTIMATES

The basis of cost estimates concerns the source of the data and the involved assumptions. These will vary when considering economic costs, and financial costs as well as the identification of local and foreign cost components. Such sources and assumptions should always be clearly identified so that later adjustments can be made if necessary.

Economic Versus Financial Costs

Since the emphasis of the study is to determine economic feasibility of small-scale hydro, the project cost estimates are to be prepared to reflect true economic resource costs. While financial and accounting costs are important in developing comparisons of potential returns to the investor and the possibilities for recovery of project costs which are nominally priced in the current market structure (regardless of the level of institutional constraints), the purpose here would be to provide insight on economic efficiency from the national view point. Thus major abnormalities in the pricing system should be avoided through shadow price analysis. This will then account for distortions in the pricing mechanism involving government subsidies, taxes, duties, and other factors that inhibit the pricing of labor and materials at their economical value. The project economist should derive the pertinent parameters to be used for preparing the project cost estimates early in the appraisal process. This will include analyses of exchange rates, fuel prices, government policies regarding taxes and subsidies, if applicable, to be used for preparing the cost estimates. Sources of information would be the national planning office or the country desks of international agencies such as the World Bank or the regional development banks.

Local and Foreign Cost Components

Since it is anticipated that development of most small-scale hydro power projects will be funded in part by external loans, it is important to separately estimate the local and foreign components of the cost of each project.

The local component is that portion of the cost attributable to direct local expenditures. Included would be costs of local materials and supplies and salaries paid in local currencies. The foreign component is that portion of the project cost which includes such items as foreign mobilization; a foreign company's overhead and profit; imported materials and supplies; and foreign salaries, wages and incidental expenses. Many items purchased locally also have an indirect foreign cost component composed of such things as expense to the economy connected with the importation of components and raw materials such are then subjected to further local processing. However, unless such a component is a very high proportion of the final price, which in turn is a significant project cost, it is generally not considered and the first order local price would instead be used with no foreign component consideration.

Fuel may fall either within the foreign or local category, depending on whether or not the local economy is a net fuel importer. However, regardless of the import situation, it is normally the international price rather than the domestic price that should be used in the cost and economic analyses since that is the actual value of the fuel if it were exported rather than used domestically.

DIRECT CONSTRUCTION COSTS

Direct construction costs normally include all costs which would be entailed in obtaining all necessary equipment and materials and constructing the hydroelectric projects. As a general rule, all turbine/generator and control equipment would be imported and costs would be based on current quotes from manufacturers. Civil costs would be based on quantities from the project layouts and local economic labor and material prices.

The cost of acquiring private lands would be a project economic cost, but those for government lands would not, since payment for these lands and rights of way would merely involve an income redistribution among government agencies rather than a true economic cost to the country as a whole. In the case of government lands where current or potential future income will be foregone, an imputed value can be placed on the capitalized income and an appropriate adjustment showing a possible addition to economic costs or a reduction in the project benefits.

A component for transmission system costs from the hydro project to the service area would always be included as a direct construction cost while the distribution system may or may not be so included, depending on the analysis of the future base project conditions, without hydro. The important point is that the transmission and distribution system assumptions be comparable under both conditions without and with the hydro proposal assumptions. (See Chapter XI - "Economic Analyses".)

A contingency of 15 to 30 percent would be included to the total direct construction costs to cover unknown and unforeseeable changed conditions. Separate contingencies for price and quantities are sometimes utilized. The value to be used for contingencies will be judgmental and will vary with the investigator's opinion of the accuracy of the estimated prices and quantities.

INDIRECT COSTS

Certain indirect costs are added to the direct construction cost estimates to derive an estimate of the total capital cost for development of each project. These items are engineering services and legal and administrative costs that would be incurred during the subsequent implementation phase of the project. The cost added for these engineering, legal and administrative services (ELA) is usually estimated as a percentage of the total direct construction costs. This rate used will generally vary from 20 to 25 percent, depending on the number of projects, the total cost and other factors and is based on the normal cost range for similar projects. Where possible, estimates of actual expected costs for these items should be made because engineering costs, in particular, are subject to wide variation for small hydro projects.

OPERATION, MAINTENANCE AND REPLACEMENT COSTS

In analysing the economic feasibility of hydroelectric developments (see Chapter XI - Economic Analyses) it is necessary to include an allowance for annual operation, maintenance and replacement (OM&R) costs.

For large hydroelectric plants it is usual to estimate these costs for the initial year of project operation as 1.0 to 2.0 percent of the project capital cost for each plant. For small scale hydroelectric projects, however, the cost of operating a 100 kW site will be almost the same as for a 1,000 kW site. The required manpower for operation and maintenance will actually be the same but the replacement component of the OM&R costs will be higher for the larger plants. A normal operating procedure for a system with a large number of small scale sites would be to have a full-time semi-skilled operator for each site for day-to-day routine maintenance and to serve as a facility guard. A mobile crew of skilled technicians located at a central location would perform emergency repairs and detailed technical maintenance as required for periodic OM&R.

