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SMALL HYDRO POTENTIAL IN DEVELOPING COUNTRIES

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874

INTRODUCTION

Flowing water has been used for centuries as a source of energy. Water wheels of various types launched the industrial age by contributing energy other than human and animal muscle power. Hydropower is a well established, proven technology. Reliable performance expectations can be made, with efficiencies of site specific equipment now reaching as high as 95%.

The technical simplicity of small hydropower systems is a primary advantage. Moving parts are few in number and many can be fabricated locally. This is significantly important for the successful introduction of small hydropower systems into remote, rural areas of developing countries.

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A large, yet unexploited, hydropower potential exists worldwide. This renewable energy resource is one of the most promising energy options for developing countries, which on the average have developed less than 7% of their potential. (Armstrong, 1980).

Relative to other renewable energy sources, mini-hydropower is more immediately available and converts directly and easily to mechanical, electrical, and thermal energy. Wind power, while more widely distributed than hydropower, yields relatively low amounts of energy and requires large structures. At isolated sites, storage facilities must also be provided to make up for high variability. Harnessing solar power through photovoltaic cells requires no moving parts but only produces electricity, and storage needs must be met. Photovoltaic cells and other solar hardware are still expensive and cannot be produced locally. The caloric energy value obtained from biogas production from dung is actually greater than burning an equivalent portion of dung, and a valuable fertilizer is also produced. But this energy source relies on often touchy biological processes and requires a large feedstock to replenish the digestor and receptive social conditions in order to implement it. Biomass is the most conventional renewable energy source and is one which can be developed with the least capital and technological inputs. It is potentially accessible to all at virtually no cost. But in many less developed countries, the natural ecosystem is suffering from overuse of this once-plentiful resource. Problems of deforestation, top-soil erosion, and heavy silt deposits in riverbeds and behind dams are pointing out the need to reforest large areas and to find a rural energy source which can be, at least partially, a substitute for biomass until the forests can again be harvested under properly managed schemes.

Small-scale hydropower is also a wise alternative to petroleum and other imported fuels. Foreign debts of many developing countries are being aggravated by escalating prices brought about by a dependence on limited and increasingly expensive supplies of

petroleum fuels. On the other hand, the initial investment required for small hydropower schemes can be quickly repaid because recurring costs are low, and the fuel, available in the rural as well as urban areas is virtually free.

The underlying concern for developing rural hydropower systems is the need for an indigenous, reliable energy source that is affordable. Such an energy base can act as a catalyst for the development of other local resources and the creation of productive opportunities, breaking the poverty cycle so common in rural areas of developing countries. This leads to potential improvement in the well-being of the rural poor on a long-term basis, rather than short-term "band-aid" development approaches that treat symptoms only and must be repeated over and over again.

EXPERIENCES TO DATE

With an increasing awareness of the effect of a dependence on imported petroleum-based fuels on a nation's economy on the one hand and the potential of small hydropower plants on the other, a number of countries have recently begun considering this power source in earnest. Previously, it was often individuals from the Western countries who, because of their access to financial resources or possession of specialized skills, first installed such plants in the developing countries. One finds, for example, numerous mission stations as well as old gold mining sites throughout Papua New Guinea, all installed and operated by expatriates and utilizing expensive turbo-generating hardware available decades ago. In Colombia can be found a number of small foundries which have been casting runners for decades as well as numerous skilled and resourceful individuals, generally of overseas origin who have installed their own plants.

More recently, national governments have taken an increased interest in exploiting their hydropower potential by means of small plants. The People's Republic of China is the first and only country to undertake this on a large scale. To date, more than 50,000 plants under 500 kW capacity have been installed, most of them built by the people's communes at the county level and used by the commune members, supplying electrical power for local industries and small workshops. Whereas virtually all hydropower generating sets were previously imported, China began local manufacture of a wide range of turbines in the early 1950's. In the early 1970's, standardization of turbo-generating equipment with outputs 12-12,000 kW was undertaken. Recently the Tianjin Electro Driving Institute has developed small compact turbo-generating sets from below a kilowatt to 20 kW. Thousands of these are produced annually. In the construction of their plants, stress is placed on maximizing use of locally available materials. This results in low costs, ranging from 1-3 cents/kW, and a return of investment for a small hydropower station of 3-4 years (Jing and Li, 1979).

In the Asian region, a number of other nations have initiated small hydropower programs.

