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ABSTRACT

Described are the history, current status and future potential of hydroelectric power in the world. Issues discussed include the environmental and social impacts of dam construction, and the use of small-scale hydroelectric installations in developing nations. Also considered are hydroelectric development of the world's remote regions, the need to make better use of existing dams, and new directions in hydropower. (WB)

Rivers of Energy: The Hydropower Potential

Daniel Deudney

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Falling water is the source of one-quarter of the world's electricity today. Whether harnessed by a slowly turning wooden waterwheel on a tiny stream in Nepal or by a hundred-ton steel dynamo at Aswan on the mighty Nile, all hydropower comes from the ceaseless cycle of evaporation, rainfall, and runoff set in motion by the sun's heat and the earth's pull. By harnessing water in one step of this cycle, as it flows back to the sea, waterwheels and turbines convert this natural and endlessly renewable energy into a usable form.

Yet hydropower is a neglected energy resource, too often forgotten in the scramble to cope with the energy crunch of the seventies. Hydropower is so much a part of the landscape that its enormous untapped potential is in danger of being shortchanged by energy planners, whose decisions today will shape the economic and environmental prospects of future generations.

Despite the billions of dollars spent subsidizing nuclear power, hydropower provides a great deal more electricity on a worldwide basis. And in the United States, the world's largest producer of nuclear-generated electricity, hydropower maintains a substantial lead over nuclear energy. Given the myriad economic and environmental problems facing nuclear power, hydropower's lead seems certain to widen in the years ahead.[1]

Compared with other sources of electricity—oil, coal, and nuclear—hydropower has environmental advantages. While large dams can cause environmental damage if not carefully planned, hydropower emits no health-threatening pollutants. Nor does it threaten the earth with catastrophic and irreversible change, as does nuclear waste and the carbon dioxide emitted from coal-and oil-fired generating plants. These environmental concerns are too often neglected both in choosing between hydro and thermal power plants and in implementing hydropower projects.

In a world suffering from inflation and fossil-fuel depletion, hydropower offers stable prices and permanence. If properly managed, hydroelectric complexes will be producing power long after the oil

I wish to thank Ann Thrupp for her assistance with the research for this paper

wells run dry and the coal fields are exhausted. Economic development based on energy from running water offers something unique among major resources in use today: sustainability. The transience of oil wealth compared to water wealth has not been lost on the oil-exporting nations with undeveloped water potential. Venezuela, Iran, and Mexico have all launched ambitious and costly plans to invest their newfound—but easily dissipated—oil wealth in hydropower. Flush with revenues from North Slope oil, the state of Alaska is seeking ways to harness its 140,000 megawatts of hydro potential.[2]

The fact that water resources exist in abundance in many of the world's poorest regions and nations places hydropower high on the global development agenda. The oil-price explosion that made a traditional oil-based economy unattainable for many Third World countries underscores the importance of indigenous water resources. Unfortunately, the rise in oil prices that made hydro development more attractive also weakened the ability of many poorer nations to borrow money for large programs. Small-scale hydro projects, however, could profitably use indigenous labor and materials and help developing countries break the cycle of impoverishment and dependence.

Hydropower will occupy a pivotal role in the emerging effort to put the world economy on a sustainable basis. Alone among renewable energy sources, hydropower is a proven technology that can provide the large, concentrated quantities of electricity needed to run factories and to light cities. If all the world's economically available hydropower were harnessed, most of the world's electricity needs could be satisfied. On a planet threatened by nuclear power's faustian bargain, coal-induced climate changes, and shrinking oil reserves, water's power should not be allowed to slip by.

A Long History, A Bright Future

The use of hydropower throughout history has been shaped more by social and political conditions than by the availability of a particular technology. Although the Romans knew of waterwheels, they did not make extensive use of them because slavery and, later, wide-

"If all the world's economically available hydropower were harnessed, most of the world's electricity needs could be satisfied."

spread underemployment removed any incentive to save human labor Wars and famines accompanying the fall of Rome, combined with the Black Plague that killed a third of Europe's population in the fourteenth century, made labor-saving water mills more attractive: tens of thousands were in use throughout the continent by the end of the eighteenth century.

The spread of this use of hydropower was accompanied by social dislocation and conflict as small farmers resisted bringing their corn to village mills, preferring to rely on traditional hand grinders. In France, the government outlawed hand mills in an attempt to stimulate the use of water mills and to force peasants to use supervised facilities, where tax collectors could accurately assess and tax the grain. Waterwheel technology spread to the New World and flourished in regions without slaves, such as the English colonies of North America, where labor was always in short supply By the end of the eighteenth century, there were about 10,000 waterwheels in New England alone.[3]

It was during the nineteenth century that hydropower became a source of electricity as well as of mechanical power In 1820 the French engineer Benoit Fourneyron invented the turbine. The turbine was to the waterwheel what the propeller was to the side paddle—a submersible, compact, and more efficient machine for energy exchange. Turbines were linked to generators to produce electricity for the first time in Wisconsin in 1882, and the development of alternating current by George Westinghouse at Niagara Falls in 1901 made the transmission of power over distances economical The essential contours of the technology have been refined since then, but not surpassed.[4]

Hydropower technology typically is used at dams where falling water can be regulated and stored, although the early mills rarely had dams big enough to store much water. The first hydro facilities, known as run-of-the-river plants, cease to generate power during the dry season when streams and rivers are low. Until the costs of inundated land began to emerge as a constraint, planners built large dams if they wanted continuous power. Since the oil shock of 1973, there has been a renewal of interest in the intermittent power from run-of-the-river dams, many of which were abandoned when petroleum was cheap.

Rising energy prices have also sparked interest in a largely forgotten hydropower technology that does not depend on dams at all During the Middle Ages, before dams were common, waterwheels affixed to barges anchored in rivers were widely used. Such floating hydro plants do not need expensive and ecologically disruptive dams and
8 can tap otherwise inaccessible water flows Several countries are now trying to modernize this old technique and to assess its costs If this technology proves economical, the amount of practically available hydropower in the world could increase dramatically.[5]

Since the thirties, most of the new energy from hydropower has been from major dams with reservoirs in the middle and lower sections of large rivers, first in the United States and the Soviet Union and then, since World War II, in the developing world as well. China has recently revived the use of small dams, although it has lagged in building larger facilities. Since 1882, when water power was first used to produce electricity, hydro's contribution to the world's electricity supply has increased steadily. In 1980, hydropower produced 23 percent of the world's electricity, accounting for about 5 percent of total world consumption of energy. This power was generated at dams having a combined capacity to produce 363,000 megawatts.[6]

Yet most of the world's hydropower potential is untapped. If all the energy contained in the water flowing to the oceans were harnessed, a staggering 73,000 trillion watt-hours could be produced annually. By comparison, total world hydro production is currently 1,300 trillion watt-hours However, only a small fraction of the theoretical potential can actually be tapped, given technical constraints. The World Energy Conference estimates that the world's technically usable potential is 19,000 trillion watt-hours, produced at dams with a capacity of 2,214,700 megawatts Environmental and economic constraints that are difficult to quantify will prevent use of an indeterminate amount of this resource Yet even taking all constraints into account, world hydro production could reach between four and six times its present level[7]

This potential is so great that theoretically all the world's electricity needs could be met Of course, the absence of significant hydropower resources in regions like the dry Middle East will prevent complete reliance on hydroelectricity. Nevertheless, a quadrupling of global hydroelectric production—a realistic goal—would yield roughly as much electricity as the world currently consumes. If augmented with other locally available renewable sources of electricity such as wind systems, photovoltaic cells, or geothermal plants and made more productive through cost-effective efficiency improvements, the world's hydropower resources are large enough to permit a healthy growth rate in electricity use. An expansion of hydropower's role along these lines could largely eliminate the need to build the coal and nuclear power plants favored by energy planners in the wake of the oil-price revolution of the seventies.