With this general approach in mind, it is suggested that the basis of the annual OM&R costs be the cost of one full-time semi-skilled operator, one half-time skilled technician, and about 2.0 to 3.0 percent of the initial turbine, generator and electrical cost as an annual replacement component. It is further suggested that the entity which would actually have responsibility for operating the site be consulted in determining the final OM&R costs to be used for estimating purposes.

ALTERNATIVE PROJECT COSTS

To establish the economic value of hydroelectric power and energy it will sometimes be necessary to formulate alternative means to supply the projected regional or local demands. The value of the lowest cost comparable alternative then becomes the project benefits or the "avoided costs." This would entail a careful estimate of the alternative economic costs over the estimated study life. To make those cost studies comparable, similar assumptions and approaches to those used for the hydro projects should be used for the non-hydro alternatives in the cost estimating process. The general principles covered above for hydroelectric costs dealing with the basis of the cost estimate, the direct construction costs, the indirect costs and the operation, maintenance, and replacement costs should be used in this process.

CHAPTER XI
ECONOMIC ANALYSES

A careful delineation of economic parameters is a crucial step in accomplishing the objective of developing analytical procedures that would permit selection of worthwhile small-scale hydroelectric projects from the "hydropotential zones." Once likely electrification alternatives without hydro are identified, initial screening and finally a ranking of potentials can be prepared if necessary and an array of meritorious projects identified to meet the targeted demand. This can be accomplished in several ways: (i) if comparing incremental sales benefits with project cost, through the use of conventional benefit cost ratios, or an analysis of net financial benefits or returns, (ii) if a least-cost approach is chosen, through the computations of equalizing discount rates. Adequate data would thus be provided for the particular developing country and/or the financing entities involved to make the necessary investment decisions. Additional data on secondary or indirect economic effects could also be useful in the evaluation process.

SCOPE

The scope of the economic analyses presented in this chapter covers a comparison of economic costs, equivalent to approach (ii) above. As a measure of alternative system costs, long-run marginal costs can be used for grid-tie sites, while the costs of alternative local energy systems, usually small diesel generation, are used for isolated sites.

An inherent assumption is that studies to justify the electrification of the region have already been conducted, with affirmaive conclusions. If such studies have not been carried out, they would be necessary prior to conducting any form of detailed hydroelectric assessment. Obviously, a project can be justified only if a market exists for its output at prices which would repay its cost. The necessary studies would include a comparison of the costs and benefits to the region with electricity and without electricity, and an investigation of the most economic means to accomplish this electrification. Such base studies, while necessary, are outside the scope of this chapter which covers comparative hydroelectric assessment only.

Financial analyses, which concentrate on the repayment of loans at specified interest rates and time periods, tariff establishment, and the meeting of operating expenses with a projected flow of revenues, are also not addressed. Such financial analyses are very important to ensure that a project is financially viable as well as economically desirable, but are also outside the scope of this study.

METHODOLOGY AND APPROACH

As mentioned, the basic framework of analysis assumes that the future condition without a small hydro project is either the continuation of existing electric services - with consideration of improvements if consistent with country policy - or, if no electric services currently exist, the new installation of the most likely non-hydro generation alternative. In essence, this constitutes a least-cost analytical approach.

Following a determination that electrification per se is economically justified, the alternatives to the hydro electrification of the villages under analysis would be represented by measurements of long run likely alternative costs displaced or marginally avoided after comparing conditions with and without small-scale hydro. Cost differentials are expressed here in terms of savings reflecting the difference between hydro project costs and non-hydro "avoided costs." It should be emphasized at this point that the proper formulation of the future without-hydro condition, which for convenience is referred to here as the "base case," is vital to the least-cost analysis. For most villages in developing countries, especially those that are rural and not tied to a transmission grid, diesel generation is the most likely assumption under the isolated case.

The general approach is to select representative base cases within the sample areas for new sites or near the typical projects for existing sites. From these cases, typical values of system costs in the absence of the hydro project per unit of physical output of electricity would be established. These would become target values against which individual hydro project costs can be compared, and economic decisions made on individual sites. The number of economically viable sites would then be extrapolated to the total number of meritorious small hydro sites that could ultimately be developed within the study area.

Before proceeding to procedural details, several other economic factors should be mentioned: (i) Due to the built-in reliability and longevity of hydro, recognition of long-run conditions as opposed to short-term is important. The short-term being defined as 10 to 20 years where major replacement of alternative generation facilities may not be required and where pervasive price escalation pressures, either nominal or real, are not recognized over long periods of time. "Nominal" refers to average price changes over a broad spectrum of goods and services, while "real" refers to significant differential price changes (deviations from "nominal"), such as the recent history of fuel costs. Life cycle analyses where plant replacements and price escalation are recognized, employing a present worth discounted cash flow, provides important insight into economic comparisons. (ii) Sensitivity studies should be provided to test the effects of major assumptions used in the economic analyses. Included would be such items as the opportunity cost of capital, price escalation rates, both nominal and real; and availability of fossil fuels. (iii) As discussed in a previous chapter, in costing hydro facilities, major abnormalities or distortions in the market system should be recognized in deriving economic prices. Thus "shadow" pricing to eliminate such factors as subsidies or taxes should apply equally to the evaluation of avoided costs and hydro project costs.

