# INTERNATIONAL TRADE IN ENERGY: THE CHUKHA HYDROELECTRIC PROJECT IN BHUTAN

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## Abstract

Historically, one of the most fruitful applications of financial and economic cost-benefit analysis has been in electricity systems planning. Because of the capital intensive nature of the production technology and the possibilities of substitution between capital and fuel, the potential for savings through correct choice of timing, technology, and scale are immense. This particular project is unique because these decisions involve two political jurisdictions: India and Bhutan. Furthermore, the value of Bhutan's unique natural resources -- its hydroelectric sites -- is entirely determined by their potential to save India's scarce economic resources, both capital and fuel.

The 336 MW Chukha hydroelectricity project was built by India on a turnkey basis, with India providing 60 percent of the capital in a grant and 40 percent in a loan at highly concessional terms and conditions. In the arrangement, India receives in turn all the electricity generated from the project in excess of Bhutan's demand at much cheaper prices than India's generation cost from alternative sources. The analysis, therefore, involves an ex ante financial and economic evaluation of the project from the viewpoint of Bhutan and India, taking into consideration the project's terms and conditions, the alternative cost of power generation for India, and the engineering risks and environmental costs. The project is considered beneficial to both Bhutan and India, although its terms and conditions are not inflation-proof. With a rise in the inflation rate, there is a significant reallocation of the project's benefits in favor of India.

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**Introduction**

The Chukha hydroelectricity (hydel) project is a major engineering work undertaken by Bhutan with India's assistance. The project was conceived in 1961, the time at which Bhutan began a planned process of economic development. Upon completion, the project was expected to generate substantial revenue to the government, while providing a sustainable power supply to Bhutan and India. Today, the project generates about rupees (Rs) 300 million in annual revenue and supplies over 1.8 billion kilo watt hours (kWh) of electricity to India, in addition to meeting Bhutan's requirements.

It is expected that Chukha is the first in a series of hydroelectric projects that India will consider building in Bhutan to tap the estimated generation potential of 41.3 billion kWh. On its own, Bhutan neither has the financial resources to tap the hydropotential nor will it require that much electricity for its domestic consumption. On the other hand, India has an expanding electricity market and would like to tap Bhutan's potential to increase the share of hydro in its eastern region.[1] Development of hydroelectric potential could be mutually beneficial to both Bhutan and India since Bhutan needs revenue to finance its development program and India needs electricity to accelerate its industrial development.

Hydroelectric projects are, however, environmentally

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[1]India has five electricity regions: eastern, northern, southern, western, and northeastern. The states of Bihar, Orissa, West Bengal, and Sikkim constitute the eastern region.

sensitive. They submerge large areas of upstream productive land in water. Construction of project roads and excavation of construction sites cause frequent land slides and debris flows which accelerate the soil erosion process. Furthermore, the upstream population has to forego economic activities, such as mining and logging, in order to reduce the risks of quicker reservoir sedimentation. Finally, the danger of flooding and severe damage to the homesteads of the downstream population in the event of catastrophies like earthquakes is substantially increased.

Unless the benefits of hydroelectric projects are greater than the costs, Bhutan has no incentive to develop its hydropotential primarily for meeting India's requirements. Chukha is a test case for Bhutan to know whether or not the benefits of the projects are worth the costs. A close examination of the financial and economic benefits, including environmental costs and engineering risks, will be useful for Bhutan in making future decisions.

**Market for Electricity in India and Bhutan**

Bhutan had no electricity consumption records at the time the Chukha Hydel project was conceived. With 90% of its 1.3 million[2] people involved in subsistence agriculture, Bhutan was not expected to consume the 1.94 billion kWh of Chukha's generation even by the middle of 21st century. Bhutan's domestic demand in 1988 was 70

[2] This is an official figure. The actual population may be less than one million.

million kWh. It was estimated to rise to 130 million kWh after the completion of a calcium carbide project with a capacity of 100 tons per day. After this quantum increase, annual growth is expected to rise by not more than 5% per annum in the region to which Chukha could supply its electricity.

The project was built by India with an energy buy-back arrangement for 99 years. As such, the discussion of the electricity market is not relevant in Chukha's context. Chukha is located on the Wangchu river, which has prospects to house one 1,000 MW (mega watt) run-of-the-river downstream project and another 630 MW high dam project. Together with Chukha, the three potential hydroelectric projects are estimated to generate 8.7 billion kWh of hydroelectricity on the Wangchu river while providing a peak capacity of 1,966 MW[3]. India had taken note of this potential at the design stage of Chukha with a view to obtaining a large quantity of electricity from the Wangchu for its eastern region (Fig. 1).

At present, India's eastern region draws as much as 1.8 billion kWh of electricity from Chukha. India's National Hydro Power Corporation (NHPC) buys Chukha's electricity at the bus-bar and transmits it to its power network for distribution through five regional agencies: Bihar State Electricity Board (BSEB), West Bengal State Electricity Board (WBSEB), Orissa State Electricity Board (OSEB), Damodar Valley Corporation (DVC), and the Calcutta

[3]See Dhakal, D.N.S, 1990, "Hydropower Development in Bhutan:An Analytical Framework for Evaluating Prospects and Strategies," Ph.D. Diss., Colorado School of Mines, Chapter 8, P.162

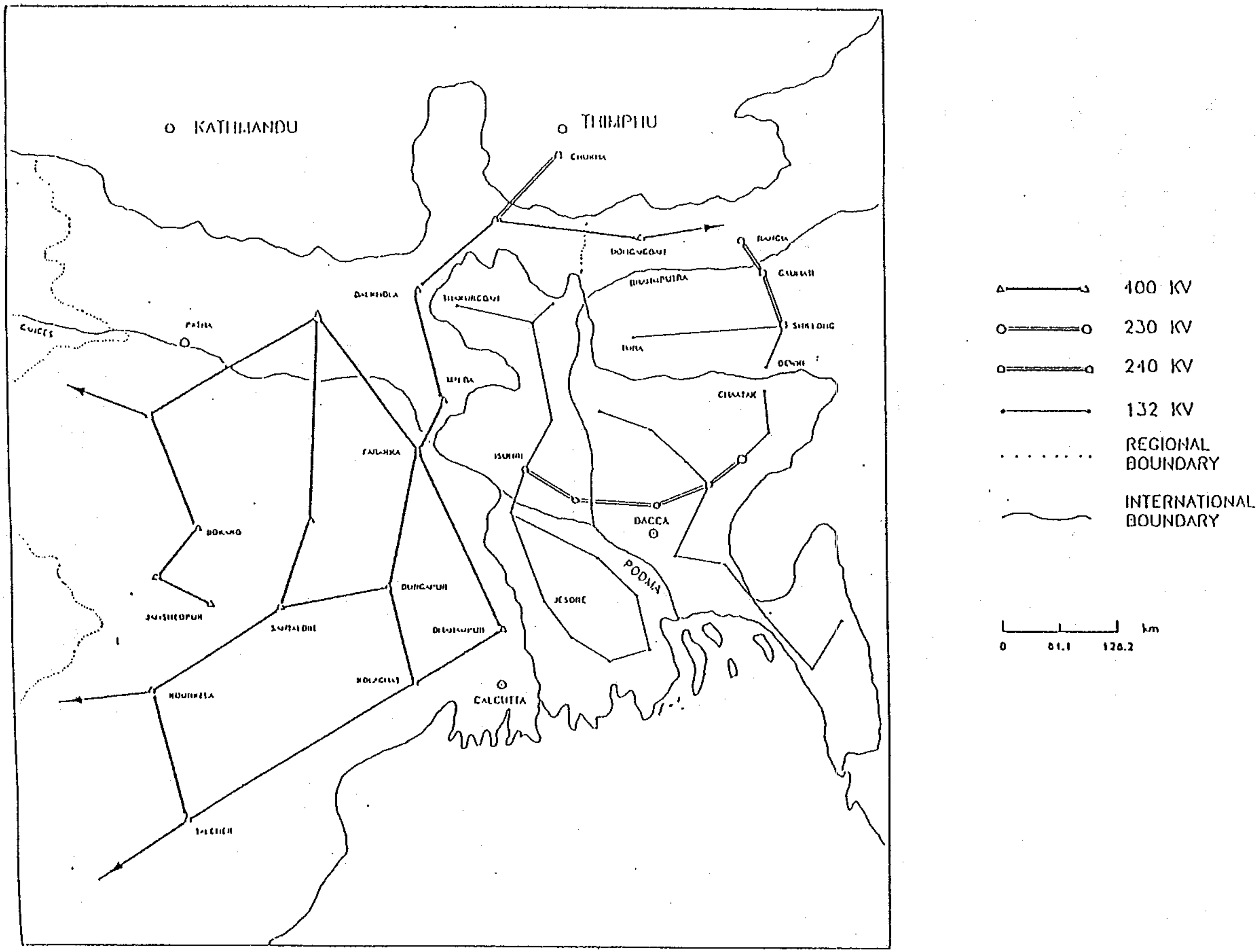


Fig. 1 Electricity Regional Market

Electricity Supply Corporation (CESC). Chukha's supply is synchronized and integrated with the region's other supply sources (Fig. 2). The region uses Chukha's supply for peak load generation in the evening and morning hours, in addition to a sustained base load of about 100 MW throughout the year.