Although hydropower potential is widely distributed, the areas with the greatest resources are typically mountainous zones. Asia has 28 percent of the world's potential, South America, 20 percent, Africa and North America (including Central America), 16 percent each, the USSR, 11 percent, Europe, 7 percent, and Oceania, 2 percent. Some regions are much further along than others in using their water resources. (See Table 1.) Europe, Japan, the United States, eastern Soviet Union, and southern Canada have done the most to harness this power source. Indeed, Europe has exploited almost 60 percent of its potential. With a fourth of Asia's potential, Europe produces nearly twice as much power. Africa has developed only about 5 percent of its potential, half of which comes from just three dams—Kariba in East Africa, Aswan on the Nile, and Akosombo in Ghana.[8]

Table 1: Hydropower Potential and Use, By Region, 1980

Region	Technically Exploitable Potential	Exploited Resources	Share of Potential Exploited
	(megawatts)		(percent)
Asia	610,100	53,079	9
South America	431,900	34,049	8
Africa	358,300	17,184	5
North America	356,400	128,872	36
USSR	250,000	30,250	12
Europe	163,000	96,007	59
Oceania	45,000	6,795	15
World	2,200,000	363,000	17

Source: World Energy Conference, *Survey of Energy Resources*

Table 2: Selected Countries Obtaining Most of Their Electricity from Hydropower, 1980

Country	Share of Electricity from Hydropower
	(percent)
Ghana	99
Norway	99
Zambia	99
Mozambique	96
Zaire	95
Sri Lanka	94
Brazil	87
Portugal	77
New Zealand	75
Nepal	74
Switzerland	74
Austria	67
Canada	67

Source: United Nations, *World Energy Supplies*

In a few areas, hydropower generates a major share of the electricity supply Over 35 countries—covering a range of developing and industrial nations—already receive more than two-thirds of their electricity from falling water (See Table 2.) In South America, 73 percent of the electricity used comes from hydropower, and in the developing world as a whole the figure is 44 percent.[9]

Water is so abundant in some countries and regions that it can meet most, if not all, of the area's energy needs when supplemented with other locally available energy sources such as biomass, geothermal, and solar collectors. Already Norway receives 99 percent of its electricity and 50 percent of all its energy from water. The neighboring Scandinavian countries of Sweden and Finland are also heavily dependent on hydropower. Quebec has so much hydropower potential that its leaders are talking seriously about building a fully electrified economy based on water power. In the heavily oil-dependent Central American countries, rich untapped hydro and geothermal resources offer the prospect of energy self-sufficiency. With only 6 percent of

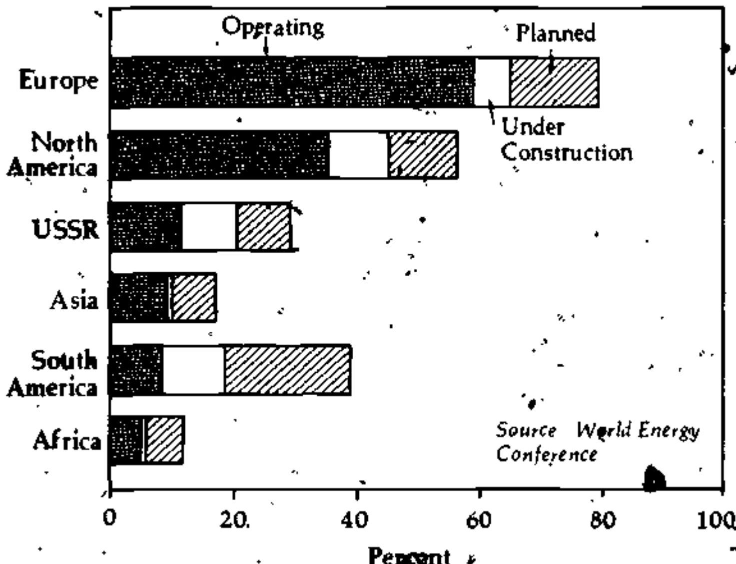

Figure 1: Status of Hydropower Development, By Region, 1980

its hydro potential tapped. Costa Rica, for example, already gets 35 percent of its total energy supply from hydroelectric plants.[10]

Some nations have enough hydropower to become exporters of electricity. Having tapped the swift-flowing headwaters of Europe's rivers in the Alps, Switzerland exports electricity to neighboring France and Italy. Nepal and Peru are similarly blessed with abundant hydropower resources, still largely untapped. Nepal could become the Switzerland of Asia, exporting electricity to the Indian subcontinent. Where distance makes transmission of electricity impractical, hydro-rich countries can export energy-intensive products like aluminum.[11]

The pace of current hydro development efforts varies greatly from continent to continent and nation to nation. (See Figure 1.) The regions with the most hydropower in use—North America, the USSR, and Europe—have substantial construction under way or planned. Among the regions with the greatest untapped potential—Asia, South America, and Africa—South America is pulling ahead rapidly. Brazil is setting the pace there, with a well-established program that is currently increasing hydroelectric production at an average rate of 11 percent per year.[12]

Because hydro plants, especially large ones, take years to plan and construct, short-term projections can be made with some confidence. At present some 123,000 megawatts of capacity are under construction, and an additional 239,800 megawatts are planned. The plants being built plus those being planned will approximately double worldwide hydroelectric output. Yet even after these are completed, only a third of the feasible potential in the world will have been tapped.[13]

Looking beyond plants in the construction or planning stage, the picture is less clear. The World Energy Conference optimistically projects that by the year 2020, hydropower will supply some 7,920 trillion watt-hours of power, almost six times the present level. Achieving this will take a concerted effort on the part of governments and international financing groups.[14]

Unlike some alternative energy resources, high prices alone will not be sufficient to develop hydropower. Since rivers are everywhere publicly owned, and since water projects touch upon so many aspects of life, governments rather than corporations or individuals have a unique role as catalysts of hydropower development. In an era of public resistance to government initiative and declining support for development aid, the energy that could be obtained from falling water is in danger of being neglected. Without committed and far-sighted political leadership, development of the world's hydropower potential will lag, forestalling the advent of a sustainable, nonpolluting, inflation-proof energy economy.[15]

Big Opportunities and Big Problems

Since before the beginnings of recorded history people have been altering the surface of the earth in major ways. The twentieth cen-

"Since rivers are everywhere publicly owned, governments rather than corporations or individuals have a unique role as catalysts of hydropower development."

tury has seen an unprecedented increase in the speed and scale of these transformations of the environment. Few technological changes so dramatically and visibly alter the landscape as large dams and artificial lakes

Large dams, constructed mainly since 1930, are among humanity's greatest civil engineering accomplishments, dwarfing even the grandest monuments of antiquity The world's largest impoundment, Egypt's Aswan High Dam, weighs 17 times as much as the Great Pyramid of Cheops The world's most powerful dam, the Itiapu between Brazil and Paraguay on the Paraná, will soon generate 12,600 megawatts—as much power as 13 large nuclear power plants—making it the biggest power complex on earth. The lakes created by such dams are among the largest freshwater bodies on the planet. Ghana's Lake Volta covers 8,500 square kilometers—an area almost the size of Lebanon and larger than the state of Delaware The total surface area of the 31 artificial lakes that each exceed 1,000 square kilometers equals 115,500 square kilometers, an area three times the size of Switzerland [16]

Today's gargantuan dams and lakes pale, however, beside those on the drawing board. At the Three Gorges site on the Yangtze River, China has begun preliminary work on what will probably be the world's biggest dam, capable of generating 25,000 megawatts of power. Brazil's tentative plans to harness the 66,000-megawatt potential of the Amazon River and its tributaries will collectively flood an area the size of Montana American, Canadian, and Soviet planners have even more grandiose visions of damming the waters of giant rivers flowing into the Arctic—the Yukon, the MacKenzie, the Ob, the Lena. And Egypt has begun work on a project to harness the energy of water pouring from the Mediterranean Sea through an artificial canal into the Qattara Depression, an 18,000 square kilometer region of the Sahara that is below sea level.[17]

The modern era of large-dam construction can be traced to the establishment of the Tennessee Valley Authority (TVA) in 1933. Prior to the creation of this government body, conflict between private power companies who wanted to dam major rivers for power generation and individuals fighting for public ownership of dams delayed the harnessing of major rivers in the United States. The advocates of public power development argued that private companies would neglect the many nonmarketable benefits of river development and that a river's energy belonged to all the people of the region.[16]

Franklin Roosevelt's creation of the Tennessee Valley Authority established public responsibility for hydro development and launched a basin-wide development program centered around, but not limited to, the production of energy. TVA was given broad powers to build dams, borrow money, and condemn private property, and an equally broad mandate to promote rural electrification, control soil erosion, improve navigation, and harness power. A unique blend of centralized planning and grass-roots participation, TVA organized construction throughout an area of one million square miles, agricultural extension, rural electrification, and soil conservation programs spread the development benefits to thousands of small farmers and townspeople whose efforts to control erosion and plant trees were essential to the agency's success. TVA's comprehensive approach to the development of river basins has become the model everywhere.

Since World War II, efforts to construct large dams have shifted increasingly to the Third World and to remote regions where most of the untapped major dam sites are located. The success of basin-wide schemes like the TVA and of the Soviet development of the Volga and Dneiper rivers has drawn many Third World leaders to this energy source And because large dams are highly visible symbols of progress that facilitate the growth of heavy industry, their prestige value in developing countries is great. The generous financing terms and management assistance offered by the industrial world makes the construction of large dams even more attractive to nations facing chronic capital and technology shortages.

