POTENTIAL FOR SMALL, MINI AND MICROHYDEL PROJECTS IN THE INDIAN HIMALAYA

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INTRODUCTION

Generation of power in India from small hydroelectric units dates back to the late nineteenth century. The first 130 kW hydroelectric generator was set up in Darjeeling in 1897. Two 100 kW units were set up in Simla in 1908, followed by three units of 250 kW and two units of 500 kW in Chaba (60 km from Simla) between 1912 and 1918. These efforts to develop hydroelectric generation were to meet the requirements of the British government which had its summer capital in Simla. Darjeeling, famous for its tea estates, also was a popular summer resort in the eastern region. The hydel units in Sivasamudram were commissioned to meet the power requirement for the Kolar gold fields. When the British left India, total installed capacity was about 2300 MW, of which nearly 40 MW of power was generated by small, mini, and microhydel, mainly in the hill regions.

Today, the total installed capacity in India is about 44,000 MW, a 19-fold increase in 38 years. Small hydel power generation in the mountain regions has increased only about three times during this period and is still a meagre 117 MW.

Little was done during the fifties or the sixties to electrify the hill regions. It was in 1974 that the government of India set up a committee to investigate rural electrification. This committee strongly recommended that intensive efforts be made for setting up microhydel units, particularly in the north-eastern region. Thus, Arunachal Pradesh has come to have a number of microhydel units during the past decade. The impact of electrification on that region is discussed in the latter part of this paper.

Recent worldwide efforts to harness renewable energy sources and the warnings of ecologists about the threats of large-scale hydroelectric systems have turned attention to an age-old method of generating power: using small, mini, and microhydel units. Small hydropower generation has begun to receive official attention.

To follow the definition of the Central Electricity Authority (CEA) of India, the classification of small, mini, and microhydel plants is as follows:

- Small hydel project: 2001 kW - 15000 kW and no individual units ratedmore than 5000 kW
- Minihydel project: 101 kW - 2000 kW each unit usually less than 1000 kW
- Microhydel project: Up to 100 kW

(For the sake of convenience all these categories have been occasionally referred to as SHP in this paper).

All these hydel schemes can again be categorized into:

- High head schemes > 50 meters
- Medium head schemes 20-50 meters
- Low head schemes < 20 meters

The first two categories particularly are of interest. Small hydel units, usually installed at canals, operate at low head drops. These are primarily in the plains (Map 1) and will not be discussed in detail in this paper.

THE PRESENT STATUS AND FUTURE POTENTIAL OF SMALL, MINI, AND MICROHYDEL UNITS IN INDIA

The growth of SHP in India has been extremely poor. The total number of plants in operation in India is 84, generating about 168 MW.

- In India, SHP constitutes about 1.2 percent of total hydropower and 0.38 percent of the total installed capacity:

- Out of the 84 SHP **in operation in** India, 20 small hydel units generate 129.3 MW (77 percent), 51 minihydel units generate 37.9 MW (22.5 percent), and 13 microhydel units generate 0.675 MW (0.5 percent).

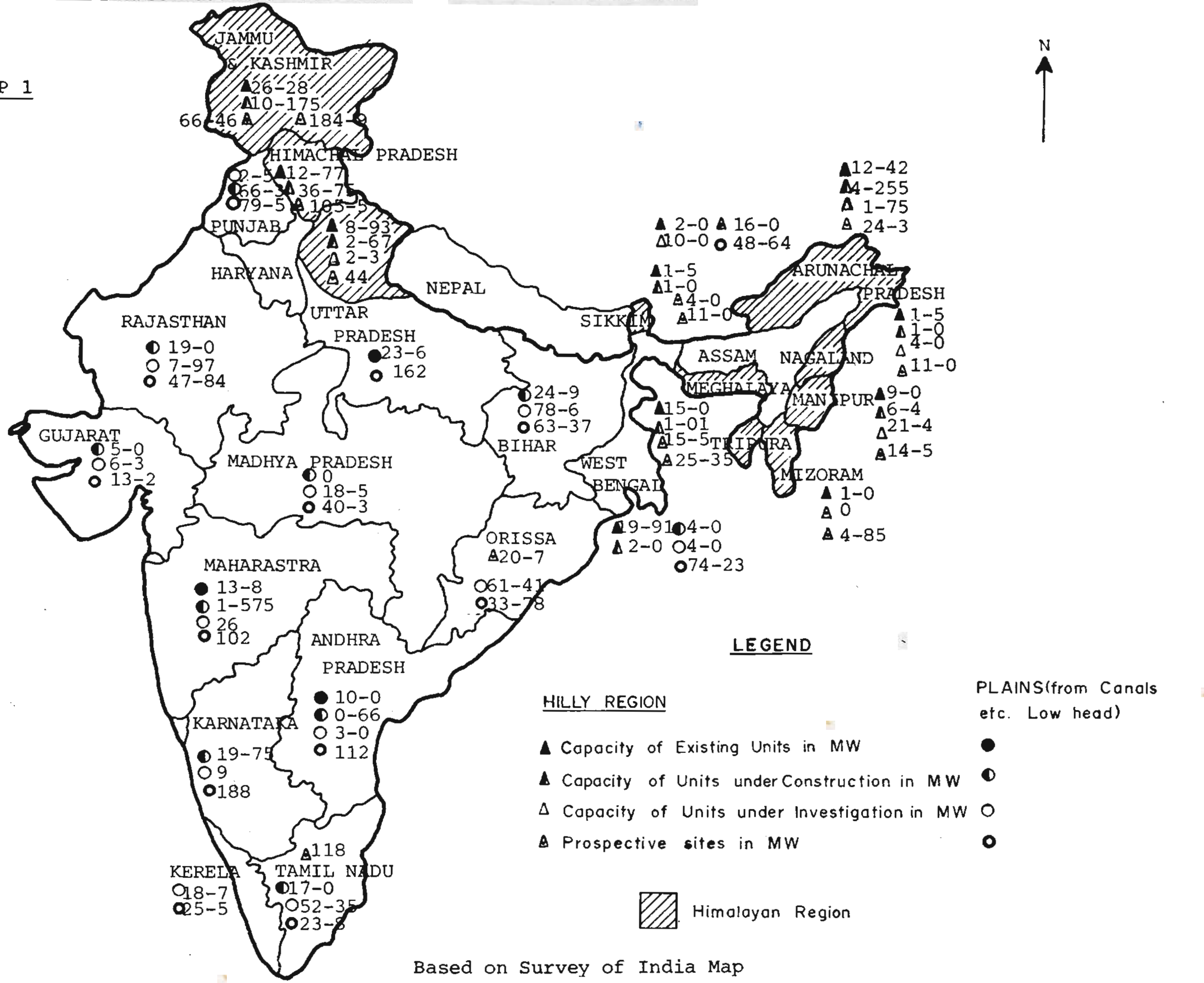
- Out of the 71 SHP **under construction** in India, 18 small hydel units will generate 125.65 MW (78.78 percent), 39 minihydel units will generate 33.0 MW (20.7 percent), and 14 microhydel units will generate 0.8 MW (0.52 percent).

It is interesting to note that the relative emphasis on small, mini, and microhydel units has not altered much over the years. For one small hydel unit, India has four mini or micro units in operation.

The following section provides information about the SHP in operation in India (Map 1) and a summary of the potential explored so far[1].

MAP 1

EXISTING AND POTENTIAL SMALL/MINI/MICRO HYDEL CAPACITY IN INDIA



Based on Survey of India Map

Table 1: SHP in Operation, under Construction and Investigation

	In hill regions		In the plains	
	No. of sites	Installed capacity in MW	No. of sites	Installed capacity in MW
SHP in operation	72	116.7	12	51.3
SHP under construction	50	67.76	21	90.4
Projects under investigation (CEA)	55	130.4	143	358.6
*Prospective sites (REC)	250	660	810	1068

* Approximate figures REC - Rural Electrification Corporation

Of the figures in the hill regions, nearly 450 sites have been identified, and these will provide about 660 MW at high head. These sites are not all in the Indian Himalaya region.

It may not be possible to install SHP in all the prospective sites listed by the REC. On the other hand, this list is not necessarily exhaustive. It is likely that India's SHP potential is significantly more than the 1800 MW indicated in Map 1. A figure of 5000 to 6000 MW has been suggested (Newsletter of the Asia Pacific Regional Network for Small Hydro Power 1985). The potential in the Himalaya region is likely to be correspondingly high.

