Nepal: Private Sector Approach to Implementing Micro-Hydropower Schemes

by Allen Inversin

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A case study

NRECA Small Decentralized Hydropower (SDH) Program

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A case study

Allen R. Inversin

with major contributions by Robert Yoder

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Introduction

Since the turn of the century, numerous small decentralized hydropower plants have been installed in the generally more remote areas of developing countries. These often have been installed on an individual basis to provide power to mission hospitals, government outposts, mining operations, plantations, and others with a specific need for power. The turbogenerating equipment was often expensive and usually required the skills of expatriates to install, maintain, and operate on a continuing basis.

More recently, governments of some developing countries have attempted to install hydropower schemes on a larger scale, as part of an overall energy supply program. Indonesia, Pakistan, India, China, Peru, and Papua New Guinea are among these countries. In the 1970's, the increasing cost of oil gave such programs added impetus. Leaving aside the Chinese experience because of the unique circumstances under which the extensive implementation of small hydropower schemes occurred there, many of the efforts pursued by other nations proved costly and frequently discouraged further undertakings.

Nepal is another country whose government has undertaken a small hydropower program. Faced with a difficult situation—few roads, a scattered but dense population in certain parts of the country, rugged terrain, major deforestation, and no indigenous oil reserves—the Nepalese see decentralized hydropower as a promising option. But the government approach to installing small hydropower plants in Nepal manifests some of the same characteristics encountered by other nations, characteristics which discourage replication on a broader scale. Among these characteristics are the bureaucratic delays which result in long gestation periods before a plant is operational, the high cost of schemes, and the growing dependency on external financing to cover these costs.

But in the 1960's, Balaju Yantra Shala (BYS), a private machine shop in Kathmandu established under a Swiss aid program, undertook to design, fabricate, and install several propeller turbines to drive grain-milling machines. This effort provided a catalyst for another group, the United Mission to Nepal (UMN), through its Butwal Engineering Works Private Limited (BEW) and Development and Consulting Services (DCS), to become involved not only in designing, fabricating, and testing turbines and associated hardware but also in developing a viable, virtually non-subsidized approach to field implementation of small water-powered mill installations. This private sector approach to the implementation of a micro-hydro program illustrates an encouraging alternative to the generally more costly, bureaucratic governmental approach. It is an approach which lends itself to replication in other countries where sufficient interest and motivation can be found and where appropriate end-uses exist to take advantage of the power generated.

The effectiveness of the approach used by BEW and DCS in implementing their micro-hydropower installations is apparent in the fact that, since the mid-1970's, over sixty mills have been installed, most in very remote areas. And, as existing hydropower mills provide those living in the rural areas with verifiable evidence of their usefulness, viability, and profitability, the pace of

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Fig. 1. A two-story mill house with the turbine and milling equipment on ground level and living quarters above is visible on the right. The penstock can be seen emerging from the forebay in the upper center of the figure.

implementation is increasing. This case study documents in some detail both the evolution and characteristics of the BEW and DCS approach in order to provide ideas to those interested in initiating a micro-hydro program on a broad scale and to provide a possible framework within which such a program could evolve.

BYS is also involved in a similar program in Nepal but its experiences are not described here. Further information on their experiences can be found in the publication, Local Experience with Micro-Hydro Technology, which is available from the Swiss Center for Appropriate Technology (SKAT), Varnbüelstrasse 14, CH-9000 St. Gallen, Switzerland.

Background

Butwal

The United Mission to Nepal (UMN), the organization at the root of these developments, is a private voluntary organization, headquartered in Nepal, comprised of nearly forty Protestant mission groups and church-related aid agencies. In addition to work in the health and education fields, rural and industrial development is carried out under its Economic Development Board. The Butwal Technical Institute (BTI), begun in 1963, was the first such undertaking. As this project grew beyond the function of apprenticeship training with its machine shops, new organizations were created. BTI was subsequently redefined as the holding organization for the various workshops which were formed into private limited companies. Among these were the Butwal Plywood Factory, the Butwal Power Company, the Gobar Gas and Agricultural Equipment Company, the Butwal Wood Industries, and the Himal Hydro Construction Company. The mechanical workshop became the Butwal Engineering Works Private Limited (BEW). Another organizational structure, Development and Consulting Services (DCS), now carries out most of the non-workshop-oriented consulting and field work. The private limited companies and DCS are located in Butwal, a small Nepalese town on the northern edge of the flat rice-growing plains spreading up from India, at the base of the foothills of the Himalayan range. This town is situated on the road from Gorakpur, India, to Pokhara, Nepal.

Except where specific reference is made to DCS or BEW, the term "Butwal" is used to indicate the overall grouping of individuals and organizations involved in designing, fabricating, and installing small hydropower plants.

Program history

Harnessing its water resources is not new to the Nepalese. For centuries, its streams and rivers have been tapped for irrigation, and canals, often kilometers long, crisscross the hill and valleys, perched on steep mountain slopes and occasionally tunneled through

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Fig. 2. The janto is a stone mill used by each household for grinding corn, wheat, and millet.

Fig. 3. The dhiki, a foot-powered mortar and pestle, has traditionally been used by women to hull paddy (rice).

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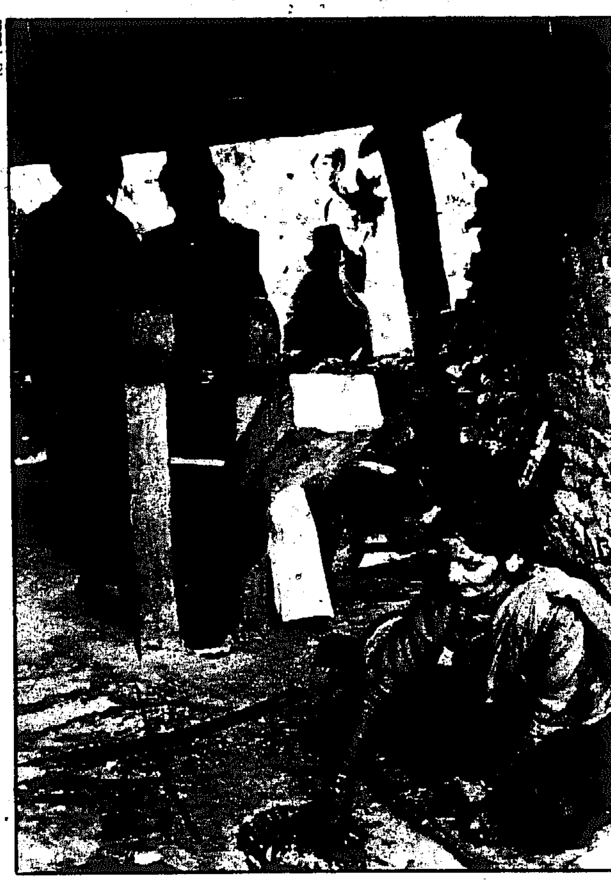

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Fig. 4. The kol is used for extracting oil from seed. A heavy timber is rotated within a hollowed out boulder containing the seed. The process is arduous and time-consuming and the yield is relatively low.

rock. Rice, corn, wheat, and other crops are grown on irrigated plots. The processing of some of the produce—the hulling of rice, milling of grain, and the expelling of oil from seed—are tasks which traditionally have been performed largely by hand using rudimentary tools. One of these tasks had also been mechanized centuries ago with the development of the vertical-axis water wheel to directly drive millstones for milling grain. Thousands of these water-powered mills dot the countryside.

More recently, diesel-powered mills which perform all three of these tasks were introduced in the mountains. Despite the higher cost for processing grain and oil seed because of the capital cost of diesel-powered mills and the high cost of diesel fuel in remote areas, these mills have proved popular. They can be found thoughout the country in areas distant from the main roads and population centers. It was to provide an alternative source of motive power for these mills that BYS first fabricated and installed propeller, and later cross-flow, turbines.

BTI occasionally undertook repair jobs on the BYS turbines in its workshop facilities. An increasing number of people who had seen these few turbines operating successfully in the hills went to Butwal requesting assistance in installing similar plants in their own villages. Initially, because of BTI's limited capacity, its involvement with other work (including fabrication of foot suspension bridges, ropeways, and the Tinau Hydro Project which eventually supplied 1 MW of electrical power to Butwal and the surrounding area), and its inability to dedicate sufficient time and staff to the design of turbines, these potential customers went elsewhere. But as BTI's workshop capacity increased, there was increasing pressure to look for new manufacturing ventures. Following considerable discussion with potential customers, local staff, and employees on existing needs which might be met by the workshop, the board of directors of both BTI and DCS approved a proposal for a pilot hydropower project.

Though electricity for lighting is frequently sought by both villagers and the government, this is not a primary need. Some kerosene is used for lighting, but, aside from firewood used primarily for cooking, diesel fuel for milling is more essential to the rural population. The proposed pilot project, therefore, focused on providing energy for milling. By placing emphasis on this need, it was possible to develop and perfect designs for a turbine and associated hardware to directly drive agro-processing machinery without being encumbered by the need to introduce the more expensive and technologically complex electrical components.

Based on BTI's experience with the BYS turbines and on observations of existing hydropower installations, it was apparent that there was a need for a broad, well-coordinated program. This program needed not only to include the design and fabrication of reliable, low-cost turbines but also to field teams of individuals with a broad range of expertise to evaluate sites, discuss options for technical designs and financing with prospective customers, design the necessary civil and mechanical works, install machinery, and undertake the necessary follow-up maintenance work.

In 1975, the UMN received a grant for $24,000 to establish such a program. In addition, BTI funded the cost of both the turbine development and part of the test site facility. Two full-time, and several part-time, expatriate engineers and staff members were fully supported by their sponsoring organizations. Since the program was envisioned to be financially self-supporting, with income from sales covering overhead and development costs, the grant reflected only working capital and start-up costs.

DCS took primary responsibility for field work. This included customer contact, site survey, plant layout, ordering and assembling all machinery and materials for delivery, installation, and follow-up repairs. BTI (and later BEW) became the contractor for the fabricated

Fig. 5. Diesel engines used to drive milling and oil-expelling equipment are found scattered throughout Nepal.