Evaluation of indirect or secondary economic impacts could also be important in the decision process, but is not the main thrust of this analysis. This would entail evaluation of such factors as employment of local labor and materials, import requirements, and effects on international trade balances.

Interest or Discount Rates

It is well known that controversies and conflicting theories exist on the establishment of the "proper" interest rate for converting all monetary values to a common time basis where investments in natural, locally available, renewable resources are being considered. Whether the "social time preference" theory; "inflation-free" discount rates; average cost, or "opportunity cost" of capital approach is applied could result in a wide variation in rates. For example, the World Bank uses the opportunity cost of capital to the country involved. As a guideline the Bank is currently using rates of about 10 percent in most countries to reflect the likely return on other projects, competing for the same (limited) resources. Used in this fashion, the opportunity cost of capital is a resource allocation mechanism. To provide a basis for sensitivity analysis, a range of discount rates should be used in the analysis. Lower rates favor more capital-intensive long-life projects, such as hydro. The rate selected may be related to the capital formation rate of the country involved as well as a consideration of alternative resource investment opportunities. It is important to note that, in this type of analysis, the actual cost of the financing to be used for the project is not relevant to the economic justification. In other words, the fact that low-cost or concessional financing might be available for a hydro project, should not be allowed to influence the economic justification, except perhaps in those rare cases where the concessional financing would be lost to the country unless used for this project or technology.

Thus, the analysis can be done using on the one hand, an inflation-free discount rate, and constant dollars except for real price shifts, or alternatively, the approach could be to use interest rates which already incorporate expectations of future inflation, with explicit recognition of future escalation of prices at assumed rates, with differential rates applied to those elements where price shifts are anticipated. The latter is more in keeping with conventional financial life-cycle analysis assumptions, but, international financial institutions commonly use the former approach.

The appropriate interest or discount rate and the assumptions with regard to price escalation would be subject to ground rules established by the particular country and the financing entity involved. Regardless of the assumptions, all values are converted to present values either in terms of lump sums or average annual equivalents over the period of analysis in order to compare economic costs and benefits. Adjustments in the discount rate to reflect unique project-related benefits should be avoided. Instead, attempts should be made to express secondary effects in monetary terms (i.e., for example, $/kW for the increased reliability of hydro).

Inflation and Escalation

When using a real discount rate, it is suggested that constant dollars be used except for fuel which should reflect forecast conditions of real price escalation. Unless better local data is available, a two percent real fuel escalation rate is suggested. It is important that some upper limit be established on fuel escalation to aovid distortion in the analysis. Because of the difficulties of making future projections, escalation should be limited to a period of 10 to 15 years.

If a higher interest rate including inflation is used, a life cycle approach would be appropriate where all cost factors are subjected to price escalation. A uniform rate would be assumed to reflect general price escalation, which could be assumed to range from 5 to 10 percent, with an add-on of 2 percent (or some other locally justified rate) to reflect real fuel escalation. This would result in an overall rate of 7 to 12 percent for the fuel component over the selected escalation period. All cost components, both initial capital and operation, maintenance and replacement costs would be subjected to price escalation as they are considered to occur on a schedule extending from the current date until the end of the period of study.

The above comments apply as well to some developing countries where hyperinflation prevails. The general approach for the economic analyses would be as generally covered above, but the financial analyses would be considerably more complex than countries with relatively low inflation rates. For these cases it is suggested that the lending institution involved be contacted for their current policies regarding project appraisals under those specific circumstances.

Study Life

An important characteristic difference for hydropower as compared to various thermal energy generation alternatives is the durability of the hydropower generating equipment over a long period of time. To allow for the economic consequences, up to a 50-year study life is suggested. Many large hydropower facilities are considered to have economic lives beyond that period, extending to 100 years. Depending on local conditions, it should be recognized that small hydro projects may sometimes have lives shorter than 50 years due to sedimentation, flood frequency, or maintenance problems. Emphasis on and training in preventive maintenance programs can have a significant influence on the successful operating period of the small hydro. The relatively longer life for hydro generating equipment recognizes that thermal alternatives, especially diesel, where equipment life is only 10 to 15 years, would require replacement several times through the study period. This is especially important where the life-cycle analytical approach is used and price escalation is made explicit to all cost components including major replacement of facilities. The effect would not be as great if a relatively high interest rate and constant dollars were used in the analysis because of the high discounts applicable to long-term future values.