The State Electric Power Company (P.L.N.) in Indonesia began the installation of small hydropower projects with their Five Year Plan of 1969. Over the first ten years, 26 plants with capacities up to 500 kW were installed and contributed a total of 4 MW. Another 8 plants with a total capacity of another 3.5 MW were still under construction. Initially the aim was electrification of isolated rural areas with units whose capacities ranged up to about 100 kW. However, with the growing global energy crisis, present efforts are focused on larger units, on interconnection with the grid, and on optimizing and maximizing plant capacity. Many of the turbines are manufactured locally in one or two large workshops. Small workshops are entrusted with fabrication of turbine

components (Elliott, ed., 1981). Several groups are involved in addressing needs of remote isolated communities through the development of small micro hydro systems.

In 1979, the National Electrification Administration, which had developed a nationwide system of locally owned and operated electric distribution cooperatives in the Philippines was assigned the task of executing a mini-hydro development program. Less than three years later, it has placed five power plants in operation, initiated construction on five more sites, placed equipment orders for about 20 plants and have completed 45 feasibility studies. Initially overseas firms are supplying most of the electro-mechanical equipment but within the next several years, a majority of the equipment should be manufactured locally. By the end of 1987, at least 250 plants with a total installed capacity of 300 MW are expected to be operational. (Elliott, ed., 1981).

Urged by the looming firewood crisis and the need to assist rural development, the government of Nepal has initiated a small hydropower program and 20 schemes, from 60-1000 kW, are under various stages of design or construction. (Elliott, ed., 1981). Several private companies have developed designs for small cross flow turbines with the assistance of expatriate expertise and these are being installed at an increasing pace, primarily to directly drive agricultural processing equipment in the remote parts of the country. More than 50 plants, with capacities averaging 10 kW, have been installed to date. Only the processing equipment and bearings are imported from India.

Pakistan's Appropriate Technology Development Organization has also been involved with installation in the remote northern areas of the country. These involve rudimentary, locally fabricated, cross-flow turbines used to drive both generators and a wide variety of agricultural processing and workshop equipment. All aspects of installation, operation, maintenance, and management is undertaken by the local villagers. This

coupled with the use of locally available materials wherever possible contribute to the unusually low total installed cost of US$250-400/kW. (ATDO)

Several agencies of the government of Thailand have recently embarked on small hydropower programs to tap the resources in the rural, mountainous portions of the country. Whereas most of the equipment used to date has been imported, the National Energy Administration is developing and testing turbines in the micro range. Several have already been installed to date.

Whereas there are scores of private micro-hydro installations through the rugged mountains of Papua New Guinea, it is only recently that the national government has become involved. It is presently involved in the installation of four plants with outputs ranging from 200-500 kW. In order to reduce the costs of small units, the Appropriate Technology Development Institute and the University of Technology are involved in the design, testing, and fabrication of turbines and related equipment and in their installation in village settings. (Elliott, ed., 1981).

Other developing countries is Asia, including Sri Lanka, Malaysia, Fiji, and Turkey have also been involved in some aspects of research or implementation of small hydropower schemes.

Some work has also be undertaken in Latin America.

History in the use of small hydro plants in Colombia extends back to the end of the last century. To this date there are numerous small foundries which can cast turbines and fabricate and install hydro units. At the national level, the Instituto Colombiane de Energia Electrica (ICEL) has been charged in 1973 with the development of small

hydropower schemes up to 10 MW to cover some of the many areas which will remain with no possibility of grid electricity. After making a preliminary survey, further studies were justified at twenty sites and a dozen schemes in the 40-1,000 kW range are presently in the feasibility and design stage, with the work being undertaken by five national consulting firms. (C.CH.LG. Ltda, 1980).

Before launching the national grid, fifty small hydropower plants were installed throughout Ecuador. Many of these have been superceded by the grid. At present efforts by the Ecuadorian Electrical Institute (INECEL) are underway to initiate a small hydropower program which would include refurbishing some of these old sites. (USAID,1980).

In 1978, a program was initiated by the Ministry of Energy and Mines in Peru to undertake all aspects of new and ongoing small hydropower work. The following year, activities from feasibility studies through to actual site construction of both new and reactivitated projects at 38 sites were undertaken, with capacities of from 80 to 2,000 kW, averaging 400 kW. (Ministerio de Energia y Minas, 1980).