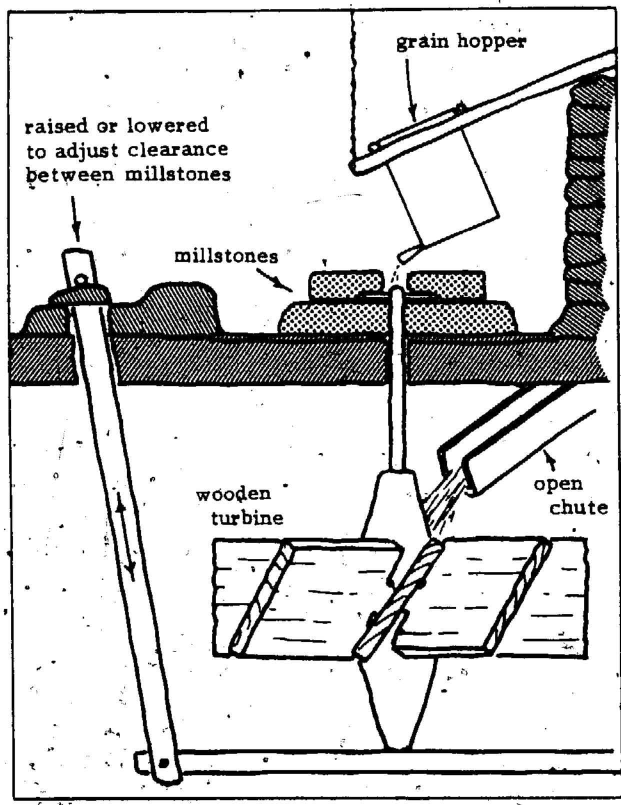

Fig. 6. Cross-sectional view of a traditional mill.

Fig. 7. One of the thousands of traditional water-powered mills found in Nepal.

parts. In addition, BTI retained responsibility for turbine research, development, and testing since these contributed to its manufacturing and marketing activities.

Organizationally, it might have seemed more straightforward if the entire program had been kept within BTI. However, its previous experience with a footbridge program indicated that sending workshop personnel into the field disrupted installation work, workshop planning, and production. In addition, salaries for workers in the field were also necessarily higher than those for workshop staff, creating conflict between workers. Since this program had potential for growth, it was decided to make it a separate program within the DCS framework from the beginning.

During the initial phases of the project, progress was slow. The self-imposed limitation of using only materials available in Nepal and the Indian subcontinent required that many items be designed and manufactured in Nepal instead of resorting to the far easier method of importing. In 1977, the first three water turbine-powered mills were installed in the hills of Nepal. This was followed by 11 installations in 1978 and increasing numbers in subsequent years. A total of 65 mills have been installed to date.

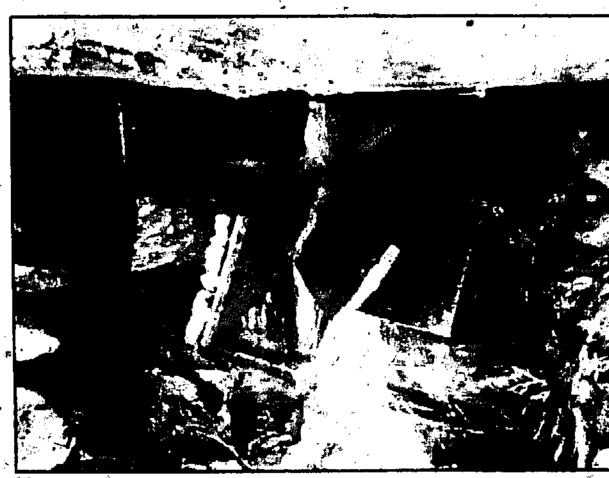

Fig. 8. Water falling several meters through an open wooden channel (seen emerging to the right of the shaft) provides power to drive the grindstones.

Technical designs

Selection of turbine type

Innumerable small streams with steep gradients are located in the central hill region of Nepal which supports most of that country's population. Peaks rise to a height of 3,000 meters. But, unlike the Himalayas to the north with their perennial snow-fed streams, streams in the central region are entirely rain- and spring-fed. Whereas monsoon rains lead to heavy floods, stream flows are extremely low by the end of the dry season in April and May. These conditions are not uncommon to many tropical countries with hydro potential. Under those circumstances, it appeared that a Pelton turbine which operates under a high head and requires relatively low flows would be most appropriate. However, even the single Pelton turbine fabricated by Butwal has never been installed and is still in its workshop.

There are several reasons why turbines operating under high heads have proved less appropriate in Nepal than those operating under lower heads:

Fig. 9. Inside a traditional mill. Grain placed in the rectangular tin is automatically fed through the center of the grindstone which is rotated by the waterwheel underneath the building. The wooden pole through the floor in the foreground is used to adjust the clearance between the stones.

- conflict with irrigation—In the hills covered with terraces for growing rice and other crops, use of water for irrigation assumes primary importance. Water rights are carefully protected. If any water found in the streams were to be used for hydropower generation, it would bypass all the land located between the elevation of the intake to a hydropower scheme and the elevation of the powerhouse and would no longer be available for irrigation. For high-head units, the extent of this land may be considerable. The possibility of the owner of a water-powered mill depriving farmers of their water is inconceivable. Even in several cases where excess water for power generation would have been available, the farmers anticipated eventual loss of control and blocked further developments. It soon became apparent that the best sites to develop were those where the potential mill owner controlled or could purchase the land between the intake and powerhouse. This implied that, to minimize conflict, sites with low heads would have to be developed. Of course, another alternative might have been to exploit high-head sites as a cooperative venture among all the affected farmers. However, given the social setting, it initially proved easier to deal with individual entrepreneurs than to initiate such ventures.
- inappropriate location of potential sites—Another critical factor turned out to be that high-head sites, though numerous, were usually at impractical locations—either on steep slopes prone to landslides or too far from a village to be convenient. Observation and understanding of traditional mill locations and water control rights would have revealed this problem earlier.
- cost of penstock—High-head sites generally require a longer and usually costlier penstock pipe. In several locations where a higher head site was technically and socially acceptable, the cost of the penstock alone was twice as much as that for the turbine.

As a result of a review of these and other factors, it was decided to develop low-head sites. In the mid-1960's, BYS had initiated their hydropower work with the design, fabrication, and installation of propeller turbines. However, because of the complexity of the design and the manufacturing requirements, this work was not pursued by either BYS or Butwal. Both BYS and Butwal decided that their work would center on the fabrication and use of the (Michell-Banki) cross-flow turbine. This type of turbine seemed more appropriate because it is relatively easier to fabricate. It was also possible to accomodate a wide range of flows and heads with only minor design modifications. The same jigs could be utilized in fabricating turbines of different capacity.

Turbine design

By focusing their effort on turbines for low-head sites with nearly identical operating conditions, it was possible to develop a single basic design and then to

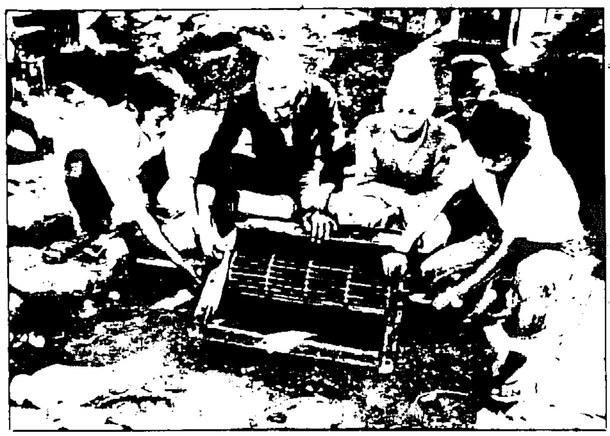

Fig. 10. A cross-flow turbine fabricated by BEW. This 200 mm runner is 560 mm long, the longest runner presently manufactured by BEW. When in use, the turbine's draft tube is connected to the rectangular flange shown.

learn from ensuing experiences in order to improve subsequent units. Most mills operate under heads of from 5 to 15 meters. To date, about 65 units have been fabricated and installed and the experience gained has been incorporated in what is now a well-engineered turbine design.

The design which evolved uses a cross-flow runner either 200 mm or 400 mm in diameter and is manufactured in 10 standardized widths to suit a range of flows. The flow is controlled manually by means of a single guide vane with the same width as the runner. The runner, housing, transition piece between the penstock and turbine, and the draft tube are fabricated of steel plate. A hydraulic press is used to form the runner blades, guide vanes, flanges of the housing, and other components formed by bending. Initially, difficulty was encountered in locating suitable bearings

Fig. 11. The test site located at the workshop of BEW. Sections of penstock pipe in the foreground are ready for pressure testing.

Fig. 12. One of the first turbines fabricated by BEW being installed at Dobilla.

to support the shaft of the runner. The limited life of imported bearings bought in India proved a problem until it was discovered that these were actually old imported bearings, reconditioned, and sometimes resold as originals. A source of new, sealed, self-aligning bearings made in Japan was later located in India.

A complete set of mechanical drawings, a list of required materials, a description of the technical aspects of the design, and a description of the jigs and techniques utilized in the fabrication of its cross-flow turbine are included in Small Water Turbine by Helmut Scheurer, Reinhold Metzler, and Robert Yoder (September 1980). This is available from the German Appropriate Technology Exchange (GATE), Postfach 5180, D-6236 Eschborn 1, Federal Republic of Germany. Because that publication clearly documents the design, technical details will not be repeated here.

After fabrication, the turbine and all sections of the penstock are tested at the test site adjoining BEW. Any misalignment, poor threads, or leaks can then be repaired easily in the workshop. After the unit is sent to the field, only hand-crafted repairs can be made.

Design of a typical mill installation

The civil works necessary to convey water from a stream to the area of the powerhouse are virtually identical to the those used with irrigation schemes throughout Nepal. A row of stones, sometimes interwoven with branches, forms a temporary diversion structure across either part, or the entire width, of the stream, and an unlined earth canal conveys water to the intake of the penstock. On occasion, water from an existing irrigation canal itself is used, though this canal might have to be widened to insure an adequate flow of water. Irrigation canals are cleaned once before the rice planting season each year and then after each flood during the monsoon season.

Generally, water from the canal enters the penstock directly. A trashrack before the penstock intake retains the larger floating debris. The forebay is often simply a transition structure between the canal and penstock pipe and does not serve as a significant settling area. Usually, most of the water-borne sediment which would prove injurious to the turbine settles in the canal itself before entry into the penstock. Incorporating a large forebay when it is unnecessary results in additional costs due to the concrete and labor requirements for such a structure.

The penstock pipe is made by Butwal of 2.5 mm mild steel plate in two-meter lengths. Flanges are made by hand-forging strips of flat iron, and a groove for an O-ring is machined in one of the two flanges welded to each penstock pipe segment. An O-ring has proven to be much better than flat gaskets in providing a leak-proof seal. No provision has been made for thermal expansion of the penstock pipe used with its low-head installations. Leakage from the connection of the penstock to the forebay structure, although expected, has never been a problem. An attempt is made to select a penstock alignment which avoids any deviations from a straight line except for the portion immediately before the turbine. But if bends are required, the size of these bends is determined using rudimentary field measurements.