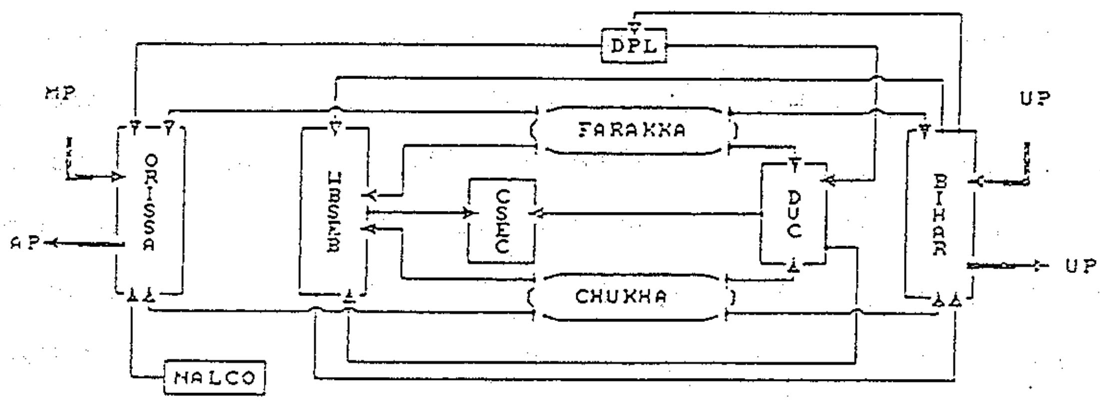


Fig. 2 Power Exchange System, Eastern Region

The eastern region has a growing electricity demand, which is expected to rise from 24 billion kWh currently to 104 billion kWh by the year 2000.[4] In addition, India is moving towards an

[4]See "National Power Plan 1985-2000, A Long Term Development Profile," 1987, Vol. 1, Central Electricity Authority (CEA), Ministry of Energy, New Delhi, p.52

integrated electricity network with the potential to transfer power from one region to another. Once that happens, the supply from Chukha could reach as far as Uttar Pradesh in the northern region and Andhra Pradesh in the Southern region. The projected demands of these regions are equally large. Therefore, it can be safely concluded that the project will not face problems of marketing the hydroelectricity as long as the export prices are competitive with India's other supply sources.

India is, by and large, rich in hydro resources. These resources are, however, unevenly distributed with more than 30% of the total potential located in the Brahmaputra basin. The Brahmaputra basin, that includes the states of Arunachal Pradesh, Assam, Manipur, Meghalaya, Nagaland and Tripura, is located a long distance from the main consumption centers in peninsular India. In addition, its unstable political situation has made this area unsuitable for large commitments of financial resources for hydroelectric projects. Outside the Brahmaputra basin, India has only 6,150 MW of total hydro generation potential to replace the needs for hydroelectricity imports in the eastern region.[5]

At a 30% load factor, the eastern region of India could generate as much as 25 billion kWh if it taps all the hydroelectric sites for power generation. This quantity will be only 24% of the

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[5]The potential hydroelectric sites in the Brahmaputra basin are between 1,000 to 2,000 km away from Calcutta, one of the farthest load centers in the eastern region. Essentially, India could tap the hydropotential of the Brahmaputra basin to meet the requirements of the eastern region by constructing high voltage AC or DC transmission lines.

total projected demand in AD 2000. Hydroelectricity, which is clean and sometimes cheap, is not only flexible for power generation but if available in adequate quantity, it could reduce system costs by improving the system load factor. For India, the optimal recommended hydro-thermal mix is 40:60.[6] At this ratio, the eastern region alone will need an additional 10 billion kWh of hydroelectricity supply even after it exploits all the identified generation sites.

The above discussions make amply clear that the market for hydroelectricity in India's eastern region is large enough to absorb not only Chukha's generation but also that of the entire basin. The underlying factor, however, is not the size of the electricity market, but the negotiation for the selling prices, which are dependent on how each country perceives its economic benefits.

The value of the electricity produced by this project is directly linked to the opportunity cost of electricity generated by alternative means in India. This key part of the analysis is covered later in the economic analysis module.

## Technical Aspects of Project Design

The Chukha Hydel project is a run-of-the-river scheme[7] with

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[6]See CEA, 1987, p.245.

[7]In a run-of-the-river project, a dam is built across the river to divert water onto the turbines for generating base load only. If storage space is availale upstream of the dam location, a larger dam can be built to store water flow in the river for a few hours in order to provide a higher peaking capacity in addition to

a peak load generation capacity of 336 MW. It is designed to take advantage of the monsoon flow by generating a large quantity of secondary energy during summer and sustained peak and base loads throughout the year.

Located on the Wangchu gorge below Chimakoti on the Thimphu-Phuntsholing highway, the project region spreads over an area of about 36 square kilometers in the interior part of the country at an elevation of 6,000 ft. It comprises a 45-meter-high diversion dam, a 6.8 km long head race tunnel (HRT), and an underground power house cavern with dimensions of 141 X 24 X 37 meters for housing turbines, generators, and the control room (Fig. 3). In addition, the project is equipped with two parallel desilting chambers, two inclined shafts, a surge shaft, and a 890 meter long tail race tunnel. Four pelton-type turbines are each coupled with an 84 MW generator. The dam has a storage capacity to generate a year-round 100 MW load for 24 hours and a 336 MW peak load for four hours. From June through September there is excess water in the river and all the generators run at full capacity during this period.

The physiography of the area permits the creation of a water head of 404 meters in a horizontal distance of less than 2 km. For the greatest benefit, engineering risks have been taken into consideration in the design by locating the dam on a highly sheared rock formation, aligning the head race tunnel below the mebari slip with only 20 m of protective rock cover at some places, and by locating the power house cavern at a distance less than one km

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base load generation.

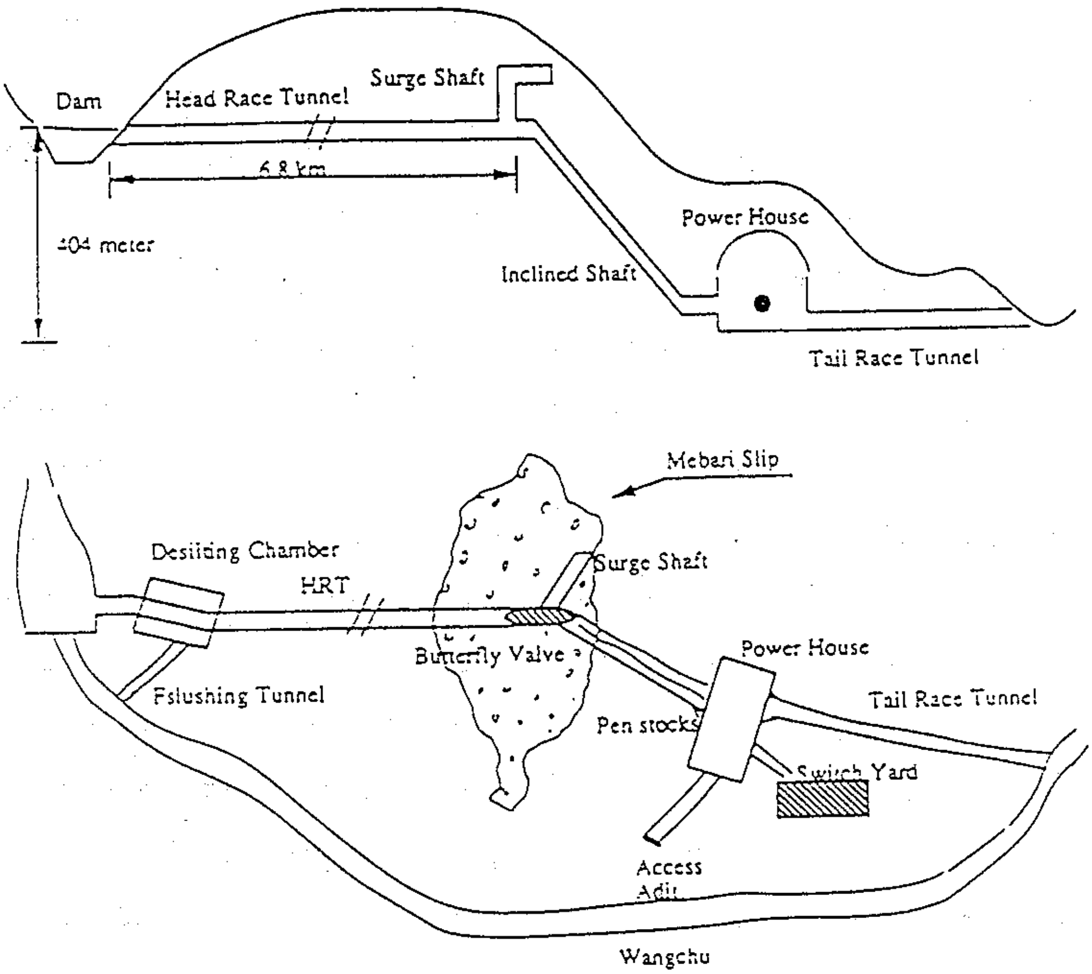


Fig. 3 Cross-sectional and Plan View of Chukha Hydel Project

upstream from the Thimphu-Paro formation thrust zone.[8]

Large engineering projects usually have long gestation periods, especially hydroelectric projects. Construction alone takes about 5 to 6 years even in technologically advanced countries. As a result, expenditures on hydroelectric projects spread out over a long period of time, creating the necessity to record both cash inflows and outflows on a regular basis.