The assumed economic life would normally begin at the completion of the construction of the proposed hydro project. The period of time prior to the hydro completion date would need to be accounted for in order to determine total economic costs during the construction period. This would have the effect of extending the total number of years in the study period beyond the assumed economic life. For life cycle analysis, costs would be escalated from the current to the beginning of major expenditures for the project, at which time the study period begins. The assumed construction period, which could be as short as two years, including equipment procurement, would reflect typical local conditions.

Equipment Lives

Equipment lives of major facilities would need to be established in order to facilitate the economic analyses and to provide for the economic costs of replacement and recovery of capital costs. Major facilities would normally be the hydro and alternative generating equipment and the transmission facilities. A suggested list of major components requiring replacement and typical service lives in developing countries is provided in Table XI-1. A brief study of local conditions may warrant some modifications to these suggested lives.

ANALYSIS OF BASE CASES WITHOUT HYDRO

In establishing the economic parameters, three typical base cases would be prepared in the sample areas as needed. They would reflect three fundamental situations:

1. Isolated sites, where the electric system would be remote from any grid-ties and would be completely self-contained;

2. Grid-tie projects, that would reflect service provided from a hydro project integrated into a larger system;

3. Delayed grid-tie sites, where there is a projected interim period before the transition from the condition (1) to condition (2) described above.

Variations within these cases could be provided to reflect certain thresholds or major breaks in significant cost factors related to the size of the power market, equipment availability, or location.

It is important at the outset to assume an equality in reliability of the systems under both the base case without hydro and the with hydro case. The degree of reliability would be a policy matter which could be subjected to economic analyses of optimality. The interrelationship between various levels of reliability and associated outage costs are treated in considerable detail in a publication available from the World Bank. 1/ It is expected that reliability levels could vary substantially in isolated sites not presently receiving electric service as compared to those sites which have grid-ties. In

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1/ See Mohan Munasinghe, The Economics of Power Systems Reliability and Planning - Theory and Case Study, Baltimore and London, The Johns Hopkins University Press, 1979.

the latter situation the reliability standards have probably been established. This step is important in determining avoided costs, for in some instances reliability requirements could necessitate "0" or 100 percent reserves in the form of standby units.

Since the primary or direct system cost savings from hydro are based on the most likely alternative or the avoided costs, proper identification and estimation of major cost components is critical to the economic analysis. For most developing countries, fuel oil that would be used for diesel generation is the most important factor. The extent to which local labor and materials are employed and the proportions of imported equipment and services are also of high concern. This data would also be useful where indirect or secondary economic effects are brought in as an added evaluation factor in analyzing the total small hydro program.

As discussed, fuel cost data should be normalized to remove obvious price distortions. Distinctions would normally be made for the cost of fuel in coastal areas as opposed to remote interior locations which require added transportation expenses. Analysis of historical price trends should provide insight on nominal and real price escalation rates. Transportation costs may be subject to different escalation rates depending on the mode of conveyance, and whether petroleum-fueled.

Annual costs of operation and maintenance should be separately identified to permit the application of escalation rates which are probably different than that assumed for diesel fuel. Lubrication costs would also be identified separately if the involved expenditures would be significant. Labor components in order to determine source and origin should be set out for both costing and for analyzing economic implications. Particular care should be taken to estimate operating and maintenance costs accurately since these can be larger for the small dispersed sites under consideration, both hydro and thermal. If rule-of-thumb estimates are used (e.g., a selected % of capital costs), these should be checked to ascertain that they will in fact be sufficient to pay for actual labor, spare parts, and similar expenses. (See Chapter X - Cost Analyses.)

The replacement of major facilities should be independently shown. In isolated non-grid situations, the replacement of diesel generators will normally represent a relatively small proportion of the total annual variable costs where the fuel cost will be by far the largest component. The continuous need for future refunding is also demonstrated by scheduling new plant requirements.

In grid-tie projects, the likely alternative costs may reflect much larger units and a different type of thermal plant because of displacement of system costs. In such cases system marginal costs would be displaced which would reflect the least efficient units. In the majority of locations, it will seldom be possible to show savings in system capacity costs due to the high variability of the hydrologic cycle from year to year, and thus the uncertainty of the availability of the hydro generation. The only cost effect normally resulting from small-scale hydroelectric projects will therefore ordinarily be for fuel displacement, and not for capacity displacement or deferral. However, if the hydrologic cycle is historically consistent from year to year, it may be possible to claim some capacity cost effects. If the hydro energy can be shown to be available comparable to that for large thermal plants (i.e., 80% to 90% of the time), capacity cost savings can be claimed.

The analysis of delayed grid-tie sites would be a combination of the data developed for the isolated and grid-tie cases. An interim period would need to be set at which time the costs would change to match the transition from one case to the other. In the sample case, a quick test could be made to determine whether salvage values of the facilities serving the isolated site stage have a significant influence on the delayed grid-tie base case.