In existing mills, it was also observed that all the machinery was independently mounted on the mill floor. Careless installation of the machinery frequently

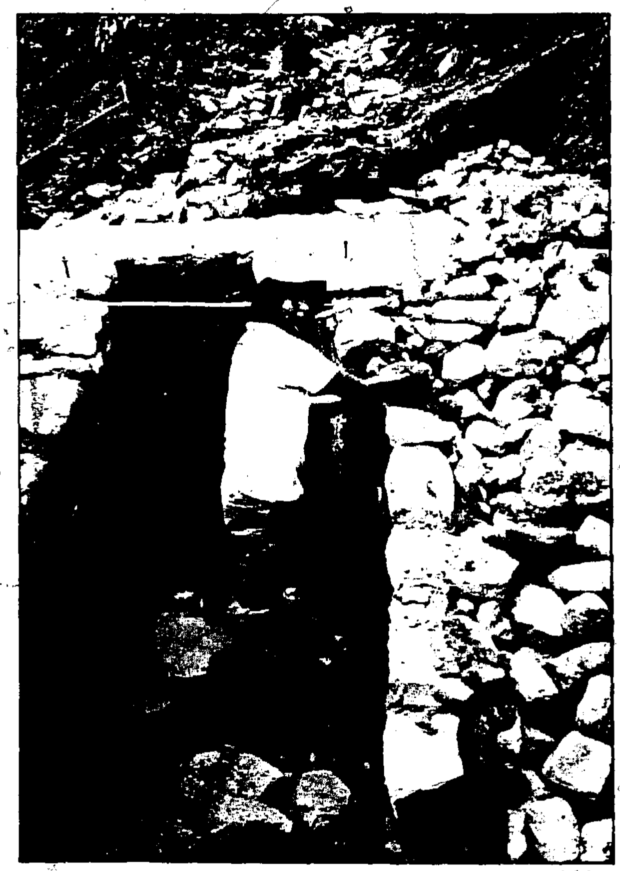

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Fig. 13. A mason completing work on a forebay. The trashrack is located behind him.

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Fig. 14. The penstock descends from the forebay to a mill under construction.

Fig. 15. At Ampchaur, the turbine is placed below floor level.

resulted in misalignment of shafts and pulleys. To minimize the occurrence of this problem, Butwal developed a single frame on which all the machinery required in an average mill, that is, a turbine, rice huller, flour mill, and oil expeller, could be mounted. In this way, the machinery could be fitted and aligned in the workshop under proper supervision. Machinery could also be secured on site with a minimum of concrete. It was Butwal's policy that, unless a customer owned processing machinery in an earlier mill (diesel- or water-powered), machinery for a new mill had to be purchased through Butwal. This helped to ensure that all the processing machinery would be properly integrated into the overall mill design.

Initially, the turbine with a 400 mm runner was placed in a recess below floor level so that additional head could be gained with minimum additional excavation (Fig. 15). The higher resultant level of the mill house floor made possible by this arrangement also meant that the possibility of flood waters reaching the floor was reduced. In addition, lowering the turbine also overcame the problem of wetting of the mill floor caused by water dripping from the seals. On the other hand, it made the turbine somewhat less accessible. At present, the newer, higher speed turbine with the smaller, 200 mm runner is more popular and is mounted half a meter above the mill floor on a four-legged stand (Fig. 16 and 17).

Fig. 16. A mill layout using one of the new turbines mounted on a common frame with the processing equipment. An intermediate drive shaft is not a usual component of the new layout. It has been included in this installation because the mill owner is considering adding other machinery later.

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Fig. 17. *The new turbines are mounted above the mill floor on a common mounting frame which is eventually set in concrete. Here the installation team is shown using a string to align the pulleys.*

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Butwal also incorporated a change in the layout of the machinery in the mill. One problem which had been observed at the first water-powered mills installed by BYS was that the turbine essentially replaced the diesel engine in the typical installation but left the basic layout of the mill, with its long intermediate drive shaft, unchanged (Fig. 19). This drive shaft, up to six meters long, was supported by three or four bearings (Fig. 20). These long shafts were rarely straight and this resulted in rapid bearing failure. An initial solution was to introduce a new layout for the machinery which permitted the low-speed oil expeller to be driven directly off one side of the turbine and the two smaller machines to be driven off a short intermediate drive shaft off the other side of the turbine (Fig. 30). At present, by using a 200 mm diameter runner at most sites, the speed is high enough for all machines to be driven directly off the turbine shaft. The intermediate drive shaft has now been discontinued altogether and the turbine shaft extended to accept two pulleys on one side (Fig. 17 and 18). A third bearing is necessary along the turbine shaft to support the pulley load. This results in an even more compact layout. However, misalignment of the third bearing may account for some of the recent problems with fracture of the runner shaft.

Another problem in existing mills involved the use of flat belts. The shafts and pulleys were rarely aligned and poles implanted in the floor, or otherwise secured, were frequently used to prevent the belts from running off the pulleys (Fig. 20). This resulted in loss of power and rapid wear of the belts. To overcome this problem, Butwal turned to the use of V-belts throughout its mills. These belts transmit power more efficiently than commonly available flat belts, require no connectors which are necessary with flat belts, and reduce the

Fig. 18. *At this new mill, no intermediate drive shaft is used between the turbine and agro-processing equipment.*

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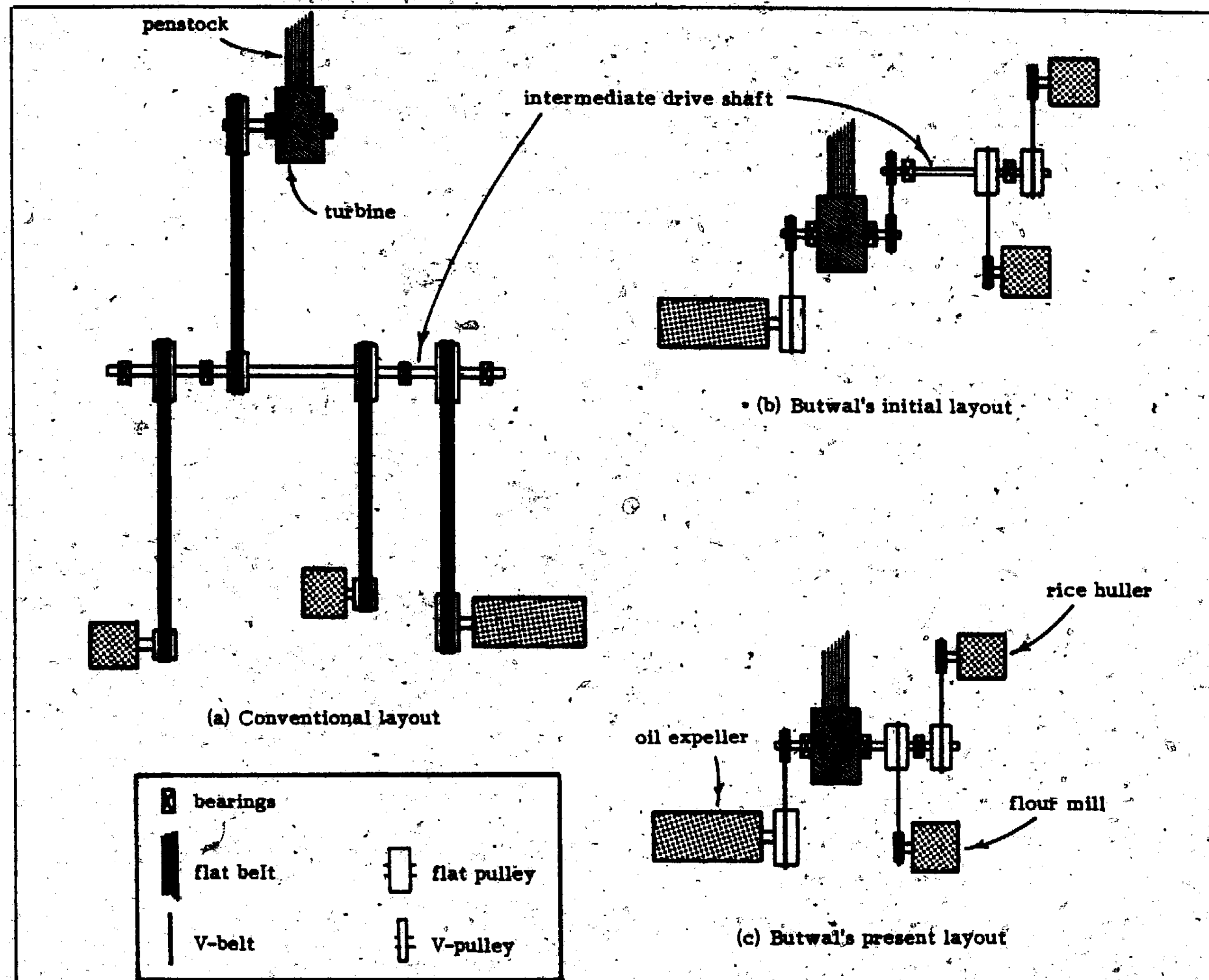


Fig. 19. These drawings illustrate the evolution of the standard equipment layout in a mill. Note that the floor area is reduced as are the number of bearings and the overall complexity.

distance required between pulleys. From the drive shaft, a flat pulley to V-pulley is used to permit easy belt removal. Individual machines can then be disengaged while the turbine is running. To facilitate the replacement of belts, a single-length D-section V-belt is used throughout the mill.

Installation teams

An expatriate DCS director serves as project leader for the Small Turbine and Mill Project, but the day-to-day running of the project is the responsibility of the Business Chief. A Technical Supervisor, accountant, and storekeeper complete the permanent office staff.

The heart of the installation program consists of three or four teams which undertake work in the field. Initially, each team was comprised of a team leader who was a skilled mechanical tradesman (to date, each has had BTI apprenticeship training), a mason, and a helper. More recently, most teams consist of only two people. This reduces the cost of the installation to the customer. The only time a third person accompanies the team is when he is a new employee being trained.

If it is possible, the team leader is present during initial discussions with a new customer desiring to install a water-powered mill. When the team then goes to the field, it acts independently. It is responsible for the survey, site selection with the customer, and price quotation. When the team returns from its initial field visit, the leader prepares the layout design and order list for the sites surveyed. He also supervises his team in the workshop assembly and in checking and packing all the machinery for an installation in preparation for handing it over to the customer for transport. The team is then responsible for installing the machinery and for-any necessary follow-up repair work. To minimize confusion, it would be best if one team dealt with a customer from initial contact to final installation. However, practicalities make this impossible. By insisting on uniform information-recording procedures, it has been possible to have one team survey and a second team complete the installation.