In the case of Chukha, expenditures were spread out from the time the exploratory work began in 1973 to the project's completion in 1988. In addition, the nature of the work and inaccessibility of the site forced the project management to stock a large inventory of construction materials and spare parts. At the time of Chukha's construction, Bhutan did not have its own reliable power source. The project tapped a supply from the WSEB and also maintained a captive diesel generating set to supply electricity not only for its own use but also for the Thimphu and Phuntsholing areas of Bhutan on a regular basis. As a result, the project had both cash outflows and inflows during the construction period. Table 1 gives cash flows in nominal rupees, booked under proper account heads or sub-heads.

The inflows during the construction period are from: (1) the sale of electricity to Bhutan, (2) sale of land that was purchased earlier, (3) liquidation of used equipment, machinery, inventories,

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[8]Thrust zones are contact boundaries between two different geological formations with different rock types and geological ages. Such boundary zones are vulnerable to strata movement at the time of earth tremor and may cause damage to manmade structures.

and salvage value of the temporary buildings, and (4) the sale of inventories to the contractors shown under the sub-head "suspense". They were recorded when received.

The outflows comprise: (1) expenditure on preliminary work and land purchase; (2) payment for construction work including the dam, building, plantation, transmission lines and communication facilities; (3) purchase of equipment and machinery; and (4) recurring expenses on maintenance and establishment. A description of each category of expenditures is given in Appendix A.

## Management and Contractual Arrangement

The Chukha Hydel project was a turnkey arrangement with the government of India. From the time of its conception to the time of detailed project preparation, the project work was the responsibility of the National Hydropower Corporation (NHPC), although other Indian organizations, such as the Central Water and Power Commission (CWPC), Geological Survey, and the Geophysical Survey were actively involved. For implementation of the project, the Chukha Project Authority (CPA)-an autonomous body accountable to the board of directors, three nominated by Bhutan and two by India- was created in 1974. The board was given the power to make any decisions deemed necessary to complete the project.

It took 27 years to complete the project. Between 1963 and 1973, pre-feasibility and feasibility reports were prepared. This period was also used for geological investigations and hydrological studies because Bhutan had no records on precipitation,

# Table 1 Historic Costs of Chukha Hydel Project

(Million Rupee)

| Item/year | 73/74 | 74/75 | 75/76 | 76/77 | 77/78 | 78/79 | 79/80 | 80/81 | 81/82 | 82/83 | 83/84 | 84/85 | 85/86 | 86/87 | 87/88 | 88/89 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RECEIPT | | | | | | | | | | | | | | | | | |
| Sale of Energy | | | | | | | | | | | | | | | | | |
| 1.Revenue & Receipt | | | | | | 1.64 | 2.15 | 2.20 | 2.30 | 2.74 | 8.51 | 43.53 | 16.09 | 11.38 | 4.19 | 25.95 | 120.7 |
| 2.Land | | | | | | | | | | | | | 0.06 | | | | 0.06 |
| 3.Liquidation (AC) | | | | | | | | | | | | | | | | | |
| -building | | | | | | | | | | | | | | | | 0.08 | 0.08 |
| -equipment | | | | | | | | | | | | | 0.31 | 3.70 | 1.75 | 0.56 | 6.31 |
| -transmission | | | | | | | | | | | | 10.27 | | | | | 10.3 |
| -communication | | | | | | | | | | | 2.14 | 0.00 | 4.84 | | | | 7.0 |
| -suspense | | | | | | | | | | | 43.62 | 14.91 | 11.42 | 20.49 | 10.56 | 64.95 | 166.0 |
| TOTAL CASH INFLOW | | | | | | 1.64 | 2.15 | 2.20 | 2.30 | 2.7 | 54.3 | 68.7 | 32.7 | 35.6 | 16.5 | 91.5 | 310.3 |
| EXPENDITURE | | | | | | | | | | | | | | | | | |
| 1.Preliminary Work | 0.02 | 0.01 | 0.02 | 0.02 | 0.03 | 2.06 | 2.50 | 2.32 | 1.35 | 0.41 | 1.46 | 2.52 | 1.94 | 1.42 | 0.70 | 0.82 | 17.59 |
| 2.Land | | 0.06 | | | | | | | | | | | | | | | 0.06 |
| 3.Civil Work | | | | | | | | | | | | | | | | | |
| -diversion dam | | | | | | | 0.02 | 14.76 | 19.74 | 35.37 | 60.26 | 46.98 | 5.95 | 9.27 | 2.04 | 0.06 | 194.4 |
| -intake structure | | | | | | | 0.18 | 15.06 | 12.75 | 12.45 | 29.97 | 32.02 | 31.76 | 5.57 | 4.50 | 18.19 | 162.4 |
| -hydro-mech. gate | | | | | | | | 2.19 | 1.88 | 4.94 | 6.56 | 9.28 | 6.90 | 10.27 | 1.28 | | 43.3 |
| -head race tunnel | | | | | | 5.63 | 26.78 | 30.10 | 31.01 | 38.47 | 37.71 | 39.36 | 53.37 | 13.99 | 6.78 | | 283.2 |
| -power house | | | | 0.10 | 0.15 | 0.42 | 15.42 | 17.26 | 32.04 | 34.51 | 56.12 | 46.63 | 44.80 | 33.33 | 25.52 | 21.76 | 328.1 |
| -audits & tunnels | | 0.64 | 1.41 | 5.78 | 5.04 | 7.13 | 6.91 | 6.53 | 3.00 | 0.74 | 2.89 | 0.02 | | | 0.99 | | 41.1 |

TABLE 1: EXPENDITURE (CONT.)

| | 73/74 | 74/75 | 75/76 | 76/77 | 77/78 | 78/79 | 79/80 | 80/81 | 81/82 | 82/83 | 83/84 | 84/85 | 85/86 | 86/87 | 87/88 | 88/89 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4.Building | | | | | | | | | | | | | | | | | |
| -temporary | 0.90 | 2.00 | 3.71 | 4.50 | 14.10 | 10.90 | 2.70 | 2.50 | 2.29 | 2.13 | 1.54 | | | | | | 47.3 |
| -permanent | 0.20 | 0.50 | 0.60 | 2.30 | 6.00 | 6.50 | 6.36 | 2.70 | 2.50 | 2.61 | 1.88 | 0.96 | 5.50 | 0.55 | | | 39.2 |
| 5.Plantation | | | | | 0.04 | 0.04 | 0.05 | 0.05 | 0.06 | 0.06 | 0.06 | 0.10 | 0.13 | 0.08 | 0.04 | 0.06 | 0.8 |
| 6.Communication | | 4.00 | 4.30 | 4.30 | 5.70 | 6.10 | 4.88 | 3.96 | 6.40 | 6.33 | 0.00 | 2.46 | 0.00 | 1.58 | 1.10 | 0.00 | 51.1 |
| 7.Transmission | | | | | 4.67 | 11.46 | 10.10 | 10.10 | 10.23 | 30.99 | 22.61 | 0.00 | 22.72 | 26.72 | 27.23 | 69.11 | 245.9 |
| 8.Establishment | 0.95 | 2.00 | 4.10 | 4.10 | 6.80 | 11.20 | 15.10 | 16.20 | 19.32 | 20.15 | 23.55 | 24.21 | 30.45 | 21.98 | 14.40 | 14.51 | 229.0 |
| 9.Suspense | | 4.50 | 4.50 | 7.76 | 21.63 | 29.30 | 17.50 | 16.20 | 13.30 | 51.26 | | | | | | | 166.0 |
| 10.Production Equip. | | | | | | 76.78 | | 10.00 | 60.00 | 81.80 | 179.7 | 79.06 | 35.04 | 22.38 | 13.31 | 20.79 | 578.9 |
| 12.Special Equipment | | | | | | | | | | | | | | | | | |
| -Quarry T&P | | 3.40 | 1.20 | 3.92 | 0.50 | | | 5.32 | 5.17 | 9.50 | 3.51 | 0.67 | 3.42 | | | | 36.6 |
| -III T&P | | | 2.62 | 2.48 | | | 3.40 | 1.40 | 1.50 | 2.51 | 6.80 | 4.80 | | | 1.01 | | 26.5 |
| 13.Miscellaneous | 1.17 | 7.20 | 7.60 | 7.56 | 7.47 | 7.56 | 7.60 | 8.49 | 10.10 | 14.73 | 22.13 | 55.45 | 34.61 | 25.71 | 9.46 | 5.62 | 232.5 |
| 14.Maintenance | | | 0.10 | 0.20 | 0.30 | 1.04 | 1.20 | 1.40 | 1.45 | 2.36 | 3.02 | 3.16 | 3.24 | 3.74 | 2.30 | 2.72 | 26.2 |
| 15.Depreciation | | | | | | | | | | | | | | | | | |
| 16.Interest | | | | | | | | | | | | | | | | | |
| TOTAL CASH OUTFLOW | 3.24 | 24.31 | 30.16 | 43.02 | 72.43 | 176 | 121 | 167 | 234 | 351 | 460 | 348 | 280 | 177 | 111 | 154 | 2750 |
| NET CASH FLOW | -3.24 | -24.3 | -30.2 | -43.0 | -72.4 | -174 | -119 | -164 | -232 | -349 | -406 | -279 | -247 | -141 | -94 | -62 | -2440 |