To date there seems to have generally been little work done to date in Africa in the area of small hydropower. A number of mission stations in remote areas in the central and eastern portions of the continent have installed small schemes.

SYSTEM VARIETY

There are several ways of classifying or categorizing small hydropower plants. One of the most common is based on system capacity. Plants generating under about 100 kW are

classified as "micro". These are generally found in remote areas far from the main grid. They may serve rural communities, hospitals, mission stations and government outposts. These installations might be very capital-intensive but they often need not be. Local materials may be used for a large part of the scheme, and these units can often be designed simply and fabricated in-country. These schemes are often managed and operated by local personnel. Plants above the micro range, up through about 1000 kW are generally considered "mini". These are often installed to serve small towns and it becomes economically advisable to consider connecting these units on to the national grid if it is readily accessible. Proper management of these plants becomes more complex but increasingly essential. Larger civil works are generally required and the turbo-generating and control hardware become more sophisticated, often with less of an opportunity for local manufacture.

In each of these two categories, hydroplants can be classified according to their requirement for water. They can either be run-of-the-river schemes or else require impoundment. Where the river flow is more than sufficient to meet the power requirements year-round, a run-of-the-river scheme can be constructed. This simply involves the diversion of a portion of the flow in the river through the intake to the hydro scheme. No dam is usually necessary though a permanent weir can be built across the river bed to prevent the gradual lowering of the river bed in the vicinity of the intake through erosion over the years. In areas where no noticeable lowering of the bed is apparent, a weir may be built simply to ensure that the water is diverted toward the intake during periods of low flow.

A scheme requiring impoundment may be required either in regions of pronounced dry periods during which time the flow of the river is not adequate to supply the power requirements or on streams where the flow is more than adequate during one portion of

the day but insufficient during another portion due to increased power requirements during that time. Schemes requiring impoundment require the construction of a dam and these require careful design and site location.

These schemes can be further classified according to head requirements. A low-head installation requires a larger flow of water than high-head sites for the same power generation. This implies larger and therefore more costly turbines and the necessity of tapping a large river. With the large and intense rainfall in many parts of the tropics, tapping large rivers can lead to major problems with the intake structure. The intake must be able to handle a river whose depth may vary widely and which often transports large quantities of debris, of tree trunks, bouiders, gravel, and sediment. Also because of the requirement for higher flow, if an impoundment is required, it must be of a much larger size than an impoundment for an equivalent power, high-head site. More thought need then be placed on the technical and environmental implications of such a large inmpoundment.

A high-head site, on the other hand, would require lower flows to produce the same desired power and possess a number of advantages. The lower flow implies the need for a turbine smaller in physical size and cost. It also means that a smaller source of water need be tapped, simplifying the design of the civil works at the intake.

INTEGRATED SYSTEMS

The cost of the civil works for small hydropower schemes often accounts for a large portion of their overall costs. This is especially true when more conventional approaches are adopted as, for example, in the heavy use of concrete for headrace canal and the use

of relatively large dams or weirs. It is however possible to integrate small hydropower schemes into broader water-related projects — flood control, irrigation systems and water supplies — and thereby share costs of the common components among several projects.

Indonesia has, for example, a large irrigation network on its most populous island of Java. Integration into that system has been a part of its small hydropower program. This integration has taken two forms:

1. Circumventing the water around existing irrigation drops. A plant at Wonodadi, for example, which uses a drop of 3-4 meters to generate 200 kW required the construction of only a power house and a short length of intake canal. Canal flow remains unaffected.
2. Using canal flows in excess of those required for the immediate irrigation needs. At these sites, irrigation water is diverted to an appropriate point where energy can be extracted from the water before it is returned to the river.

Alternatively, as part of a flood control scheme, a series of dams might be constructed. Turbo-generating units might be included as part of these structure to make use of the variable flows which are probably available year-round.

Or, on occasion, the source of water for a community or town water supply might be at such an elevation as to require pressure reducers. Turbines could be installed to serve that purpose and generate electrical power in addition.

ISSUES

A. Paucity of hydrologic data for adequate planning

After locating sites for SDH schemes which seem to possess sufficient head, are near end-users or a grid connection, etc., there is a need to determine whether sufficient flow is available year around. This is required for several reasons:

1. Funding is generally conditional to the site being economically viable and adequate flow is an essential condition for this to be possible
2. Cost-effective choice of turbine equipment and design of the civil works requires that the flow characteristics are known with some degree of accuracy.