Participating in decisionmaking has prepared each team to set up its own independent installation operation should DCS decide to discontinue its operation.

Installation of a mill

Site selection

Due to the growing reputation of an increasing number of successful water-powered mills, there is no need now to promote small turbines in order to get business. Ever since BYS installed the first modern water-powered mills in the 1960's, they have promoted themselves. Villagers familiar with traditional water-powered mills and, more recently, diesel mills, are quick to see the merits of this compact, trouble-free source of power with its low recurring costs. After becoming aware of the operation of mills and of their potential, individuals with likely sites make their interest known to Butwal either by visiting the office in Butwal, by contacting one of the DCS teams installing a new water-powered mill in the area, or by notifying an officer of the Agricultural Development Bank of Nepal (ADB-N) which has branches throughout the country.

In the dry season, after as many requests as possible have been gathered from a certain geographical area or when there is reason for a team to go near that area for installation or repair work, they take the necessary information for contacting the new potential customers. The loan officer from the nearest ADB-N office is also notified and invited to join in the survey. The team travels by public transport to as near to the site as possible and then they continue on foot for up to a week in some cases. The team restricts its surveying equipment to the minimum required for the task—a hand-held sighting level or inclinometer, a vinyl ribbon staff, a 30-meter fiberglass measuring tape, and several square meters of plastic sheet to assist in making flow measurements. These provide adequate accuracy for determining the parameters necessary for layout and design.

A nominal charge of Rs. 200 is now charged for each site survey to insure more commitment on the part of the customer to following through with the project. With the increasing number of small local workshops which are beginning to fabricate cross-flow turbines, there is also an increasing risk that perspective mill owners will take the results of the survey to another workshop to have the machinery fabricated. This initial nominal charge therefore also covers, in part, the cost of the initial survey. In addition to Rs. 200, if a site is found feasible, an additional Rs. 1600 is charged as part of the final quote for the installation. This is to cover

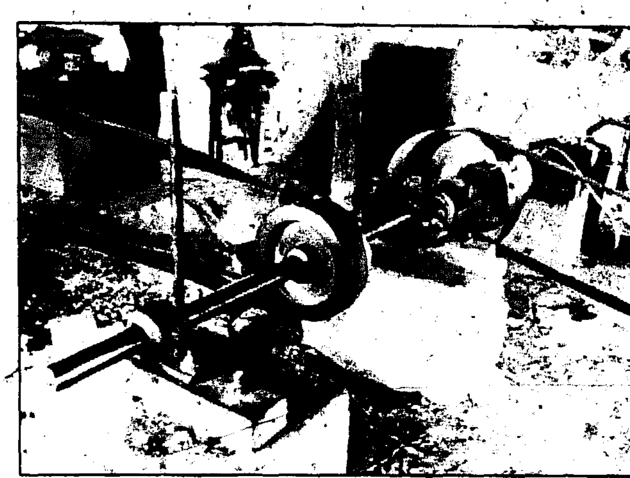


Fig. 20. A common sight in mills using flat belts—a metal or wooden stake is used to prevent the flat belt from slipping off misaligned pulleys. This mill has a conventional layout with a long intermediate drive shaft. The shaft was also bent, forcing the removal of the fourth bearing.

expenses incurred during preliminary surveys of both feasible and infeasible sites.

In every case, site selection requires that the potential customer find a location where he either owns or can purchase land for the mill and obtain rights to the required water. For this reason, it is extremely important that the customer understand the requirements of head and flow, so that he can choose likely spots before the survey team arrives. The ideal situation is for a new customer to visit an operating water-powered mill to understand the principles involved. Due to their experience with irrigation, Nepalese farmers have an good eye for determining the prospective location and size of a canal necessary to carry sufficient water from the stream to the area selected for the forebay. This usually enables them to select a site with adequate water if one exists. However, the concept that the head is the elevation difference and not the slope distance has often been difficult to explain. And because of their interest in installing a mill, there is frequently an overly optimistic estimate of the available flow in the stream to be harnessed.

If stream flows are small, even careful flow measurements made at one point in time are of little use. But since irrigation is often practiced in the same area, the local population usually has a very good idea of how small the flow in a stream gets in an average dry season and what happens during drought years. During their visit to the site, the team therefore measures the stream flow and, from interviewing the local farmers, determines what proportion of the average and drought year flows this represents. Flow measurements are made using a temporary weir, with a plastic sheet used to seal around the weir, and virtually never using the float method. Frequently, it is clear that, for at least

Fig. 21. A mill house with the owner's house in the background. The forebay and penstock can be seen at the left.

several months, there will not be enough water to run even one machine but that, for most of the year, two can be operated simultaneously. This is carefully explained to the customer. Sometimes, a second, more suitable stream can be located in the area. At other times, the solution has been to look for a site with a higher head, but frequently, in such cases, Butwal will recommend that the site be rejected. Gathering all available information to estimate flows and clearly explaining to the customer the implications of less-than-expected flows has avoided misunderstandings.

With the experience gained in selecting dozens of sites, the field team can usually tell at a glance if the site is feasible. Since approximately three kilowatts of mechanical power are required for each of the typical milling machines, and three machines are customary in every mill, three kilowatts is the minimum desirable and nine kilowatt is the maximum operating power which would be necessary. Depending on the available sites, the customer must decide if he will be satisfied with the output that can be expected.

Site layout

After the customer indicates his preferred site, the exact location of the mill is determined by carefully establishing the maximum flood level of any nearby streams and by checking the stability of the ground above the mill to ensure safety from landslides. Minimizing the length of the penstock by selecting a point where the slope is steep or where the millhouse can be dug back into the ground must be balanced against the stability of the ground and the difficulty of digging a canal to the desired point. In many cases, an existing irrigation canal can be used. This simplifies developing the site and reduces the cost of the installation although it also reduces the number of options for site location. It may also limit the power potential at the site since the available head might be lower than could have been developed by digging a new canal with a more gradual slope.

At most sites, a spillway is included in the forebay wall so that any excess water can be led away in a controlled manner. When choosing a site for a mill, the location of both the spillway and the course followed by any of the excess water as it returns to the stream must be considered. Otherwise, this water might cause erosion and undermine the penstock or mill.

The next step is to establish the canal alignment. If an existing irrigation canal cannot be used and a new canal has to be dug, a hand-held sighting level is used to run a level from the intake of the penstock to a point on the stream which is to be tapped. The actual intake to the power canal would then be slightly upstream of this point, the exact location being a function of both the length of the canal and the nature of the terrain. Digging the canal is entirely the customer's responsibility. The villagers' experience with irrigation makes them more qualified than outsiders to determine the cost and feasibility of the alignment. The customer also consults with villagers who specialize in canal digging and frequently hires them to excavate sections requiring rock-cutting. In almost every case, indicating the fraction of the stream that needs to be conveyed by a canal is sufficient for the customer to determine the dimensions and slope necessary for that canal.

After the site is selected and the canal elevation determined, the elevation of the mill floor to keep it safe from flooding must be established. This choice is best left up to the customer since he has the best knowledge of the site and must live with the consequences of the choice. The desired area to be excavated for the mill floor and tailrace canal can then be marked out. The head and other information required to design the penstock are obtained by making a series of measurements, usually using the hand-held sighting level and the ribbon tape which is supported on a bamboo or other suitable pole (Fig. 22). An elevation profile is then run along the expected penstock alignment from the proposed turbine location up to the end of the proposed or existing canal elevation. All the information is recorded on a sketch of the site in the field notebook. A permanent mark on the root of a tree or large stone is also made and its position recorded in the field notes for future reference. Direct measurements of the length and profile of the penstock can seldom be made without excavation, but by making several simple linear and angular measurements, these can be calculated.

It is also important to examine and note the soil and rock formations for possible potential problems in excavating for the mill house, draft tube, tailrace canal, or penstock pipe. Shifting the site slightly can usually avoid the necessity for a bend in the penstock pipe; but, if a bend is required, more careful measurements must be taken.

If there is adequate flow in the stream so that only part of it will need to be diverted for use by the mill, the design flow will only depend on the head available and the power required. The maximum flow easily conveyed in a traditional unlined irrigation canal is about

200 liters per second. The flow for the most convenient canal design is from 80 to 120 liters per second.

Quote for the installation

After all the information has been recorded in the field notes, the Technical Supervisor completes a price quotation based on the survey. The cost of most items remains approximately the same from site to site, with the notable exception of the penstock pipe which varies the most in price. The choice of the kinds of processing machinery also comes into play but most customers want all three—a flour mill, rice huller, and oil expeller. The quotations are valid for only three months, after which time a new quote must be obtained for the loan procedure. If the customer does not take delivery of the machinery within a certain period after he has been told it is ready, Butwal may sell it to another customer. In such cases, Butwal is no longer bound by the quotation given the original customer. BEW gives a six-month guarantee on its machinery and DCS gives a one-year guarantee against errors in installation, provided the work was done according to the instructions from the leader of the installation team

D. Nafziger

Fig. 22. The team surveys using a hand-held level and a vinyl surveying tape suspended from a pole.

* Rs. 12 = US $1 (approximate)

from Butwal. For the Indian processing machinery, no guarantee is given.

The terms of the quotation, as well as the details of the guarantee, are explained to the customer. He must be aware of exactly what DCS will provide and undertake and precisely what his responsibilities are (Table 1). He must understand that he must first receive from the Department of Cottage Industries a license to build and then another to operate the mill. He must place a firm order with the required advance before any further action can be taken by DCS. Formerly, a customer had to include an advance Rs. 2,500* in "earnest money" with his order before DCS would take any action. However, customers often waited until the last minute to make arrangements for a loan and this led to cash-flow problems. Since mid-1981, an advance of 50% of the DCS quotation along with a letter of guarantee from the ADB-N has been required. This places more pressure on the customer to get things moving.

For financing, most customers turn to the ADB-N which, with an interest rate of 11% and a loan repayment period of seven years, offers better financial terms than commercial banks. To date, only four mills have been paid for without loans. The ADB-N has officers and personnel at every level which actively promote a loan program for water-powered mill development, having withdrawn a similar program for diesel mills. Once an application has been received, a loan officer would gather information about the economic feasibility of a specific project before approving such a loan. This loan would also require physical property as collateral. A typical loan covers all the machinery and installation costs, 85% of the land purchase, and 65% of the cost of the labor necessary to undertake the excavation and to install the machinery. A typical ADB-N loan covers about 80% of the entire project cost. Once approved, a customer who secures a loan from the ADB-N receives a coupon which he then submits to DCS. With this guarantee of payment, DCS will deliver and install the mill, collecting payment directly from the ADB-N upon submission of the bill signed by the customer.