Total Capitalized Expenditure -2440

Capital Cost/kw Rs. 7261

temperature, discharge rate, and sedimentation. Construction of offices, research stations, schools, hospitals, and residential quarters for professionals, technicians, and clerical staff was needed before the project could begin. The period 1974 to 1977 was spent primarily in the creation of these basic infrastructures.

Construction work on the hydro electric project itself began only in 1977. Construction work on the dam, HRT, and the power house complex started simultaneously. Six major Indian contractors worked on the project on piece-rated contracts. The project provided them free expert services, but recovered the cost of materials, rental cost of equipment and machinery, and incidental expenditures.

The project used mostly local resources. A cement plant with a production capacity of 300 tons per day was built in Bhutan to supply cement for the project. A number of Indian manufacturers were awarded contracts to supply materials, machinery, and equipment. Only a few special machines and a limited quantity of construction materials were imported from other countries.

The project was completed in November 1988. In total, 216,036 metric tons of cement, 33,303 metric tons of steel, and 1,067 metric tons of gelatine were used. On the average, the project employed about 5,000 people each year between 1977 to 1988, peaking at 10,605 in 1983.

The project was fully funded by India. The initial cost estimate in 1973 was Rs 640 million. This figure was revised to Rs 830 million in March 1974; Rs 1,494 million in December 1980; Rs

1,997 million in December 1982; Rs 2,042 million in April 1984; and Rs 2,438 million in September 1985. At the completion of the project in November 1988, the total cost was estimated at Rs 6,445 million. The Rs/$ exchange rate in this period varied from 7 to 19. These repeated cost revisions were a major concern for India.

For India, the success of Chukha was crucial for its prestige and future cooperation in other major engineering undertakings in the Kingdom. For Bhutan it was a source of constant worry about the intention of its giant neighbor which had swallowed Sikkim[9], a sister Himalayan Kingdom during the time the project had begun construction. Visiting foreign dignitaries who travelled on the Thimphu-Phuntsholing highway, often stopped at the project site and questioned the wisdom of building such a large project primarily for electricity export, further increasing Bhutanese doubts about the project benefits. The project management, therefore, had to be extremely cautious in dealing with the local people, its labor force, and the pace of construction work.

In addition to day-to-day management, project managers of large engineering projects have to handle mini-crises created by technical problems. Such problems often halt project work for several days, putting a large number of laborers and machines out of work. The financial cost of such a breakdown can be enormous unless immediate decisions are made about procurement and

[9] Sikkim was a satellite nation-state of India from the time of the British Empire. According to India, Sikkim was integrated within the Indian Republic in 1974 after the Sikkimese chose to become one of India's states in the public referendum.

employment of resources.

Normally, technical problems arise because of uncertainties associated with projects. Civil engineering work of Chukha's nature requires an intensive study of the sub-surface conditions to fully understand the nature of rock strata, locations of fault and fold zones, and enclosure of any water body or unconsolidated rock fragments trapped under pressure between the geological strata. Whether it was due to negligence on the part of the study team or because of the geological complexity of the Himalayan formation, the Chukha Project Authority faced many technical problems during the course of construction.

The foundation of the diversion dam required reinforcement with intensive cement injection and grouting to tie up the bed rock which had developed extensive fissures and fractures due to faulting. After digging a few hundred meters, the HRT alignment was changed to avoid penetration through an unconsolidated rock mass at a depth of 500 meters into the mountain. While blasting the head race tunnel, a gusher of sub-surface water killed a score of underground workers. The construction work was suspended until the natural flow stopped on its own after three weeks. These and other geological surprises were partly responsible for cost revisions.

Although undesirable, revisions of the cost of hydroelectric projects seem unavoidable. Nevertheless, in the case of Chukha, the total cost almost doubled the first estimate in real terms, giving rise to complaints of mismanagement of funds. Unfortunately, it is a common practice for project engineers to underestimate project costs to obtain government clearance. Once the projects are started, governments are compelled to allocate more resources to complete them, often at the cost of other social programs.

How far this was the case with Chukha is difficult to say. The Indian managers had scope to misuse the project resources as they had the power to procure materials and machines, to hire and fire employees, and to tender contracts for the project. Nevertheless, despite the repeated cost revisions, there are no grounds to question the integrity of the Indian managers as they completed the project at Rs 6,445/KW in 1980 rupees. The cost is several times smaller per KW than the capital cost for Nepal's Kulekhani hydroelectric project which was built concurrently with foreign assistance.

The capital cost and the efficiency of project management during the construction period, however, are not the only grounds for complaints. The contractual agreement between the two countries is also important since its terms and conditions would affect the benefits flow in the long run. The salient features of the Chukha agreement are paraphrased below for consideration in the financial and economic analysis:

(1) The project will be managed by the Chukha Project Authority (CPA) until the time of its completion. After its completion, the CPA will hand over the management to the government of Bhutan.

(2) India will provide the total investment on the project, 60% as grant and 40% as loan. Bhutan is required to repay the loan

at 5% interest rate in twelve equal installments, repayment beginning three years after completion of the project.

(3) Bhutan will provide free land, timber and firewood for the project and will not impose taxes on construction materials and capital goods procured for the project.

(4) Employment at the project will be restricted to nationals of Bhutan and India. If necessary, low cadre staff and laborers could be imported from a third country.

(5) Taking into consideration the time-series data of the last 20 years, both Bhutan and India have agreed upon prices for firm and secondary energy. In 1988 rupees, selling prices of firm energy will be Rs 0.27/kWh and secondary energy Rs 0.135/kWh. Out of its total generation, only 832 million kWh will be considered firm energy. The prices will be adjusted for inflation after every four years to maintain their real values.

(6) Electricity derived from the project will be supplied only to Bhutan and India. For 99 years India will buy all the electricity generated from the project in excess of Bhutan's requirements.

(7) Any dispute concerning the arrangement will be settled by an independent jury instituted jointly by Bhutan and India. Members of the jury will be either citizens of Bhutan or India; the chairperson, however, will be nominated by Bhutan.

Upon completion of the project in November 1988, the government of India transferred the management of the project to the government of Bhutan in a ceremony attended by the President

Venkataraman and King Jigme Singhe Dorji Wangchuck. The hydroelectric project is now in operation under the Ministry of Industries, Power, and Mines of the royal government of Bhutan.

## Financial Analysis

Chukha is the largest industrial enterprise in Bhutan. In the absence of other reliable sources of income, the magnitude of annual revenue flow from the project will be important for Bhutan to allocate resources for its development work in five-year plans. We shall therefore do the financial analysis to estimate the present value of the long run financial net benefits created by the project and to evaluate the annual revenue flow (ARF) from the project to the government treasury.

As the project is financed under highly concessionary terms by the Government of India, the determining factors of financial viability that are the normal focus of a financial analysis are of secondary importance here.

### Assumptions

Before we undertake the cash flow analysis we have to make assumptions on certain key parameters.

(a) Financial Discount rate The choice of a financial discount rate will affect the net present value (NPV) but not the annual revenue flow (ARF). Financial discount rates are the borrowing rates with an adjustment for market risks and inflation. In the case of Chukha, the actual borrowing rate for Bhutan is nonexistent, except for the interest rate on the loan. For this public sector project, the appropriate financial discount rate is the target financial rate of return that would be sufficient for the project to meet all its financial obligations. In this case it was concluded that an 8% real discount rate would be an appropriate rate to ensure financial feasibility.

