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Pakistan

Proposed small hydropower project

NRECA Small Decentralized Hydropower (SDH) Program

Pakistan: Proposed Small Hydropower Project

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ABBREVIATIONS

ACE Ltd.	Associated Consulting Engineers, Ltd.
ATDO	Appropriate Technology Development Organization
ERDC	Energy Research and Development Centre (proposed)
NAWO	Northern Areas Works Organization
NCC	National Construction Company
NWFP	North-West Frontier Province
SHRDC	Small Hydro Research and Development Centre (proposed)
WAPDA	Water and Power Development Authority

SUMMARY

In order to assist the Government of Pakistan in formulating and implementing programs to assess, develop, and use its indigenous energy resources, the AID Mission in Islamabad will embark on a major multi-faceted energy program, one component of which is the planning and development of a small-hydro program in the North-West Frontier Province (NWFP). To assist with the task of writing the Project Paper, separate design teams were required. A three-man team from NRECA addressed certain design issues, gathered materials, and prepared recommendations relevant to the small-hydro component, to be integrated into the Project Paper by the Project Leader. This report summarizes the findings of that team.

Evaluation, analysis, and planning, followed by integrated development of its indigenous energy resources, are high priority targets for the overall economic development program of Pakistan. The central government's Water and Power Development Authority (WAPDA) is responsible for implementing the electric power sector of that program. WAPDA is continuing to expand a large hydro generation and transmission system in the Indus River Basin feeding into urban and rural electric distribution subsystems in the basin, including a major system serving the city of Karachi. This monumental program will continue to tax the financial and technical resources of WAPDA. Consequently, the NWFP, where major transmission lines have not yet penetrated, will not have central station service from the main power grid for many years.

However, the NWFP has hydropower resources which could be harnessed to provide energy for development activities. The NRECA team found several factors which favored development of this resource. First, although this province is one of the most densely populated which is not served by the national grid, it has the largest small hydropower potential, which is as dispersed as the population. Secondly, several organizations operating at the provincial level in the mountainous portion of the NWFP already have experience in the implementation, operation, and management of small hydropower plants on which to build. Village-level initiative has been fostered successfully for some 40 existing micro-hydro projects, and this effort can be expanded and replicated. Finally, WAPDA which is responsible for the generation, distribution, and sale of electricity in Pakistan, is fully supportive of any potential efforts by other agencies to meet, through mini- or micro-hydro installations, the electrical power needs of the population residing outside areas which are to be served by the national grid within the foreseeable future.

Within the imposed time constraints, an NRECA team examined the energy supply and consumption patterns to attempt to assess the power demand and hydropower resources of the NWFP. Based on considerations concerning institutional, technical, and economic analyses outlined in this report, the following recommendations are made:

- Develop a long-range plan for implementing small hydro plants in the NWFP which complements WAPDA activities.
- Obtain base-line data on energy needs and load patterns for the NWFP. Data on existing cottage industries and cashflow patterns within the communities should be gathered at typical potential small hydro sites.
- Encourage industrial activities to make use of power generated at small hydropower sites to increase economic justification for these schemes.
- Develop site-selection criteria for mini- and micro-hydropower schemes.
- Support the nascent mini-hydro activities of the Irrigation Department should be supported through training and assistance in program development. Coordination with bilateral donors for loan sources for capital expenditures for equipment should be fostered, as should the creation of a consortium to fund these projects.
- Foster micro-hydro activities should be fostered both by supporting the activities of ATDO in adaptive research and development, promoting local fabrication, undertaking evaluations of all aspects of micro-

hydro projects in the field, and establishing an organization for planning, implementing, and coordinating micro-hydro projects initially on a provincial basis.

- Fully evaluate existing mini- and micro-hydro projects. This should include perceived versus actual social and economic impacts on the communities, technical performance and adequacy of designs, management options and their efficacy, and any other aspects which affect the viability of such small hydropower schemes.
- Organize training programs in all stages of small hydropower development (from planning to implementation, operation, and maintenance). Training of appropriate local individuals to promote community self-reliance should be encouraged.

INTRODUCTION

This report proposes to establish local institutional capability by 1987 in the NWFP to provide rural energy by means of small hydropower plants. This will serve a larger project goal of assisting the government of Pakistan in planning and developing indigenous energy resources. The development of 20 prototype hydro schemes (5 mini- and 15 micro-hydro) will strengthen the institutional capabilities of the Irrigation and Health Engineering Department of the NWFP or other local institutions, should the former have inadequate resources, and will contribute to the research and development activities coordinated by the Appropriate Technology Development Organization (ATDO).

Approximately 40 units of various capacities are presently operating or are under construction in the NWFP. There is a critical need to evaluate the technical, social, and economic aspects of this experience. Then an expanded hydropower development program can be designed to extend small hydropower use beyond its present limited capacity.

A number of obstacles now hinder the extension of small hydro generation. Performance, economic, and baseline data on energy needs in the NWFP are insufficient to adequately evaluate present performance and impact or to project the sound design of an efficient small hydro program. Adaptive research and development efforts on turbine design and manufacture and on control systems are insufficient due to limited funding and staffing. Institutions suffer from significant staffing constraints; basic skills are lacking. Mini-hydro experience is limited, particularly since most projects are only in the design or construction stages. The ATDO was the first organization to implement micro-hydro schemes in Pakistan. It has a small staff and insufficient resources and primarily coordinates research activities, with no mandate or interest in large-scale implementation. At present, however, the ATDO is forced to rely primarily on its limited staff and resources to implement these schemes.

Development of the 20 prototype schemes will provide the requisite data to expand the NWFP's small hydropower program. A needs' assessment program will provide the information requirements to set its future direction. A research and development program will permit increased local design and manufacture of hydro units. Provision of training, technical assistance, and some commodities for developing the prototypes will assist the local institutions in implementing small hydropower projects. This pattern can be replicated to expand the small hydropower program.

Background

The NWFP varies greatly from north to south. The Himalayan foothills and mountains make up the more heavily forested north, with an average rainfall of 20 to 40 inches annually. Its northern settlements are widely scattered and access is restricted by the terrain and by political considerations. The Indus Plains comprise the southern part of the NWFP. Due to deforestation for cultivation and low rainfall, averaging 10 to 20 inches annually, the vegetation there consists of grasses and scrub bushes and trees.