Generally, nearly a year elapses between the time a team from Butwal visits the proposed site and the time the customer places his order. During this time, the customer has the land for his proposed site surveyed, gains clear title to that land, and arranges for water rights and necessary financing.

Design, fabrication, and delivery

After the customer places his order, the Technical Supervisor fills out an order form. From the field notes and sketches, any necessary modifications are made to the standard designs. Only items which require a special design, such as a penstock bend, require a new drawing. Items from India, such as grain-milling machines, belts, pulleys, and bearings, are kept in stock due to unreliable delivery times. Items such as penstock pipe, intermediate drive shaft, and mounting frames are

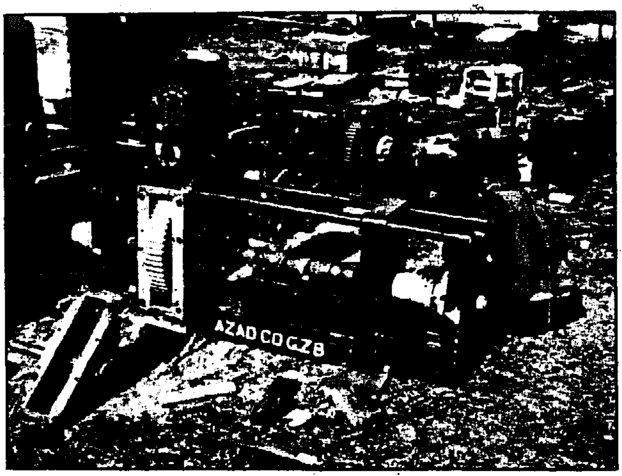


Fig. 23. A recently received stock of oil expellers from India at Butwal.

usually ordered in quantity for stock. Orders for items not already in stock, including the turbine and penstock bends, are placed with BEW which undertakes their fabrication.

A year's supply of grease and a tool kit, adequate for complete maintenance, are supplied to the customer. This solves the problem of a customer buying inferior quality grease and the wrong tools. It also allows a field team to go to a site and perform maintenance work even if it does not happen to bring along its own tool kit.

Before packing begins, all the machinery, parts, and supplies are gathered together and checked against the order list. Part are assembled and checked by one of the field teams. They are then packaged in loads which can be carried by porters. The order is then ready to hand over to the owner who is responsible for arranging for porters to carry the materials to the site. Full payment is required before the order is handed over. Formerly, the per-day installation charges were paid after completing the installation of the mill to give the customer some leverage and to ensure his satisfaction with the work. Because there has been some difficulty in collecting this sum after completion of the work, payment is now required in advance. This sum is based on an installation time estimated at 30 days and any extra is refunded after completing the work.

Installation

After the customer has seen to it that all the machinery is at the site, that all materials noted on the project cost form have been stockpiled near the site, and that all necessary excavation work has been completed, he notifies the installation team to come from Butwal. The difficulty of transporting several tons of machinery and the seasonal difficulty of locating porters are usually underestimated by the owner. The gear box for the oil expeller, weighing 110 kilograms, is the single heaviest part. This requires an exceptionally strong porter. If the load can be supported on a sling, two porters can be used to carry the load. However, since the trails are narrow and steep, a load that needs to be carried by more than one person is often passed up in favor of more convenient weights and sizes.

Tasks undertaken by Butwal	Responsibilities of the mill owner
• perform initial survey	• obtain the necessary license to build and operate a mill
• design and fabricate turbine, penstock, and other required hardware	• purchase the land and right-of-way for the power canal and tailrace (as needed)
• purchase, inspect, and pack the milling, hulling, and oil expelling machinery for transport as needed	• arrange for water rights
• provide technical guidance and assistance in installing and commissioning of the plant	• locate sufficient cash to cover at least a portion of total cost of the installation and apply for a loan for the balance necessary
• train one of the local persons designated as mill operator how to operate and maintain the machinery	• organize local labor to undertake the necessary work
	• undertake the necessary excavation and collection of locally available materials (sand, stone, gravel)
	• transport all the hardware and materials from Butwal to the site

Table 1. Division of responsibilities for the installation of a water-powered mill

The team takes any special equipment, such as ropes, mason's tools, and a level, for the installation. All of this, however, easily fits into their backpacks.

A per-day installation fee of Rs. 180 is charged for the work performed by the installation team. This rate, which is considered extremely high for these remote areas, encourages the customer to do as much of the work as possible in advance and to supply labor to reduce the installation time. Since the masonry requires curing time, it takes priority over other jobs. The tailrace canal is prepared first, using stone masonry for the floor and dry stone for the sidewalls and top.

Butwal utilizes a unique approach to install the penstock, turbine, and draft tube which eliminates the need for detailed and costly site surveys. These components are first assembled and bolted together near their final location and then temporarily braced by wooden cross-frames or piles of stones (Fig. 29). The empty pipe is strong enough to be self-supporting. The entire assembly is then maneuvered around slightly until a suitable alignment is found. Though this may be the most difficult part of the installation, this approach makes it possible to circumvent boulders or other obstacles which might have been encountered during the excavation. It also makes it possible to make up for small discrepancies between the configuration of the penstock-turbine-draft tube assembly designed according to data gathered during the initial survey and the layout of the area actually excavated. To further facilitate this task when penstock bends are used, the bolt holes in one flange of the bend are slotted to permit another degree of freedom. In addition, an extra meter-length of penstock is supplied should it be needed. Any excess length can be cut off using a hacksaw blade. By this method, any minor deviations can be easily accomodated. There is, therefore, no need to interrupt work for several weeks in order to return to the workshop in Butwal to fabricate or modify the bends for the penstock. After the turbine shaft has been leveled, both to reduce bearing loads and to simplify alignment of the other machines, the turbine and draft tube are secured in a foundation and the penstock supports built up.

The machines are all assembled on a mounting frame and set in place. Correct spacing is assured by placing the belts on the pulleys. Alignments must be carefully done using a string and level to assure that the shafts are parallel and the pulleys in line. The string is stretched parallel to the turbine shaft and the line shaft is adjusted parallel to it. The string is also used to line up the V-pulleys from their machined outer surface (Fig. 17). The mounting frame is supported on rocks, allowing sufficient space around the anchor bolts for placing the concrete without disturbing the frame.

The mill owner and whomever he has designated to help operate the mill are encouraged to participate in fitting and mounting of the milling machines and transmission system to understand how the parts fit together. The team leader uses this opportunity to explain the need for proper belt tension, adjustment of the machines, and clean and adequate lubrication.

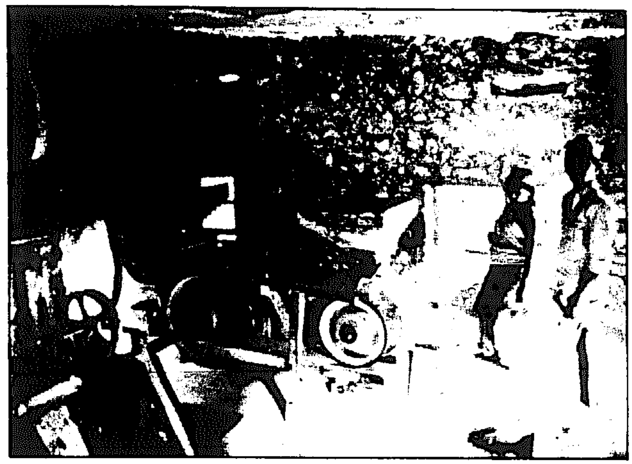


Fig. 24. The mill, whose construction is shown in the following figures (Fig. 26-31), is open for business.

Usually the team spends from three to four weeks at a site to complete the installation. Since a few days must be allowed for the masonry to cure before testing, there are often a few free days between completing the installation and testing. This time is used to undertake surveys of new nearby sites or to follow-up on already operating mills that may be in the area.

After completing the installation, the team makes all final adjustments and operates each of the machines under full load for several hours. The owner or operator is also required to run the mill under the supervision of the team until they are satisfied that he understands the operating procedures and safety requirements.

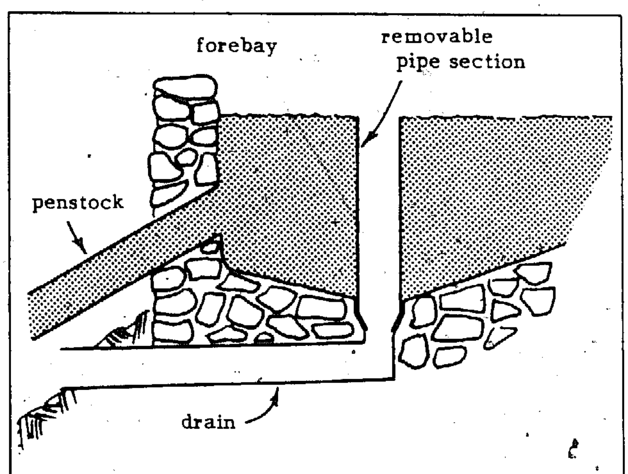


Fig. 25. A removable standpipe recently incorporated in the forebay design facilitates removing the sediment. It also serves as an overflow.

R. Yoder

Fig. 26. A major responsibility of the mill owner is to undertake the necessary excavation. Here the excavation for the tailrace is underway and excavation for the mill house has been completed.

R. Yoder

Fig. 27. After the site excavation has been completed and the equipment fabricated at Butwal, porters carry the necessary materials to the site. The two sections of penstock shown weigh about 100 kilograms.

R. Yoder

Fig. 28. Before the installation team arrives from Butwal, all the necessary materials have been transported to the site.

Fig. 29. The penstock, turbine, and draft tube are all assembled and properly aligned before set in concrete. A portion of the tailrace canal has already been completed.

Fig. 30. The tailrace and forebay have been completed and the processing equipment is being installed.

Fig. 31. All the equipment has been aligned and set in concrete.

Design modifications

To obtain continuing feedback from the field in order to improve their designs, DCS initiated a policy that team members would visit mills, free of charge, for follow-up adjustments, repair, possible replacement of bearings, and observation of operating problems, whenever passing through or working in an area. Even though this sometimes has required an extra day of walking, valuable information which has led to design improvements has been gathered.