(b) Inflation Rate Under the existing contractual agreement, the choice of inflation rate will affect both NPV and ARF considerably. Bhutan and India have free trade, and the rupee is used freely in Bhutan at parity with the nulgtrum.[10] The inflation rate will be the same for both countries. In the past, India has reported a one digit inflation rate, averaging 7 to 8%, though this is believed to be underestimated. For this analysis, we have assumed the prospective inflation rate of 8% per annum.

(c) Project Life The choice of length of a project's life affects only its NPV but not the ARF. The life of a hydroelectric project depends on its reservoir's life. A run-of-the-river project, which is less dependent on stored water for power generation, lasts longer than a high dam project. With scheduled replacement of mechanical and electrical equipment and quality maintenance, hydroelectric projects could function for more than 50 years. Nonetheless, in Chukha's case, we shall assume an economic life of only 35 years.

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[10] Nulgtrum is the denomination of Bhutanese currency. It is pegged one for one with the rupee.

Cash Flow Analysis

The financial cash flow is an extension of Table 1 for the next 35 years. It extends from 1973 to the year 2024 and includes all costs and incomes, including the recurring costs and revenues from 1989 onwards. The inflows include sales revenue, changes in accounts receivable, and the liquidation of assets. The outflows include overhead costs, operating costs, costs of repair and maintenance, loan repayments, changes in accounts payable, and changes in cash balances.

For the analysis, the data will be presented in constant rupees. The historical costs are given in nominal values and the projected costs and the revenues are estimated with an 8% compounding inflation rate to maintain uniformity. To deflate the data, GDP deflator indexes have been constructed. Since 1980 is the base year for India, all the costs and the revenues are expressed in 1980 rupees by multiplying each entry with appropriate deflation factors.

For estimating the annual revenue, the selling prices are used as stipulated in the contract document. The contract price of firm energy is Rs 0.27/kWh and secondary energy is Rs 0.14/kWh in 1988 rupees. These prices are adjusted for inflation every four years to make the real sales price constant at the end of the fourth year. Hence, the selling prices are allowed to be eroded by inflation and restored to their original real values in a saw-tooth cyclic fashion. The revenue is then calculated by adding the sales of electricity at Nu 0.27/kWh to domestic consumers with the sales to India.

Accounts receivable are estimated at 8.3% of the total sales revenue. The changes in accounts receivable, not the total accounts receivable, are included in the analysis as cash outflows.

Liquidation values of capital assets are cash inflows, which will not be realized until the end of the project life. Approximately 77% of the total investment was spent for civil structures, production equipment, transmission lines, and permanent buildings. The liquidation values are estimated to be 10% of their original costs in nominal values.

When the project commenced, the land was purchased for Rs 60,000. Land typically appreciates in value. Since the project area is located in the interior and is largely of inferior quality, it is assumed that land prices will grow only at the inflation rate, maintaining a constant real price.

Recurring expenditures and loan repayments are cash outflows. The recurring expenditure comprises overhead, operating costs, and the cost of repair and maintenance. In 1988 rupee, overhead is 0.5% of the nominal investment cost and is estimated at Rs 11.15 million; repair and maintenance is 10% of the nominal investment and comes to Rs 24.34 million.

In addition, the project must maintain a percentage of the recurring expenditure in liquid cash. It is assumed that 8.3% of the recurring expenditure will have to be maintained in cash. The cash balance is locked up capital and is considered an expenditure. As with accounts receivable, however, it is the changes from year to year and not the absolute balance amounts that affect the cash outflows.

Accounts payable are also assumed to be 8.3% of the repair and maintenance costs. The changes in accounts payable are entered as cash inflows.

The last item is the loan repayment. It is included in the cash outflow from 1991 through 2003. Each year's nominal payment is fixed at Rs 111 million, but the constant nominal rupee payments become smaller in real value over this period as a result of inflation.

After including these items in the analysis and extending the revenues and recurrent costs throughout the project's economic life, the NPV and average ARF are estimated. Two cases are considered for the financial analysis: (a) when prices are adjusted every year for inflation, and (b) when prices are adjusted every four years. In 1980 prices, the NPV in case (a) is Rs 708 million and Rs 633 million in case (b). The corresponding ARFs are Rs 164 million and Rs 145 million respectively.

The NPV indicates the project's economic viability, but does not tell us about the magnitude of annual revenue available from the project. Instead, the net annual cashflow gives us a picture of the financial strength of the project. Without the inflation adjustment every year, Bhutan will be losing a considerable amount of revenue over the year as depicted in figure 4. Some loss of revenue during the loan repayment period will be cancelled out because India also loses a portion of the loan collection to Bhutan

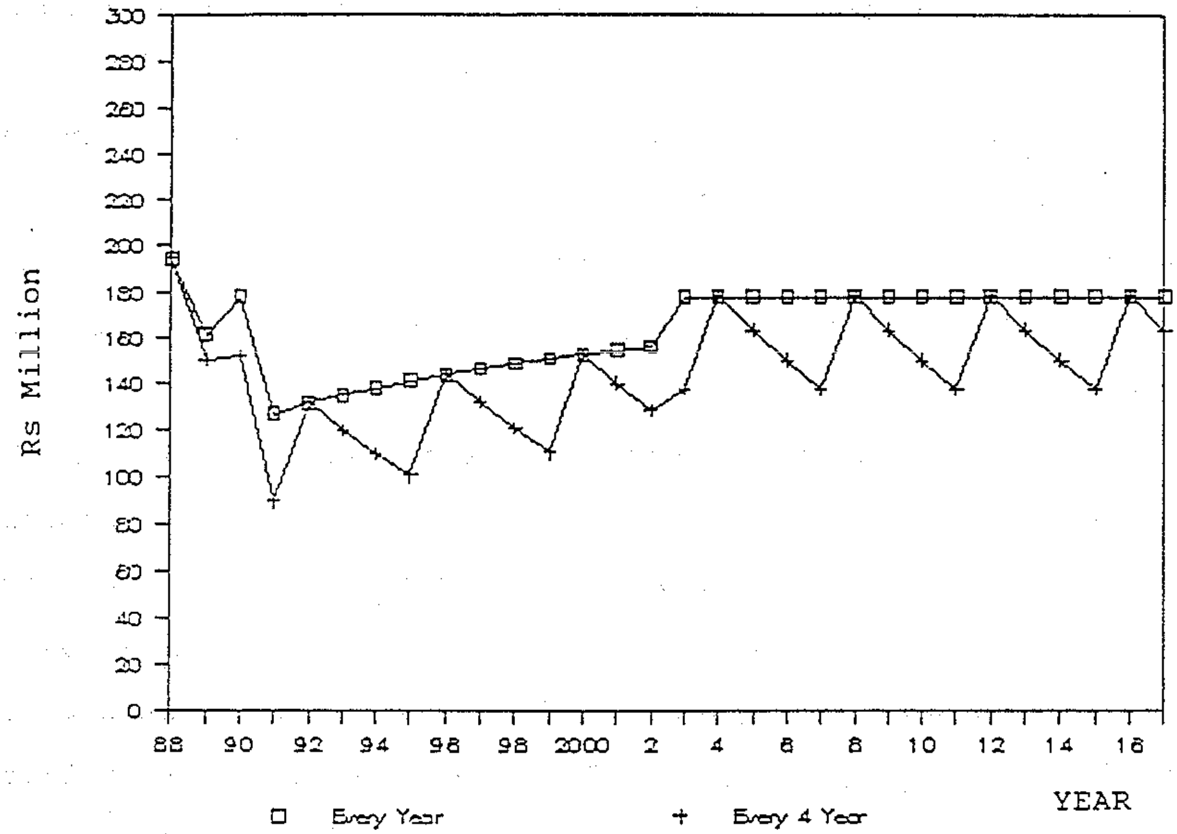


Fig. 4 Annual Fluctuations in Revenue Generation:
Case (a) every year and case (b) every four years

due to the inflation rate.[11] Nevertheless, the loss to Bhutan is much larger than to India since India buys a large quantity of electricity.

Summary Results: Financial Analysis

The financial analysis is done for two cases: (a) when the selling prices are adjusted every year and (b) when the prices are adjusted every four years. The NPV for case (a) is Rs 708 million and case (b) is Rs 633 million. The corresponding average annual revenue flows are Rs 164 million and Rs 145 million. On the average, Bhutan stands to lose Rs 19 million per year in 1980 rupees if the inflation rate is 8%.

## Economic Analysis

As we have already mentioned in the text, the financial benefits are exclusive to Bhutan. This leaves us with the question of what is the incentive for India to invest such a large sum of money in this project. Is this an altruistic attitude towards the smaller neighbor or is it for its own gain?