Sample base case studies would be prepared for each of the basic conditions: isolated sites, grid-tie projects, and delayed grid-tie projects as representative of predominant factors within the hydropotential development zones. From general inspection and analysis of the area, major variations in size and characteristics in generating and transmission requirements would be tested to develop short-cut adjustment factors and generalized avoided-cost curves within the various cases.

ANALYSIS OF WITH-HYDRO PROJECT CASE

The unique characteristics of hydropower - its high reliability, longevity, quick response - as well as its reliance on variable hydrologic flows, makes the precise matching of output under alternative non-hydro generation somewhat difficult. As indicated earlier, hydropower has great flexibility and can be designed to serve base load, intermediate load or short-term peaking needs. Because of its usual superiority in mechanical availability and flexibility, it normally earns additional credits for difficult-to-measure savings in system costs. 1/ In reconnaissance level surveys such as this, experienced judgment will be required in assessing that the with-hydro project at a minimum will be comparable in overall service under the three non-hydro base case conditions studied.

Isolated Sites

In the isolated site case, the degree of reliability assumed has a direct impact on the with-hydro case. The provision of limited electric service and the tolerance of occasional maintenance outages, for example, could mean that the hydro plant could stand alone. On the other hand, if a high degree of reliability is required, a combined hydro plant with diesel back-up may be warranted. Either of these situations could produce substantial differences in comparison with costs of the alternative.

1/ See especially Chapter 6, Evaluating Hydropower Benefits, Water and Energy Task Force; prepared by the Field Test Team, U.S. Water Resources Council, Dec. 1981.

Where standby diesel is required, the average annual generation mix of diesel and hydro can be determined for use in estimating alternative costs on a year-by-year basis. Usually, its limited use will permit the assumption of longer-life of the mechanical facilities before replacement.

For isolated sites where electrical power is presently available from small diesel generators, the rural systems may be designed to provide only 12-hour service. Also no provision may be made for back-up reserves. A small hydro-power plant could be extended to provide 24 hour service, and be considerably more reliable. Under this situation credits should be given to the hydro plant by cost additions to the existing base case to allow for the least costly alternative means for providing comparable standby reserves, and for the marginal equivalent of variable generation costs for the extra hours of service. There should be some indication that this incremental cost is equal to or is exceeded by the consumer's willingness to pay for this extra service. As mentioned earlier, this should be part of an initial cost/benefit analysis of electrification per se. Observations of willingness to pay in comparable areas in size and income where comparable electrical service is provided, could provide sufficient support that willingness to pay is at least equivalent to the marginal cost.

Even though 24-hour service will be available from the hydroelectric sites, this does not mean that all available power will be utilized at all hours of the day. Much more likely is a large decrease in night time and early morning consumption for isolated areas. This may decrease the total cost of alternative generation at an isolated site as compared to a grid-tie site where all potential power generation would ordinarily be utilized by the grid. Daily studies should therefore be used to assess usage for isolated sites since monthly studies would tend to obscure this diurnal variation in power and energy usage.

Grid-Tie Sites

The analysis of the condition where current or future projected electric service would be provided as part of an interconnected system is somewhat more complex than for the isolated system. As described above, the demand for energy in the local area may account for only a small proportion of the potential hydro output. Furthermore, the hydro unit could function differently in the type of service provided to the locality than that performed for the interconnected system; for example, the provision of late night and early morning generation, spinning reserves, and energy peaking power.

In all likelihood, however, fuel cost would probably be the major system cost difference between with- and without-hydro cases, due to the seasonality of hydro power availability. Grid systems which reflect a mix of fuels, including coal, for example, would require more careful analysis since the long-run marginal cost may involve more than one fuel. In those cases where central systems have production cost models, or where long-run marginal cost studies are available, information on the effects on variable energy costs and the particular fuel or fuels displaced should be available. Otherwise, simplified load-duration curves which show generation origin among various type plants could provide a rough basis for approximating variable energy costs displaced at the margin in order to assess the alternative fuel costs.

Delayed Grid-Tie Sites

The eventual connection of an isolated site to a transmission grid combines elements of analysis considered in the above two sections on isolated and grid-tie projects. As previously mentioned, a grid-tie hydro site will ordinarily be more efficient for the system than an isolated site due to increased utilization of the energy production. For a given hydro project at a specific site, therefore, the corresponding alternative generation costs will be higher when it becomes a grid-tie site. A consideration for delayed grid-tie sites is that the timing of the interconnection may influence the sizing of the initial installation which is based on the net cost differential as well as local demand. A short interim period may justify the provision of future capacity in all physical features of the hydro project, while a longer period may warrant provisions for deferred capacity in the civil works only. In either circumstance, the sample case would address the typical situation based on informed judgment of available power load and resources studies on future generation and transmission.