Specifically there is a need for a knowledge of the peak stream flow at a site for the design of the civil works at intake as well as for a flow duration curve at the site. The latter is a curve relating the flow frequency to time throughout an average year. Its use is for equipment selection and forecast of project capacity and economic viability. The gauging of rivers is usually used to obtain the required information. However, in most developing countries, this is not performed except possibly on larger rivers and tributaries. The chance is better that meteorological data has been obtained more widely and methods must be designed so that this data coupled with topological and geographical information can be used to predict peak flows and flow duration curves. Even then, high accuracies cannot be expected.

B. Equipment and Design

Is there a net advantage to importing and installing sophisticated, well-engineered units bought from the West by developing countries? What effects does this have on system cost, on the ability of these countries to repair and maintain them, and on the ability to reproduce similar schemes elsewhere in the country.

Western equipment is designed specifically to cater to Western needs (such as precise frequency control and maximization of efficiency) and realities (such as availability of sophisticated or costly materials or the need for automation because of the high labor cost). But the realities in developing countries may not always coincide with these needs and realities. Local manufacture may be more attractive: lack of capital, need for wide-scale reproducibility, desire to maximize use of local workshops and available indigenous skills. Towards this end, China has,for example, fabricated turbines of wood and concrete and Pakistan completely avoids the use of governors and can make up lower efficiencies by slightly increasing the size of the runner.

What are the possibilities of local manufacture? China, India, and Indonesia have been manufacturing a range of turbine sizes for years. The Philippines also is entering the field. With smaller schemes, local fabrications becomes more widespread. Several companies in Nepal have been manufacturing well-engineered turbines and now a growing number of small workshops are also beginning to manufacture these. Similar examples can also be found in Colombia, Pakistan, Thailand, and Papua New Guinea.

At what point should a nation consider the advisability of fabricating the other components essential to a hydropower program? Some countries have the necessary resources and expertise and are fabricating their own generators. On the other hand,

very few are involved in the manufacture of governors, primarily because this is a component for which quality control is essential and for which little demand exists to date.

What designs for the civil works should be adopted? Reinforced concrete structures are commonly used but are costly and often over-designed. Designs and materials should address the specific conditions prevalent in many tropical countries, e.g. immense variations of flow, poor quality control in manufacture, and large bed and silt load due to deforestation. Local materials, including stone, brick, timber and soil, might be more appropriate, and designs to make best use of these should be considered. Pakistan uses wooden penstocks where appropriate, Nepal avoids permanent structures in its streams and uses temporary stone weirs to deflect water into the intake, and in Colombia, a soil-cement mixture has been used in the contruction of headraces.

C. Economics

(Opportunity Costs)

When considering limited national budgets, sinking funds into rural development projects that offer little if any hope for a worthwhile economic return, and continuing to commit valuable funds to foreign energy suppliers is surely not desirable. The opportunity costs associated with a nation's energy plan need careful thought. How are the country's own natural resources being utilized? Endangered woodlands can provide internal and external markets with valuable raw and/or processed materials, rather than the wood being used solely as a direct fuel source. Colombian officials report, "Wood has represented a participation between 41% and 23% in the consumption of energy during the period 1965-1977 and it is hoped that its contribution will have been reduced to 10%

by 1990....In this way the serious effects of wood burning upon the ecosystem may be avoided." (C.CH.LG. Ltda, 1980).

In the same way, questions can be asked conerning the present activities of the rural poor. How are particular tasks such as cooking and the transport of water performed. In Nepal and northern India, pumping drinking water reduces time and effort spent by women fetching and carrying water from nearby streams which can in some countries entail round trips of many kilometers. In what other activities that would be more productive could so many participate?

Some activities from which the rural population benefit require an outlay of cash on their part. In these cases, the introduction of a mini-hydro system will bring a cash savings or consumers' surplus benefit to the community. This extra capital, whether from an existing or contemplated cost, is then free to be spent elsewhere.