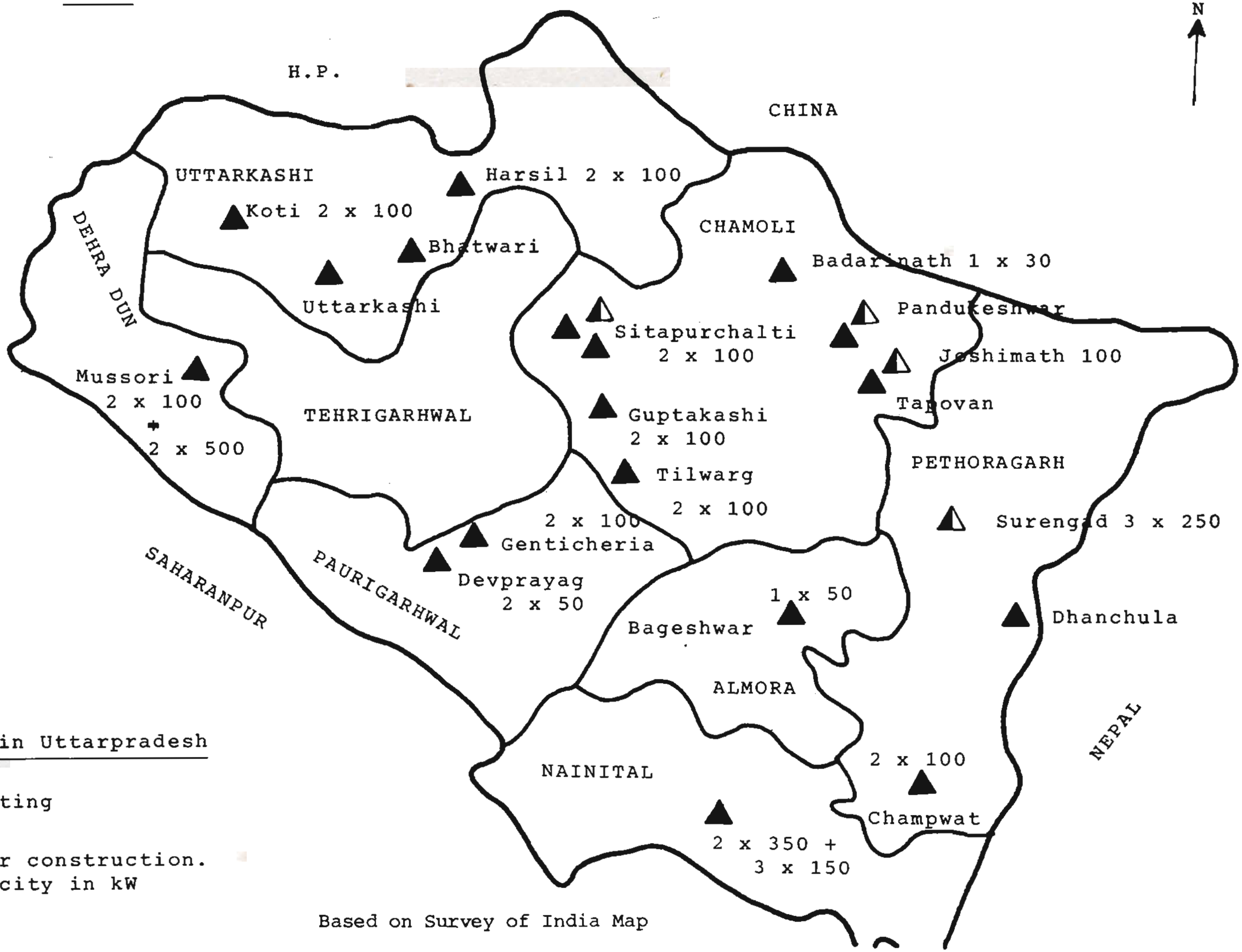
The states that contain parts of the Indian Himalaya are Jammu and Kashmir (J and K), Himachal Pradesh (HP), Uttar Pradesh, Sikkim, Arunachal Pradesh, Nagaland, and Manipur (shaded in Map 1 ; Meghalaya, Mizoram, and Tripura may also be included. Map 2 gives a typical distribution of SHP in northern Uttar Pradesh as well. The potential and feasibility of SHP in these areas need to be studied.

TECHNOLOGY OF MINI AND MICROHYDEL UNITS

A brief outline of the SHP technology, obviously not intended for experts in this field, follows.

Small hydrogeneration at canal drops or low dams falls into the low head range (i.e. 20 meters or less). In this paper, however, we shall concentrate on the medium and high head types which are more prevalent in the Himalaya region. Figure 1 represents a typical mini or microhydel system which consists of a diversion weir, an intake structure, a desilting chamber, a penstock or other conveyance facility, a power house, hydro-generating equipment, a transmission line, and an access road.

MAP 2



S.H.P. in Uttarpradesh

▲ Existing

◭ Under construction.
Capacity in kW

Based on Survey of India Map

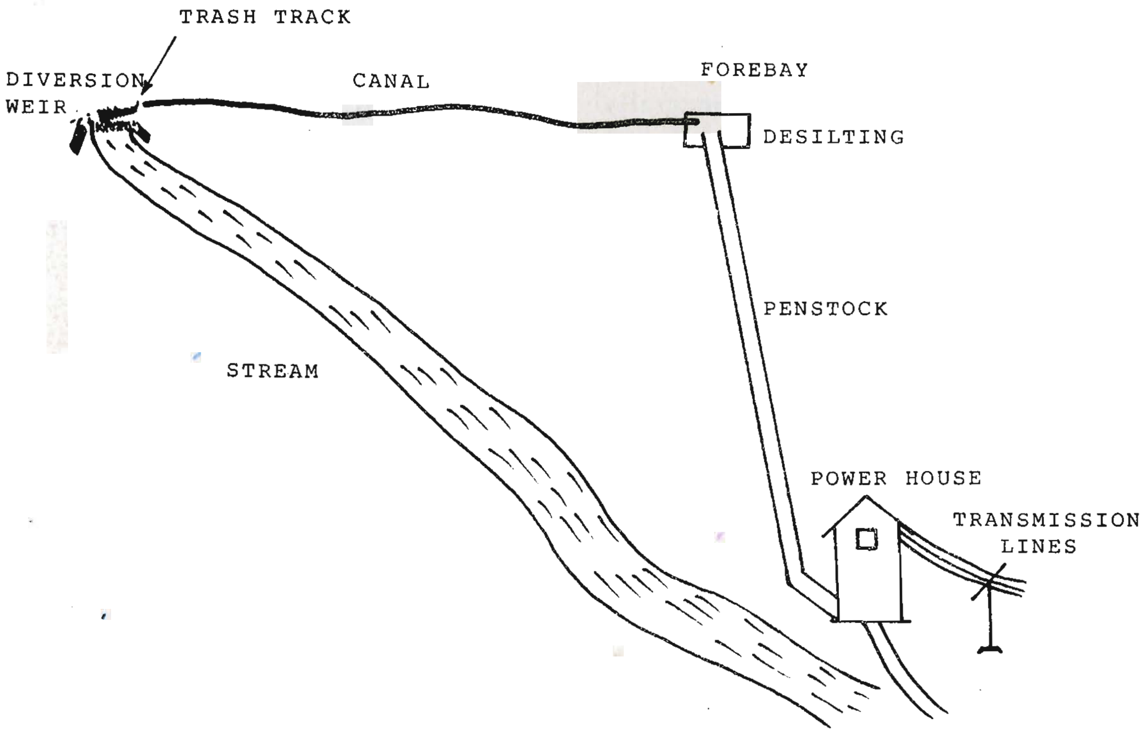


Figure 1. A Typical Mini/Micro Hydel Run of the River Scheme

A **diversion weir** diverts water out of the stream into a channel or directly into a penstock via an **offtake structure** which incorporates a **trashtrack** to exclude floating debris and the larger sediment. The diversion weir may be of two types: boulder structure which is a trapezoidal structure of boulders or rubble masonry section one or two meters high with a slanting upstream face, or a trench-type weir which is particularly suitable where boulder structures are vulnerable to damage from other boulders. It is a simple trapezoidal trough made of masonry or concrete covered with a trashtrack over the full width of the stream. One of the major requirements in mini and microhydel projects in the Himalaya region is a desilting chamber. Generally hill streams carry appreciable silt and sand during rainy seasons causing considerable damage to the turbine runner. The **conveyance facility** transports the water from the diversion weir area to the power house and can be a **penstock** or a combination of **canal** and penstock. A canal (or a channel as it is often called) combined with a penstock is more commonly used. The gradient of the channel is kept low (about 1:750, for example). The stream has a higher gradient (typically above 1 in 40). Water diverted from the stream flows down the channel a distance of 2 to 3 km and develops a head of about 50 to 75 meters (Figure 2). The canal ends in a **forebay** from which a penstock then carries this water to the power house.