For example, one of the earliest turbine designs developed a problem with the operation of the turbine intake valve. Careful examination determined that the valve shaft had been twisted, preventing the valve from closing completely. While observing the operator in action, it became clear that when the valve was in a closed position, he had forgotten in which direction to turn the spindle to open it again and applied a substantial force in the wrong direction. The initial solution was to paint arrows to indicate the directions for opening and closing. The final solution, however, was to provide blocks limiting the valve arm travel, reducing all possibility of damage due to operator error.

The clean-out opening above the turbine runner was another design improvement which resulted from a service call. A stick that a boy had floated down the canal had lodged in the runner. Without this opening, the complete turbine had to be disassembled to gain access to the runner.

Though the forebay is small, sediment still eventually accumulates on the bottom. With no sluice gate, its removal proved a problem. Incorporating a removable standpipe in the floor of the forebay area resolved the problem (Fig. 25). When the forebay is to be cleaned, the pipe is removed and the sediment is flushed out. During normal operation, this standpipe serves as a drop spillway.

Observing mills in operation has also resulted in the relocation of the turbine valve control handle, changes in the machine disengagement mechanisms, and other changes for the convenience and safety of the operators.

Costs

The cost of implementing a water-powered mill is clearly site-specific. Table 2 presents the costs of a typical mill installed with the assistance of Butwal. Though the total cost might seem high, the owner of a water-powered mill generally still charges only slightly less than the diesel mill owner. With his low recurring costs of operation, he can repay his loan in four to seven years depending on the terms of his contract.

Most mills installed by Butwal range from 8 to 12 kW. The total cost of the entire water-powered mill installation, including the agro-processing machinery, is on the order of US$8,000 or about US$1,000 per kW. The actual cost is influenced by the length of the canal required, the length and size of the penstock, the capacity of the turbine, and the size of the agro-processing machinery used. Had the mills been built for the purpose of generating electrical power, the costs per installed kilowatt would amount to approximately the same value, with the cost of the generator replacing the cost of the agro-processing machinery. This, of course, assumes that no governor is necessary, either because direct current is generated or because the plant is manually controlled, as in the case of the Pakistani schemes implemented by the ATDO (see Pakistan: Villager-Implemented Micro-Hydropower Schemes, A Case Study also available from NRECA).

Other developments

Hardware

The introduction of modern water-powered mills in the mountains of Nepal has permitted more efficient exploitation of an indigenous resource to process grains and oil seed on a village scale. This has led to a decreased reliance on increasingly expensive diesel fuel which has to be carried by porters long distances over mountain trails. Though clearly a positive development, a more pressing problem for Nepal is not the increasing cost of diesel fuel but the depletion of its forests. Food requirements for Nepal's expanding population have

Table 2. Cost breakdown for a typical water-powered mill (presented in 1981 U.S. dollars)

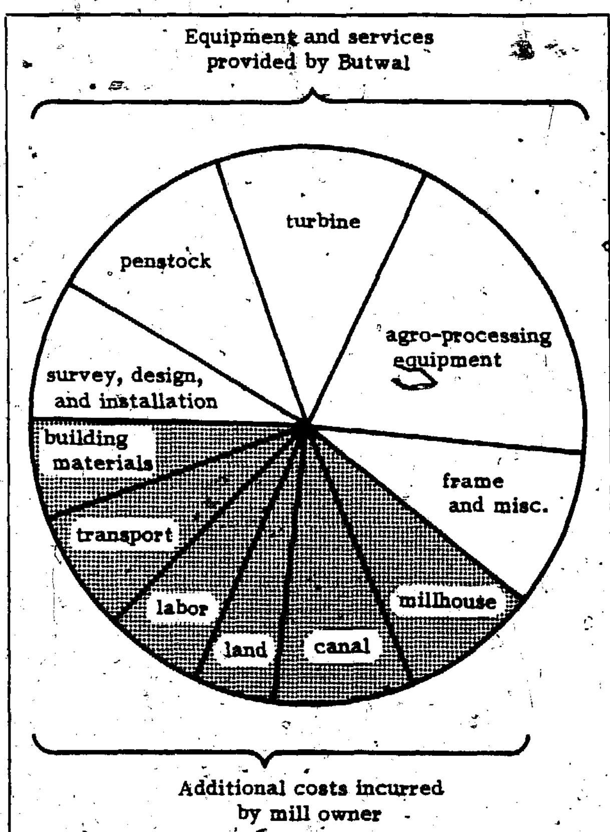
Machinery and services provided by Butwal	
Survey and design	200
Turbine	1,100
Mounting frame, pulleys, belts, and misc. hardware	800
Agro-processing machinery (flour mills, rice huller, and oil expeller)	1,700
Penstock	1,000
Installation (est. 30 days)	500
Sub-total	$5,300
Additional costs incurred by mill owner	
Land and canal right-of-way	400
License	40
Transportation of machinery and materials	600
Canal excavation	700
Mill house	700
Workers (fitters, masons, etc.)	500
Cement ($14/bag)	400
Sand, stones, and other materials	100
Sub-total	$3,440

forced farmers to clear forests and cultivate even marginal land areas. Once deforestation reaches a critical point, fuelwood extraction becomes an additional factor in deforestation. Fuelwood is used both for cooking food as well as for a number of village industries including drying ginger, tea, and tobacco, making paper, soap, and cheese, alcohol production, and dyeing yarn.

Individuals presently working at Butwal and others who worked there previously have been undertaking research directed toward finding means of using hydropower to reduce firewood consumption. Two areas of research are the development of a mechanical heat generator for village industries and a heat storage cooker for household cooking. These are examples of new approaches to addressing an increasingly pressing problem. The technical feasibility of these approaches has been demonstrated, but a critical question remains—will villagers adopt them and will they meet the need they set out to address? Numerous cultural, social, and economic factors come into play and the answer is, as yet, unknown.

Mechanical heat generator. An obvious approach to drying agricultural produce using hydropower would be first to generate electricity and then to use this to

Fig. 32. A graphic representation of the breakdown of the total cost.



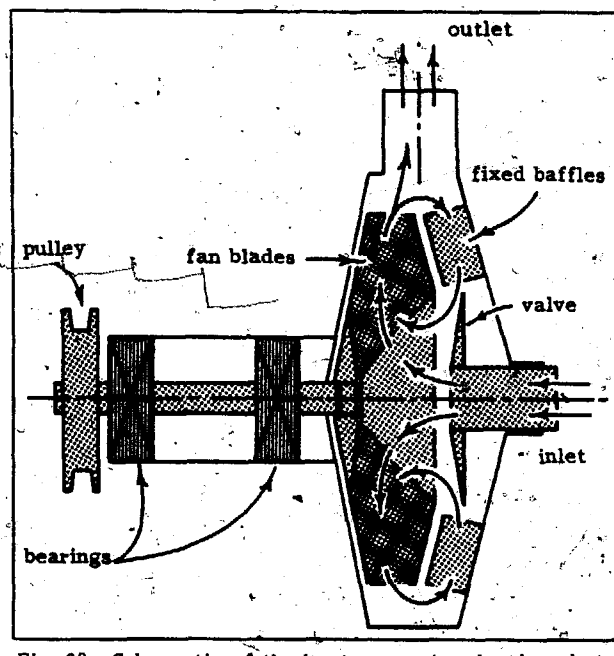


Fig. 33. Schematic of the heat generator developed at Butwal.

operate a fan to force air past electrical resistance heaters. However, this approach has several disadvantages. The primary disadvantage is the additional cost and complexity of the generator and associated electrical hardware in a situation where simplicity has a number of distinct virtues. Secondly, converting mechanical into electrical energy introduces inefficiencies and, at most, only 70–80% of the power available at the turbine shaft can be converted into high-grade heat.

An alternative, which virtually converts 100% of the available shaft power into heat, is based on original research work on the equivalence of mechanical and thermal energy undertaken by James Joule in the mid-19th century. Though several individuals have undertaken further research on various aspects of this effect, it is only recently that there has been an increased interest in the practical application of this process for generating usable heat.

At Butwal, work to date on this alternative has centered on a heat generator which can be coupled to a turbine to heat air through viscous friction. Fig. 33 presents the layout of this design. Air is drawn through the inlet by the fan and part of it leaves through the outlet into the drying racks. The other portion flows back over the baffles which are arranged radially. The kinetic energy imparted to the air is changed into heat by the creation of eddies. This hot air passes the valve, mixes with the incoming cooler air, and is drawn in again by the fan. The amount of air leaving the generator and its temperature depend mainly on the position of the valve. When it is closed, the generator is simply a fan blowing air at near-ambient temperature through the generator. If the valve is fully opened, nearly all the air leaving the fan is drawn back through the baffles, thereby heating it to the maximum temperature. Any temperature between these two limits can be obtained by varying the opening of the valve.

The generator is driven at about 2000 rpm and temperatures above 100 °C have been obtained. However, for crop-drying purposes, temperatures ranging from 60-80 °C are sufficient. Tests have shown that the temperature stays constant after an initial heating up period provided that the ambient temperature does not change.

After successful test runs, Butwal has fabricated two generators. A 10 kW unit has been installed at a trade school in Jumla, in the far western region of Nepal. It is planned that the school will use this unit to dry apples and vegetables, seasonably available in this area, to cover its annual needs. Another unit has been installed at a cooperatively run mill in Arkhala in mid-west Nepal (see p. 22). It has already been used to dry a large quantity of ginger and it is planned to use this unit to determine the influence of artificially drying crops on post-harvest losses during storage.

Both projects are still under UMN management and therefore there is enough freedom for tests and modifications without putting the farmers to risk. One example of such a risk was the experience in drying 600 kg of ginger. Whereas the drying was successful, the final product did not have the appearance of ginger which is traditionally dried over a fire. As a result, the product fared poorly on the market.

While field work is continuing in Nepal, Reinhold Metzler, former product development engineer in Butwal, is continuing research work at Furtwangen Technical University, Germany, in several areas:

- testing the present design to gather reliable data on its performance
- improving the design with a view towards a simpler and more efficient design
- developing a system to provide heat for boiling for rural industries—Temperatures up to 200 °C are required. The first unit is intended for a small soap factory in Nepal and is presently undergoing tests in Furtwangen. Though the unit operates satisfactorily, improvements to reduce heat losses are still required. Field tests of the unit are expected in January 1983.
- designing and testing methods of storing heat produced by the heat generator when the mill is not otherwise in use.

Heat storage cooker. An argument often advanced in favor of small hydropower plants in deforested rural areas is their use as an alternative source of energy for household cooking. But this poses several problems. In the first place, since power requirements of conventional hot plates range from 750-1500 W, micro-hydropower plants can only provide electric power to a very limited number of homes. Secondly, cooking evening meals coincides with the peak lighting load, a fact which does not contribute to ameliorating the two problems of low load factor and high peak loads which tend to characterize small decentralized electricity schemes. And, finally, there are also additional costs incurred in purchasing cooking pots and kettles with flat bottoms which would be required for cooking on hot plates and in purchasing and repairing or replacing these hot plates.