In 1981, the population of the NWFP numbered 10.9 million, averaging 380 people per square mile. Population densities of 1,000 per square mile in the area of the main city of Peshawar decrease to 250-500 in Kohistan, Mansehra, and Abbottabad Districts, and to 125-250 in Swat and Dir Districts and in the Malakand Protected Area. A population increase of 30% occurred between 1972 and 1981, and by June 1981, 1.8 million Afghan refugees had immigrated to the NWFP. Fully 89% of the population lives in the rural areas; the literacy rate in the NWFP is 21%.

Agriculture is the primary economic activity, complimented by small support industries; there are also considerable mineral resources in the mountainous areas. Administratively the NWFP is divided into 11 Districts and a number of tribal agencies, overseen by the Chief Secretary, with assistance from Divisional Commissioners. Deputy Commissioners head the Districts. Provincially controlled agencies such as the Federal Administered Tribal Area Development Council and the Kohistan Development Board dominate the industrial and agricultural sectors.

Energy supply and consumption

In the NWFP, energy is supplied by commercial hydropower and petroleum products (kerosene and diesel fuel) and by non-commercial firewood, animal waste, and bagasse. Grid-supplied electricity from WAPDA consists of a few 66 kV lines into the mountains and several 11 kV lines extending further into the NWFP. By mid-1981, only 2,438 villages (35%) of the NWFP were electrified by WAPDA; most unelectrified villages are remote and ineligible for electrification funding under existing programs. The WAPDA system-wide demand exceeds capacity; this shortage will increase to 14% of demand (500 MW) by 1983. In the NWFP, small subsystems have been built or are under construction, usually consisting of a hydro station of two units of 50 or 100 kW each, with 11 kV primary distribution to a town and with secondary distribution to 500 to 1,000 houses. However, intiatives by the NWFP to utilize hydropower resources are recent. Unless assistance is provided, most isolated villages of the NWFP will continue to rely on kerosene, which is costly and depletes Pakistan's foreign exchange reserves, and wood, which also must be conserved as a raw material for industrial use. In 1981 in the NWFP, 40% of the total energy consumption was commercial, 60% was noncommercial. The NWFP accounted for 7.5% of the petroleum, 3.4% of the natural gas and 9.5% of the electricity consumed in Pakistan. Residential consumers use energy for cooking and heating but primarily for lighting. Small commercial and industrial firms use energy for light, heat, and motive power, derived from diesel engines or from water-powered mills.

Hydropower activities

The WAPDA and the Federal Ministry of Water and Power were first involved in the development of six mini-hydro plants between 1966 and 1976. Subsequently, development responsibility shifted to the NWFP; the Department of Irrigation and Public Health Engineering, the Kohistan Development Board of the NWFP, the Northern Area Works Organization, and the Electricity Department of Azad Kashmir began implementing mini-hydro projects. WAPDA developed 10 sites with a total of 1.6 MW capacity by mid-1983, and the Provinces have since initiated the development of additional sites. There is a high cost associated with implementing conventional micro-hydro schemes; the ATDO pioneered cost reductions by successfully using local participation to initiate, implement, manage, operate, and maintain each plant, as well as to fabricate equipment. ATDO implemented 40 plants with a total capacity of about 300 kW. Recently, the Irrigation Department and the Kohistan Development Board have become interested in adopting the ATDO approach for micro-hydro implementation. Further technical, financial, and institutional assistance is required to develop the potential for both mini- and micro-hydropower plants.

Assessment of hydropower resources and power demand

A lack of stream guaging in the NWFP has resulted in a paucity of data with which to assess the small hydropower potential. Extrapolation from existing data is made difficult by rainfall variations from one catchment area to another and by the potential contribution of snow-melt and groundwater inflow. Detailed data on population and population density are also lacking. No data base for hydro potential in the southern portion was found, and very limited data for the north is available. Given the specific discharges for the area based on minimum streamflows and assuming that only a sixth of this is readily exploitable, a total of 100 MW could be located in the five districts, excluding Chitral, a region with a low population density. The Kohistan Development Board's survey of sites on tributaries of the Indus is consistant with this estimate. Clearly, there is also a large potential for micro-hydro plants (up to 50 kW) in the NWFP. Even several hundred such sites would contribute at least another 10 MW of capacity. The socio-economic impact of the implementation of micro-hydro schemes would probably be much larger than the impact for plants of similar capacity providing power to the urban areas, as more people are likely to be served by the same amount of power. These figures represent a firm small hydro potential based on minimum flow in the streams. If the larger flows usually found in streams in the NWFP are utilized for power generation, then a potential of 1,000 MW

can be attained from mini-hydro plants, and, at certain times of the year, it could be considerably higher.

At present, most of the mountainous area of the NWFP is beyond the national grid and electricity is not available; therefore, no data exist on consumption patterns. If a figure of 100 W per non-commercial consumer were to be applied to the population of 0.8 million families/consumers in the five districts, a total installed capacity of 80 MW would be required to meet the lighting demand for several hours each evening. Presently there is virtually no established industrial demand for electric power.

Need for project implementation

Despite the growing interest in developing hydropower resources, organizations face severe obstacles. The costs incurred in implementing mini-hydropower plants are high but are not out of line with experience worldwide. Capital and recurring costs require substantial financial assistance and subsidies from the government. There is a need to provide assistance to these organizations in Pakistan so that they can formulate economically viable design and implementation strategies for mini-hydro projects. For micro-hydro projects, it is important that the approach developed by ATDO be transferred to another organization so that it may be replicated on a larger scale.

Adaptive research and development initiatives to provide equipment capable of greater output and for new designs to operate under new conditions, and the continued local manufacture of equipment are critical if the costs of small hydropower projects are to be reduced. Potential revenues and other benefits must also be increased by developing appropriate end uses for the excess power which will be generated. The planning of prototype plants and a rationalized approach to their implementation and administration will provide an infrastructural model for the Pakistan organizations to follow. The prototype plants will improve institutional capabilities by exposing public officials and planners to the potential for hydropower and its beneficial and synergistic impact on rural development in isolated remote areas.

Around the world, a growing number of developing countries have begun small hydro programs; very few of these have addressed the question of making mini- and micro-hydropower plants financially self-supporting. The small hydro component of the proposed energy project is unique, with wide-ranging potential impact. A good start has already been made in Pakistan with the existing plants; now it is necessary to assist Pakistan institutions to establish a financially viable small hydropower program.