Bhutan and Nepal are India's smaller neighbors on the southern slopes of the great Himalayan ranges. Because of their locations, they are endowed with enormous hydropower potential, which, in

[11]The loan collection begins in 1991 and ends in the year 2003. In 1988, cash flow is larger because of the liquidation of assets used in the project during the construction period.

fact, cannot be developed without India's cooperation. Neither India nor any international organizations has suggested a reliable framework for sharing the benefits of hydropower development, although the World Bank has been actively involved in negotiations on the Karnali high dam project in Nepal since the 60s.[12]

Our approach in this study is based on cost differences in the supply of electricity from Chukha versus its potential substitutes in India. In the Himalayas many hydroelectric sites are available with different costs for power generation. Some sites will be cheaper than others depending upon their physiographic locations, availability of natural hydraulic gradients, and proximity to markets for acquiring construction materials and machinery for construction. Such sites have different generation costs. Consequently, the potential benefit generated by each site will be different. Figure 5 shows the generation costs of five different sites- A, B, C, D, and E.

In the case of Chukha, the benefits of the hydroelectricity depend not only on its generation cost but also on the cost of power generation from alternative sources in the eastern region of India . A hydroelectric project could supply all load types-peak, intermediate, and base-depending upon the capacity of its reservoir and the pattern of load demand. For example, the design of Chukha

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[12] Nepal has proposed to build a 12,000 MW peak load generation high dam project on the Karnali river in its western region, bordering the Indian state of Uttar Pradesh. Its generation is expected to feed India's northern region, which lacks a reliable peak load generation source. India and Nepal have not yet reached an agreement about the nature of project finance, the construction contract, and the prices of electricity.

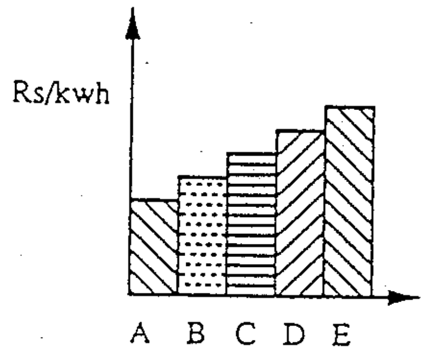


Fig. 5 Hypothetical Generation Costs:
Hydroelectric Sites

permits 4 hours of peak load generation every day in addition to a 100 MW year-round supply for base load. The peak load generation cost is no different from the cost for base load generation since its design is site-specific and the physiographic conditions are unique.

Conversely, the cost of generating peak and base loads are different in the case of thermal power generation. Plausibly, a combination of gas and coal-fired plants could be a substitute for the Chukha supply. Gas based generation is economical for peak load generation since it has a low capital cost but high operating cost, while coal-based generation is economical for base and intermediate load generation since it has high capital cost but low operating cost. The long run cost of peak hydro supply is therefore given by the intersection of the long run marginal cost of a gas-fired plant

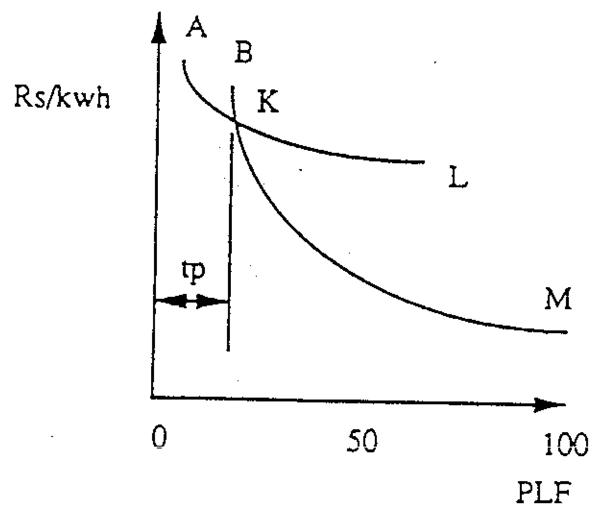


Fig. 6 Hypothetical Marginal Cost Curves:
Gas and Coal-fired Plants

and a coal-fired power plant (Fig. 6). The long run cost of supplying base and intermediate load will be in the marginal cost curve segment KM, depending upon the capacity for utilization of the coal-fired plant.

Thus the long run costs for India to substitute the supply from Chukha are the marginal costs of gas generation for peak load import and the marginal costs of coal-fired plants for the base load import. The difference between these marginal costs and the cost of supply from Chukha is a project's resource rent. This rent has been shared by India and Bhutan in terms of economic benefits. The magnitude of economic benefits would depend not only on the supply costs of Chukha and the alternative sources, but also on the discount rate. Following the estimations done by R. Bhaskaran and P. Bhattacharya, we use a rate of 9.1% as the real social discount rate for both Bhutan and India.

In addition, there are external benefits and costs of the project. For example, flood control provisions, irrigation by stored water, and substitution of air-polluting thermal generation are external benefits. Damage to the natural environment and risk of dam collapse are external costs. In the absence of reliable information, we shall not quantify either the external benefits or the external costs in the case of Chukha. In the economic analysis, we shall only explore how the project's resource rent has been distributed between Bhutan and India, given India's substantial contribution in capital investment.

## Economic Benefits for Bhutan

Bhutan is a small, underdeveloped country whose own capacity to capture the economic benefits of such a large hydroelectric project is small. Its economic NPV may not be perceptibly different from the financial NPV if both are discounted with the same discount rate. Nonetheless, there is a need to do an economic analysis because the availability of Chukha supply has increased consumer surplus by lowering the electricity price to domestic users.

The economic benefits are estimated from the economic cash flows. The economic cash flow for Bhutan is the extension of the financial cash flow, case (b). The difference in the economic analysis is in the adjustment for distortions and in the accounting of benefits not captured in the financial analysis.

The forgone benefit from the land occupied by the project is an economic cost, which is not captured in the financial cashflows. The project occupies an area of 300 acres, only 10% of which is cultivable land. It has a potential net income per year of Rs 200 per acre. An additional 40% can be used for ranching, which yields as much as Rs 50 per acre. The remaining 50% is barren, rocky, sloped terrain with practically no income potential. The total forgone benefit is, therefore, the summation of all these categories of income and is included as a cost in the cashflows.

On the benefit side, Bhutan gains from an increase in consumer surplus (Fig. 7). Before the project, Bhutan bought Q(0) quantity of electricity at a price of p(1). After the project the price was reduced to p(2). The reduction in price has induced a change in quantity demanded from Q(0) to Q(1)', yielding a consumer surplus equal to the area ABCD. In addition to the price response, there was a jump in electricity demand because of the new 100 tons per day calcium carbide project in Bhutan. As a result, the demand shifts to the right making the total quantity demanded Q(1). Since the calcium carbide project was not conceived independently of the Chukha Hydel project, it has no impact on the measure of consumer surplus. The consumer surplus can be segregated into the rectangle ABED and the triangle BCE. The increase in consumer surplus ch(CS) is, therefore, given by the summation of these two areas.

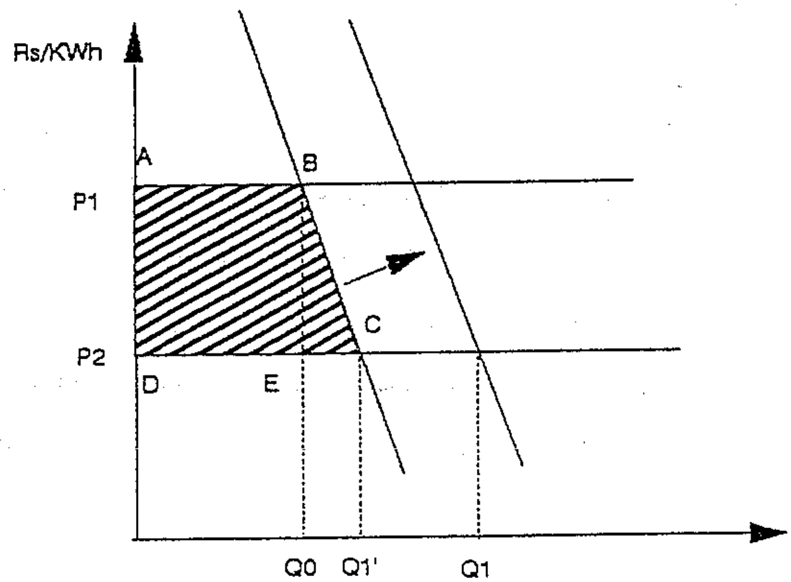


Fig. 7 Increase in Domestic Consumer Surplus

ch(CS) = ABED +BCE

ch(CS) = {p(1)-p(2)}* {Q(0) + 0.5*[Q(1)' - Q(0)]} (1)

where: p(1) = 0.70; p(2) = 0.27; Q(0) = 70; Q(1)'= 74

Bhutan's annual electricity consumption before the project was 70 million kWh; after the project it will increase to 130 million kWh. This increase is attributable to the 100 ton per day calcium carbide project, which alone accounts for 56 million kWh. The remaining supply response is only 4 million kWh, indicating a low elasticity of electricity demand for Bhutan. Furthermore, it is assumed that the demand for Chukha electricity will grow at a maximum of 5% per annum irrespective of the Chukha Hydel project. This growth rate will bring changes in the consumer surplus. The incremental consumer surplus for each year is calculated by shifting the demand curve to the right by 5% every year from its position in the preceding year.