For micro-hydroelectric power to be a technically and economically viable source of energy for cooking requires a storage device that will allow energy that is generated <u>between</u> the normal cooking times to be used <u>during</u> these times. The full capacity of the generating equipment could then be utilized by delivering energy to the storage system continuously. This would result in a higher load factor as well as in a reduced peak load requirement.

As hydroelectric power use expanded in the United States and Europe during the first half of this century, commercial heat storage cookers which met this requirement were developed and marketed. These were essentially electrical elements embedded in well-insulated cast iron blocks that stored heat until needed. These became popular because of a tariff structure which encouraged the consumer to use, at a fixed tariff, all the power to a maximum limit. The last company known to have manufactured storage cookers discontinued marketing in Norway in the early 1950's.

Robert Yoder has recently completed research on heat storage cookers at Cornell University. Prior to this work, he had been involved for eight years in a number of activities with DCS, ranging from project engineer on Butwal's 1,000 kW Tinau Hydroelectric Power Project to project leader for Butwal's water-powered mill projects described in this study. The research at Cornell University focused on a design incorporating stones rather than an expensive, heavy cast iron mass in which to store heat. Because of the low conduction of heat both within a bed of stones and between the stones and the cooking vessel, heat transfer from the stones to the cooking vessel is accomplished by dripping water into the hot stone bed to generate steam at atmospheric pressure. The steam then conveys heat to the cooking vessel where it condenses, drops back into the stone bed, and is recycled.

The laboratory unit, with a power input of 275 W was used for eight consecutive days to cook a typical Nepalese meal on a twice-daily basis as is done in Nepal. These trials confirmed that heat storage in a bed of stones would work for water-based cooking.

The stage has now been reached where the viability and social acceptability of a locally-built unit must be determined. Fig. 34 illustrates a possible storage cooker design utilizing local materials. Whereas constructing and operating such a design is competitive with using fuelwood with the current prices of electricity and fuelwood in urban areas, its

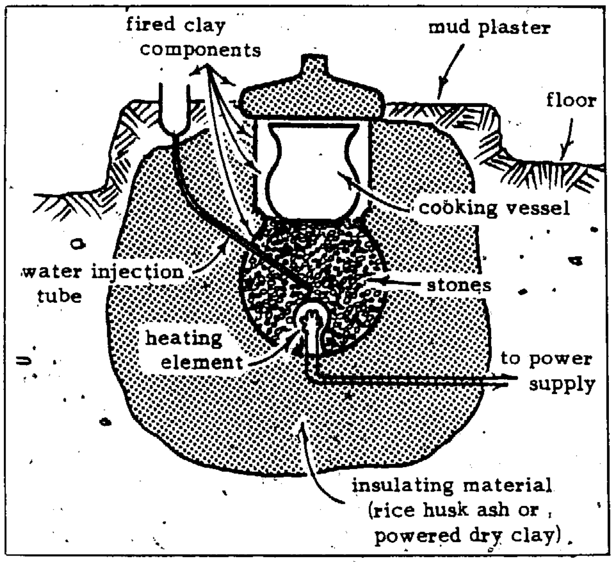


Fig. 34. Schematic of the heat storage cooker based on research undertaken at Cornell University.

acceptability by villagers is not assured. One of the problems is that, to conserve heat, it would not be possible to observe or stir the food while it is cooking. Perhaps of greater significance would be the loss of space heating and social value traditionally associated with an open fireplace. It is interesting to note that even among those who can easily afford it in Kathmandu, electricity is used rarely for cooking. It might well be that no change in cooking habits will occur until firewood becomes essentially unavailable. DCS is continuing with experiments, but there is a need to gather hard field data on the appropriateness and acceptability of this device under differing conditions.

Mill lighting. Though most work to date has involved hydropower plants used to power food-processing machinery, there has been continuing interest among mill owners in generating electricity for lighting. As a result, a dc mill-lighting system has been developed.

In designing a system for use in the hills of Nepal, where most mill installations are several day's walk from the road and an understanding of electricity is a rarity, several basic design criteria were established. First, Butwal decided to design a system with sufficient power to light a minimum of six bulbs. It was further decided that since a lead-acid battery is both heavy and requires maintenance, it should not be part of the system. Other criteria included the requirements that the voltage output of the alternator remain constant over the wide range of speeds at which the turbine actually runs and that the system be designed for reliable operation.

The system which evolved utilizes an automobile alternator and a DCS-designed voltage regulator. An alternator manufactured in Bombay and costing about $100 was initially used but a source of $40 U.S. alternators has since been found. This 12 V alternator is connected in such a way as to generate 24 V, thereby permitting twice the power from the same unit as would

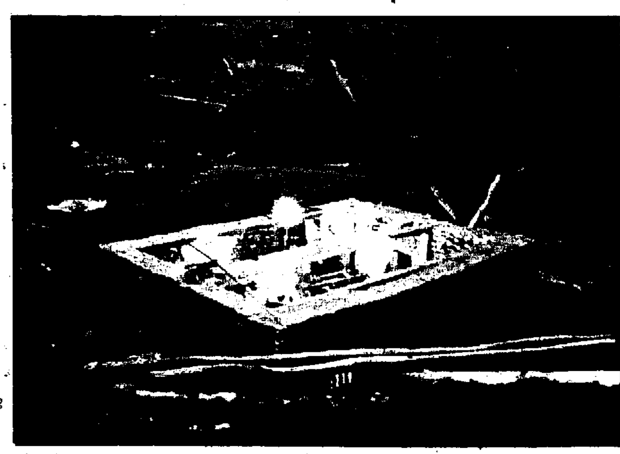


Fig. 35. As evening approaches, the lights at a still incomplete mill are already working.

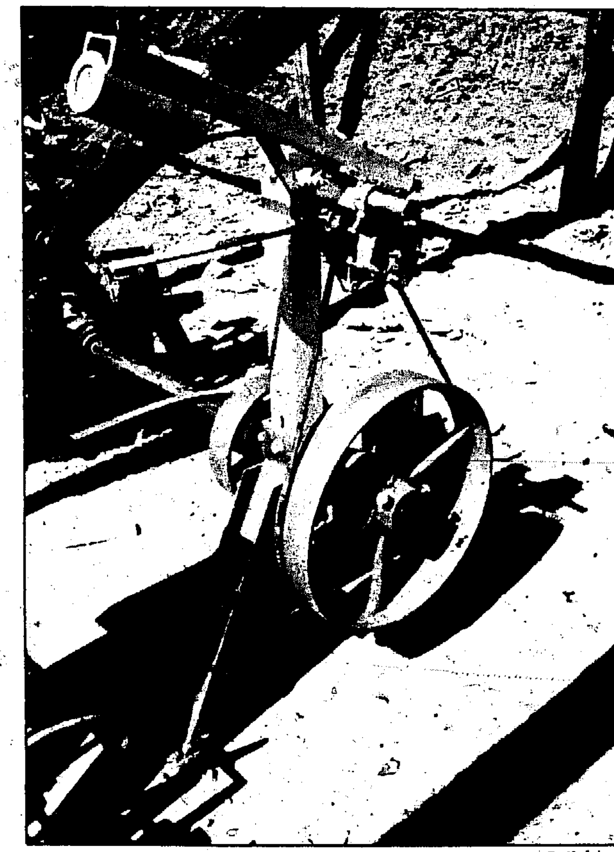


Fig. 36. An alternator, mounted at one end of a balance beam, will provide light for milling during evening hours.

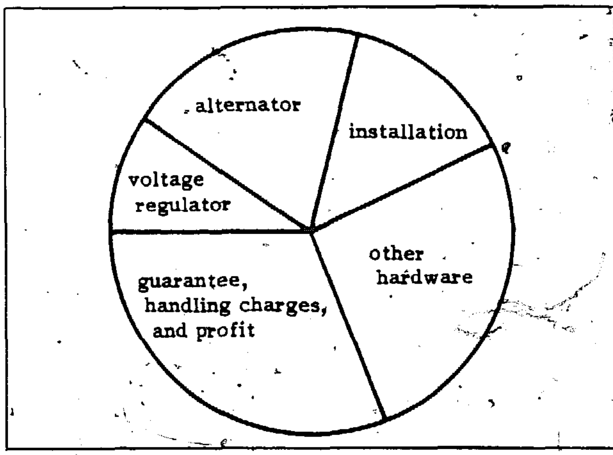


Fig. 37. Breakdown of the cost for a standard lighting installation.

otherwise be available. Incandescent bulbs running at 24 V are widely used on the Indian railway system and are easily available.

The voltage regulator was designed to maintain the voltage output at a nearly constant level over the wide range of speeds to which it is exposed. Most of the components are mounted on a laminated printed circuit board designed by DCS and manufactured in India. The present design incorporates a plug-in circuit board rather than a permanent circuit board used in earlier versions. The difficulty of performing good quality soldering in the hills of Nepal, away from any source of electricity, necessitated this change.

The alternator is mounted on a balance arm, with the counterbalance regulating the driving belt tension. It is driven off the same pulley that powers the rice huller (Fig. 36). The alternator pulley is selected to drive the alternator at 3,000 rpm when the turbine is running at design speed.

As of the beginning of 1982, seven mill-lighting units were installed. A standard installation with a total of eight incandescent lights costs about $420. In addition to the basic installation, optional items are now also available. These include wiring additional areas (with a maximum total of 12 bulbs), electric fans, fluorescent tube lighting, and an electric horn. This horn is necessary to notify the villagers in the area that the mill is open for business. The diesel mills had the advantage that a small container could be partially inverted over the outlet of the exhaust pipe. This would create short intermittent toots and alert villagers, often several kilometers away, when the mill was in service. This approach was not available to owners of turbine-powered mills.

Cooperative approach to implementation

Individuals who have inquired about developing a modern water-powered mill scheme represent a cross-section of the social and ethnic groups in the hills. Some who have completed their installation have turned to milling as a business venture, either because of a lack of other options for a livelihood or because they saw this as an attractive investment. However, the majority have a high social, economic, or political standing in their community. It is clear that the local entrepreneur who owns and operates his water-powered mill is the primary beneficiary of this technology. He charges approximately the same rate as that charged by diesel mill owners, has fewer recurring costs, and can repay his ADB-N loan in four to seven years. After that time, all income beyond that required to cover operating and maintenance expenses represents a net profit. Consequently, the question of whether these water-powered mills are merely enriching the already wealthy has been raised.