The study period would be divided into two time frames. The first, reflecting the isolated project period, and the second, the conversion to the grid-tie period. Several factors during the transition would need to be included: (i) additional transmission costs and losses in the grid, (ii) changes in generation magnitude and patterns of both the village supply and the grid system, (iii) modifications and enlargements of initial facilities, if any, and (iv) adjustments for salvage values of diesel facilities, if important. Both the base case without-hydro and the case with hydro would need to be carefully structured so that future electric demands would be met at comparable electrical service standards.

COST COMPARISONS AND RANKING

There are various ways to compare the system costs with and without individual hydroelectric sites and aggregate projects consisting of a large number of such sites. These are primarily the ratio of costs with and without hydro, the present value of the stream of cost differentials, and the equalizing discount rate (EDR). All of those parameters utilize discounted cash flows and present values of costs. The ratio of the present values of project and alternative costs, at a specific discount rate, is a very useful parameter to quickly establish the relative ranking of individual potential projects and is often thus used as a screening tool. The present values of cost differences, which is the difference between the present value of project costs and alternative costs, also for a specific discount rate, is often used in optimizing the sizing of various elements of an individual project. This would include features such as conduit size and installed generating capacity. The optimum project configuration is the one with the highest present value.

The EDR, which is the discount rate that causes the present worth of project costs to equal the present worth of alternative cost (i.e., cost ratio = 1.0 and net present value = 0), is a traditional least-cost evaluation parameter for projects in developing countries. The real opportunity cost of capital established for the study country is the minimum acceptable EDR.

Cost Ratios

For convenience of analysis and comparison, the present value of marginal system costs avoided by the hydro project would be converted to unit values expressed in terms of marginal annual dollars per kilowatt-year of capacity equivalent and marginal annual cost per kilowatt-hour. Optimally, appropriate components of long-run marginal cost of the system should be utilized. These would constitute the costs of the alternative which would be compared to proposed hydropower costs under the with-hydro condition. These would be composite values, reflecting both fixed capital costs and annual variable costs.

Representative without-hydro costs would be developed for each of the base cases, as well as for important variations within those base cases if deemed necessary. For illustrative purposes it may be necessary under the delayed grid-tie case to test the timing of integration into the main grid and appropriate adjustment factors developed to reflect variations in delays. Considering the number of possible interest rates and price escalation rates, early decisions should be made on reducing those variables to a manageable number that would be meaningful in establishing unit values for use in the final selection process.

Present Value and Equalizing Discount Rates

Present values and equalizing discount rates can easily be calculated using essentially the same basic data and assumptions utilized for the cost ratio analyses. The derivation of the present value is simply a matter of addition and subtraction and the derivation of the EDR simply solves for a discount rate which equates the present value of project costs with the estimated present value of costs of the alternative in the absence of the project. Analyses of present values of costs differences and equilizing discount rates as suggested previously, would be most useful in ranking projects, and in establishing the least-cost nature of a water resource/hydropower investment program.

ECONOMIC EXTERNALITIES

Normally, the evaluation of other than the "direct" avoided costs discussed above (such as costs or net benefits incurred in other sectors as a result of the hydro project implementation), would be most appropriate on a broad programmatic basis where national investments in various resources are compared. Ideally, this should be the subject of a cost/benefit analysis, comparing net present values of projects, rather than the least-cost analysis discussed here. The local effects of electrification, impacts on local employment, effects on export-import balances are important in this broader sense of justification and should be common to all electrification project analyses. If studies of the sample hydro potential zones indicate significant variations in secondary effects, some recognition may be warranted. This could be handled by establishing adjustment factors to allow for important differences where appropriate.

CHAPTER XII
ENVIRONMENTAL AND SOCIAL CONSIDERATIONS

This chapter covers the general environmental and social considerations which would be part of the regional assessment process. For both the social and environmental aspects only a fairly broad qualitative overview can be presented at this level, especially since the recommended methodology relies on representative sampling and extrapolation for both new and existing projects to get the overall results. However, each site studied in detail can be analysed and general qualitative conclusions then drawn for the region as a whole.

ENVIRONMENTAL AND SOCIAL RATINGS

For regional assessment analyses at a reconnaissance level, the basic purpose of social and environmental evaluations is to identify those problems at a qualitative overview level which would add to the project costs, or would cause significant time delays in the implementation of the projects. More detailed qualitative analyses can and should be conducted for each specific project to be constructed during the implementation phase of project development. Points to be considered in more detail are well covered in the listed references.

It is suggested that simplified overview rating forms for both the environmental and social aspects be utilized for the sites to be studied in detail. These preliminary overview ratings, together with general observations of the larger overall areas, should then enable the investigators to draw adequate conclusions for a qualitative regional assessment of environmental and social factors. The exact rating factors used will vary somewhat from location to location depending on which factors are locally critical. Table XII-1 and XII-2 are included with this Chapter as general format examples for the suggested environmental and social overview ratings respectively. The rating factors for a specific project would be modified as locally suitable, since no one form would be universally suitable. A number of common factors are listed in the tables and the primary factors are discussed below.