(Substitution)

Reserves of fossil fuels (oil, natural gas, coal) are decreasing day by day and their prices are increasingly high, unstable and unpredictable. For use in rural areas, these problems are compounded by difficulty in transportation and handling, and complicated maintenance requirements of the systems. The development of small hydroelectric plants can play a very important role in a nation's energy plan, by decreasing energy costs and reducing dependence on imports. Kenya's energy consumption, for example, is mainly dependent on imported petroleum based sources and exceeds 30% of total national imports. (Industrial Survey and Promotion Center, 1979). Similar situations exists in a number of other nations. To the extent that mini-hydro units can replace fuels used in diesel generators, kerosene lamps and stoves, and other petroleum-consuming devices, they can serve to marginally reduce foreign exchange costs.

Mechanical and electrical power from a mini-hydro plant can also serve as needed substitute for traditional energy sources. For example, either form of power can be harnessed for use in domestic cooking which accounts for most of all rural energy use. This can replace charcoal or wood burning which has caused the rapid depletion of valuable forest resources, leaving the land exposed to soil erosion and further reducing its fertility.

(Infrastructure)

A major source of domestic instability in developing countries is the migration of poor people from the countryside to the major cities and the costly burdens that this places on the national governments. The development of an adequate and affordable rural energy supply can facilitate the improvement and development of infrastructure, of medical and educational facilities, of communications and transportation systems. It can assist in the provision of basic necessities, of adequate food, clothing, sheiter, and employment. All these factors should tend toward offsetting the attraction of the urban areas and serve as the foundation for any successful rural development program.

The case of Colombia, for example, shows that the principle necessity is for electrical power for lighting for health centers and schools. The possibility then exists of using energy for local industry. (C.CH.LG. Ltda, 1980). Overcoming the disequilibrium between rural and urban production and consumption and resulting socio-economic problems is of great concern to developing country leaders.

(Income Generation, Employment)

Even if rural infrastructure is developed, the lack of a secure energy supply restrains

further economic development. Potentials in both income generation and employment opportunities depend on an energy which small hydropower might provide. Most people in rural areas rely heavily on agriculture for their livelihood. Even the landless, who comprise the lowest-income group, have much to gain from the introduction of an energy system that will increase employment potential. (World Bank, 1975).

Hydropower has great potential for increasing the productivity of local agriculture. When used in conjunction with irrigation schemes, raising yields can be accomplished by expanding the amount of arable land, lengthening the growing season and increasing the number of plantings. Grinding and milling of grain, extracting oil, and other agricultural processes are greatly enhanced by mini-hydropower's mechanical and electrical capabilities. Both time and finished product are conserved. The Chinese have simultaneously developed forestry, livestock and fishery activites around their small hydro stations. (Jing and Li, 1979).

Described as the key to the economic advancement of the poor, rural employment opportunities utilize the labor productivity of the millions otherwise unemployed or underemployed. Industrial production techniques at even the smallest scale, require energy as an essential input in one form or another. (Industrial Survey and Promotion Center, 1979) Craft industries, commercial activities and other side-occupation industrial are able to expand operation. Refrigeration in shops and services, motive power in workshops (carpentry, welding and repair shops), water pumping, mills, etc. raise the community level of output and subsequently, the level of rural income also rises. Increased production can be used to more adequately meet local needs, and any surplus can be exported for increased local income generation.

(Convenience/Indirect Benefits)

The category of indirect or "convenience" benefits is much more difficult to quantify but is of great value to rural people. Household and community lighting are popular initial uses of electrification. Within the financial and technical constraints of the system, household convenience appliances are then added. In addition, income-generating activities such as ironing and sewing can be conducted from within the home.

D. Environmental Impact

Especially in subsistenance agricultural communities where life is tied so closely to the natural environment, the environmental impacts of any proposed energy system need careful consideration. If the system has been properly designed and constructed, small-scale hydropower schemes cause only negligible adverse impacts to water quality and land use. In the water system, increased siltation may occur, but is easily controlled by choosing the proper design for the geologic conditions of the site. Aquatic life may be adversely affected, especially when impoundments are involved. If desired, smaller versions of common fish ladders can be added to larger structures. If no impoundment is needed and only part of the flow of the stream is diverted to the intake, then no special structures are needed.

Except for plants in the micro range, the construction of hydroelectric schemes may produce some impacts with regard to land use. A reservoir may result in flooding of arable land. Other project components such as canals, penstock, power house, and transmission and distribution lines will also impose some land demands. Canal design and construction is a factor of particular importance due to the risks of erosion and therefore potential loss of productive soils and also the possibility of increased incidences of

bilharzia (schistosomiasis). If planned properly, with special regard given to variability of weather patterns, this should pose little problem.