To increase the benefits of water-powered mills to the users rather than to a few entrepreneurs, UMN embarked on an experiment to establish a 'cooperative mill. The first project was undertaken in Buling Arkhala, Nawal Parasi District in the Lumbini Zone. In

Fig. 38. One of two water-powered mills installed by Butwal near Majuwa, 2-3 days from the nearest road. The irrigation/power canal and forebay can be seen on the right, with the penstock entering the powerhouse.

the late 1960's, UMN had established a dispensary in the area and more recently had been involved in a Food for Work Programme. There was, therefore, already a good relationship between UMN and the people of the area. During discussions with the villagers of how they might improve their economic standing, it was apparent that they saw the biggest potential in developing the locally-grown ginger and improving its marketing. With Butwal's work on a mechanically-driven crop drier, the idea of installing a water-powered mill evolved. In addition to drying ginger, it could also be used to process their grain and seed, a task which otherwise required a day's walk to the nearest (diesel) mill.

UMN advanced a loan for the cooperative mill and later trained the local people in operating and maintaining the mill as well as in accounting and management. Representatives from each of the wards in the panchayat formed a building committee.

The canal to the mill was built during a Food for Work Programme. The remaining work was undertaken by the villagers who were paid either in cash or in coupons which could later be used to either buy shares in the cooperative or services at the mill. Initial work was slow because of weak leadership in certain villages, the villagers' preoccupation with other tasks in their fields, and the low wages agreed upon by the committee. To speed up progress, contracts were let for specific tasks, as is the tradition in the area.

In spite of the low promotional rates set when the mill became operational, because of the low yields from the small oil expeller which had been installed, villagers preferred walking to the nearest diesel mill where they could obtain higher yields. After the installation of a standard-size oil expeller, a rice huller, and a heat generator, the mill's popularity increased to the point that often the villagers had to wait several days to get their mustard seed processed. A shop which sold basic necessities to those waiting to process their grain and oil seed was also built as part of the cooperative.

As the mill became operational, the villagers and UMN discussed how to actually set up a cooperative. With assistance from the ADB-N, it was decided that minimum shares should be available at Rs. 20 each but that each shareholder should strive to eventually purchase Rs. 200 worth of shares. This maximum value of shares which could be held by a single individual was set to avoid large differences among shareholders. A management committee of one or two members from each ward, depending on the number of shareholders from that ward, was formed. This committee meets on a monthly basis.

The advantages of a cooperative approach are readily apparent. Besides relieving the villagers of the work of processing their crops by hand or carrying it long distances to have it processed, this can be done locally at an affordable cost. The money is kept within the community, jobs are created where many men are otherwise forced to go to the southern plains or to India, and any cash surplus is reinvested in projects which benefit the entire community. The mill area becomes a center for market activities and for exchanging views and information. Possibly most importantly, such an undertaking can be an incentive for active community involvement in other projects. This can reinforce among the villagers the idea that they can play a useful role in bringing about change largely through their own efforts without relying on substantial assistance from outside.

This has been a learning experience for both the villagers and UMN. The low initial motivation might have been reversed had the villagers and their leaders been better informed of the organization, objectives, and operation of a cooperative and the role of the committee and the members, especially in light of the failure of several government-initiated cooperatives in the past. Villagers' involvement in the decisions made by the committee would have avoided such problems as implementing the project at the wrong time of the year. Also, the role played by the "agent of change" (UMN) should have been clarified.

Despite problems encountered in implementating the cooperative, water-powered mill project, it is now operating successfully. It has recently expanded into other types of work. Agricultural supplies such as insecticide and seed dressing (for storage) are now available at the mill. The cooperative is paying the salaries of two part-time local health workers, has established a health subcenter, and is building a nursery. UMN provides the training, and a loan or grant if needed, but the cooperative is responsible for setting up the organization and management structure for these new undertakings.

A second cooperative mill project in Bangbari has since been undertaken. In that case, the project was less rushed and more participation on the part of the villagers was demanded. UMN paid only for the milling machinery, with all other costs borne by the community. Initially nine villages were interested in participating, but, because of the demand the project placed on the villagers, only four undertook the project. It, too, is now well managed and running smoothly. Registering these cooperatives in order to give their members legal protection is the only remaining problem. Because of the government's experience with innumerable cooperatives which have failed in the past, it is reluctant to register new groups.

Observations

Micro-hydro projects, as well as related development projects in remote rural areas of Nepal and around the world, frequently encounter difficulty in effecting a positive impact on the rural sector and then maintaining it without significant continuing support of one form or other. Butwal's Small Turbine and Mill Project seems to present one exception to this trend. For those concerned with increasing the effectiveness of micro-hydro projects, there is a need to analyze the factors which have contributed to the success of Butwal's efforts. The following discussion reflects impressions gained by the author in the course of preparing this study.

End-uses and viability of small hydropower plants

Installing micro-hydropower plants can be costly ventures. Their high cost is compounded if imported machinery is used and if the plants are located in remote areas. Consequently, subsidies are often necessary in order to install and operate these plants, especially if revenues rely primarily on domestic consumer uses of the power. It is, therefore, important to introduce and encourage income-generating or productive end-uses to place the plants on a more sound financial footing.

Experiences in rural areas around the world have shown that, though those installing plants in these areas might expect that numerous rural industries will automatically be established to take advantage of electrical power once it is available, this rarely happens. Without incorporating specific income-generating end-uses in the design of a project, the power is often used almost exclusively for lighting. This is probably a foregone conclusion since lighting is the end-use most apparent to villagers from rural areas visiting towns and cities. Moreover, this use requires minimum additional capital investment on the part of the user, and it often meets an existing need. Lighting generally does not generate income, although it can result in possible cash savings when electricity replaces kerosene and can also enhance income-generating activities. Yet, continued operation of installations providing electricity primarily for lighting generally will continue to require a sizable subsidy.

Butwal's approach to implementing water-powered mills directly addresses this income-generating aspect. Butwal decided to work with a technology which would improve the profitability of an already existing income-generating end-use in rural areas and which would introduce the minimum departure from existing technologies which had already been mastered by the people of the area. In so doing, economically viable end-uses were automatically an integral component of the project and not something to be added at some later date. In addition to generating income, Butwal's small decentralized hydropower plants are also less costly to operate and maintain than the diesel plants they often replace. It is true that electricity could have been generated and used to drive motors to power the same processing machinery. This would have been advantageous insofar as it would have more easily permitted the location of the mill to have been dictated by the location of the need for power and not by the location of the water resource to be tapped. However, Butwal elected to use the mechanical power directly since this technology was already well understood. A mechanical system was also cheaper to install and maintain than the alternator, motor(s), and other electrical components which would have been required to perform the same task. Therefore, it is not by chance that Butwal's small decentralized hydropower plants are not subsidized yet viable—they are designed to be so in the context of rural Nepal.

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Fig. 39. Mill lighting permits 24-hour operation of the mill during the busy season.

But the potential usefulness of electricity can not be discounted. A number of the owners of mills which have been in operation for some time have expressed an interest in adding an electricity-generating capacity to their plants. Of course, by this time, most of these mills have paid for themselves and an electricity-generating capacity could be added at minimum cost. To address these growing requests in a natural, evolutionary manner, the mounting frame for the new machinery now fabricated at Butwal provides for mounting a car alternator. In this manner, a small quantity of "safe" (24 V) electricity can be made available for lighting the mill to permit work in the evening and possibly for several homes in the vicinity of the mill. Owners of several mills which are located sufficiently near to a village have expressed an interest in including a 240 V ac alternator of sufficient capacity in their mill to provide power, primarily for lighting, to the villagers. Though clearly technically feasible, legal questions regarding generation and supply of electricity still have to be resolved.

The appropriateness of small hydropower technology

A number of governments and aid organizations around the world have been or are presently involved in small decentralized hydropower projects in developing countries. The avowed purpose of many of these projects has been to evaluate the appropriateness of this technology. But, whereas the results of the applications of small hydropower technology by Butwal have been definitely favorable, the same can not often be said of results elsewhere. Can a conclusion regarding the appropriateness or inappropriateness of small hydropower technology per se be drawn from all these experiences or do the results reflect more on the approach to the implementation of such projects than on the technology itself?

The achievements due to the efforts of Butwal are numerous. The UMN began establishing workshops and technical training in the early 1960's. Only in 1975 did it begin to seriously consider fabricating turbines and installing small hydropower plants. Since then, Butwal has installed 65 virtually nonsubsidized water-powered mills around the country. The skills found in Nepal as well as the level of economic development are no different from those found in many developing countries. Yet the turbines used are designed and fabricated in-country, and the mills are installed, maintained, and operated largely by the Nepalese, and virtually all continue to operate successfully. As the pace of implementation is picking up, other small workshops in the area are becoming aware of the technology and its implications and, completely on their own, are fabricating machinery. In summary, the experience of Butwal leads to the conclusion that micro-hydropower technology is indeed appropriate. But why do projects elsewhere often seem to lead to opposite conclusions?


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Fig. 40. An installation team securing the flour mill to its base.


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Fig. 41. An expatriate staff contributes to an exchange between DCS staff and a customer.

Like numerous development projects, Butwal's micro-hydro program was not the outgrowth of an indigenous effort. Outside expertise and financial assistance were essential. But differences with conventional aid approaches are numerous. As with other foreign aid projects, expatriate engineers and staff are involved in the Butwal project, but they are there primarily because of a genuine personal commitment to the work. Unlike many consultants, they are involved in this work, not for weeks but, often, for years. They have time to learn first-hand about the realities in the countries in which they are working. Rather than simply talking about the rural areas in the abstract, they often spend days traveling on foot to those areas, staying long enough to get an understanding of the way of life of the people, of their hopes, aspirations, and frustrations. Many speak Nepalese and thereby guard against the loss of sometimes significant information as it is filtered through the mind of the interpreter. Development generally is regarded as a long-term, on-going process and yet most aid projects effectively demand short-term results. Progress is often measured by reaching physical milestones, whereas the real problems are often with the intangible aspects—cultural, social, environmental, economic, psychological, and others—which influence or are influenced by the technology. Butwal has the time and experience to deal with many of these problems whereas, faced with largely inflexible deadlines, most aid projects do not.

This gulf between the approach used by Butwal and that adopted by more conventional aid projects in implementing small hydropower projects may well explain the difference in the conclusions drawn about the appropriateness of this technology. If so, this implies that the approach to implementation and not the technology itself should be examined and improved if micro-hydropower technology is to be a viable technology in the rural setting of developing countries.

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