If the bed slope of the stream is steep (for example one in ten) it will be cheaper and faster to adopt a direct penstock for conveyance of the water.

The **power house** shelters the turbine-generating equipment and controller and is designed according to local practice. The selection of the turbine/generating equipment depends on the flow, hydraulic head, and other factors.

For the higher heads, usually with a diversion-type project, the turbines are often the impulse or Francis type. Where long penstocks are involved, the impulse-type unit is usually preferred since water-hammer stresses are minimized. This is due to the use of jet deflectors and the slower allowance valve closing times when outages occur and rapid shutdowns are necessary. Impulse units also suffer less damage from sediment than do Francis units.

As far as the choice of generators is concerned, it depends very much on the power market a SHP has to serve. The SHP may serve an isolated site, as is frequently the case in the Himalaya region, or it may serve a power market which is located so that the hydropower may be fed into the main grid.

In case the power market is an isolated site, the more expensive *synchronous generators* are used. For grid ties, induction generators (Allan 1960) are recommended because they are cheap and rugged, and need less control.

For mini and microhydel units, power is generated at 440 V, and a transformer is not required unless power is to be transmitted to a distance greater than 5 km. For minihydel units it is not uncommon to have two, three or four turbines or generators for operating from a common header fed by the penstock. Hydroelectrical power can be computed by a very simple formula:

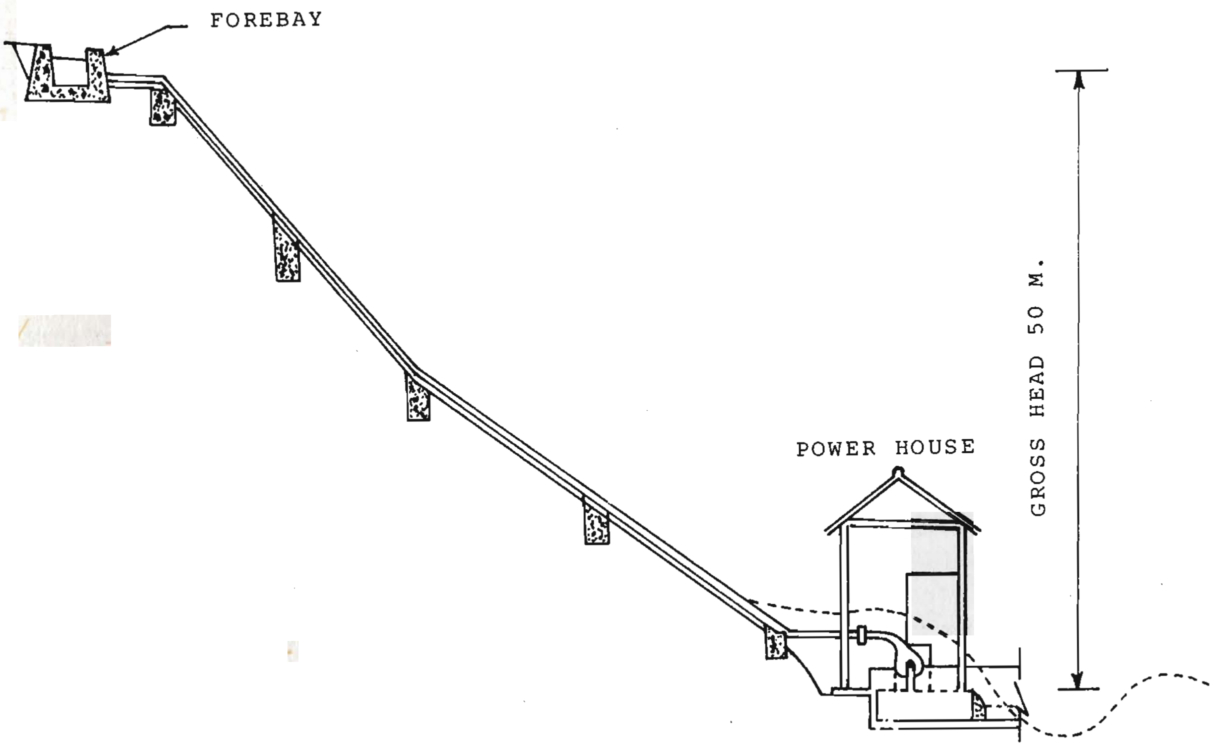


Figure 2. SECTION OF PENSTOCK

$$P = 9.81Q.H.e$$

where P = power in kW
Q = flow in cubic meters per sec (cms)
H = head in meters
e = turbine/generator efficiency

A 20 kW microhydel unit that was set up in Karnataka for H=70 m, Q=0.07 cms (70 liters/sec), P was calculated as 24 kW assuming e = 0.51 ($e_{Generator}$ = 85 %, $e_{Turbine}$ = 60 %; e is usually higher and can be taken as 0.75 - 0.8). It is critical that Q and H should be measured carefully before selecting a site and the installed capacity.

SITE SELECTION

Map 1 indicates the hydro-potential in different states. The primary parameters which define the hydro-potential zones are topography, hydrology, power market area and site accessibility.

Topography

For run-of-the-stream, diversion-type hydroelectric developments, fairly steep topography is essential.

Hydrology

Suitable run-off in conjunction with topography must be available for hydroelectric development.

The primary data required for hydrologic analyses of stream flow are:

- Catchment area
- Annual steam flows
- Annual basin precipitation
- Meteorological records including air temperature, relative humidity, wind speed and evapotranspiration

Annual discharge at the hydropower site is given as:

$$Q = A(P-E)$$

where Q = annual run-off at the hydropower site
A = catchment area at the hydropower site
P = catchment precipitation at the hydropower site
E = annual evapotranspiration for the catchment

Hydrologists often use the following correlation model:

$$Q = RA^aP^bS^c$$

where Q = annual stream flow at flow site
P = annual precipitation
A = catchment area
S = slope of the catchment

and obtain the constants using multiple regression and correlation analysis. It is unlikely that hydrological data available for the Himalaya region and it may be necessary to depend on simple empirical formulae. For certain areas, data on rainfall may be available. Allowing an average of about 70 percent for evapotranspiration, we can assume Q = 0.3AP cumecs.

C. R. Rao (Retired Chief Engineer CPWD) suggests on the basis of long practical experience in Arunachal Pradesh that a catchment area of 1 km^2 yields a flow of 0.5 cusecs or about 15 liters/sec (during lean months). It is worthwhile to develop such thumb rules for different regions in the Himalaya.

The preliminary information necessary for site location and hydrological studies of a mini or microhydel unit may be based on the survey of India toposheets (scale: 1:50,000) which also give an approximate idea of catchment area of the river or the stream, general slope of the river bed, and the river width. Normally, bed slopes of more than 1 in 40 suggest high potential for a mini or microhydel unit. The toposheets give an approximate idea of the hydro-potential of a particular area, based on which site studies may be made.

Bed slope and flow have to be measured. Obviously, the flow or discharge is unsteady and varies seasonally. Figure 3 represents a typical annual hydrograph. Flow may be measured during the lean months of January, February, and March. The design of hydro-generation may be based on a flow 20 to 30 percent greater than the average flow measured during lean months.

Exhaustive hydrological studies are expensive, time-consuming, and may not be worthwhile. Considering that resources and manpower are limited, it is desirable to have a larger number of sub-optimal mini or microhydel plants than a few optimally designed plants.

Various techniques ranging from the use of floats to current meters may be used for measuring discharge. The flow is measured at the site selected for the diversion weir. The velocity is measured at 0.6 *d* where *d* is the depth of the channel at different points (Figure 4) and the average discharge is calculated.