Assuming no change in the elasticity of electricity demand, the incremental consumer surplus {ch(CS)t}, for a year t, is given by the area of the trapezoid GG'F'C' (Fig. 8):

$$ch(CS) = GG'F'C'$$

Adding the incremental consumer surplus in equation (2), the annual economic benefit to Bhutan in terms of total annual consumer surplus can be obtained from equation (2).

$$(CS)t = \{p(1)-p(2)\}\{Qt - Q(1)'] + 0.5*[Q(1)' + Q(0)]\} \qquad (2)$$

where: g = 0.05; the annual demand growth in Bhutan

t = 1 to 35; operation period of the project

Qt = Qt-1*(1+g); million kWh

Q(2)= 130; million kWh

The economic benefits are estimated in nominal prices. It is necessary to convert to constant rupees before adopting the benefits in the financial cashflow model. Then the economic cashflows are obtained by including the adjustment of the foregone benefit of the land occupied by the project, and the benefits of consumer surplus. The economic cash flows are then discounted by a 9.1% real social discount rate to estimate the economic NPV. In 1980 prices, the economic NPV is estimated at Rs 561 million.

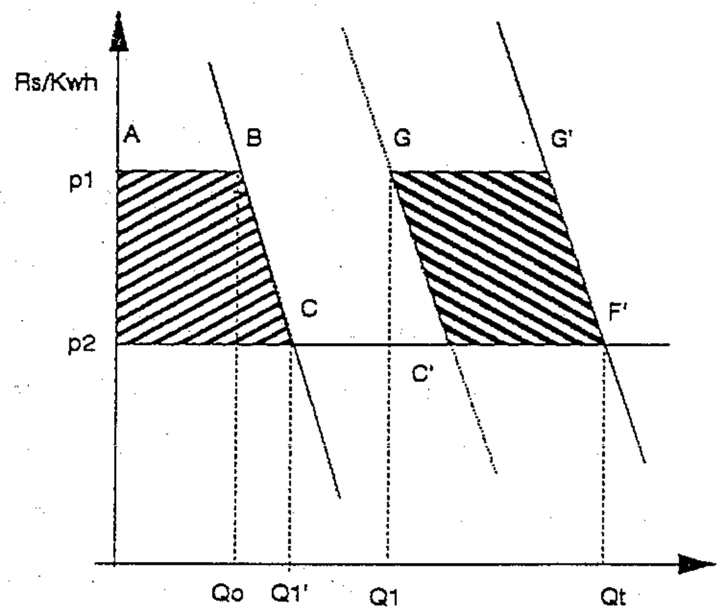


Fig. 8 Changes in Domestic Consumer Surplus
with a growth in Domestic Demand

Economic Benefits for India

The economic cash flow for India is different from that of Bhutan. The cost streams include the adjusted historical expenditures, the buying prices, the cost of transmission management, and the long distance transmission loss. The benefit streams include the increase in consumer surplus, the resource savings because of the differences in the costs of hydro supply and the alternative sources, the loan repayment, and the perpetuity. An adjustment to the historical costs for distortions and the addition of the above mentioned cost and benefit streams in Table 1 will yield the economic cashflow for India.

The need to adjust historical expenditures arises because of the differences in economic and financial costs of tradeable goods. Chukha was a turnkey project; except for specialized equipment and machinery, all the project's requirements were procured locally (with the exception of cement, everything came from India). In India, the costs of tradeable goods are notoriously distorted from their economic costs because of taxes, subsidies, and market controls. There are no distortions in the market for non-tradeables. Technically, we must divide each item used in the project into tradeable and non-tradeable goods and estimate the economic conversion factors for the tradeable goods to obtain real costs.

In the case of Chukha, however, we do not attempt to do all this. It is both due to unavailability of data and because of our limited objective of highlighting only the minimum possible benefit accruing to India from the joint undertaking of the project. In India, economic costs of most tradeable goods used by the project are smaller than their financial costs. Steel, equipment, machinery, furniture, and fixtures of equivalent quality would be available at much cheaper prices in international markets than those produced in India, even after adjusting the opportunity cost of foreign exchange (OCFE). Therefore, we assert that India's investments in the historical expenditures reflect the upper most margin of resource cost for India and, consequently, will not overestimate its economic benefits.

It is necessary, however, to adjust for the opportunity cost of foreign exchange (OCFE) for tradeable goods. In India, the use of foreign exchange is highly regulated. India levies high tariffs on imports but does not provide subsidies for exports. During the period of these purchases, tea and jute were the main hard currency earning products. Construction of the project also coincided with the period of the "oil crisis" when India faced severe foreign exchange shortages. This led India to adopt a stricter foreign exchange management policy for overcoming the hard currency crunch. This policy further distorted the resource cost of the foreign exchange.

The method adopted here for estimating the OCFE depends upon the elasticities of imports and exports, the import and export volumes, import tariffs, and export taxes. The OCFE is then calculated by using equation (3)[13].

$$E^c = E^m\{E_x(1+K) - N_i(Q_i/Q_x)*(1+T)\}/\{E_x - N_i(Q_i/Q_x)\} \qquad (3)$$

where $E^c$: shadow price of foreign exchange

$E^m$: official exchange rate

$E_x$: supply elasticity of exports

$N_i$: demand elasticity of imports

$Q_i$: volume of imports

[13] See chapter 10 in the unpublished 'Manual for Cost Benefit Analysis of Investment Decisions' prepared by Jenkins, Glenn P. (Harvard University) and Harberger, Arnold C. (University of Chicago).

$Q_x$: volume of exports

K: exports subsidy

T: imports tariff

In this analysis, the elasticities are assumed to be $E_x$= 0.5 and $N_i$ = -1.5. These assumptions closely reflect the Indian situation of low export potential and high demand for imports.[14] The volume of imports and exports changes from year to year. As a result, we obtain a series of OCFE for the years 1976 through 1985, when most of the importing was done for the project (Table 2). Each OCFE is then divided by the official exchange rate for calculating the conversion factors. The relevant financial costs are then multiplied by the conversion factor to obtain the true resource costs of the imported items.

After its capital investment, India pays Rs 0.27/kWh for firm energy and Rs 0.135/kWh for secondary energy at the bus-bar. In addition, India had to build a 220 KV line, extending from Birpara to Malda, to transmit electricity from Chukha. Technically, the cost of the transmission line should be included in the supply cost since India would have avoided the need for a transmission line if electricity were generated from alternative sources, such as gas turbines or coal-fired plants. Nevertheless, the transmission line

[14] Because of quantitative restrictions on imports, there is an implicit tariff on imported goods. The estimated OCFE is therefore reduced for India since the implicit tariff will increase T in equation (3). Since the share of foreign exchange in the total investment is small, its underestimation is unlikely to distort the estimate of minimum benefits for India.

# Table 2 Economic Cost of Foreign Exchange

TABLE 4.2 Input Data for Estimating the Economic Cost of Foreign Exchange

Ex 0.5
Eta(m) = -1.5

| Items | 73/74 | 74/75 | 75/76 | 76/77 | 77/78 | 78/79 | 79/80 | 80/81 | 81/82 | 82/83 | 83/84 | 84/85 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ER | 7.742 | 8.102 | 8.376 | 8.96 | 8.739 | 8.193 | 8.126 | 7.863 | 8.659 | 9.455 | 10.099 | 11.363 |
| Exports | 28.3 | 38.4 | 48.1 | 61.4 | 66.4 | 71.2 | 83.4 | 90.3 | 102.6 | 116.7 | 132.4 | 159.6 |
| Imports | 31.8 | 47.8 | 56.6 | 56.1 | 65.2 | 74.2 | 100.9 | 136 | 148.2 | 158.1 | 176.1 | 195.3 |
| Import duties | | 0 | 0 | 15.95 | 21.97 | 27.96 | 32.92 | 42.39 | 50.52 | 55.01 | 69.59 | 95.25 |
| Tariffs | | 0.00 | 0.00 | 0.28 | 0.34 | 0.38 | 0.33 | 0.31 | 0.34 | 0.35 | 0.40 | 0.49 |
| Subsidies | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Px | | | | 8.96 | 8.74 | 8.19 | 8.13 | 7.86 | 8.66 | 9.46 | 10.10 | 11.36 |
| Pm | | | | 11.51 | 11.68 | 11.28 | 10.78 | 10.31 | 11.61 | 12.74 | 14.09 | 16.90 |
| ECFE | | | | 10.83 | 10.94 | 10.53 | 10.20 | 9.87 | 11.06 | 12.10 | 13.29 | 15.72 |
| Ratio | | | | 1.21 | 1.25 | 1.29 | 1.26 | 1.26 | 1.28 | 1.28 | 1.32 | 1.38 |

<u>Source</u>: The base data are adopted from International Financial Statistics, 1988, (IMF)

can be viewed as an integral part of the eastern region's electricity network and should not be considered to be specifically built for Chukha. A smaller user fee should suffice to reflect the cost of electricity transfer from Birpara to the consuming centers even though the user fee will be irrelevant if the bulk of the supply is consumed in North Bengal. Since there is a cost to India in managing the electricity supply between Bhutan and the consumption centers, a user fee of Rs 0.10/kWh is considered appropriate.