Extending the national grid into the NWFP is not justifiable because of its topography and because of other demands placed on the grid by the densely populated, more industrialized areas in the south. Forest reserves providing firewood for domestic energy are dwindling. Transportation costs make kerosene, used for lighting, rarer and more expensive than in the south. The only energy resource readily available in the area is hydropower.

Implementation of mini-hydropower schemes in the 1960s and 1970s by WAPDA and the Small Hydel Stations Project Directorate proved costly and time-consuming. Turbo-generating sets purchased by the federal government were consequently distributed to other organizations working in the mountainous, northern portion of the country. Several newer mini-hydro schemes are now operational, but these plants have required significant government financial backing. Use of electricity primarily for domestic lighting has resulted in little chance that costs of mini-hydro plants, other than recurring costs, can be recouped. Lower cost micro-hydro schemes implemented by the ATDO have also required government financing because villagers do not have access to capital. Nevertheless, it seems clear that the hydropower resources of the province can provide non-subsidized power to the area if means can be found of providing villagers access to capital through a loan program.

Technical assistance to two organizations within the NWFP to assist in developing an institutional capability to make small hydropower financially viable is proposed. The ATDO would handle research and development, while the Irrigation Department would be responsible for implementation and organization. If demands placed on the Irrigation and Public Health Engineering Department preclude its implementing micro-hydro schemes, another organization would have to be found or established. Institutions will be developed and staff trained to design, implement, operate, and evaluate these prototype schemes.

For micro-hydro prototypes, work will include standardizing designs, implementation strategies, and operational approaches. Developing designs for a range of turbines, assisting with the fabrication of turbines within the province, and contributing to a revolving fund to provide loans to cover costs of the turbo-generating equipment will be encouraged at the local level. For mini-hydro prototypes, designs and approaches to reduce the costs of implementation and operation will be developed. Establishing small industries to make productive use of power generated would be an essential component of these schemes.

The Irrigation Department will have the capability of, and resources to, continue to implement mini- and micro-hydro projects which are financially, environmentally, and socially sound. The ATDO will continue to help solve the technical problems which hinder cost-effective micro-hydro schemes. Program requirements consist of technical assistance, training, commodities, and credit. Twenty financially viable installed and operating small hydro prototype schemes are proposed.

Institutional development

The Irrigation Department of the NWFP is implementing its first mini-hydro plant and is funding some ATDO work at micro-hydro sites. Two engineers have been detailed from WAPDA to the Power Wing of that department which will be responsible for small hydro development. The Universities of Engineering and Technology in Peshawar and Lahore have instituted adaptive research and development on micro-hydro under ATDO guidance. The establishment of a Small Hydro Research and Development Centre (SHRDC) at the university at Peshawar is proposed which would be part of the Energy Research and Development Centre (ERDC) proposed by the university. Efforts of the SHRDC would be coordinated by a directorate including representatives of agencies involved in the mini- and micro-hydro efforts, ATDO, the Irrigation Department, the universities, and the Planning and Finance Departments. Institutional capabilities of these participating organizations will be developed to implement small-hydro prototype units and an adaptive research and development program.

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Prototype development and financial monitoring

Fifteen micro-hydro prototype installations and five mini-hydro prototype installations will be implemented during the course of the proposed project. They will provide a realistic scope-of-work for the Irrigation Department. Assistance will be provided in the following areas: training of staff to design, implement, and manage mini-hydro projects; training of staff to implement micro-hydro projects, and providing for a revolving loan fund for the latter prospects.

The Irrigation Department has designed and is implementing its first mini-hydro plant, but the new Power Wing has no trained staff or overall program direction. There is a need to improve overall program management, staff selection and training. This should include procedures for site survey and selection, feasibility reports, and technical designs—including hydraulic, mechanical, electrical, and distribution facilities. Plant implementation procedures should include contract preparation, installation supervision, facility management and maintenance, and plant performance evaluation.

Mini-hydro plants need to be integrated with industrial end-use planning to increase their financial viability. It is suggested that one man-year of short-term managerial and small industries technical assistance should be provided to the Power Wing of the Irrigation Department. A structure to develop strategies for all stages of implementing mini- and micro-hydro plants should be devised. A means of interacting with the small industries agencies of the provincial and federal government needs to be established and coordinated. End-use planning is to be an integral aspect of the proposed development of mini-hydro plants.

Proposed sites need careful financial evaluation. Tariffs need to be properly designed, and a regular and recurrent system of collecting and accounting for revenues is also necessary. A method for monitoring plant planning and implementation must be developed for small hydropower projects; local expertise is available to undertake this financial monitoring, including billing and accounting data analysis. Commodity assistance in the form of a simple word processor/computer will be needed. This unit will also be utilized for data mangement in the Power Wing.

For micro-hydro prototype projects, the development of the following institutional capabilities is to be stressed: a technical and financial assistance extension program for villagers, identification and technical needs assessment for individual sites, equipment and materials procurement, plant installation assistance to villagers, and socio-economic impact studies.

A loan fund for micro-hydro plants needs to be established and managed. ATDO originally covered all the costs of the turbo-generating equipment; with project expansion, the NWFP Government has begun to contribute. While micro-hydro plants can be financially viable, even if used only for evening domestic lighting, the lack of ready capital in the village is the major obstacle to covering the relatively large initial cost of turbo-generating equipment. A cash contribution to a revolving fund will be provided, to assist in covering the capital costs of the turbo-generating equipment. Loans from the fund to the villagers will be made and repaid at an established rate from revenue derived from the sale of electricity. Costs of other components will be collected from the villagers during implementation of the project, with the turbo-generating equipment serving as collateral.

Training

Training funds would be provided for the Director of the Power Wing to visit Nepal to learn their methods of implementing small hydro. Procedures for system design, civil works design, construction, equipment selection and installation, construction of the distribution system and house wiring, and the establishment of operation and maintenance procedures are needed. Given the limited staffing of the Power Wing, construction of the civil works and the distribution systems and the house wiring are to be contracted out. The Irrigation Department needs training and technical assistance to design, evaluate, and manage these contracts. It is proposed that the civil works for the hydro plants, the preparation of equipment specifications, and the establishment of requirements and procedures for plant operation and maintenance will be taught during two man-years of long-term assistance by a civil engineer with experience in small hydro,

who will train local staff. One man-year of short-term technical assistance will provide training in areas outside the expertise of the civil engineer. Funds will also be provided for visits of the Director to observe projects in Nepal, Thailand, or the Philippines.