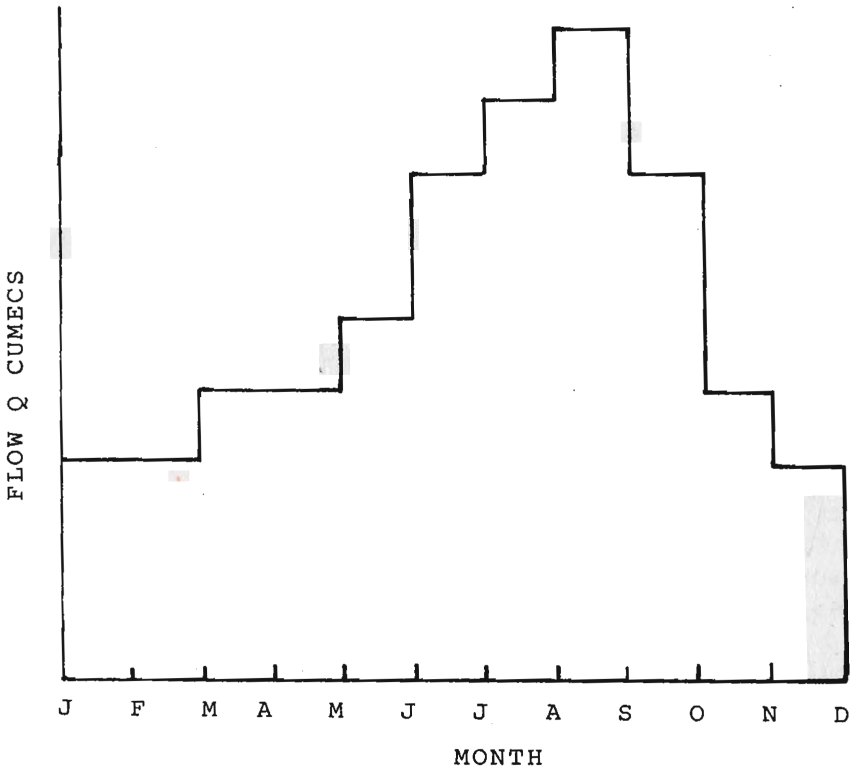
It is also necessary to collect as much data as possible about the flashfloods typical in the Himalaya region. A suitable location for the diversion weir on the stream is a flat bed from which the stream begins a steep descent in its undulating course. A 50 to 70 meter drop in the bed level over 2 to 3 km is suitable for the location of the power house.

For constructing the power channel (Figure 2) a trace cutting is done with a gradual slope of about 1:750 after having decided whether the left bank or the right bank of the river is more suitable. The forebay is generally located on the spur of a hill above the power house.

The main considerations in these selections are to ensure stability of the power channel and forebay, penstock alignment, and low costs for construction and maintenance. Needless to say, experience plays an important role in making judicious selections. A question that frequently arises in the case of small hydroelectric projects is regarding the necessity to have additional storage. For a run-of-the-river type, storage capacity of 10 to 15 minutes in the forebay is usual. The main problem that may be faced in meeting peak loads is not only diurnal but monthly as well.

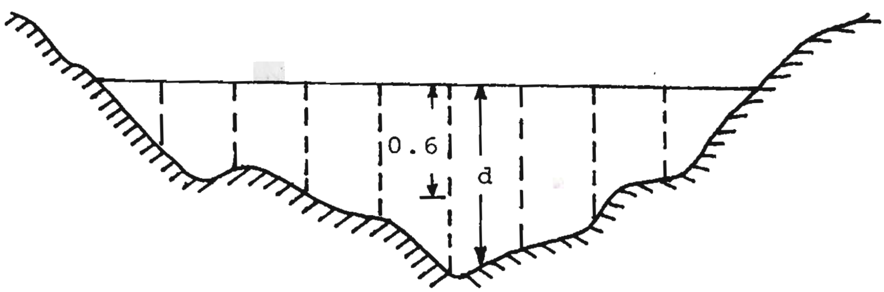
If the peak demand is 1000 kW between 6 A.M. and 9 P.M. and the average discharge can generate 600 kW, it may be necessary to meet the deficit of 400 kW by diesel generation which is costly. The off-peak demand may be 200 to 300 kW, in which case, surplus water spills over. The idea of providing additional

Figure 3



MONTHLY HYDROGRAPH

Figure 4



FLOW MEASUREMENT

storage is to store surplus water at off-peak hours in order to meet peak demand. Ideally, storage facilities should be provided. The decision depends, however, on the power market, available funds, and topography.

EXPERIENCE OF CONSTRUCTION IN THE INDIAN HIMALAYA

It has been indicated that India's experience of constructing mini and microhydel units in the Himalaya is rather limited. The Central Board of Irrigation and Power recently published a document ('Small Hydro Stations: Standardization', Publication 175, February 1985) which provides design details of SHP. References have been made in this publication to details of construction as given in Indian Standards Specifications. Whereas these specifications are useful general guidelines, local variations become the decisive factors, particularly in the hill regions.

Cost is an important criterion and it becomes prohibitive if all the specifications have to be adhered to. Engineers who have been involved in construction in the Himalaya region claim the cost of construction can be significantly reduced if local labor and materials are utilized, and variations in design made in accordance with local requirements. Access is a major problem and access roads are expensive to construct. Engineers have to decide how access roads should be constructed in difficult terrain. Shah and Moral (1983) observed with reference to Gharola Microhydel Scheme, "whereas the construction (of diversion) did not pose a problem, a jeepable road of about 2 km had to be cut through vertical rock face in some lengths at half arch as well, so as to enable the jeeps to ply so that construction materials, equipment, and penstock pipes could be taken... Experience indicates that it will be better to have equipment in crate packages that can withstand rough handling and that it does not exceed 200 kg in weight".

For diversion, the trench-type weir has been strongly recommended (Sood et al 1984) for use in hill regions. On the other hand, an engineer engaged in SHP in the Himalaya region made the following observations: "According to old practice, we have been constructing trench-type weirs. These are costly and time- consuming and at the same time, a height of 3 to 4 meters is lost in this process. The power channel after its off-take from trench-type diversion has to be secured well for a long length. This long length of protection is costly and liable to erosion, interrupting power supply ... To overcome this, it is desirable to construct a solid weir of concrete or stone masonry in cement mortar of about 2 meters in height, with suitable scour pipes at the bottom".

This observation may be pertinent to a particular area but is unlikely to be universally valid and it is here that judgment and discretion play a significant role. For example, in Rongtong Microhydel Scheme it was decided that the intake structure and diversion channel should be the trench-type weir.

The power channel is a very expensive item in mini and microhydel construction. Discussing the water conductor system in the Himalaya region, Singh (1983) observes, "The water conductor systems have included channels lined in masonry, concrete, and other ways such as wood flumes, metal flumes of thin steel pipe, and concrete pipe. Although preference for channels and flumes has been kept in mind in many places, interposition of small tunnel sections has been necessary to overcome difficult hill sections."

Rao observes, "Wherever mountain slips were anticipated, covered rectangular sections for the power channel were adopted. At some places, the covering of the power channel was done with wooden sleepers obtained from the felled trees along the power channel alignment to make use of local material and labor..."

In this context, Shah and Moral (1983) observe, based on Rongtong Microhydel experience, "It (the water conductor system) has also to be kept covered by removable concrete slabs so that no debris falls into the power channel during the rains and when thawing takes place after winter."

Once again, an appropriate decision has to be made depending on the project site. If there are possibilities of avalanche over the power channel, it has to be secured by concrete slabs despite the cost involved.

Engineers who have worked in the Himalaya agree that for penstocks, mild steel pipe joints should be welded and flanged joints should be avoided. For small microhydel plants, high density polythene pipes have been recommended.

One of the major considerations in the design and construction of mini and microhydel units in the Himalaya is desilting. Quoting once again from Bhargava et al (1983), "Intakes for high head power plants on Himalayan streams carrying very heavy sediment charge pose problems of exclusion of sediment over a wide range of particle size. The problem magnifies further in the case of small hydrostations where settling basins in the form of large reservoirs are not practical and the head available is more than 100 meters necessitating removal of very fine sediment from considerations of safety of the machines."

The need for desilting has been repeatedly emphasized by engineers who have worked in the Himalaya, although the attempt to exclude very small silt particles can be costly. An analysis for a small hydro project in Ladakh indicated that the cost of a desilting basin to exclude silt particles up to 0.2 mm would cost nearly four times as much as a basin required to remove particles of 0.5 mm and above. "It may be worthwhile," comments Narasimhan (1983), "to have turbine runner made of material of high erosion resistance or even to keep a spare runner rather than resorting to expensive desilting arrangements."

On the other hand, the recommendations of the Central Board of Irrigation and Power document (Publication 175) are:

Head	Size of silt particle to be removed should be greater than
Medium head	0.2 to 0.5 mm
High head	0.1 to 0.2 mm

Like various specifications set out in the documents, the recommendation made above may be costly for the Himalaya region with high head hydel projects. Finding enough flat space for desilting may not always be possible either.