Successful hydroelectric development projects have already made substantial contributions to the economic well-being of some developing nations. With power from Aswan, Egypt has been able to electrify 99 percent of its villages and create many new jobs in labor-intensive local industries. Companies attracted by the power of the São Francisco River in northeast Brazil have brought almost a million new jobs to this poor region. With an energy consumption that doubles every decade, the Brazilian Government hopes to more than double its hydroelectric production during the eighties. Venezuela expects to spend tens of billions of dollars over several decades to harness 40,000 megawatts of power from the Caroni River at Guri. And the Philip-

"Soil erosion has already ruined several large dams in poor nations that can ill afford the loss of either soil, power, or water-storage capacity."

pines, heavily dependent on imported oil, envisions a 45 percent increase in hydroelectric production in its current five-year energy program.[19]

For most people affected by large dams, the number of kilowatts produced is not the most important consideration. The impacts on agriculture, fisheries, health, employment, and income distribution must all be weighed to determine whether a project is beneficial. Unfortunately, the construction of a large dam in a developing country does not necessarily improve the standard of living for the vast majority of people living in rural areas. Energy-intensive industries located near large dams seldom provide many jobs for the largely unskilled local population. A case in point is the Asahan aluminum and hydroelectric project in Sumatra, which at the cost of $2 billion will employ only 2,100 of the island's estimated 30 million people. Often the power not used by nearby industry will be transmitted to major cities hundreds of miles away, leaving dozens of villages unlit along the way.[20]

The ecological changes wrought by large dams bring both opportunities and dangers. Large dams change a self-regulating ecosystem into one that must be managed. If the construction of a large-scale dam is the only planned intervention into a river's ecosystem, disaster—human and natural—is sure to result. Ways of life appropriate to a river ecosystem can mean human and ecological damage if followed near a lake, so any plans for a dam must include changes in long-established patterns of living in the area. The same water that makes irrigated agriculture possible can also spread waterborne disease. Soil erosion and pollution must be controlled if a dam's water-storage and power capacities are to be preserved.[21]

Although an infusion of funds has helped Third World nations build large hydropower facilities, efforts to control erosion, introduce sound irrigation methods, enhance fisheries, control waterborne diseases, and relocate displaced populations have been less successful. Rapid silting of reservoirs caused by uncontrolled soil erosion from the surrounding lands is a major threat to dams worldwide. When a reservoir fills with sediment washed from the land, a dam's ability to store water and to generate energy are drastically curtailed. Soil erosion has already ruined several large dams in poor nations that can ill afford the loss of either soil, power, or water-storage capacity.[22]

The Sanman Gorge Dam in the Shanxi Province of China, for example, has lost three-quarters of its 1,000 megawatt power capacity due to the buildup of sediment in the Yellow River. Widespread deforestation and soil erosion in Ethiopia are reducing the reservoir life of the Aswan High Dam much faster than its planners anticipated. There is little Egypt can do to reverse the destruction of this major economic resource by Ethiopian peasants a thousand miles upstream. Similarly, uncontrolled tree cutting and farming on steep lands in Nepal are a serious threat to the few dams already built on the rivers that run out of the Himalayas. Until the topsoil of Nepal and northern India can be stabilized through reforestation and improved farming practices, India's ambitious hydroelectric and irrigation plans will have to be postponed.[23]

The value of water that can be stored for irrigation would be enough reason to build many dams even if power were never produced. By storing water from the rainy season for use in the dry months and from wet years for use in dry ones, dams reduce the effects of droughts, permit additional crops on presently farmed lands, and extend agriculture to dry uncultivated areas. Often the electricity produced from the dam powers pumps that extend irrigation over large areas. The value of this new farmland must be measured, of course, against the value of the river bottomlands flooded by the dam, which often are prime agricultural soil.

Irrigation itself can often lead to a permanent loss of cropland if not carefully managed. Irrigated soils can become waterlogged and loaded with crop-destroying salts if adequate, expensive drainage systems are not provided. Egypt, often cited as a prime example of an area where a dam had a double-edged impact on agriculture, has been forced to spend billions on pipes to drain newly irrigated land threatened by waterlogging and salinization. In countries where spring floods—now controlled by a dam—previously deposited rich silt on the land, artificial fertilizers must be applied to preserve the soil's fertility. Fertilizer production can consume a major share of the dam's power output.[24]

Another attraction of dams is the expansion of food supply they permit by enhancing fisheries. Unfortunately, the impact of large dams on fisheries varies widely and in unexpected ways from project to project. Predicting that impact is especially difficult in tropical regions of Africa, Asia, and Latin America where the life cycles of many important fish species are poorly understood. Where fish species migrate long distances to breed, dams can decimate fish stocks—and the diets of those dependent on fish protein. The rich Columbia River salmon fisheries in North America declined sharply after dams were built on the river—despite well-funded programs to build fish ladders and to restock the river.[25] 17

The construction of a large dam often increases the total amount of fish that can be caught in an area, leading to considerable changes in the location and structure of the fishing industry. The destruction of the Eastern Mediterranean sardine fishery by the Aswan High Dam—largely unanticipated by dam designers—has been more than counterbalanced by the emergence of a fishing industry on newly created Lake Nasser in Upper Egypt and Sudan. Unfortunately, the replacement of 18,000 tons of sardines harvested yearly with 20,000 tons of Lake Nasser fish is of little solace to the sardine harvesters who lost their livelihoods. Egyptian officials optimistically predict that Lake Nasser will eventually yield 60,000 tons of fish per year, but if experience with other African dams is any guide, production may fall as the lake grows older and the ecology becomes more settled.[26]

The health impacts of large hydropower projects are less ambiguous. In tropical regions, dams threaten hundreds of millions of people by spreading waterborne diseases. Reservoir lakes and irrigation canals provide ideal breeding grounds for snails that transmit schistosomiasis—also called bilharzia—a debilitating, sometimes fatal disease that currently afflicts some 200 million people in tropical countries. Better sanitation facilities and improved hygiene could largely wipe out schistosomiasis, since the cycle of infection would be broken if raw human wastes were kept out of contact with surface waters. Despite efforts of planners and governments, however, people near newly created lakes have not yet adopted the sanitary habits that could halt the spread of disease.[27]

The Gezira area of Sudan illustrates well the mix of problems and opportunities presented by large multipurpose dams. Water stored at Sennar Dam on the Blue Nile irrigates over 800,000 hectares of land, forming an island of relative prosperity where tenants' average income is six times that in the rest of the country. The largest farm under single management in the world. Gezira supports over two million people and grows enough cotton to generate 60 percent of Sudan's foreign exchange. However, this abundance has exacted a high price in people's health. Some 50 to 70 percent of the Gezirans are infected with schistosomiasis, malaria is endemic, and diarrheal diseases threaten children. The overall ill health in the area is so great that it is a major barrier to reaching full agricultural productivity.[28]

An often neglected cost of large dams is the effect of relocation on people whose homes are flooded by the project. Substantial numbers of people have been made refugees by large dams: 80,000 were displaced by the Aswan High Dam in Egypt; 75,000 by Lake Volta in Ghana; 57,000 by Lake Kariba in East Africa; and 50,000 by Lake Kainji in northern Nigeria. China's planned Three Gorges Dam will mean some two million people have to leave their homes. Plans to resettle and reemploy displaced people do not figure prominently in many dam projects, and when they do appear they often fail for lack of funding. Even where resettlement programs are adequately funded, people forced from their homes are typically passive, dispirited, and lacking in initiative. No amount of government aid can compensate for the loss of land handed down through generations.[29]

The development of hydroelectric potential in remote regions, whether in developing or industrial countries, holds problems for native tribes and wildlife long preserved by isolation. The already beleaguered and shrinking Indian tribes of Amazonia, for example, are threatened by Brazil's ambitious dam-development program. Although building dams in remote areas seldom requires the relocation of as many people as it would in more-populated areas, the native people in such locations are least able to cope with resettlement and the intrusion of modern civilization in their lives. In some cases, they have chosen to resist government resettlement programs, and armed clashes and angry protests have occurred. Tribes in central Luzon, resisting the Philippine Government's plan to build on the swift-flowing Chico River Southeast Asia's largest hydro project, have fought repeatedly with federal troops and held protests attracting the attention of international human rights groups.[30]

Opposition by threatened indigenous people can seldom stop a dam, but substantial concessions can often be won. Native people in the area inundated by Quebec's giant James Bay project delayed construction through the courts and forced the government to grant them $250 million, title to 12,950 square kilometers of land, and preferential employment rights on the project. Isolated tribes in poorer, less developed countries are unlikely to fare so well, although support groups like Survival International have recently emerged to lobby for the rights of these threatened groups.[31]

Dams built in remote areas can also endanger little-known and rare plant and animal species. In Quebec, careful environmental monitoring revealed no wildlife threatened by the new dams and impoundments. Yet in tropical regions, where ecosystems support an abundance of species still unknown to humanity, dam construction can result in the permanent loss of plants or animals with potentially high economic value. If governments sponsoring dam projects include careful ecological surveys and rescue efforts in the project planning, the payoff can be high. Before a remote agricultural valley in northern Mexico was flooded by a dam, ecologists located and saved several previously unknown varieties of corn with unique disease-resistant abilities that proved to be highly valuable.[32]

The threat to endangered species from dam construction is not limited to developing countries. Nations that can afford alternatives are some of the worst offenders. Despite the marginal economic value of the Tellico Dam on the Little Tennessee River, for instance, the U.S. Congress rewrote the Endangered Species Act—a model of a progressive species-protection law—to permit the flooding of one of the last known habitats of the once-plentiful snail darter. South Africa is planning to build a dam 39 stories high in one of the most important floral wilderness areas of the continent. And over the heated protests of environmentalists, Australia has built a hydroelectric complex in Lake Pedder National Park, flooding the habitats of dozens of species found only in the island state of Tasmania.[33]