Staff from University of Engineering and Technology in Peshawar have been implementing micro-hydro schemes under the direction of the ATDO. A gradual transfer of responsibility to the Power Wing of the Irrigation Department is anticipated, as staff there are trained. This training will be provided by the SHRDC, until the Power Wing can take over that function. After Power Wing and other Irrigation Department personnel have received on-the-job training on several micro-hydro schemes, two representatives from ATDO and the Irrigation Department will also be funded for a one-month visit to Nepalese micro-hydro sites owned by private entrepreneurs and village cooperatives to broaden their perspectives. They may also have the opportunity to observe actual sites being installed.

Adaptive research and development

The ATDO is the only organization in Pakistan which coordinates research on various small hydro technologies. Although the University of Engineering and Technology in Peshawar has undertaken most of the actual research and development work to date for low-cost micro-hydro plants in rural areas, implementation is to be gradually taken over by the Power Wing of the Irrigation Department. There is a continued need to research and develop equipment and hardware, specifically turbine design, local manufacture of turbines, end-uses, evaluation of operational mini- and micro-hydropower sites, and long range planning for the implementation of small hydro projects.

Local fabrication of turbines reduces the high cost of conventionally implemented small hydropower plants. To continue the work of ATDO in this field, the cross-flow turbine presently used needs to be properly designed and tested. Standardized drawings and procedures for fabrication of this turbine type must be prepared and new designs of turbines for use in both the mountainous region of the country as well as along irrigation canals in the flatter reaches of the country must be conceived. Turbines with larger (up to 100 kW) capacities than those used at present must be developed. One-half man-year of short-term technical assistance will be provided to the staff of the SHRDC to design and fabricate turbines. Commodity assistance will consist of equipment for a simple turbine test stand and other equipment to complement existing University materials for testing the fabricated prototypes.

A small workshop in Peshawar has fabricated most of the crossflow turbines, with some components purchased locally and some machining done outside. An existing machine shop with the necessary tools and experienced staff will be selected to fabricate crossflow turbines and related hardware based on the new standardized designs. An engineer with the SHRDC will make this selection and be responsible for developing suitable fabrication techniques and maintaining quality control. Funds will be provided to cover one-month visits to turbine manufacturers in Nepal and the United States to familiarize that engineer with turbine-manufacturing techniques. Commodity support in the form of basic machine shop equipment will be provided if the shop fulfills certain project requirements which will have to be specified.

There are other technologies which could improve the financial viability of small hydropower projects, but which have not been fully researched to date, including storage cookers, mechanical air heaters for crop-drying, fertilizer production, and the manufacture of calcium carbide to provide a source of light through the generation of acetylene. This research on end-use technologies would be conducted by the staff of the SHRDC and the University. Funds would be provided for six man-months of short-term technical assistance to further specific end-use research and development, and to cover the cost of several visits to countries where relevant research and development is underway.

In order to develop sound hydropower projects, it is essential to build on past experience and to evaluate the results of efforts to date. As new prototype plants are installed, their technical, economic, and social impacts must be evaluated. Four man-months of short-term technical assistance will be provided to design the monitoring and evaluation program. Commodity assistance will be provided in the form of miscellaneous electrical monitoring equipment to obtain the necessary data and a

small word processor for the SHRDC to help in data management.

A long-range plan for continuing such adaptive research and development will be formulated. It is proposed that the SHRDC be joined with the Irrigation Department in a cooperative agreement to evaluate existing plants and to propose a long-range plan for implementing both micro- and mini-hydro plants.

Project results

The project is expected to produce the following results:

Small hydro prototype units—

- The Power Wing of the Irrigation Department will have been organized to meet the functional requirements for implementing and administering small hydropower plants.
- Fifteen micro-hydro and five mini-hydro prototype schemes will be implemented, operational, and will have been evaluated.
- Two engineers with the Irrigation Department will have been trained in the design of mini-hydro plants and six engineers will have been trained in the implementation of micro-hydro schemes.
- A revolving loan fund inaugurated for the implementation of micro-hydro schemes will have been institutionalized and will be operational.

Adaptive research and development—

- A long range plan for the implementation of micro- and mini-hydro schemes in the NWFP will have been developed and partially implemented.
- A Small-Hydro Research and Development Centre will have been established and will be operating in the NWFP.
- Standardized micro-hydro turbine designs and fabrication procedures will have been developed, evaluated, and used in production.
- A thorough study of the impact of electrification by means of small hydro plants in rural areas will have been completed and fed back into the implementation plan.
- A local machine shop will have been provided with assistance and will have been manufacturing micro-hydro turbines and related equipment to meet the needs of the province.

This section discusses the technical soundness and feasibility of local fabrication of various micro-hydro turbine types, the local manufacture of turbines and related equipment, the basis for the number of prototype units, choice of training sites, and an approach to the implementation of both mini- and micro-hydro schemes.

Types of micro-hydro turbines

Micro-hydro installations implemented by ATDO make use of a locally fabricated crossflow turbine, a popular choice in such developing countries as Nepal, Thailand, Papua New Guinea, and Indonesia. No complex design work is required and it can be fabricated by welding easily formed components. Welding is more commonly done throughout Pakistan than is casting. A fabricated turbine can be repaired readily in any welding shop. It can operate under hydraulic heads as low as several meters and installations can then be designed to minimize the length of costly penstock pipe. This turbine can accomodate a wide range of flows and provide a range of power outputs. Although its efficiency may be less than that of other turbine types, this is of little consequence since there is generally no need to maximize output for a given streamflow. This turbine type is a sound choice given the realities found in the NWFP.

When more data on the magnitude of the head from a representative sample of sites in Pakistan is available, there may be other turbine types, such as Pelton, propeller, and Francis units, which could also be locally fabricated. The Pelton turbine is suitable for sites with heads greater than about 20 meters; it requires a foundry and casting skills. A standard design can be used for a wide range of operating conditions so that costs can be kept low. The Pelton turbine provides the advantage that since larger heads are utilized, proportionally lower flows are required to produce a given amount of power; or, for the same flow, greater power could be harnessed at higher heads. Since smaller flows are generally used, civil works associated with Pelton units are generally less costly and elaborate than would be the case with lower-head units. Disadvantages are that a longer, more expensive, penstock would be required and that a longer swath of terrain, possibly used for agricultural purposes, would be traversed. Small Pelton sets have been locally manufactured and installed in North and South America and elsewhere and assistance with the manufacture of Pelton turbines can be obtained several from U.S. firms.