There are, of course, a number of construction problems at high altitudes. Recalling their experience in Rukti Microhydel Scheme at Sangla village of Kinnaur District, Shah and Moral (1983) observe, "The construction of this scheme did not present difficulty during execution because of the existing road, enabling jeeps to carry the equipment and construction materials. Since the project is located at a high altitude, there was difficulty in doing the civil construction work during the winter months from November onwards. This was because the cement would not set on account of low temperature. The work was, therefore, planned so that the bulk of the construction work could be executed during the summer months." While the problems presented by mountainous areas vary widely, the account above gives a glimpse of some of the problems faced by engineers who worked in the Himalaya region in India in the recent past.

COST ANALYSIS OF MINI/ MICROHYDEL INSTALLATIONS

The major resistance to SHP seems to be its high cost per kW and low return. Different figures are quoted, ranging from Rs. 15,000 to 35,000 per kW for installation cost. In remote hill areas, cost of construction tends to go up and since the generated power has to be locally consumed, returns are low.

Cost details of six small hydel stations in hill regions have been quoted by Narasimhan (1983) and are presented below.

Table 2: Cost details of Six Small Hydel Stations in Hill Region

S. No.	Installed capacity, in kW	Total cost Rs. 100,000	Cost/kW	Remarks
1.	2 x 500	136	13600	1.87 km water conductor
2.	3 x 5000	2150	14333	7 km tunnel
3.	750 + 250	178	17800	2.2 km open channel
4.	2 x 4000	1738	21725	3 km water conductor
5.	2 x 1000	738	36900	1 km water conductor
6.	4 x 500	787	38350	8 km water conductor

It is clear that construction costs varied from Rs. 13,600 kW to Rs38,350 kW. Rao, based on his experience in Arunachal Pradesh, claims that using local techniques and 90 percent local labor, a microhydel station on its completion used to cost between Rs. 5500 and Rs. 8000 per kW of installed capacity during the years 1976-1980. He gives the breakdown of expenditure in support of his argument.

	Approx expenditure per kW installed capacity	
1. Civil Works such as Diversion Weir, Channel, Power House, and Forebay	Rs. 2000	30%
2. Penstock Pipes along with Anchor Block, etc.	Rs. 1000	15%
3. Power House Equipment such as Turbine, and Alternators	Rs. 3000	40%
4. Miscellaneous such as Approach Roads	Rs. 1000	15%
	Rs. 7000	100%

Rs. 7,000 per kW during 1976-80 appears to be on the low side (allowing for escalation, this amount would probably come to Rs. 14,000 in 1986) and Rs. 9000/kW would have been closer to the mark. Figure 5 represents approximate cost distribution for mini and microhydel plants of a few typical ratings.

In this context, a set of data is presented pertaining to manufacturing cost, operation and maintenance charges, and cost of generation for 16 mini/microhydel projects in Arunachal Pradesh during 1971 and 1981. This example is chosen because a large number of installations in the entire spectrum of micro and minihydel plants were commissioned within 10 years (1971 - 1981) and necessary data was available. Figure 6 is a plot of cost/kW against kW of installed capacity. In two cases in the microhydel range, cost/kW exceeded Rs. 32,000. In all the other cases the cost was within Rs. 15,000/kW with an average cost of Rs. 8850 per kW. One 10 kW microhydel plant was set up at an expenditure of Rs. 132,000 and hence the two cases referred to above could be ignored and fit an approximate exponential curve (y=A+BE-Kx) developed as shown. This exponential gives the average cost/kW for a certain installed capacity and indicates that microhydel units are more costly per kilowatt than minihydel units.

Stray cases of high cost/kW will invariably reflect difficult terrain. However, experiments carried out in Nepal with home- made crossflow turbine (or centrifugal pump operated in an inverted mode), high density polyethylene pipes for penstock, and the utilization of local material and labor, indicate that it is possible to bring down the cost/kW for microhydel units significantly.

Cost Comparison between Large and Small Hydel Plants

Unfair comparisons are frequently made between large hydropower (LHP) and SHP. Apart from ecological questions and many other intangible factors which

APPROXIMATE COST DISTRIBUTION FOR CONSTRUCTION OF TYPICAL MINI/MICRO HYDEL SCHEMES

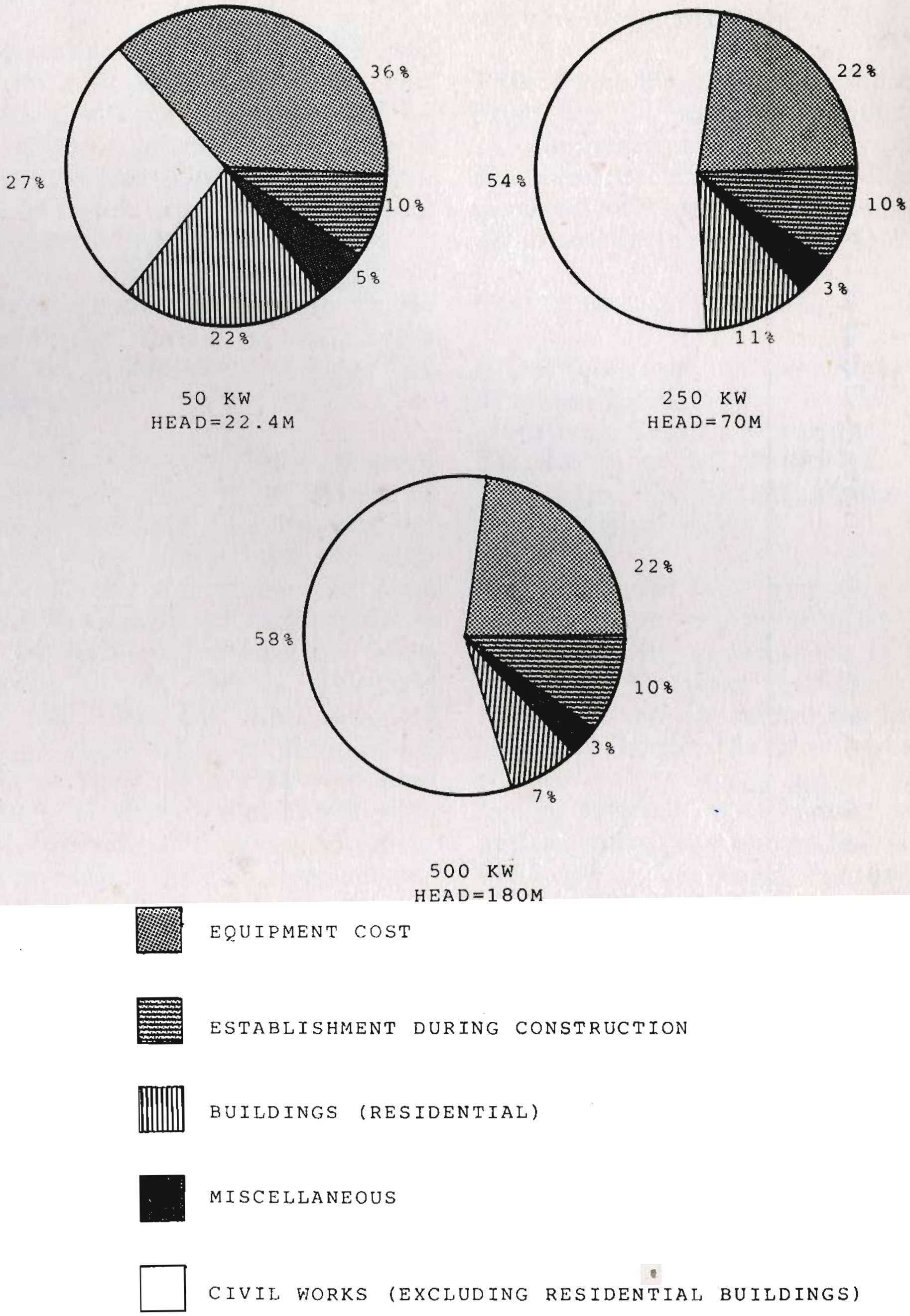
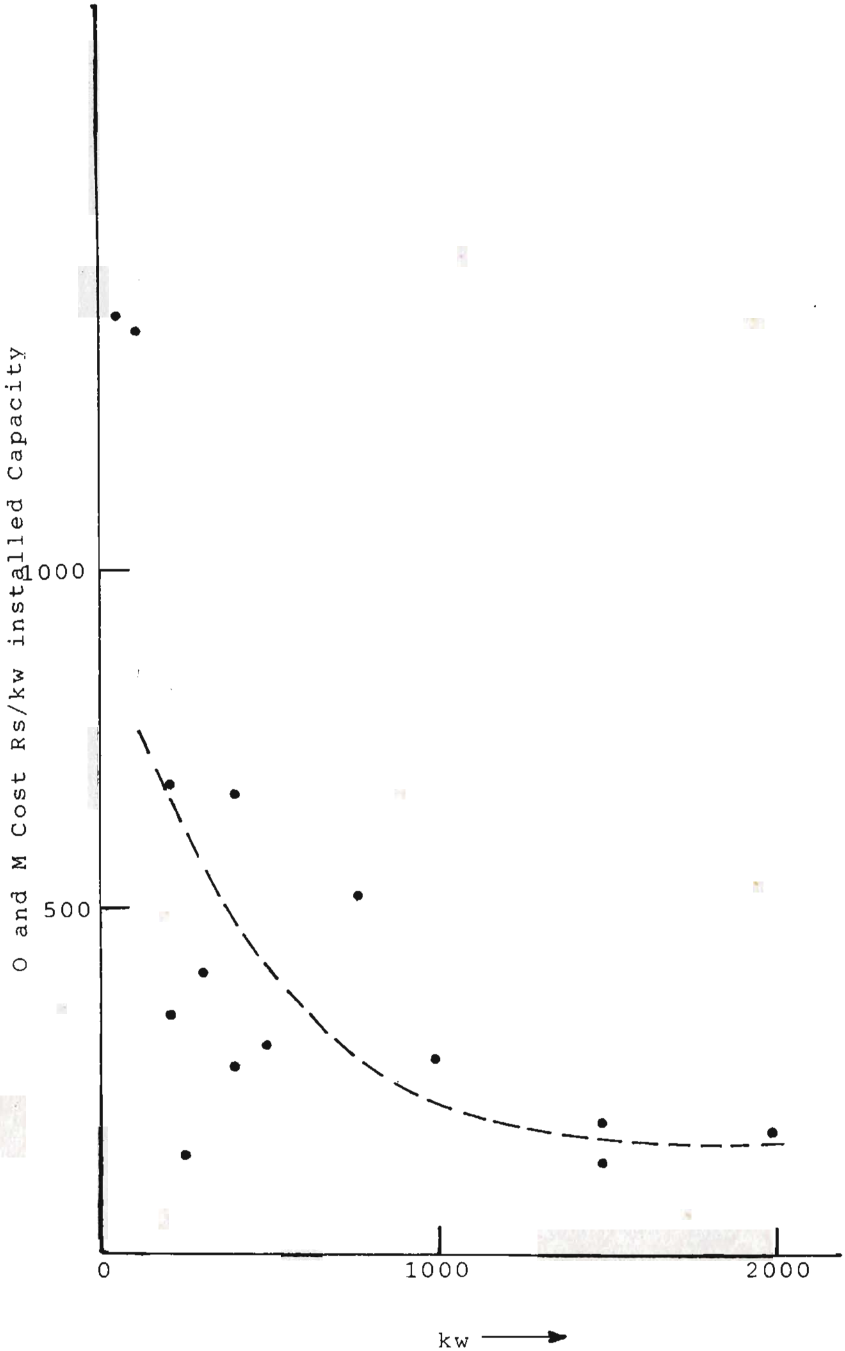