Perceiving a dam simply as a civil engineering and industrial development project is a sure recipe for disaster and misery for many whose lives are touched by the structure. There are a few hopeful signs that development planners are learning from past mistakes. Many of the hazards of dam construction in the tropics are better understood now than they were 30 years ago, when the first modern dams were built there. The plans for the hydroelectric and irrigation project being built on the Senegal River by Mauritania, Mali, and Senegal have included a great deal of ecological monitoring and population adjustment programs. Brazil, on the other hand, has failed to look at the broad impact of its dam projects, and will probably pay the price in the years ahead.[34]

Although a comprehensive plan that is sensitive to local ecology is vital to the success of a hydroelectric project, local participation in its planning is the other key ingredient. Unfortunately, the grass-roots participation of farmers, owners of small businesses, and local officials that made the Tennessee Valley Authority a success has too often been absent in developing countries. Erosion along the shores of Lake Kariba between Zimbabwe and Zambia, for example, has reached dangerous levels despite efforts on the part of both governments to prevent overgrazing and to preserve a band of trees along the water's edge. Although local farmers and herders know their practices threaten the lake, they don't adopt the recommended practices because they can't afford to forgo short-term production gains.[35]

While ecological change accompanies any dam project, especially in the tropics, environmental degradation is more a product of people's inability to change behavior than an inevitable result of the structures themselves. Farmers in the Tennessee Valley were willing to control erosion and to plant trees because they received cheap loans and cheap electricity. Poor farmers on the Zambezi, on the other hand, are being asked to change their ecologically destructive behavior and offered nothing in return. Often the failure of planners to spread widely a project's benefits accelerates the impoverishment of marginal groups unable to afford sound farming, grazing, irrigation, and sanitation practices. Programs that do not rely on local initiative, local resources, and local control will alienate the impoverished rather than encourage them to participate. Since large hydropower projects cannot be initiated at the village level, they tend to stifle rather than foster the community-based mobilization of resources that alone can break the pattern of poverty and dependency.

Developing nations cannot afford to miss the opportunities offered by large dams despite the human and ecological disruption their introduction can bring. The impact of these projects must be balanced by locally controlled development efforts scaled to the needs and

"While ecological change accompanies any dam project, environmental degradation is more a product of people's inability to change behavior than an inevitable result of the structures themselves."

skills of the people. Fortunately, large dams are not the only avenue of water power development open to developing nations. As part of village-level water management programs, small-scale hydro plants can avoid many of the social and environmental problems associated with large dams.

Small-Scale Hydro in Developing Countries

Bringing electricity to rural areas has occupied an almost mythical status in development theories. Lenin called Bolshevism "rural electrification plus Soviets" and Bangladesh's constitution guarantees electric power for each village. As a result, rural electrification projects have absorbed 50 percent of all energy development funds since 1950. Yet today, only 12 percent of the people in the Third World live in areas with electricity. With costs of grid-based systems rising rapidly, this situation is unlikely to change in the foreseeable future. The Overseas Development Council estimates that by the year 2000 only 25 percent of the people in developing nations will live in villages connected by electric lines and power stations. As the costs of energy generated by nuclear, oil, and coal plants skyrocket, the dream of village electrification by the transmission of power to rural areas is fading rapidly. In a number of Third World countries, it has been replaced by the reality of small-scale hydro projects that are bringing electricity to the countryside as well as improving the quality of rural life.[36]

Among developing nations, China's approach to water development is unique. While most developing countries concentrated on building large dams to run heavy industry and to meet burgeoning urban electricity demand, the Chinese established other priorities. Rather than borrowing heavily from the industrial world and importing technology to build large dams, the Chinese have relied on indigenous labor, capital, and technology to build tens of thousands of small hydro facilities. So although major cities regularly experience brownouts and electricity for heavy industry is in short supply, the Chinese have a small-scale hydro program that is a shining example of how broad-based rural development centered around small dams can address many Third World problems.[37]

Although China historically had been a leader in hydro development, the centuries of war, revolution, and economic decay that preceded the communist revolution decimated all but 50 of the nation's hydro facilities. After 1949, the government followed the Soviet model of rural electrification, which emphasized large power plants, and the number of small hydro facilities in use actually declined in the late fifties. The Cultural Revolution in the mid-sixties galvanized the energies of hundreds of millions of Chinese in rural villages, and started a boom in small-dam construction that the current leaders continue to promote.[38]

Since 1968, an estimated 90,000 small-scale hydro units have been built, mainly in the rainy southern half of the country, and they now supply 6,330 megawatts of power. Although the average size of the units is a meager 72 kilowatts, small plants account for 40 percent of China's installed hydro capacity. In more than one-quarter of the nation's counties, these small dams are the main source of electricity, providing power to a large segment of the population who would otherwise be without it. China's enthusiasm for this source of energy is still picking up momentum. Its leaders expect to add 1,000 additional megawatts of hydro capacity in 1981, an annual 1,500 megawatts through 1990, and 2,000 megawatts per year during the following decade. By the turn of the century, the government hopes small hydro facilities will be providing six times as much energy as in 1979.[39]

The Chinese consider small hydro plants to be just one part of integrated water management schemes and rural development efforts. Driven by the need to feed and employ a billion people, the government has given highest priority to agricultural water storage, irrigation, flood control, and fishery needs. The villagers have built impoundments and irrigation ditches with simple hand tools and without expensive, heavy, earth-moving equipment. Many of the components of hydro plants—turbines, pipes, and gates—have been constructed at small shops by local artisans using local materials. With money earned and saved from agriculture and fish sales, communes have been able to upgrade the sites without funding from the central government. Technical advice from agricultural extension workers has improved dam and plant design and helped lower costs. The Chinese have developed a simple, sturdy, standardized model that sells for less than comparable Western imports.[40]

"Small plants account for 40 percent of China's installed hydro capacity."

Unlike dams that run capital-intensive export industries in so many developing countries, small dams in China support workshops that turn locally available raw materials into goods that are used in nearby areas. Hydropowered factories scattered throughout the countryside husk rice, mill grains, make soap, and produce leather and simple metal goods. Any small amount of power left over is available for lighting, movies, and telecommunications. This creation of jobs in the villages has helped stem the exodus to already overcrowded cities. And small hydro plants dramatically improve the quality of rural life by reducing the backbreaking drudgery of lifting water, sawing wood, and grinding grain by hand.[41]

Village-based self-help programs have enabled the Chinese to avoid the ecological and health problems connected with hydropower use in other developing countries. Village reforestation and erosion control efforts have slowed the silting of reservoirs with valuable topsoil and local snail eradication efforts have helped control schistosomiasis. The Chinese have taken advantage of newly created reservoirs and irrigation channels to expand the freshwater aquaculture that supplies four million metric tons of fish a year—about half the world's total of cultivated fish. The Chinese motto "wherever there is water there should be fish" has been widely applied, with more than ten million hectares of the country covered by some kind of fish farm.[42]

The leaders in Beijing emphasize that their small-scale hydro development efforts complement rather than replace their ambitious plans to build large dams. By "walking on both legs"—building small as well as large dams—they hope to exploit fully their tremendous waterpower potential without a high social and ecological cost. The early emphasis on small-scale projects—forced by necessity as much as by design—puts the nation in an excellent position to proceed with a number of large hydroelectric projects in the years ahead. With village-level programs already in place to cope with any ecological changes, China is poised to take the world lead in hydropower.[43]

The opportunity to meet the pressing social needs of the rural poor through the development of small dams is not limited to China. Although few detailed resource assessments have been made, the potential throughout the developing world appears great. Using extremely conservative criteria of economic feasibility, the World Bank estimates that 5 to 10 percent of hydro resources in the Third World are at small sites Considering the number of sites that would be economical if local labor and materials were used, the potential is even greater. Such small hydro facilities are a bargain as well, with costs running around $500 per kilowatt of capacity, compared with over $1,000 per kilowatt for conventional power. Building small hydro plants can advance overall development by converting poorer countries' most abundant and least used resource—labor—into critically needed capital.[44]

The few projects completed outside China confirm the role of small hydro plants in balanced development. In the remote mountainous Huon Peninsula in Papua New Guinea, for example, the Baindoang village schoolmaster heard about hydro power on a radio show, and asked the university for help in building a small dam. The university and a private group, the Appropriate Technology Development Unit, provided the expertise and the villagers contributed their labor. After two years, a tiny seven-kilowatt turbine was installed. Two days of celebration and dancing welcomed power to the village, where it lights the school and store and heats water for communal showers. By mobilizing enthusiastic local support the project strengthened the development of village-level institutions and gave the people of Baindoang a greater sense of control over their own lives. Among developing nations, Nepal currently is most active in developing small hydro sites, having recently opened about 60 water-powered mills.[45]

Unfortunately, small-scale hydroelectric development projects have been largely neglected by the international development banks and aid programs. Since the various benefits associated with small dams—such as fisheries enhancement and the use of local labor, materials, and initiatives—are seldom quantifiable, such projects often appear "uneconomical" in comparison with the large projects whose social costs are hidden Yet the infusion of outside funds to small-scale hydro projects that rely upon local labor and materials could transform a questionable project into an economical one Unfortunately, the World Bank, which between 1976 and 1980 loaned $1.68 billion for large-scale hydroelectric projects, has spent almost nothing to date on the development of small sites.[46]