The axial or propeller turbine is suitable for low heads of less than 10 meters and large flows which can be found in the flatter areas; they would not be as applicable in the mountainous portions of the NWFP as the crossflow or Pelton turbines. A good source of assistance for the design and fabrication of low-cost propeller turbines can be found in Colombia.

The Francis turbine is used from low to medium heads of 2 to 100 meters. It can be cast or fabricated. Because of its more sophisticated shape, this turbine is generally not used with schemes utilizing locally fabricated turbines. However, molds for standardized units of simple design, and technical assistance for their fabrication are available in the U.S.

The ATDO has expressed an interest in the use of river turbines requiring "no head" which are being developed in Canada and England, although they possess a number of disadvantages. The power density in flowing water is relatively low, requiring a large cumbersome, and therefore expensive, unit if useful power is to be generated. Debris could also easily damage the turbine. Therefore, such a turbine might only play a small role in generating power from the streams and canals of the NWFP.

Local manufacture of turbines

The ATDO's micro-hydro projects have required the fabrication and installation of more than 40 crossflow turbines, all of which have been fabricated in Pakistan. One problem found during site visits was that several blades of older turbines had fractured due to metal fatigue. Although the capability exists for local manufacture, there is a need for technical assistance in the design and fabrication of this

and other turbine types which prove appropriate. This assistance should address three areas: quality, efficiency, and standardization. The latter would facilitate manufacture on a greater scale to reduce the cost and time required for the manufacture of turbines and to permit easier repair, replacement, or overhauling of the units in the field.

Basis for the number of prototype units

It is difficult to assess the number of prototype sites which could be installed over the project life because so many variables are involved. Such an estimate assumes that work will evolve as planned; it is also based on limited field experience in Pakistan.

Micro-hydro schemes have been implemented by a single team supported by the ATDO at an average rate of about six per year, for six years. The existing schemes need to be evaluated to determine what design and implementation changes may be necessary. This evaluation will take a year before useful conclusions can be derived from the field data. Consequently, an average rate of three prototype micro-hydro sites per year seems warranted, since there is also a need to train new personnel in the implementation of these schemes. Experience with the implementation of mini-hydro schemes is more limited. A feasibility study for the 100 kW Duber hydel scheme was undertaken in 1976 for the Kohistan Development Board, estimating that construction would require 18 months; but it was completed after only seven months. Therefore a total of five mini-hydro plants seems a reasonable target for a five-year project.

Choice of training sites

Two training sites can provide useful opportunities for those associated with the micro-hydro component of the project. The first, in Nepal, would be useful to those involved both in the manufacture of crossflow turbines and associated components and in the implementation of small hydropower schemes in remote rural areas. the approach taken in Nepal is described in greater detail below because of its relevance to the Pakistani situation. In addition to a visit to Nepal, a visit to small hydro manufacturers in the United States would benefit those involved in the manufacturing aspect.

Scattered throughout the hilly regions of Nepal are a large number of mills used to grind grain, hull rice, and expel oil from seed. As in the case of Pakistan, thousands of traditional water-powered mills have been used to mill grain for generations. More recently, diesel-powered mills have increased in popularity, not only to mill grain but also to hull rice and expel oil. In the mid-1970s, an organization in Butwal in south-central Nepal initiated work on a hydraulic turbine to drive these mills. Since then, they have developed a well-engineered design for a crossflow turbine, implemented a standardized installation approach, and installed over 70 mills. A typical Butwal hydropower mill has a capacity of 10 kW and is owned by a small entrepreneur. No part of the hydro installation is subsidized; the owner of the mill obtains a loan for most of the $10,000 total cost of the installation from the Agricultural Development Bank of Nepal, which is repaid in from four to seven years.

When one of the implementation teams from Butwal undertakes work with an entrepreneur who has requested assistance to install a water-powered mill, the entrepreneur is visited, the proposed site is studied, and the development implications are discussed with the entrepreneur. If the entrepreneur then decides to undertake the project, he makes a cash deposit for the equipment, organizes the excavation of the powerhouse and power canal, and arranges for the collection of the required, locally available materials. Butwal then initiates fabrication of the turbine, penstock, and related equipment. When the entrepreneur has made final payment for the equipment, he arranges for the transportation of the equipment to the site. Then an installation team of two members arrives; this team is paid on a daily basis to encourage the entrepreneur to be well organized and prepared. Installation work on a mill is usually completed in 3-4 weeks. The mills are primarily a source of mechanical power for driving agro-processing equipment; but, by coupling a car alternator to the turbine, lighting for the mill and nearby houses can also be provided.

Butwal has a wealth of experience in successfully fabricating and testing crossflow turbines, penstock pipe, and related equipment and in implementing mill projects in rural areas

far from any roads—conditions similar to those found in the NWFP. The proximity of Nepal to Pakistan implies the most effective use of limited funds for training. Butwal therefore seems an appropriate site for those involved in the fabrication of micro-hydro equipment and those involved in its installation.

A number of small companies manufacture turbines and assemble micro- and mini-turbo-generating sets in the Pacific Northwest of the United States. Visits to these companies could involve familiarization with different shop layouts and various aspects of turbine design, fabrication, testing, and commissioning. Crossflow as well as other turbine types would be studied. Visits to sites under construction and in operation could also be included. Several companies are interested in assisting overseas efforts. They can supply basic components and provide technical assistance to fabricate the remainder locally; eventually all the technology and expertise required to fabricate complete units in Pakistan could be transferred.

Approaches to implementing mini- and micro-hydro schemes

Hydro schemes which would be implemented in the NWFP fall into two categories: schemes up to approximately 50 kW, referred to as micro-hydro schemes and those from 50 kW to perhaps several megawatts, referred to as mini-hydro schemes.

It is essential that cost-reducing designs and methods of implementation and management be adopted if micro- schemes are to be economically viable. The approach developed and used by the ATDO addresses these concerns through the use of locally fabricated turbines, locally available manpower, and appropriate system design. Lowering the standards of the generated power, yet keeping them adequate for the end uses envisioned, permits system designs which can forego the use of expensive governing and other control systems. Following less stringent, though adequate, wiring standards allows further cost reductions. Labor cost savings are derived by relying on local management and local, part-time labor. Local management also provides villagers with a vested interest in keeping their plant operating. The schemes should be designed to allow direct mechanical drive to a workshop established in the powerhouse as well as to generate electricity. This permits the least costly approach to increasing the conventionally low load factor usually associated with decentralized power schemes. Secondary benefits are derived from active village involvement in the development process and reduced demands on the provincial government.