FIG. 5



VARIATION OF COST PER KW FOR OPERATION AND MAINTENANCE WITH INSTALLED CAPACITY

FIGURE 6

usually go against large hydel projects, SHP stands on firm ground even on cost/kW comparisons.

It is essential that LHP costs take into account the cost of transmission and distribution and high power loss in the process. If one includes the cost of T and D, cost delivered power from LHP comes to between Rs. 20,000/kW and Rs. 25,000/kW.

Yet another factor that needs to be considered in this context is the relative time taken for construction of large and small hydel plants.

A large hydroplant takes about 10 years to complete, whereas a mini or microplant should not take longer than two to three years. Apart from the high rate of escalation, the opportunity cost of delayed availability is significantly in favor of SHP and should be taken into account. A simple example illustrates the financial loss incurred when diesel generation is resorted to because large hydel plants take so long to construct. If small hydel power were generated instead, the value of early availability (v.e.a.) of 1 kW of power per year would be:

v.e.a. = 1 x 8760 x PF x LF (1-LOSS) x (C_D - C_m)

where PF = plant factor 0.5 say

LF = load factor 0.3 say

Loss = T and D loss 0.2

C_D = cost/unit of diesel generation Rs. 2.50

C_m = cost of hydel generation = Rs. 0.75/unit

v.e.a.= Rs. 8760 x 0.5 x 0.3 x 0.8 x 1.75 per kW per year Rs. 1840/kW/year

If a LHP takes seven years longer to construct compared to a SHP, one should add Rs.12,880/kW, even at fixed cost, to the cost of construction of LHP.

This rather lengthy discussion on cost is prompted by remarks frequently made by engineers and administrators who maintain that high cost and high cost of generation (unit cost) are the main deterrents to the growth of SHP.

Cost of Generation

It is known that the load factor of mini or microhydel power is low unless it feeds a grid. (An average load factor of 20 percent or 0.2 means that only an average of 20 percent of the installed capacity is utilized.)

It is inevitable that the power market in the Himalaya region will be restricted since the villages are often isolated and scattered. The fact that there is little industrial activity makes the load factor poor and boosts the cost per kWh. For example, the total units generated during 1981-82 in Arunachal were 15.06 million units for an installed capacity of 9160 kW. The load factor 15.06 x $10^6/(9160 \times 8760) = 0.1877$ was a significant improvement from 0.125 of 1979-80. Obviously load grew over the years, resulting in larger consumption.

If the mini or microhydel only feeds lighting load, the load factor will be inevitably low. On the other hand, if electricity is utilized for irrigation and small-scale industries, consumption and, therefore, load factor will obviously improve. Incidentally, load factor in most of the rural areas electrified so far in India is also about 0.2; thus, the load factor of 0.1877 in Arunachal Pradesh is not so poor.

Operation and maintenance charges appear to be a burden when the units sold are not large. The O and M charges in Arunachal during 1981-82 came to about Rs. 35,00,000 and the units sold were 15.06 x 10^6. The unit charge for O and M came to over 23 paise per unit (100 paise = 1 Rupee) and 4.34 percent of the cost of installation (which is higher than the 2 percent frequently assumed). Figure 7 shows that O and M cost/kW decreases with installed capacity as may be expected. In fact these are almost inversely related (Y = k/x). It is therefore necessary to make microhydel units rugged, even at the cost of efficiency, so that O and M costs may be reduced. In Table 2 the cost of generation has been computed on the basis of 8 percent interest and 3 percent depreciation on capital investment. Take the case of Itanagar during 1981-82 when 1.75 million units were sold.

Capital invested was	Rs. 9,668,000	
Interest and depreciation at (8+3)%	Rs. 1,073,480	(1)
Operation and Maintenance	Rs. 401,446	(2)

Total, adding (1) and (2) = Rs. 14,64,926 x 10^6

Cost per unit = 83.7 Paise

Clearly, this is high and calls for subsidy. It may be pointed out in this context that the urban consumers in All Electric Homes (AEH), becoming increasingly popular in Karnataka, also receive power at a subsidized rate. If connected load is 3 kW and the consumption at peak hours is 2.5 kW (an immersion heater is rated at 1.5 - 2 kW). the investment cost would have been Rs. 50,000 (at a low value of Rs. 20,000/kW delivered power).

At 11 percent interest and depreciation and 2 percent operation and maintenance cost, the total annual revenue a consumer should pay on average is Rs. 7150 or Rs. 600 a month for about 300 units of electricity consumed. Cost per unit should be Rs. 2 which is not paid in India. In Karnataka, it is 47 paise/unit for domestic consumption.

Microhydel vs. Grid Extension

In the Himalaya region, there may be a choice between developing a microhydel unit and extending an 11 kV grid for the electrification of a village or a group of villages. In mountainous regions, grid extension is never easy. Apart from problems presented by the terrain, felling of trees may be involved. On the other hand, extending the grid improves the load factor by extending the power market, and for certain distances and power, annual cost is clearly less. Sen Gupta and Gromard (1984) presented a simple graphical method for deciding between these options based entirely on cost criterion.