By funding badly needed surveys of small-hydropower potential, development groups could draw attention to a major untapped resource and alert local groups to neglected sites. Once specific projects get under way, governments and international agencies can assist by providing experts knowledgeable about hydrology, geology, and engineering to ensure that dams are built safely and take full advantage of the water flows.[47]

There are a few signs of international interest in harnessing this neglected energy source. The U.S. Agency for International Development has loaned Peru's national power company $9 million for 28 small-scale hydro installations ranging in size from 100 to 1,000 kilowatts. France is helping several African nations build small dams and Swiss groups are helping Nepal set up factories to build small, inexpensive turbines. While these programs are a step in the right direction, they must be expanded considerably if they are to have much impact on the development of small-scale hydro in the Third World.[48]

Developing nations need to reassess and change the priority they give large-scale hydro development efforts. Using electricity from a central grid system to heat, cook, and lift water has been likened to "cutting butter with a chain saw" by energy analyst Amory Lovins. Transmission and distribution systems are expensive and lose between 10 and 25 percent of the transported power. To justify the costs of building distribution systems in rural areas, governments are forced to sell large amounts of electricity that are poorly matched to need and ability to pay.[49]

Although small- and large-scale hydro projects are complementary, not competing, efforts, integrated village-level water development should precede the construction of large dams as a general rule. The undesirable side effects of large projects—erosion, the spread of waterborne diseases, salinization of irrigated land—will be easier to manage if people have already helped design small dams in their villages. And the introduction of more small-scale hydro projects will allow the Third World to exploit its abundant water power resources in a way that contributes to balanced overall development and to meeting the neglected needs of the rural poor.

Power Shifts to the Periphery

Most of the world's untapped hydroelectric potential lies in remote regions far from present centers of industry and often far from inhabited areas. Rivers with major power potential flow through largely uninhabited parts of northern Canada, Alaska, and Siberia. In the developing world, the Amazon, the Congo, the Orinoco, and the rivers of Southeast Asia fed by the snows of the Himalayas offer sites for large-scale hydroelectric development. Remote areas of Papua New Guinea, South Africa, Borneo, Tasmania, Norway, the Philippines, Argentina, Guyana, and New Zealand also hold promise as dam sites.[50]

Throughout history, the availability of hydropower resources has been a key to the location of industry and cities and the relative power of nations. When waterwheels were the dominant hydropower technology, factories were small and dispersed throughout the countryside. Water's influence on urban location can be seen best in the eastern United States; dozens of cities, from Springfield, Massachusetts, to Augusta, Georgia, cluster on the fall line where rivers drop from the Appalachian plateau to the coastal plain. Historians rank northern Europe's abundant hydropower resources as an important reason for the eclipse of the drier Mediterranean countries over the last few centuries.

Today, the principal impetus for hydroelectric development in remote, sparsely inhabited regions comes from the power needs of mineral extraction and smelting. Hydroelectric projects in the Amazon Valley, New Guinea, Quebec, and Siberia are linked with mining ventures. Where prime hydro sites are not close to rich mineral deposits, the main economic force behind large-dam construction is the aluminum smelting industry. For the foreseeable future, therefore, the pace of dam construction in remote regions will be set primarily by energy-intensive metal industries.[51]

Quebec provides the most dramatic contemporary example of a region's rise to prominence due to its water resources. Launched ten years ago, La Grande Complex in northern Quebec will soon produce 11,400 megawatts, enough power to double the province's installed electrical capacity. Further additions on other rivers could bring the total to 27,500 megawatts. Using cheap power shipped south on giant 735-kilovolt transmission lines, Quebec hopes to revitalize its economy by attracting new industries. Electrification of oil-using sectors of the economy and exports of power to the United States will reduce the area's burden of costly imported oil and provide a permanent source

"Often 10 to 15 years can elapse between the beginning of a project and the first surge of power, so planners must consider large hydro facilities in remote areas as investments in the future."

of foreign exchange. In a pattern of dependence certain to grow, New York City by 1984 will receive 12 percent of its power from Quebec. This ambitious hydro program will give the French-speaking province new prominence within Canada and new leverage in its battle for greater autonomy and cultural independence.[52]

The explosive rise to influence and wealth of the petroleum-producing nations dominated world politics in the seventies. Within countries, shifts of power have been just as dramatic—the United States, Canada, and Australia have all seen people and power move to their fossil-fuel producing regions. Yet these changes have drawn attention away from a slower—but more permanent—realignment of power and wealth to regions rich in water power. The development of hydroelectric resources in peripheral regions will extend this shift in the balance of political power within and between nations. Just as factories and towns clustered around the mill sites of 100 years ago, so, too, new industries will locate near new dams in sparsely populated regions.

These opportunities at the periphery of civilization will not be tapped without a major long-term commitment of resources by central governments and international lending institutions. Often 10 to 15 years can elapse between the beginning of a project and the first surge of power, so planners must consider large hydro facilities in remote areas as investments in the future. And large dams are extremely expensive. Aswan, for example, cost $1.5 billion when it was built in the sixties. Itiapu will cost between $5 billion and $6 billion, and China's Three Gorges project could run to an estimated $12 billion. The World Bank estimates that $100 billion will be spent in developing countries between 1980 and 2000 on large hydro plants that generate over 100 megawatts each. Since the largely uninhabited regions lack the considerable sums of capital needed to launch such projects, outside support is crucial. Despite the heavy demand these expenditures make on critically short development capital, an early return can be expected, as in the case of the Aswan, which paid for itself in three years through power sales.[53]

Large hydroelectric facilities in developing countries are usually financed with loans from major commercial banks and international lending agencies like the World Bank. Capital for such projects is readily available because sales of power—mainly to energy-intensive factories owned by multinational corporations—generate a steady, predictable flow of revenue. Banks and development agencies in the industrial world have favored large hydroelectric projects because much of the loaned money is used in turn to purchase generators, turbines, transmission facilities, and engineering services from major corporations in the developed world. As the income from power sales, which are usually set at bargain rates, is needed to pay back foreign loans, the Third World country derives little immediate economic return from its new dam.

The importation of foreign skilled labor, engineering services, and construction and power-generating equipment can further strain a developing nation's balance of payments during the building phase, which may last for years. China, in particular, will have serious financial problems if it uses foreign capital and technology to put a large-scale hydro program in high gear. Once completed, however, a well-conceived and well-implemented dam project slowly begins to improve a nation's foreign trade position.

The prospect for hydroelectric development is brightest for nations with oil to sell or those that are willing to go into debt to finance hydro development. Venezuela and Mexico are investing their oil wealth in hydro facilities and Brazil has borrowed heavily to keep its hydroelectric expansion program going. Other countries are going to find it difficult to come up with the money to develop their extensive water resources. Fearful of dependence on outsiders, China is hoping to fund hydro development with revenues from oil the government expects to find. Zaire, with the highest hydropower potential of any nation in Africa, lacks both foreign exchange and a record of political stability that would inspire a lender's confidence.[54]

One important result of the exploitation of large hydro sites in remote regions will be better relations between nations that have not been on the best terms in the past. Since 200 of the world's rivers cross international boundaries, the success of a large hydro project often hinges on cooperation between neighbors. The regions of the world where hydropower is most developed—North America and Europe—are those that have successfully devised political mechanisms for cooperative river development and conflict resolution. In North America, for example, the Columbia and St. Lawrence rivers could not have been harnessed without the close cooperation of the U.S. and Canadian Governments. In Europe, the development of the Rhine and the

Danube was due to agreements between previously suspicious, often warring nations.[55]

Unresolved conflicts over water rights remain one of the major barriers to the development of many promising large hydro sites. Long-simmering disputes between India, Nepal, and Bangladesh over the waters from the Himalayas frustrate efforts to harness one of the world's major energy resources. Although India has unilaterally decided to move ahead with several large projects on tributaries of the Ganges, neighboring countries must cooperate to develop the bulk of the power and to halt the ruinous soil erosion in Nepal that threatens to cut short the useful life of the reservoirs. In Canada, a long-standing dispute between Newfoundland and Quebec over power pricing at Churchill Falls has delayed construction of a 2,300-megawatt complex of dams on the Lower Churchill River. And the hydroelectric and irrigation potential of the Mekong River in Southeast Asia remains untapped because of conflict between Laos, Thailand, Kampuchea, and Vietnam.[56]

Beyond the cooperation that a successful project can foster, hydroelectric development can often bind former enemies together into a state of mutual dependence. Brazil and Argentina, long rivals for Latin American leadership, overcame years of hostility to develop the rich energy resources of the Paraná River, which forms the boundary between the two countries. War between these neighbors would now be far more costly since a major part of the national wealth of each depends upon the continued operation of expensive dams on the Paraná.[57]

Once international antagonisms have been overcome and dams built, permanent bonds—and vulnerabilities—link the nations involved. Although hydropower can reduce a nation's dependence on imported fuels, large dams are also easy targets for attack during time of war. With a significant part of national wealth invested in or dependent upon a major facility, dam destruction could cripple a nation for decades. And the immediate impact on civilians would be severe; just one hole in a wall can place extensive river valleys and major cities under water. Large dams are societal jugular veins in wartime—inviting targets virtually impossible to protect from modern bomber or missile attack.