Consideration must also be given to area land use and subsequent impact on water rights and dependable flow, i.e. irrigation withdrawals, water supply, etc. Another important factor in land use is the degree of existing development. If the environment is already severely stressed by various forms of development, then an additional incremental project, no matter how small, may have a disproportionate impact.

As previously stated, the greatest potential environmental impact of small hydropower is a positive one — that of reducing the need for traditional energy sources and the subsequent overuse of local forest and woodland areas.

E. Development Approach

With little interest in small hydropower until recently, most hydropower undertakings were limited to large schemes. Now, with growing interest in smaller schemes, the capital intensive approach used in large schemes continues to be used. This approach is often reinforced by a reliance on Western consultants whose training and experience has to datea primarily been restricted to capital-intensive projects. The use of sophisticated western technology results in increased costs and potentially continuing reliance on external expertise for maintenance and repair.

Of all energy sources, the development of hydropower can make maximum use of local materials. Local materials such as stone, gravel, sand and wood are easily obtained in

rural areas. To minimize costs, imported materials such as concrete and reinforcing steel bars should be used only where essential and designs must cater to this option.

Realities in a number of the less developed countries is such that capital is at a premium, but that a large labor pool exists. Both India and PRC are examples of countries placing a heavy reliance on locally available labor, supplemented with heavy equipment only when and where appropriate, for construction of even massive civil works. Use of rural labor might be maximized especially on smaller schemes and designs might be adopted which make this possible. Maximum involvement of local villagers of course also has numerous spin-off benefits which can give further impetus to rural development.

F. Management

In many nations, the generation of electric power is an undertaking of the state and these efforts have been largely restricted to the larger hydro and thermal generating stations. These are relatively few in number, are located in population centers, and are therefore relatively easily managed centrally during construction as well as during operation.

With the advent of small decentralized hydropower generation of electricity, it seemed natural that these be managed by the same state agency. But shifting the focus of management to smaller plants is difficult because of the very nature of the small decentralized system. The plants are small in size, potentially large in number, and generally are found in more remote areas — far from both population centers and developed infrastructure. These factors combine to make small hydropower's potential role in a nation's energy plan highly dependent on a radically different management scheme.

G. Financial Aspect

Probably the most important single economic characteristic of hydropower projects is the relative absense of escalation in the total cost of power generation. Hydropower facilities have a long life. Dams and civil works will generally perform for decades with little maintenance required. As no fossil fuels are required, operating costs are low. Because of this and the long life of the facilities, a hydropower installation is essentially inflation-proof. This is a unique financial advantage to hydropower schemes.

In most developing countries, power generation is overseen by the national government or one of its appointed agencies. Funding is usually handled through the national authorities, with help from international funding institutes, regional development banks, and national funds. But funding from large funding organizations presents a problem. Because of relatively fixed administrative and overhead costs geared to single, large scale, capital-intensive projects, these organizations find small hydropower projects very expensive on a cost/kilowatt basis. According to an official of one such organization, requests for funding assistance for such projects is simply viewed by them as having a "nuisance value". One alternative for funding small hydropower projects which is being considered is the designing of one project which itself includes the installation of a series of small hydropower plants. This permits a larger financial sum to be committed toward a single umbrella project and integrating a number of similar schemes facilitates overall management and execution.

On occasion, small hydropower schemes can be implemented by local communities who are to use and directly benefit from these schemes. Local funds, possibly augmented by outside organizations, can be used. With properly designed low-cost schemes, this

approach permits the implementation of small hydropower projects on virtually a self-reliance basis with most effective use of available resources, financial and otherwise.

CONCLUSION

It may be seen then that small hydropower has a substantial potential world-wide. The most extensive development has occurred in Asia, followed by Latin America and Africa and a substantial potential still remains on these continents.

System configurations may include both run-of-river and impoundment schemes, depending on system capacity and available flow.

There is a strong potential for developing large numbers of sites in an integrated program, for multiple use schemes and for hybrid systems.

Issues are focused around a lack of hydrologic data, proper equipment and design, economic considerations, and environmental impact.

Development approaches vary between centrally planned, capital intensive and decentralized, labor intensive programs. Management entities must recognize the risks and benefits of each.

Financial considerations include advantages of life-cycle costing, care and maintenance, biases of large funding organizations and local funding abilities.

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