Annual costs may be calculated as:

$$A_g = C_{11kV} \times 8760 \times LF \times P + 0.01\, r_g\, (1 \times C_L + C_T)$$

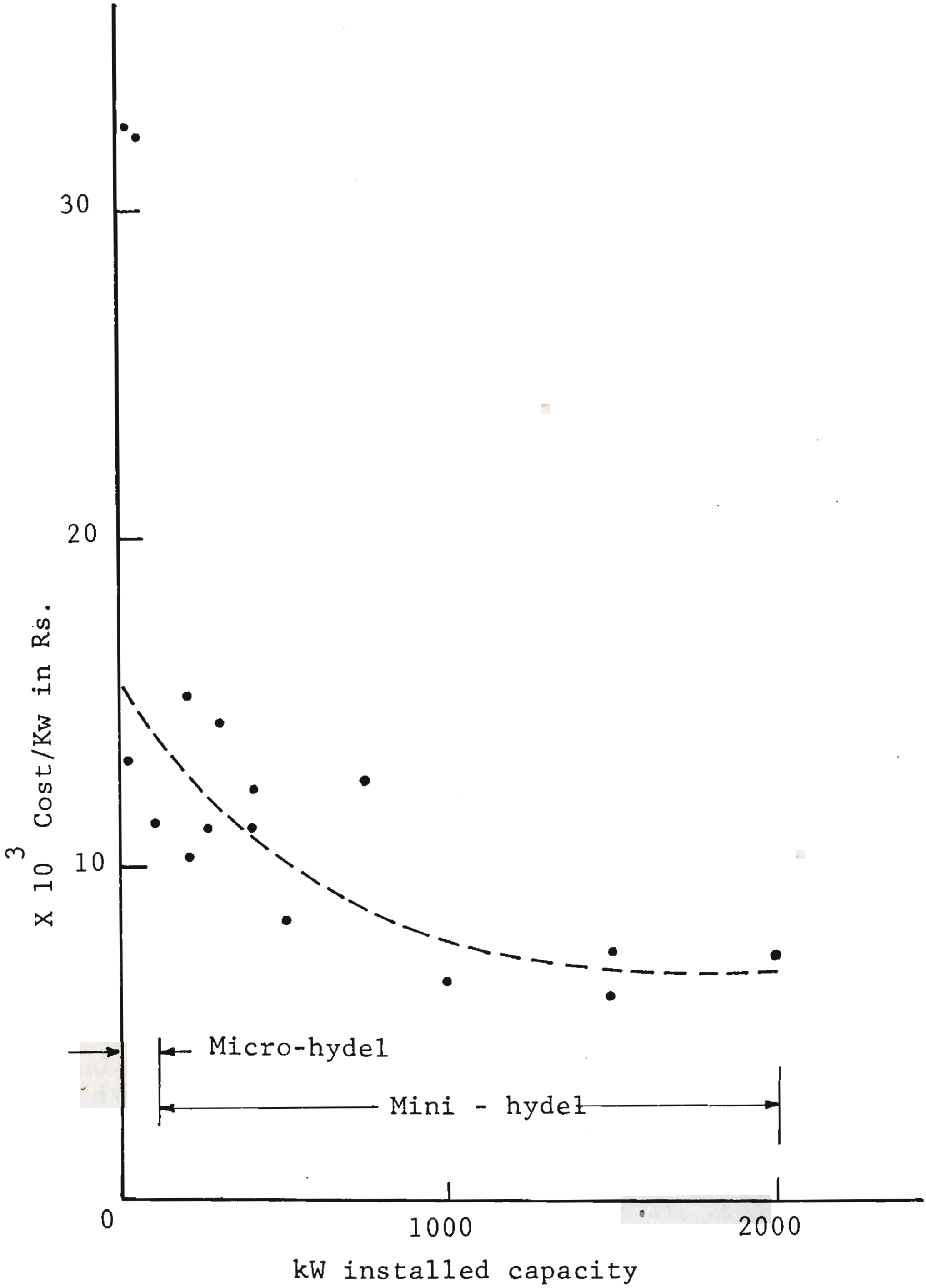
where

C_{11kV} = cost of electricity per kWh at the 11 - kV level

LF = load factor (assumed 0.2)

P = peak load in kW required for the village

Figure 7. Variation of Cost per kW with Installed Capacity



r_g = percentage interest on the capital investment depreciation and O and M (assumed 12 %)

C_L = cost of distribution line per km (assumed Rs. 25,000 for Weasel conductor)

C_T = cost of transformer (Rs. 12,000 average)

l = distance of the center of the village from the nearest 11-kV feeder in km

Annual cost of supply with a microhydel unit A_m

A_m = $0.01 r_m C_m P$

where r_m = percentage interest on the capital investment depreciation. O and M (assumed 15% = 8% + 3% + 4%)

Cost per unit is calculated below:

C_g = cost/kWh for grid

$$= \frac{A_m}{P \times LF \times 8760}$$

C_m = cost/kWh for microhydro

$$= \frac{A_m}{P \times LF \times 8760}$$

Figure 8 compares the cost/kW for these two options.

For example, a microhydel unit costing Rs.10,000/kW is always to be preferred to line extension. If cost/kW of microhydel is Rs. 25,000, it is economical up to 30 kW if the nearest grid is more than 10 km away. As regards cost/unit is concerned Figure 9 clearly indicates that unit cost for grid supply decreases with increasing power and the break-even points may be obtained from these graphs. It is certainly worthwhile making a study, where appropriate, to decide between grid extension and setting up of new microhydel units. It is needless to mention that technical or ecological constraints may override cost considerations.

DISCUSSIONS AND CONCLUSIONS

A substantial part of this paper has been devoted to cost analysis of mini or microhydel projects, to make the point that even on mere cost considerations, these projects are justifiable. It is necessary at this stage to emphasize that electrification of the numerous villages in the Himalaya region is essential, irrespective of cost considerations, and harnessing waterpower seems to be one of the most sensible solutions to the problem.

The major objectives of electrification are to provide:

1. Lighting and save kerosene generally used at present
2. Lift irrigation
3. Help with the development of cottage industries
4. Help with the setting up of industries such as poultry farming, fruit canning, tea, and other agrobased and forest industries
5. Diesel savings where diesel generation is being resorted to for strategic purposes

In most areas in the Himalaya, electrification will have to come from mini and microhydel sources.