The increased military vulnerability of nations heavily dependent on huge dams is already affecting international relations. Israel's ability to destroy the Aswan—and with it much of Egypt's population and economy—is cited by analysts as a key motivation for Egyptian willingness to negotiate a peace settlement. American technical advisers working with the Chinese on the Three Gorges project have advised the construction of three smaller dams rather than one huge one for "national security reasons"—presumably a reference to China's continued fear of Soviet attack.[58]

The development of hydropower in remote areas of the world will also have repercussions on the international economic system by altering the location of important energy-intensive industries. The most dramatic shift is likely to occur in the aluminum industry. Aluminum smelting requires prodigious amounts of electrical energy—on the average about eight kilowatt-hours for each pound of aluminum. In regions where hydropower is plentiful, aluminum smelting is often the major user of electricity. In the U.S. Pacific Northwest, the nation's richest hydro region, aluminum production accounts for over one-third of the hydroelectric power used. Aluminum smelters cluster around major dams on every continent.[59]

In the years ahead aluminum production will level off or even decline in the continental United States, Western Europe, and Japan as new aluminum smelters migrate to the world's peripheral regions, where major new hydroelectric complexes offer plentiful and cheap power. Aluminum companies are building major new plants in Brazil, Egypt, Ghana, Tanzania, and Sumatra to take advantage of newly tapped hydro sources. Japanese smelters—made uneconomical by the OPEC oil-price revolution—are closing down and relocating in Indonesia, Australia, and Papua New Guinea. Similarly, power shifts to the periphery can be seen within nations: Soviet aluminum production is moving deeper into Siberia, following new dams.[60]

The industrial nations' growing appetite for aluminum combined with the migration of smelters spells increased dependence between nations, and it could seriously affect many countries' balance of payments and oil-import reduction goals. To meet fuel-economy standards the automobile industry is increasingly substituting aluminum for heavier steel parts. Yet according to a 1980 U.S. Government study, meeting

"Aluminum production will level off or even decline in the continental United States, Western Europe, and Japan as new smelters migrate to the world's peripheral regions."

the 1985 fuel-economy standards with imported aluminum will largely cancel out the balance-of-payments gains from a reduction in oil imports. As this becomes clear, national-security and balance-of-payments arguments will be added to the already strong environmental and conservation case for the recycling of aluminum products.[61]

New aluminum smelting sites could have a great impact on global employment if labor-intensive aluminum processing and finishing industries follow the producers of raw aluminum to major new dams. Just as nations that produce and export oil have sought to lure petrochemical and refinery activity to their countries, so, too, will primary aluminum producers try to entice related industries to the area. Already Venezuela, taking a cue from its success in attracting "downstream" oil industries, is seeking to force aluminum producers using its cheap hydropower to locate their highly profitable aluminum processing and fabricating facilities on Venezuelan soil. Should other hydro-rich nations follow suit, industrial nations could suffer job losses. These could be offset, however, by gains in countries that vigorously pursue recycling, which tends to be much more labor-intensive than either aluminum smelting or processing.[62]

As aluminum plants follow the new dams to remote regions, conflicts over the pricing of power are sure to emerge. The construction of dams in previously undeveloped areas sets in motion a process of general economic development that eventually comes into conflict with the needs of the large energy consumers who made the dam possible. Governments of developing nations soon begin to realize it is in their interest to divert their cheap power to more employment-intensive activities or to raise prices.

Often low-priced power stimulates consumption to the point where shortages loom. The maturing economy of the region is then confronted by a painful choice: either raise prices for the heavy energy users, perhaps driving them elsewhere, or let smaller consumers alone bear the prohibitive cost of building new coal or nuclear power plants to meet demand. Egypt, the U.S. Pacific Northwest, and Ghana are among the regions facing this painful dilemma today. As the price of electricity produced from oil, gas, and nuclear climbs, countries selling hydroelectricity at bargain rates will be tempted to raise prices to the world average—often ten times the rate they now charge.[63]

The threat of such leapfrogging rate increases has not been lost on the handful of multinational firms that today dominate the aluminum industry. Fearful of the kind of concession that set into motion OPEC's tenfold oil-price increase, the aluminum firms have rigorously resisted big price increases for hydropower. Ghana's conflict with

Kaiser Aluminum Company over power produced at the massive Akosombo Dam on Lake Volta exemplifies this emerging high-stakes conflict over the world's cheap hydro resources. In 1967, Kaiser signed a 30-year contract with Ghana for power at a set rate. Today, Kaiser buys its electricity there at one-twentieth the world average price. Ghana wants increased revenue to accelerate faltering economic growth, while Kaiser fears that too generous a contract renegotiation would trigger a worldwide cascade of price increases, wrecking profits and aluminum's competitive position. The outcome of pricing struggles like these will affect the economics of hydro regions as well as the pace of hydro development in peripheral regions everywhere.[64]

Financial uncertainty and political conflict are currently the largest impediments to further hydroelectric development in remote parts of the world. There are many sites for dams that would profit the companies that build there, the countries that host them, and the overall world energy budget. If cooperative international water and funding agreements can be fashioned, a major expansion of hydroelectric production at the peripheries of the world economy will follow, creating new stresses and new bonds in the international arena.

Making Better Use of Existing Dams

Where the best sites already have dams or are protected from development, such as in the United States, Japan, and several European nations, there is little chance to expand hydroelectric capability by building new dams. But substantial, often overlooked, opportunities exist in these countries to increase the contribution of the many dams already in place. For the industrial world, the challenge for the rest of this century will be to upgrade and rehabilitate existing hydropower complexes.

In regions where much of the hydroelectric potential has been tapped, public pressure to preserve remaining free-flowing streams and rivers is blocking further dam construction. In North America, Europe, and Australia, acrimonious conflict between environmentalists and power companies is common. In North Carolina, for example, citizen groups mounted a grass-roots lobbying effort to prevent the construction of a hydroelectric facility on North America's oldest river, ironically named the New River. Swedish popular opposition to new dam construction forced the government to abandon an ambitious hydroelectric expansion program. And Australian dam development plans were modified and some projects abandoned after environmentalists there focused public pressure on Parliament.[65]

Although opposition from local environmental groups has stopped some projects, dam construction continues, albeit at a slower pace than in the past. As oil prices continue to rise and as the economic attractiveness of hydropower grows, controversy over remaining untapped hydro sites is sure to increase. While much of the public opposition to new dams reflects a desire to preserve white-water recreational opportunities and is fueled by local citizen hostility to remote and seemingly unaccountable utility companies, there are sound ecological reasons for preserving representative river systems in their natural state. Such rivers provide a baseline against which ecological change on other rivers can be measured as well as a sanctuary for the many threatened plant and animal species that thrive only in swift-moving waters.[66]

The United States and Sweden have been leaders in preserving ecologically significant wild rivers. Parts of 37 U.S. rivers—with a combined potential to generate 9,000 megawatts, the equivalent of nine large nuclear power plants—are protected from further development under the Wild and Scenic Rivers Act. An additional 3,500 megawatts of power potential on the lower Colorado River is unavailable for use because of similar constraints. Sweden has permanently banned dams from four undeveloped rivers in its far north.[67]

Even though potential dam sites will become more attractive in the years ahead, dam projects should be given closer scrutiny by public officials and citizens than they have in the past. Since power sales alone can seldom justify a project, the often inflated claims of recreational and flood-control benefits must be assessed carefully. Often the prime agricultural value of bottomland that must be flooded is underestimated. In many cases, the expected benefits of a project, such as saving water and flood control, could be better achieved by reducing water waste and by discouraging construction in flood plains.[68]

Instead of paying the environmental price of building additional dams, industrial countries need to make better use of existing dams. The United States, and to a lesser degree Europe, Japan, and the Soviet Union, have many small dams (under five megawatts) that are now viable sources of power due to rising oil prices. France, a pacesetter in the area of small-scale hydroelectric development, has been so successful in pressing its dams into service that 1,060 microhydro stations (less than two megawatts each) now generate 390 megawatts of electricity, 1 percent of the nation's production. Japan has also aggressively harnessed its abundant water resources with numerous small dams. Recent studies indicate underdeveloped hilly regions in Europe, such as Wales, Scotland, Spain, Sweden, and Romania, have substantial untapped hydro potential at existing small dams.[69]

The greatest opportunity in the industrial world to take advantage of small dams is in the United States, as the supply of small- and medium-sized dams ready for refurbishment there is so large. A comparison of the power contribution of the Rhone in France and the Ohio in the United States—rivers with similar power potential and many dams—illustrates the French lead. Twenty-one small dams on the Rhone produce 3,000 megawatts of power while the Ohio produces only 180 megawatts. Less than 3 percent of U.S. dams produce electricity. Estimates of the power available at small dams vary from 6,000 to 24,000 megawatts. Since present U.S. hydro output at all dams is 64,000 megawatts, small dams are clearly an important source of untapped energy.[70]