ENVIRONMENTAL OVERVIEW

The environmental impacts of small-scale hydroelectric projects are usually relatively minor, when compared to larger projects. Generally no new impoundments of appreciable size will be created and large fluctuations in water levels and flows will not occur.

For the small diversion projects which would be typical of new sites, the primary environmental impact will be the effect of the stream diversion, which will wholly or partly dry up the former stream bed between the diversion and the powerhouse. This will primarily effect aquatic life and any other diversions which pre-existed the project. These other diversions will seldom be present on a proposed project, however, since their presence would in all likelihood preclude development of the site and the site would not have been selected for detailed study. Other impacts would be the effect of the project access roads which may allow new access to formerly undeveloped areas, and any effects the project may have on parks, wilderness areas, wildlife, and other such usual environmental concern for any new project.

For installations at existing sites, the primary impact would be only the construction disturbance, since access would already exist along with the previously existing structure. Some visual disturbance from the addition of the powerhouse would also result. If hydraulic heads are low, i.e. 20 meters or less, water quality problems from dissolved oxygen would not be expected. The greatest impact from an existing site installation would result if an existing reservoir fluctuates to enhance power production. This would result in varying reservoir levels and downstream flows.

Both new sites and existing sites will require transmission lines which will primarily have a visual impact, although sometimes existing rights of way or existing poles can be utilized.

SOCIAL OVERVIEW

Because the proposed individual projects will be small, the construction will not, in most cases, produce major impacts on nearby communities. Some influx of outside workers to remote small villages will often occur, but will ordinarily be of short duration. The small scale hydroelectric project will usually have the beneficial social effect of producing some local temporary employment and the completed project will generally enhance the quality of life as any rural electrification scheme would. Most projects will not displace anyone from their residences or destroy producing farmland: both major impacts of large hydroelectric developments.

TABLE XII-1

ENVIRONMENTAL OVERVIEW RATING

ENVIRONMENTAL ASPECT	ADVERSE IMPACTS				
	None	Minor	Moderate	Substantial	Major
1) Reservoir Water Level Changes	0	1	2	3	4
2) Flow Changes	0	1	2	3	4
3) Alternative Water Uses	0	1	2	3	4
4) Construction Impact	0	1	2	4	4
5) Park and Recreation Effect	0	1	2	3	4
6) Scenic Effect	0	1	2	3	4
7) Archaeological Effect	0	1	2	3	4
8) Historical Site	0	1	2	3	4
9) Wildlife Habitat Effect	0	1	2	3	4
10) Botanical Resources	0	1	2	3	4
11) Water Quality	0	1	2	3	4
12) Fishery Considerations	0	1	2	3	4
Overall Rating	0	1	2	3	4

Comments:

TABLE XII-2

SOCIAL OVERVIEW RATING

1. Does electric power currently exist for the area? __________

2. Comment on overall effect of providing hydrogeneration rather than diesel or other forms of supplementary energy:

3. Will the quality of life for the area be enhanced? __________
Comment:

4. During the construction period how many will be employed at this project site? __________

5. How many will be local? __________

6. How many will be permanently involved with operation and maintenance? __________

7. Will access to and from the area be improved? __________

8. Will the area summer any permanent disruption? __________
Comment:

9. Other comments:

10. Overall Social Overview Rating

Negative						Positive		
-4	-3	-2	-1	0	+1	+2	+3	+4
Major Impacts	Substantial Impacts	Moderate Impacts	Minor Impacts	No Impacts	Minor Impacts	Moderate Impacts	Substantial Impacts	Major Impacts

CHAPTER XIII
PROJECT IMPLEMENTATION CONSIDERATIONS

This chapter describes the aspects that should be considered during the regional assessment investigation to facilitate further project implementation. This includes a decision as to which implementation approach to utilize, an appraisal of the existing governmental organization capabilities, recommendations for future organization and management, project implementation schedules, and the necessary primary steps to implement this schedule.

Individually the construction of each small-scale hydroelectric project will be simple and fairly straightforward. However, when a large number of such projects are under consideration, the management of such a program presents a considerable challenge to conduct the implementation in an orderly manner. It is therefore appropriate that early consideration be given to the additional steps and overall schedule necessary for logical implementation and to the organization or entity which will manage the future program.

BASIC IMPLEMENTATION APPROACHES

There are two primary approaches for implementation of a large number of small scale hydroelectric projects. These can be called the "project" approach and the "program" approach and the implementation considerations for each may be quite different.

Project Approach

The project approach is the planning and implementation of a finite number of small scale hydroelectric sites, usually over a relatively short span of time of perhaps two or three years. The project is funded and the schedule implemented on the basis of a single one-time effort to implement the given number of sites. Most small scale hydroelectric devulopment to date has used such a project approach and this can therefore be considered the conventional method.

The original planning for the project approach is usually fairly extensive, with detailed feasibility studies performed for each site to be implemented. Alternatively, a sampling methodology such as proposed herein for new sites could be used but it would either use large samples, insuring high accuracies, or would adopt a conservative approach with a reduction in the estimated number of sites to compensate for the inherent margin of error of the sampling and extrapolation process.