Though mini-hydro schemes tend to be implemented along more conventional patterns, efforts should be made to reduce costs either through the use of standardized designs where appropriate or the maximum use of local labor and materials. Since several of these plants might eventually first be interconnected and then later linked to the national grid, adherence to more conventional standards would be essential. The more sophisticated nature of these schemes and the smaller number of these presently throughout the province imply that a centralized structure would be appropriate to assume responsibility for designing, implementing, and managing these schemes.

The economic benefits and costs of the proposed small hydro project component are analysed by comparing economic internal rates of return (EIRR) on investments with the assumed opportunity cost of capital in Pakistan. The purpose is to determine if investments in small hydro schemes in Pakistan can produce sufficient net economic benefit to justify funding by financial institutions or aid agencies.

In the following analysis, the terms "participatory" and "conventional" are used. A participatory approach refers to maximum reliance on the community to be served by the power scheme for its implementation, management, and operation (the ATDO approach). A conventional approach refers to implementation of a power scheme by a private contractor. In addition, for micro-hydro schemes, use of a locally fabricated turbine and maximum use of locally available materials is assumed.

In the first part of the analysis, the cost of providing power to an unelectrified village through WAPDA grid extension is compared to the cost incurred by electrification by means of a micro-hydro scheme implemented by a conventional approach. Economic benefits and costs which result from a small hydro scheme will then be discussed and specific case studies for different types of small hydro schemes presented. Each scheme has a different size, approach, and type of load. The economic internal rate of return is calculated for each scheme.

Cost comparison of micro-hydro and grid extension

For this comparison, it is assumed that, for a typical village of 135 houses located 3.5 miles from the existing grid, a lighting load of 100 W per house is used for four hours during the evening hours. Costs common to both approaches, such as distribution within the village and house wiring, have been ignored.

The costs of connecting this village to the grid include the following:

- 3.5 miles of 11 kV line @ Rs 39,000/mile,
- one single-phase 15 kVA transformer @ Rs. 5,000,
- energy needed for annual supply of about 20 MWh of electricity @ Rs. 0.5/kWh, and
- 13.5 kW of WAPDA generating capacity (assumed to be gas turbine) @ Rs. 3,600/kW.[1]

The approximate total investment cost of extending the grid is Rs. 190,000 and the annual energy cost is Rs. 10,000.

The cost of supplying electricity via a micro-hydro scheme, implemented under a conventional approach involves the following:

- the micro-hydro installation itself @ Rs. 60,000,
- distribution to the village @ Rs. 25,000, and
- operating the plant @ Rs. 3,400 per year.

The total investment cost for the hydro scheme is Rs. 82,000, and the annual operating cost is Rs. 3,400.[2]

A micro-hydro scheme is therefore a cheaper means of supplying electricity to this "typical" village, since both the investment cost and the annual operating costs are lower.[3] This is in spite of the fact that assumptions used in this comparison have been biased in favor of the WAPDA extension. Specifically:

- the village is assumed to be only 3.5 miles from the existing grid, whereas most NWFP

[1] Unit costs are taken from the Asian Development Bank's "Appraisal of the Rural Electrification Sector Project in Pakistan" November 1981; and from the World Bank's long-run marginal cost study of the WAPDA System.

[2] Cost estimates are based on data presented in Mini and Micro Hydel Plants, ATDO, Islamabad, Pakistan (see Table 1).

[3] In fact, at a 15% discount rate, the present value over 20 years of the capital and operating costs associated with the micro-hydro scheme is less than the present value of the capital and operating costs of the WAPDA extension even if no 11 kV line cost, by far the major cost, is assumed for the WAPDA extension.

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Table 1. Economic costs of schemes using conventional approach (Rs. '000 1982)

Item	Size of scheme 5 kW	15 kW	200 kW
Civil works	32	40	2400 [1]
Turbine and generator[2]	10	20	100
Distribution	40 [3]	50 [4]	1200
House-wiring	14 [5]	40 [6]	600 [7]
Total investment cost	96	150	5200
Annual operating and maintenance cost	2.7 3.4	190	

Footnotes:

1. Includes residential building.
2. Taxes and duties equal to 35% of the market cost have been subtracted.
3. Assumes 1.2 km of line @ Rs. 33,000/km.
4. Assumes 1.5 km of line @ Rs. 33,000/km, 50% for distribution within village.
5. 45 houses are assumed to be wired at a cost of Rs. 300/house.
6. 135 houses are assumed to be wired at a cost of Rs. 300/house.
7. 1800 houses are assumed to be wired at a cost of Rs. 300/house.

Source: Government of NWFP Irrigation and Public Health Engineering Department, "P.C.-1 Proforma and Project Estimate of Kalam Hydle Scheme in Swat District"; and Malakand Irrigation Division, Mingora, Swat.

villages where micro-hydro schemes would be implemented are much farther away;

- only a residential load is assumed—if an industrial load is included, annual energy costs would be significantly higher for the WAPDA extension, but relatively unchanged for the hydro scheme;
- no energy losses have been assumed for the WAPDA system even though average system losses are about 30%; and
- the cost of the WAPDA extension is compared with that of a conventional scheme; if the comparison had been made with a participatory scheme, the difference would be that much greater (see Table 2).

Economic benefits and costs of small hydro

Electricity will be provided to consumers in the NWFP who did not have access to it before. Although it is difficult to estimate their willingness to pay for a product which does not yet exist, what consumers currently pay for the types of energy which electricity will replace gives an estimate. Part of this willingness to pay is measured by what consumers actually pay (tariff revenues and related electrical expenses); this indicates the direct benefits of electrification. Consumers may be willing to pay more than they are actually required. Such benefits obtained by consumers, and yet not paid for, are called surplus benefits. Direct and surplus benefits constitute the total benefits of

Table 2. Economic costs of schemes using participatory approach (Rs. '000 1982)

Item	Size of scheme 5 kW	15 kW
Civil works[1]	8	10
Generator and turbine[2]	10	20
Technical assistance	5	5
Distribution	5	15
House-wiring	14 [3]	40 [4]
Total investment cost	42	90
Annual operating and maintenance cost	2.7	3.4

Footnotes:

1. It is assumed that local villagers donate labor which has a zero opportunity cost.
2. Taxes and duties on the generator equal to 35% of the market cost have been subtracted.
3. 45 houses are assumed to be wired at a cost of Rs. 300/house.
4. 135 houses are assumed to be wired at a cost of Rs. 300/house.