Many small dams once produced power but were abandoned as cheap oil flooded the US and as the 40 years of useful tax concessions for initial dam construction came to a close. Since World War II almost 3,000 dams have been abandoned, mostly in the Northeast and Midwest. In the intervening years of neglect, equipment has been destroyed by vandals or sold for scrap. Often the dam structure itself has become dangerously weakened from lack of maintenance and would require costly repair and reconstruction.[71]

Fortunately, the legacy of abandonment is reversible, but at high cost. In one of the few detailed studies of the economics of small-dam

> "Even if only marginally economical today, dam renovation should be aggressively pursued because hydroelectric facilities are an inflation-proof source of energy."

renovation, the New England River Basin Commission concluded that the area had 1,750 unused small dams that could produce 1,000 megawatts if fully exploited. The commission estimated that if renovation were done with money borrowed at 7 percent and if power were sold at 4.5¢ per kilowatt-hour, it would be economical to harness 50 percent of the potential. If government incentives reduced the interest rate to 3 percent and power were sold at 6.7¢ per kilowatt-hour, 80 percent of the potential could be developed. Even if only marginally economical today, dam renovation should be aggressively pursued because hydroelectric facilities, once built, are an inflation-proof source of energy that can last for centuries if well cared for.[72]

In response to the growing public interest in small-dam restoration, the U.S. Government has taken a number of steps to encourage these investments. Low-interest loans are now available and tax depreciation benefits have been increased. Recognizing that uncertainty about a project's economic viability and the relatively high cost of initial engineering studies may impede development of small dams, Congress has provided low-interest loans for feasibility studies and stipulated that these would become outright grants for projects that proved economically unfeasible upon examination. Also, the regulatory burden on small-dam developers—who are often small farmers, small firms, or towns—has been greatly reduced.[73]

The most wide-reaching U.S Government stimulus to small-dam development is the "limited power producer" section of the Public Utility Regulatory Policies Act of 1978. Private utilities are now required to buy power from small-power producers and to pay them a rate equal to the utilities' "incremental cost"—in most cases, what the utility would have to pay for new coal or nuclear capacity. This is already having a revolutionary impact on the economics of small-scale renewable power technologies. For the first time utility executives are being forced to compare the costs of such systems with those of large, centralized generating facilities.[74]

These institutional initiatives have combined with higher oil prices to start a boom in small-dam redevelopment. Faced with lagging demand and soaring costs for giant coal and nuclear power plants, some major utilities such as California Edison, New England Electric, and the New York Power Authority are eagerly turning to small dams. Utilities are finding these sites an attractive source of power because

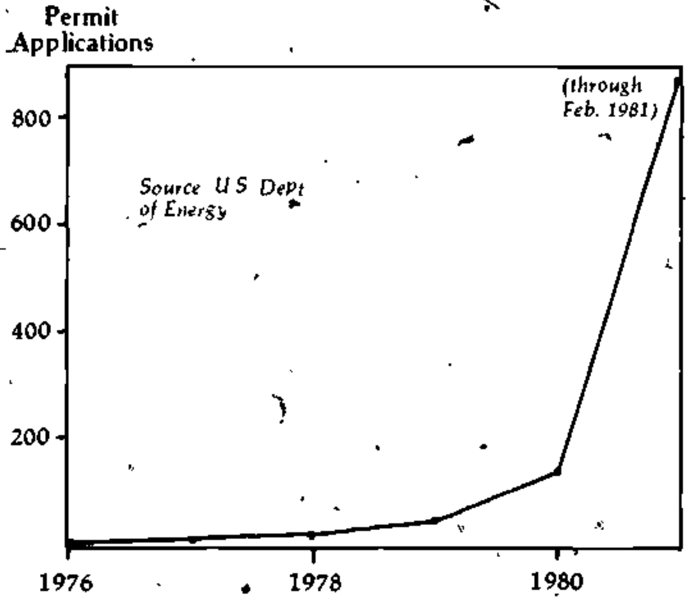

Figure 2: Applications for Federal Hydropower Licenses

electricity demand is growing so slowly that the output of large thermal units is not being fully used—forcing utilities to pay for idle plants The number of applications for permits to produce power—a good measure of hydro development activity—has shot up dramatically in the last five years.[75] (See Figure 2.)

Although public attention has recently focused on renovating small, abandoned dams, even more energy is available at medium and large dams—mostly owned by the federal government—that have never been used for that purpose. Rising power rates have made electricity generation economical at many flood-control and irrigation dams. Again, estimates vary widely, but a conservative figuring shows some 44,000 megawatts available. This enormous potential will remain untapped unless the federal government sees beyond its present austere mood and makes an inflation-proof investment in public dams. It is particularly ironic that the U.S Government is rushing to build new, ecologically disruptive dams when so much power remains to be harnessed at existing ones[76]

There is much the United States can learn from countries that have been more successful in developing small-hydro resources. While France—with one nationwide government-owned utility and a strong centralized state—is not a realistic model, Canada has a "one-step" permit system that could be adapted to both preserve the procedural protections Americans insist upon and eliminate delay and duplication. Unless the federal government reclaims its traditional leadership role in water power development, this chance to expand U S. hydroelectric production will be lost.[77]

Opportunities to boost hydro's contribution to national energy budgets also exist at dams that already generate power. The rising cost of alternative fuels combined with improvements in turbine technology creates a major opportunity to upgrade the power-generating capability of dams. At the Grand Coulee Dam on the Columbia River in the United States, for example, a new, more-efficient generator—previously uneconomical—was installed and the addition of two more 700-megawatt generators is contemplated. Dam renovation and upgrading are also widespread in Europe. Switzerland, for one, could increase hydroelectric production by almost 20 percent by installing up-to-date turbines and generators on its dams, many of which are centuries old.[78]

The heightening of existing dams can also increase power output. In California, the giant 700-foot Lake Shasta Dam may be raised an extra 200 feet. The new height would also permit a threefold increase in the capacity of the reservoir, which already holds the equivalent of 10 percent of California's annual water use. A major barrier to the economic feasibility of widespread dam elevation is the cost of buying property along reservoir shorelines and relocating people who have built there.[79]

In regions where most of the favorable sites have been tapped and where thermal power plants are numerous, the value of hydropower facilities can be increased by the addition of what is known as peaking and pumped storage capacity. Since demand for electricity is not constant throughout a day or a year, seasonal and time-of-day peaks of demand require power sources that can be easily turned off or on. As the water stored behind a dam can be used at any time, hydroelectric plants are ideal sources of peaking power. Converting a hydroelectric plant into a peaking facility requires the installation of additional turbines, many of which are unused much of the time. The conversion of hydro plants to peaking units paradoxically reduces total output while increasing greatly the value of the power produced.[60]

Pumped storage facilities further exploit hydro's flexibility by using off-peak power from continously running coal and nuclear plants to pump water uphill into storage reservoirs. At periods of peak demand the water is released to run back downhill through the turbines, which recoup two-thirds of the energy used for pumping. Worldwide, some 37,000 megawatts of these energy-storing facilities have been built, mostly in the United States, Europe, Russia, and Japan. Converting hydroelectric plants to peaking and pumped storage units may dovetail with the development of other renewable energy systems that produce power intermittently, such as wind, photovoltaics, and solar-thermal electric.[61]

In nations with mature hydroelectric regimes, only institutional inertia stands in the way of a fuller use of hydropower. The USSR, European nations, and especially the United States all have an opportunity to gain needed power by rehabilitating small dams. The technology is mature, the economics sensible. The high price of oil creates an environment where hydropower is the logical choice. The Europeans, with much of their hydropower harnessed, have led the way in showing the importance of small as well as large dam sites. Whether the rest of the industrial world has the good sense to follow remains to be seen.

New Directions

In a world suffering from resource depletion, pollution, and energy shortages, hydropower offers many attractions. With a strong commitment to development, hydro could contribute the major share of the

"Many leaders in the Third World have succumbed to the temptation of prestigious grand dams that neglect the most basic needs of their people."

world's electricity supply by the beginning of the twenty-first century. Some countries, a few of them desperately poor, could base their entire economies on energy harnessed from falling water. Unfortunately, the current use of water in rich and poor countries alike and the proposals for future development do not take the best advantage of the world's hydropower resources. New directions are needed.

To make maximum use of their extensive water resources, developing nations should follow the Chinese strategy of "walking on both legs" by building small as well as large dams. The balance between these two approaches is sorely lacking everywhere in the Third World. The recent small-scale hydro initiatives in a handful of countries provide reason to hope that they can follow China's success in mobilizing village-level action and in making government resources available to local groups. Yet many leaders in the Third World, ignoring the ecological and social consequences of large dam projects, have succumbed to the temptation of prestigious grand dams that neglect the most basic needs of the great majority of their people. Taking advantage of the opportunities for small dams will require leaders able to inspire local initiative and willing to allow local groups control of development resources.