Program Approach

The program approach would involve a long-term open-ended effort to develop a number of sites each year. The usual various stages of project development including screening studies, feasibility, design, equipment procurement and construction would be going on simultaneously under overlapping schedules for different sites or groups of sites. The program approach would lend itself well to the sampling methodology covered in Chapters II and III.

If it was determined by application of the methodology that the estimated number of sites for a given region was 120 ± 35 at a 90% confidence level, it could then be said that there were 85 sites (120 minus 35) at a 95% confidence level and this value could very well be adapted for a project approach. However, if the program approach were chosen and it was decided to develop a portion of the estimated 120 sites each year, 25% for example, development and commitment of funds for 30 sites each year could then proceed with a very high confidence that, for at least the first several years, sufficient sites for development actually exist. During each year of this period, feasibility studies for the next year's sites would be performed and the necessary funds committed. If it were ultimately found that there were actually either 85 sites or less, or 155 sites or more, the necessary adjustments to the program could be made one or two years in advance and no overplanning or overfunding would occur.

ORGANIZATION AND MANAGEMENT

As part of the resume/assessment process documentation should be made of the existing governmental organizations or entities that would potentially be involved in project implementation and operation. A general assessment should also be made of the capabilities of these entities and the local private engineering and construction sectors.

Based on this information either a specific recommendation or the available options for an institutional plan for project development can be formulated. Some countries have more than one agency involved in small scale hydroelectric development and some have highly centralized governmental organizations and some decentralized. The various organizational possibilities for regional small scale hydroelectric development will vary widely from country to country and no single recommendation can be generally applied. The one suggestion that can be made is that it is often desirable to have a single entity or task force responsible for the development, rather than having responsibility and decision making spread through several agencies.

The analyses concerning organization and management in the regional assessment study should also recommend the degree to which expatriate consultants would be needed and should offer suggestions regarding a general technology transfer plan.

IMPLEMENTATION SCHEDULE

A general suggested implementation schedule should be formulated to cover the remaining steps in project development. These remaining steps would generally be:

1. Loan Negotiation and Project Planning - This would include detailed formulation of an organization and management plan, development of a financial plan, and obtaining the necessary funds, both foreign and domestic for project completion.

2. Detailed Project Investigation - If the methodologies proposed in this report had been utilized, the resulting regional assessment report would have been based on representative sampling and extrapolation. It would still remain necessary to identify each individual site to be developed, formulate the specific development and to demonstrate specific site feasibility. This would probably require site surveys (to be used also for later design) and other investigations.

3. Preparation of Tender Documents - Detailed plans and specifications would be prepared for each site to be developed. Usually separate tenders would be prepared for the mechanical-electrical (M/E) features (turbine generator and control equipment) and for the civil features (diversion, intake, water conveyance, access roads and powerhouse). The transmission lines can be tendered separately, or included with the civil features.

4. Construction - Since the features for both new sites and retrofitting of existing sites are relatively small and straightforward, the civil features will generally take less than one year to complete for each site and often as short as several months. The M/E equipment, however, will usually take 12 to 18 months to procure per site and installation will then take usually less than two months. Since a large number of units may be tendered, final delivery dates may well be 6 to 12 months longer.

All of these steps must be completed for both the project approach and program approach. The basic difference is that for the project approach one single turbine/generator tender may be prepared and one single civil contract may be tendered, while for a program approach these activities would be annual activities, and all activities for development would overlap from year to year.

EQUIPMENT PROCUREMENT CONSIDERATIONS

Equipment that must be procured for hydroelectric projects include the turbine/generator and associated control equipment and electrical gear, penstocks, and gates. Some developing countries presently have the capabilities to manufacture all or some of this equipment and many more will have the ability to do so in the future. Such local capability may cut down on the lead time of at least 12 months for individual site equipment and longer when a number of sites are tendered.

To decrease this long lead time, consideration may be given to pre-procurement of some items in advance of specifically identified needs. This may work well for such items as penstocks and gates where a large procurement contract may be tendered by the governmental agency involved and these items then furnished to the contractor for installation on a unit price basis. It may work less well for turbine generator equipment which is usually very site specific in order to achieve maximum efficiencies even for the small sizes considered with this methodology. In instances where this has been tried, this approach has sometimes worked well, but more often regrets have been expressed that the equipment was not ordered as needed. For an ongoing program approach, it may not be advantageous since careful advance planning may well preclude the need for such an approach.

PROJECT OPERATION

A longer-term project implementation consideration is that of operating the completed sites after construction is completed. This includes such aspects as organizational issues, operation, maintenance, power sales, rate studies and the related financial (as opposed to economical) analyses. Such items are very important but are beyond the size of this study on regional assessment. The matter should, however, receive early attention in the long-range planning process.

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