Source: Mini and Micro Hydel Plants, Appropriate Technology Development Organization, 1-B, 47th Street, F-7/1, Islamabad, Pakistan.

electrification as defined in this analysis.

Studies for WAPDA by Pakistani consultants[4] indicate that kerosene lamps are used about four hours per day for lighting in unelectrified households. Electricity supplied by a small hydro scheme can replace kerosene in domestic lighting. It is assumed that half of the unelectrified households own one petromax-type lamp, and the other half own 1.5 hurricane-type lamps.[5] Kerosene consumption rates for these two lamps are approximately 125 cc and 14 cc per hour respectively.[6] An unelectrified household would then use about 27 gallons of kerosene per year for lighting at a cost of Rs. 17 per gallon and have lantern-related expenses of about Rs. 50 per year. Assuming that about three-quarters, or 20 gallons, of the kerosene consumption will be substituted for by electricity, the annual cost of the kerosene lighting for which electricity will be substituted is about Rs. 400. Given typical small hydro system tariffs, the equivalent amount of lighting from electricity will cost about Rs. 160 per year (Rs. 100 in tariff and Rs. 60 in related house-wiring and bulb costs). Surplus benefits of about Rs. 240 savings, per household per year, and direct benefits of Rs. 160 per household per year, amount to a total annual econo-

[4] The consultants were FACE (Fikri and Associates Consulting Engineers) and NESPAC.

[5] This is based on surveys in areas close to urban centers and may well have overestimated the actual kerosene usage in the rural areas.

[6] See the NESPAC feasibility study for the Dera Ghazi Khan Project, Tables 5 and 6, on p. 10.

Table 3. Summary of economic costs and benefits of various types of small hydro schemes (Rs. '000 1982)

Type of scheme	Annual economic cost		Annual economic benefit, yrs. 2-20		
	Year 1	Year 2-20	Direct	Surplus	Total
1. 5 kW participatory/no industry	42	2.7	4 [1]	11 [2]	15
2. 5 kW participatory/with industry	42	4.0 [3]	8 [4]	11 [2]	19
3. 5 kW conventional/no industry	96	2.7	4 [1]	11 [2]	15
4. 5 kW conventional/with industry	96	4.0 [3]	8 [4]	11 [2]	19
5. 15 kW participatory/no industry	90	3.4	13 [5]	32 [6]	45
6. 15 kW participatory/with industry	90	5.1 [3]	26 [7]	32 [6]	58
7. 15 kW conventional/no industry	150	3.4	13 [5]	32 [6]	45
8. 15 kW conventional/with industry	150	5.1 [3]	26 [7]	32 [6]	58
9. 200 kW conventional/no industry	5,200	190 [8]	170 [9]	430 [10]	600
10. 200 kW conventional/with industry	5,200	190 [8]	340 [11]	430 [10]	770

Footnotes:

1. Assumes tariff revenues equal to Rs. 100/house/year times 45 houses.
2. Assumes surplus benefits equal to Rs. 240/house/year times 45 houses.
3. Operating costs in years 2-20 are assumed to be 50% higher than those associated with schemes with only residential loads as a result of the daytime operation of the unit.
4. Includes Rs. 4,000 of direct benefits per year resulting from use of power by small industries.
5. Assumes tariff revenues equal to Rs. 100/house/year times 135 houses.
6. Assumes surplus benefits equal to Rs. 240/house/year times 135 houses.
7. Includes Rs. 13,000 of direct benefits per year resulting from use of power by small industries.
8. Operating costs in years 2-20 are not affected by the addition of a small industry since cost estimates already assume 24-hour operation.
9. Assumes tariff revenues equal to Rs. 100 house/year times 1,800 houses.
10. Assumes surplus benefits equal to Rs. 240/house/year times 1,800 houses.
11. Includes Rs. 170,000 of direct benefits per year resulting from use of power by small industries.

Source: Cost estimates in Table 1.

mic benefit equivalent to about Rs. 400 per household.

For small industries which develop around a hydro site, the benefits resulting from the newly available power can be measured in profits.[7] Although estimates for typical profits are not possible, benefits resulting from the power consumed are conservatively estimated to equal the tariff revenues generated by residential consumers who are assumed to use power only four hours per day. This would generate Rs. 4,000, Rs. 13,000, and Rs. 170,000 per year for 5 kW, 15 kW, and 200 kW schemes respectively. If a conscientious effort were made to incorporate productive end uses as part of small hydropower schemes, benefits could be considerably increased.

If there are no distortions, economic costs are accurately measured by financial costs, except duties and taxes which are subtracted from the costs of imported generators. Labor costs associated with a participatory approach are assumed to be zero because labor is donated in the local villages. Capital costs have been included for the generator, turbine, and penstock used in the 200 kW scheme implemented under a conventional engineering approach, even though they were excluded from the cost estimates presented in the P.C.-1.[8] Finally, the cost of house-wiring (Rs. 300 per house) has been included. All costs are measured at 1982 levels.

Case studies

Case studies of several types of small hydro schemes are presented here; their assumed characteristics, such as cost and load factor, are based on observations by the design team and are thought to be representative of the participatory schemes at Alpuri, Hercho, and Lilloni and the conventional scheme at Kalam. These illustrative schemes are:

1) a 5 kW participatory scheme with residential load
2) a 5 kW participatory scheme with residential and industrial loads
3) a 5 kW conventional scheme with residential load
4) a 5 kW conventional scheme with residential and industrial loads
5) a 15 kW participatory scheme with residential load
6) a 15 kW participatory scheme with residential and industrial loads
7) a 15 kW conventional scheme with residential load
8) a 15 kW conventional scheme with residential and industrial loads
9) a 200 kW conventional scheme with residential load
10) a 200 kW conventional scheme with residential and industrial loads

Data on the cost of each type of scheme were obtained from ATDO and the Irrigation Department of NWFP.[9] The costs and benefits of various schemes are summarized in Table 3.