This tendency to focus exclusively on large dams is too often reinforced by international lending and aid agencies whose cost-benefit formulas don't show the intangible costs of big projects and the intangible benefits of small ones. Their narrow focus on the dollars and cents of a project often leads to serious distortions in countries where most people are only marginally involved in the money economy. Foreign funds for politically visible showcase projects that generate cheap power for multinational corporations help the donor more than the recipient. If people in the Third World are to benefit fully from the large dams constructed at high human cost, the power from these dams must serve their own national development goals rather than the dictates of large power consumers from other countries.

Given the ecological, social, and equity concerns about large dams, planners must be able to allocate funds for extensive reforestation, erosion control, snail eradication, and resettlement efforts. Unless a broad view of water development is taken, the benefits of hydroelectric projects will come at the expense of the environment and of the poorer groups in developing societies. If endangered species and aboriginal tribes are neglected simply because they lack power and readily evident monetary value, energy development will be offset by a loss of long-term genetic and cultural diversity.

For many developing countries, most prominently China, the problem is less one of distortions in the direction of development caused by outside forces that it is an inability to attract the enormous sums of capital to build large dams. Brazil's technocrats have driven the country heavily into debt to make impressive strides in large-dam construction, while neglecting the needs of the rural poor. China, eschewing entry into the world economy, chose instead to focus on small-scale projects that better addressed the real needs of its immense rural population. If the search for oil in China pans out and provides the capital, the government can build more large dams and become the first developing nation to have a balanced hydropower program. Sadly, countries with major hydro potential that are perceived by international bankers as unstable, such as Zaire, or that have uncertain claims on their water resources, such as the nations of Indochina, will probably continue to suffer from a shortage of foreign capital. It will be especially important for such governments to pursue small-scale projects that can take advantage of local resources.[82]

New directions are needed in the industrial nations as well. Water development agencies, such as the U.S. Army Corps of Engineers, seem bent on building new dams, many of them economic and ecological white elephants. They could better use their resources harnessing the power available at existing little-used or abandoned dams, many of which are owned by the government and run by the very agencies so eager to flood more land. Opportunities for large-scale hydroelectric facilities in remote areas like Alaska, northern Canada, and Siberia should not be neglected by political leaders just because the payoffs are long-term and budgets are tight. As Quebec has shown, the visionary hydro project of one era can become the economic foundation of the next.

Even more important than the creation of power at old or new dams is the better use of cheap power from existing structures. The hydroelectric institutions in industrial countries were set up to solve problems that are today largely solved and that should be of low priority. The discrepancy between current needs and policies is especially pro-

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nounced in the world's two hydro production leaders. In the United States, the direction of the federal hydropower program has not altered greatly since Roosevelt's New Deal made dam construction, regional development, and rural electrification a national priority. Little has changed since the Tennessee Valley Authority was created, the harnessing of the Columbia and Colorado rivers began, and the Federal Power Act was written to guarantee public utilities access to dam sites and to the cheap power produced at federal dams. Similar goals and institutions guided Soviet hydro development. These initiatives were spectacularly successful in spurring regional economic growth and bringing cheap electricity to rural areas. Their very success has drawn attention away from the question that dominated political debates on energy during the thirties: who should have access to cheap hydroelectric power? Changing events and new opportunities bring this key question back to the top of the energy policy agenda.

In both the United States and the Soviet Union, the pricing and allocation of hydroelectric power has been largely unaffected by the revolution that swept the world energy market in the seventies. Among energy sources in widespread use at the time of the oil shock, the price of hydroelectric power stands alone in not rising rapidly. Between 1970 and 1975 the price of coal quadrupled, the price of uranium increased eightfold, and the price of oil rose tenfold. Owners of reserves in all three fuels quickly reaped a massive, still accruing, windfall as prices followed OPEC oil to dizzying new heights. Only the owners of hydroelectric facilities—the government—missed out on the profits. While the prices of oil, coal, and uranium were set by the price of imported oil, hydropower's cost continued to reflect the cost of production—the sum of dam operating costs and the interest on money borrowed long ago, neither of which rise much.[33]

This bargain-basement pricing of hydroelectricity at a time of rising energy costs sent the wrong signal to the consumer, encouraging waste and creating a voracious demand for electricity when conservation, not production, is the best energy investment. Underpricing and overdemand are already causing serious problems for the Bonneville Power Authority, the government agency that sells hydroelectric power from the Columbia River in the Pacific Northwest. With electricity prices one-eighth those in oil- and nuclear-dependent New York City, people in Washington and Oregon use five times as much electricity per capita as New Yorkers do. Nuclear plants under construction to meet the region's burgeoning electricity demand have already exceeded their budgets by more than the cost of all the federal dams on the Columbia River.[84]

With prices so low, the aluminum industry, a heavy power-user, has no incentive to become more efficient, even though such investments could save more power, at lower cost, than investments in new power could produce. Were the hydropower from federal dams sold at its true value, people would conserve or use wood or solar collectors, utilities would not have to build expensive nuclear plants, and the government would have enough money to help finance development of renewable energy resources.

In the Soviet Union, second only to the United States in hydropower production, problems of overconsumption, waste, and future shortages exacerbated by irrational energy pricing are particularly pressing. Accustomed to bargain-rate power from hydro plants and to underpriced fossil fuels, Soviet industry is even less efficient than its inefficient Western counterpart. The government's recent five-year plan assigns top priority to the elimination of waste—a goal unlikely to be met unless the country's managers face more realistic prices for fuel and electricity. Although waste of natural resources is ideologically rooted in the Soviet system's rejection of resource severance taxes and of marginal pricing of resources, consumer resistance to a more realistic pricing system should be less of a problem in the centralized Soviet economy than in the United States.[85]

The price of hydroelectric resources needs to reflect the fact that the world has entered a new energy era. Now that rural electrification and regional development have been accomplished, access to cheap, government power should be linked to other more pressing goals. Power sold at the marginal price of electricity (several times current rates) would generate funds for the conversion to a sustainable energy system and encourage consumer conservation. Or alternatively, customers unable to afford higher rates could be required to take the lead in encouraging conservation and developing renewable energy sources; continued access by the aluminum industry to underpriced power should be linked to stringent conservation and recycling goals. The added revenues from government power sales could finance additional hydro development and consumer loans for solar and conservation measures.

Directed in a socially constructive manner, cheap hydroelectric power from existing dams can serve as the bridge to a sustainable energy economy.[86]

Although such policies would be a drastic departure from current practice, they will not require the creation of any major new institutions, especially in the United States. The now rather moribund and directionless bodies created in the thirties to electrify rural America and to spearhead regional development are perfectly suited to redirect energy development throughout the country. The Tennessee Valley Authority has taken some first, small steps in this direction by providing loans for wood stoves, home insulation, and solar collectors. And rural electric cooperatives, with their long tradition of self-help and community control, are perfect vehicles for renewable energy efforts.[87]

If the United States were to develop its rich hydro potential in Alaska at the same time higher power rates were imposed in more settled regions now hooked on cheap power, regional development in both the Pacific Northwest and Alaska would be advanced. Jobs would be created in Alaska, where they are needed, and the Pacific Northwest could avoid building extremely expensive fossil and nuclear plants. By developing hydropower in a peripheral region while revising the price system in the mature economy of another area, the United States could avoid increased dependence on foreign aluminum smelters.

The establishment of a realistic hydroelectric pricing scheme in industrial nations could transform the prospects for hydro development in poorer parts of the world, making aluminum production in remote regions more attractive to aluminum companies and hence to lenders. As the migrating aluminum industry opens up ever more remote hydropower regions, the price of aluminum could gradually rise to reflect increasingly difficult terrain, which would in turn stimulate aluminum recycling. Eventually a smaller aluminum industry, located in the most remote regions, would reach equilibrium. In the wake of its wanderings would be many regions flourishing on a sustainable hydropower economy.

Increased use of the planet's water power resources holds substantial political benefits for the community of nations. By transforming many poor countries into productive contributors to the global economy, hydropower can help reduce the great disparities in wealth that underlie today's international tensions. A world with hundreds of thousands of small dams will be more decentralized, which will encourage greater local self-sufficiency and provide a welcome balance to increasingly unmanageable and overcentralized power systems. By linking the well-being of neighboring countries, hydropower development on international waters could help reduce regional conflict and hostility. To reap these political benefits a renewed commitment to hydropower is required at every institutional level: communities, nation-states, international banks, and multinational corporations.

Hydro development will have substantial long-term impacts on the global environment as well as the world economy. In developing nations, the need to protect expensive dams from ruinous sediment buildup will force urban elites and industrial leaders to take more seriously the soil erosion and deforestation caused by the firewood crisis of the rural poor. For the industrial world, judicious use and selective expansion of hydro plants will reduce the need to build more environmentally threatening coal and nuclear plants.

A concerted effort to develop the earth's hydropower resources will thus open the path to a sustainable energy supply, advance the development prospects of the poorer nations, and provide a nonpolluting source of energy desperately needed as the curtain falls on the petroleum era. Perhaps most importantly, hydropower gives to rather than takes from the future. Every barrel of oil burned is one less for the next generation, but every new hydro plant adds to the energy supply of future generations. The barriers to expanded hydroelectric development are international conflict, unequal access to the world's financial resources, and misdirected government agencies. Beyond them, in both rich and poor nations, lie rivers of energy.

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