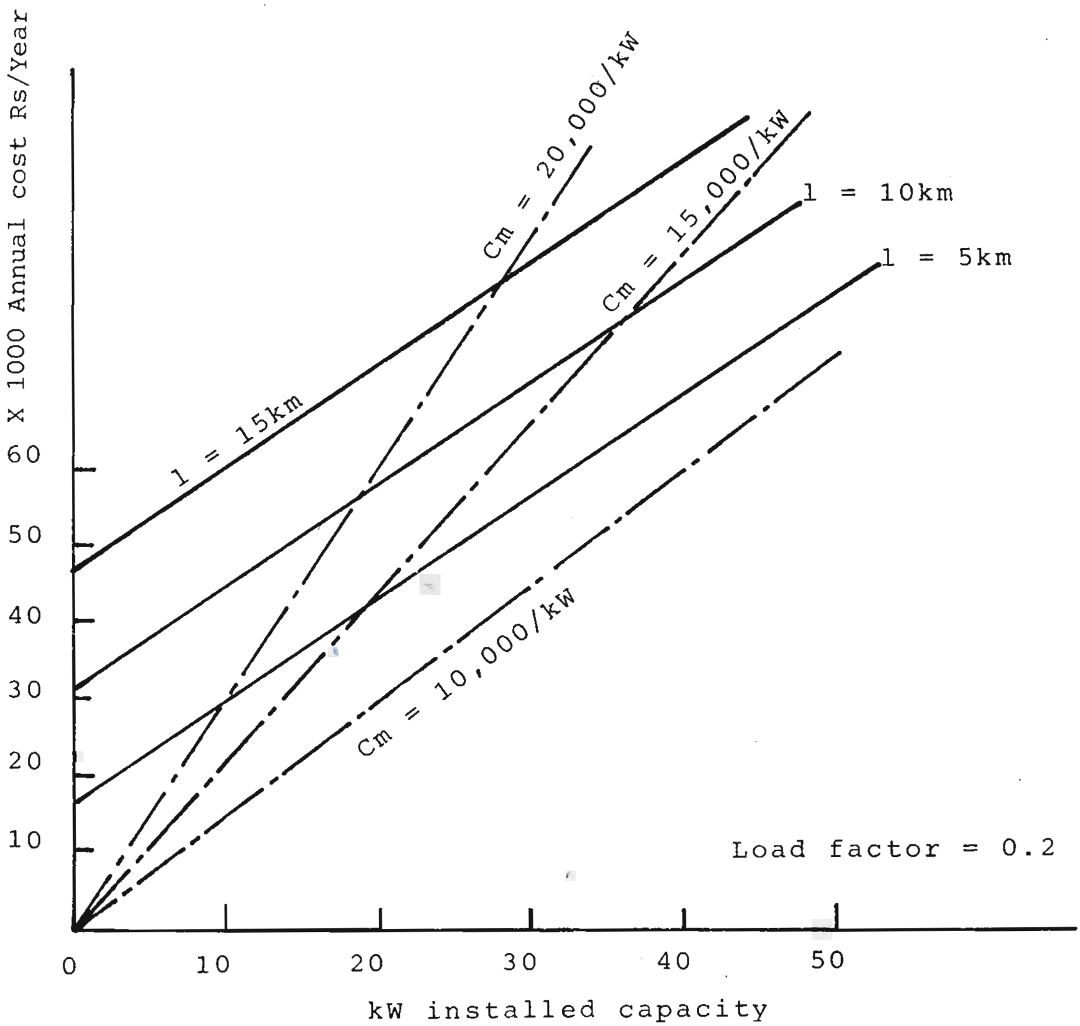
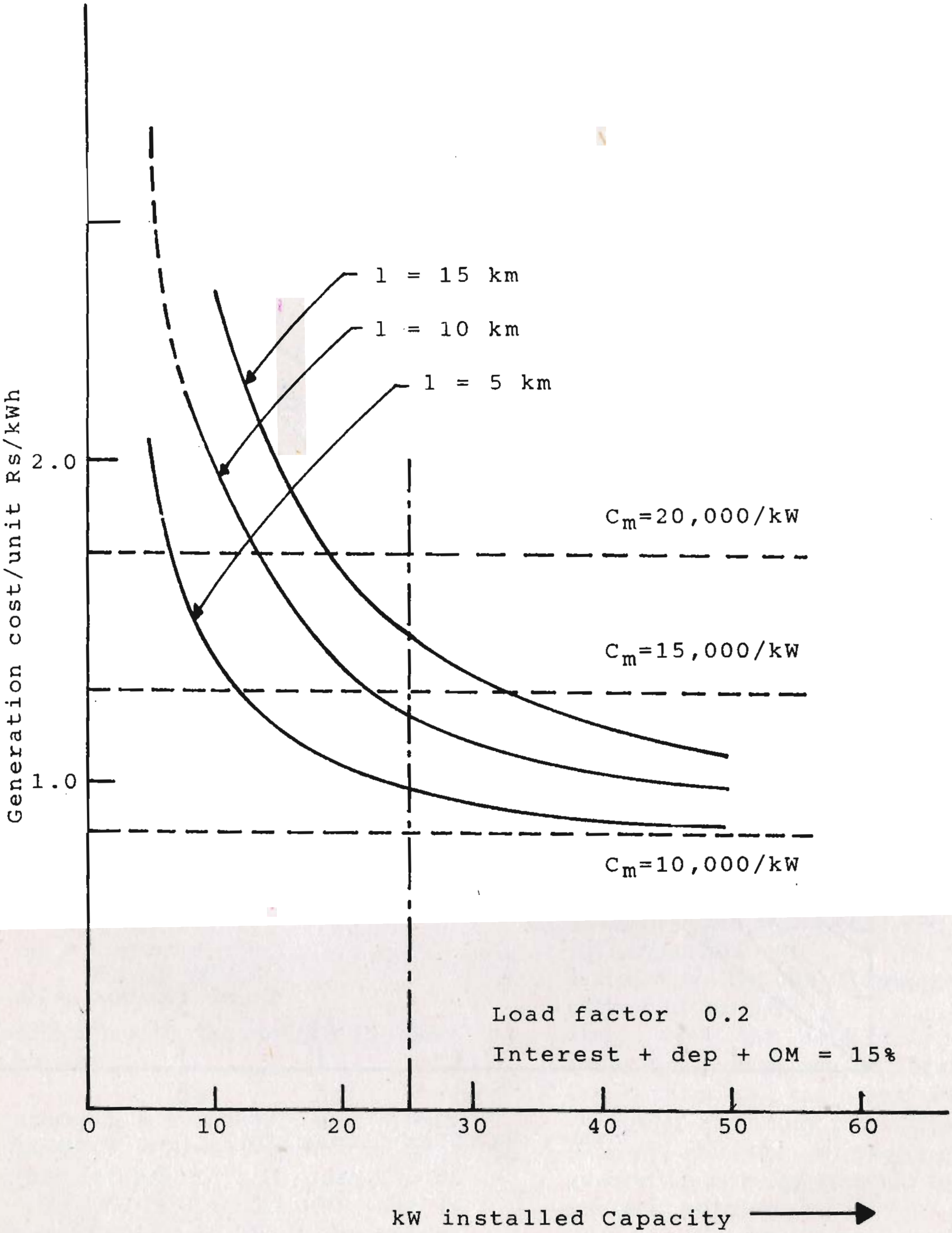


Figure 8. Variation of Annual Cost with Installed Capacity for Grid Extension and Microhydel



VARIATION OF GENERATION COST PER UNIT WITH INSTALLED CAPACITY, FOR EXTENSION AND MICROHYDEL INSTALLATIONS.

FIGURE 9

Large hydroelectric projects such as the Karnali (3800 MW) project, (a proposed Indo-Nepalese venture) or Pancheswar (1000 MW) at the Indo-Nepal border will not and in most cases cannot, meet the needs of these Himalayan villages. Besides, the wisdom of developing such a large scheme needs to be ascertained from the ecological viewpoint.

It is, however, true that electrification alone will not bring about the developments listed above unless other vital inputs are made as a deliberate policy to develop these areas. But lighting itself can bring about substantial change in the lifestyles of the villagers.

Rao, who was involved for many years in a number of mini and microhydel projects in Arunachal Pradesh, states that following the introduction of street lighting, villagers could work late hours in fields and instead of spending evenings in their dark homes drinking country liquor for and getting into brawls, they would go outdoors to the marketplace which distinctly reduced drinking and improved the lifestyle of the villagers. One major impact of electrification, Rao observes, was reduced violence on housewives--violence which invariably followed excessive drinking.

Lift irrigation provided in some villages spared the women the strenuous work of having to collect water from long distances. For these benefits alone, cost considerations should be set aside and mini and microhydel power developed in as many places as possible.

In conclusion, the following recommendations are made:

1. To consider setting up a Central Public Sector Corporation such as National Small Hydroelectric Power Corporation (NSHPC) [like the NTPC and NHPC] directly under the Department of Power. This will undertake the survey, design, and installation of SHP throughout the country in conjunction with the Rural Electrification Corporation (REC). Special funds have to be allocated for the development of SHP.

2. With regard to the development of SHP in the Himalaya region, extensive survey of the sites listed needs to be carried out and a work schedule prepared.

3. Training schemes need to be arranged to train engineers to utilize local materials and labor as much as possible in the execution of these projects. This will significantly lower costs. Operation and maintenance should be entrusted to local people trained for the purpose.

4. Although agro-industrial development has to be the ultimate objective, lighting and irrigation should be the immediate tasks following the setting up of the mini and microhydel plants. Provision of domestic connection (one light point) should be made free for the low-income group (like the Bhagyajyothi scheme in Karnataka).

Finally, and most importantly, attitudes towards rural electrification and development of micro/minihydel for the rural community in the hills or the plains must change. These services are **not to be considered as a favor**, and grudgingly carried out because they are included in the 20-point program.

Rural electrification in India, an apparently low-return investment, has provided irrigation and helped to turn a food-deficit country into a food-surplus country. In a similar way, development of the Hindu Kush-Himalaya will bring the people in those areas into the national mainstream, give them a stronger sense of belonging, and alleviate many border problems that we have been faced since independence.

ACKNOWLEDGEMENTS

This paper has been prepared after extensive discussions with various people involved in the power sector and based on some documents made available by them. The author gratefully acknowledges the help rendered by:

(1) Shri K. S. Subramanyam, Retd Chairman, CEA, New Delhi
(2) Shri M. K. Sambamurthi, Chairman, CEA, New Delhi
(3) Shri H. C. Kachwaha, Chief Engineer, CEA, New Delhi
(4) Shri T. A. Deodas, Chief Engineer, CEA, New Delhi
(5) Shri C. R. Rao, Retired Chief Engineer, CPW, New Delhi
(6) Shri N. C. Jain, CEA, New Delhi
(7) Shri H. C. Virmani, Joint Chief (PPD), REC
(8) Shri M. D. Moses, Chairman, KPC, Bangalore, Karnataka
(9) Shri P. N. Agrawal, Director, ATDA, Lucknow

ENDNOTES

1. The data has been obtained mostly from the Central Electricity Authority (CEA) of India. As may be expected there is a significant amount of overlap between the data from other sources and there are some discrepancies as well.

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