Investment costs per kilowatt for the conventional micro-hydro schemes are at least twice as high as the same costs for the participatory schemes. On the benefit side, surplus benefits account for roughly two-thirds of the total benefits from schemes without an industrial load and for roughly 55% of total benefits from schemes with an industrial load.

The economic internal rates of return for the case studies are summarized in Table 4.[10]

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[7] Out of the roughly 40 ATDO small hydro schemes currently in operation, a quarter have developed small industries. Many of these run only during part of the day and only for a portion of the year.

[8] These costs were excluded from the P.C.-1 since the equipment in question was given to the NWFP Provincial Government by the Ministry of Water and Power. Despite this fact, there is clearly an economic cost associated with this equipment.

[9] ATDO cost data is contained in Mini and Micro Hydel Plants, ATDO, Islamabad, Pakistan. Cost data for Irrigation Department schemes was obtained from the "P.C.I. Proforma and Project Estimate of Kalam, Hydle Scheme and Swat District" and from the Malakand Irrigation Division, Swat, Mingora.

[10] The EIRR measures the economic internal rate of return which is earned on resources which are used in a particular project. More technically, the EIRR is the discount rate which equates the present value of economic benefits and costs for a project.

Table 4. Economic internal rates of return for various small hydro schemes (%)

Approach	Size of Scheme 5 kW	15 kW	200 kW
Participatory			
Residential load	30	46	-
Residential + industrial load	35	57	-
Conventional			
Residential	12	29	4
Residential + industrial load	15	35	9

Source: Cost and benefit estimates presented in Table 3.

These are low estimates, since it is acknowledged by the World Bank that electrification of a rural area produces an unquantifiable variety of benefits; some benefits resulting from the proposed hydro schemes may not have been included.[11]

A review of recent IBRD and ADB financed energy projects in Pakistan shows the EIRR's of 12% to 15% were considered acceptable. There is a strong economic justification for the typical, small participatory schemes, even if they supply only residential consumers. EIRR's for the 5 kW and 15 kW participatory schemes are about 30% and 46%, respectively. If an industrial daytime load is added, the economic justification is strengthened and the EIRR's are 35% and 57%, respectively.

The economic justification for the 5 kW and 15 kW conventional schemes with only a residential load is more marginal. EIRR's are about 12% and 29%, respectively. The lower EIRR's for these schemes are the result of their significantly higher fixed costs for distribution and construction of the power station room; the addition of a small, daytime industrial load strengthens their economic justification, raising the EIRR's to 15% and 35%.

There is a weak economic rationale for larger, 200 kW conventional schemes which have only a residential load. The EIRR for this scheme is 4%. This low EIRR is the result of higher unit costs: per kilowatt costs of the penstock, the power station room, the generator and turbine, and distribution are 2.8, 3.5, 3.6, and 1.8 times higher, respectively, than for the smaller conventional schemes. Unit cost differences are even greater when compared with the participatory schemes. If daytime industrial load is added to the conventional 200 kW schemes, the EIRR increases to about 9%. Thus, a principal finding with respect to such larger conventional schemes is that they will not have a marginal economic justification unless accompanied by a productive-uses plan to utilize power at least during the day.

One weakness should be noted. This approach assumes that the same economic benefits result from a participatory or conventional scheme of a given size. Benefits occurring in a conventional scheme from improved reliability or safety of supply have not been quantified.

[11] For example, small hydro might ease demand pressure on increasingly scarce conventional energy resources such as wood; or, it might allow the use of locally produced capital for developing alternative sources of energy such as extension of the WAPDA grid or increased production of oil or gas.

Economic analysis: summary results

Conclusions of the economic analysis can be summarized as follows:

- Micro-hydro schemes are clearly a lower-cost means of supplying electricity to remote villages in the NWFP than extending the central grid.
- Results of the economic analysis indicate a strong economic justification for participatory small-hydro, even when domestic lighting rather than commercial, income-producing end uses are the case. This justification increases with the addition of a small industrial load and with an increase in the size of the unit.
- The conventional micro -hydro schemes have adequate economic justification. For the conventional mini-hydro schemes, however, the development of a suitable industrial load is necessary if the schemes are to have a marginal economic justification. A plan for industrial development and for end-use marketing of the output should be an integral part of any conventional mini-hydro program. This planning should be undertaken during site identification. Cooperation between government institutions in Pakistan which are responsible for hydro development and small industries development should be encouraged.
- Research on the application of the participatory approach to the larger mini-hydro schemes should be encouraged. The nature of benefits which result from the relatively sophisticated designs of larger conventional schemes should be also investigated.
- Financial savings resulting from the switch to electricity from kerosene have implications for pricing electricity produced by small hydro schemes. They indicate that consumers' willingness to pay for electricity is greater than the amount they are required to pay: tariffs charged to consumers could be raised considerably without reducing the number of consumers. Such a tariff increase would improve the financial viability of these projects. Local entrepreneurial participation should be encouraged, thus reducing the commitment of government resources. At some stage, it might be advantageous to put the small hydro program on a commercial basis by removing government subsidies and setting tariffs equal to costs.

CONCLUSION

The NRECA team recommends that a comprehensive plan be drawn up to implement small hydro projects in the NWFP of Pakistan. The requisite natural resources are rich and the potential benefit, both domestic and commercial, to the isolated communities of the province is great. Priority should be given to the implementation of the 20 prototype mini- and micro-hydropower schemes. Institutional evolution and the growth in planning and managerial expertise will progress if training recommendations are implemented. An ongoing evaluation process for small hydro projects must be developed, and continued local participation should be encouraged. The long-term success of small hydropower plants will be measured by the extent of continuous community commitment to the benefits accruing domestically and commercially from electrification.

APPENDIX

Contacts

In developing this project, the NRECA team contacted the following individuals:

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A. Rauf Khan	Secretary Irrigation and Public Health Engineering Department Peshawar, NWFP
Sahibzada Riaz Noor	Chief Economist Planning and Development Department Peshawar, NWFP
Imtiaz Ali Quazilbash	Managing Director Engineers International Ltd.
Nisar Mohd. Ali	Project Director (also in charge of Power Wing) Small Hydel Power Station Peshawar, NWFP
Asif Ali Sheikh	Vice Chairman Appropriate Technology Development Organization Islamabad
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Jan Nadir Khan	Chairman Kohistan Development Board Besham, NWFP