Furthermore, one can argue that India bears an additional resource cost because of the transmission loss. The bulk transmission loss for India is estimated at 4% to 7%. We shall take 5% as the appropriate energy loss during the transmission process. A 5% increase in the bus-bar prices would thus reflect the cost of energy loss for India.

These cost streams when added together will give a single stream of costs spread over the project's life from the year 1973 to 2024. Similarly, a stream of energy supply for India from the year 1988 to 2024 can be obtained after adjusting the total generation by the consumption in Bhutan. By dividing the discounted value of costs in 1988 rupees and the discounted value of energy over the life of the project, we obtain 0.15 as the levelized cost per kwh of the Chukha supply to Indian consumers.

The estimate of benefit streams, from a rise in consumer surplus and resource savings, will require the shadow price of electricity generation in the eastern region of India. As discussed above, India draws peak, base, and secondary energy from Chukha. The benefits from (a) peak hydro supply will have to be evaluated vis-a-vis the region's marginal cost for peak load generation and a rise in consumer surplus; (b) base hydro, with the region's marginal cost of base load generation and a rise in consumer surplus; and (c) the secondary energy (hydro), with the region's marginal cost for generating comparable load-type and a rise in consumer surplus, if any. In addition, India receives the repayment of the loans it has extended to the project.

(a) Benefits of Peak Hydro The eastern region generates peak load from gas-fired plants. The marginal cost of peak load generation for the region is estimated at Rs 2.1/kWh.[15] This suggests that the market equilibrium price for peak load electricity in the eastern region would have been Rs 2.1/kWh if the region had adequate peak load generation capacity. We assume that the region does not have adequate capacity and therefore the equilibrium price for peaking electricity is Rs 2.5/kWh. Our assertion is backed by the fact that the Calcutta region alone consistently had a daily reported peak load shortage of more than 100 MW in the last two decades. The Chukha supply therefore will not only save resources by replacing power generation from gas-fired plants but will also provide an increase in consumer surplus by providing an extra quantity of electricity in addition to the

[15] See Dhakal D.N.S., 1990, Chapter 3.

region's generation capacity[16] (Fig. 9). The Area ABCD gives an estimate of annual benefits in terms of consumer surplus and resource savings from the peak hydro supply.

The area ABCD can be divided into the triangle ABE and the rectangle BCDE. Its magnitude could be estimated if we know the

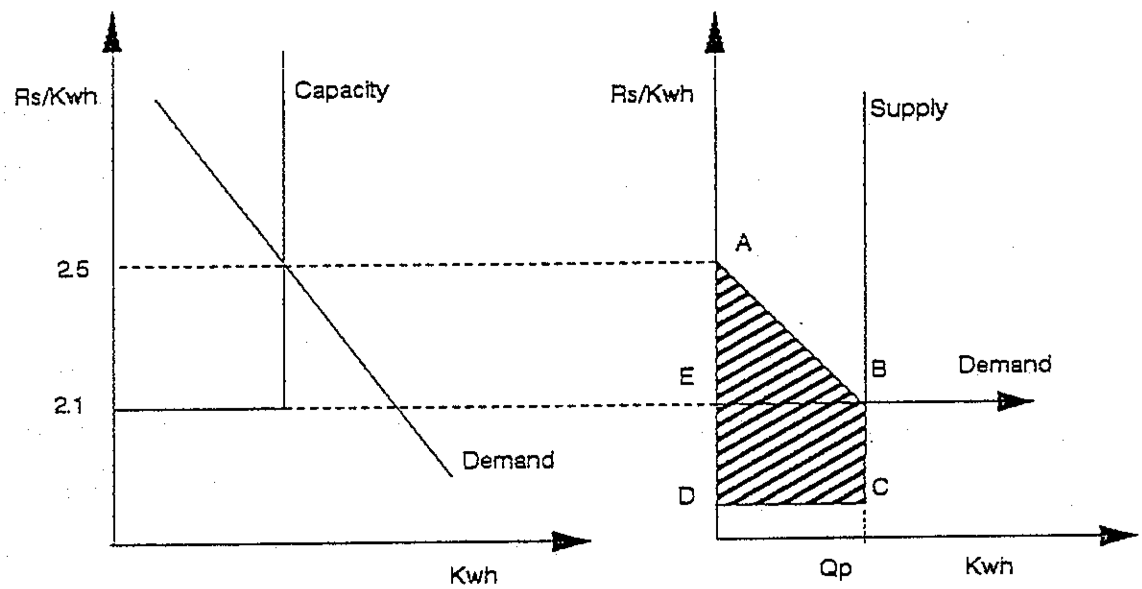


Fig. 9 Peak Load Electricity Market Vis-a-Vis Chukha's Supply

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[16]One could argue that the inclusion of consumer surplus is redundant in the analysis since India could increase its own capacity by adding more gas-fired plants. Our justification for its inclusion is that there had persistently been shortage of peak load supply in the Calcutta region in the last 20 years. Also, the region does not have its own gas resource. Its gas supply comes from the Assam oil fields, which is more than 1,000 km away from Calcutta and is politically unstable.

height of DC. DC's height is the summation of the levelized investment cost (Co), the purchase price (Pp), the management fee (Mf), and the cost of transmission loss (Tc). In this case, Co = 0.15; Pp = 0.27; Mf = 0.10; and Tc = 5% of Pp. The only other term we need to know is Qp.

The total year-round peak load generation capacity of Chukha is 490 million kWh. Bhutan's estimated peak load requirement in 1989 was 60 million kWh. Deduction of Bhutan's demand from the total peak quantity gives the value of Qp.

The area ABCD will decrease over time at a rate of 5% per annum since Bhutan will increase the share of peak energy at the same rate. To estimate the yearly changes, we have assumed the area ABCD to be a rectangle with Rs 2.30/kWh as its height.[17]

(b) Benefits of Base Hydro The eastern region generates base load from coal-fired plants. The region is believed to have adequate base load generation capacity. The region is rich in coal resources, with more than 70% of the reserves located in the states of Bihar, West Bengal, and Orissa. There is no apparent scarcity of fuel resources in the region; meeting its base load requirements is not a problem. On this premise, we shall assume the benefits of base hydro supply only in terms of resource savings since India could replace the import by its own power generation.

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[17]As the peak load supply will decrease with a 5% rate over the year, the determinant of A (Rs 2.50) is also decreased at the same rate in order to depict the adjustment in prices for the smaller quantity of import. This adjustment makes an assumption that with the import of Chukha electricity, India's peak electricity market is in equilibrium.

In 1989 rupees, the estimated marginal costs of new coal-fired plants located at the pit-heads are: Rs 0.70/kWh when capacity utilization is 70%; Rs 0.75/kWh when capacity utilization is 63%; and Rs 0.81/kWh when the capacity utilization is 54%.[18] The overall average capacity utilization in India has always been less than 60%. The situation in the eastern region has been the worst, with the average plant utilization rate between 40% and 50%. Since the import of the base hydro is a substitute for the generation from new coal-fired plants, we shall assume the marginal cost for our analysis to be Rs 0.70/kWh.[19]

The market situation for the base load in the eastern region is shown in figure 10. The area EFGH gives the estimate for the annual benefit of the peak hydro supply. Figure EFGH can be considered a rectangle for the purposes of calculation because single coal-fired plants, particularly the STPS, could generate larger quantities of electricity than the total import from Bhutan. The total base hydro generation capacity of Chukha is estimated at 342 million kWh. Deducting the 1989 base load for Bhutan's consumption of 70 million kWh gives India's base hydro import for 1989. As in the case of peak hydro, Bhutan's requirement for the base load is assumed to grow at 5% per annum. This growth will

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[18] See Dhakal, 1990, Chapter 3, for the estimates.

[19] India's future strategy is to build pit-head based large capacity coal-fired plants, known in India as Super Thermal Power Plants (STPS). The STPS normally have more than 1,000 MW capacity and have an average utilization factor of 70%.

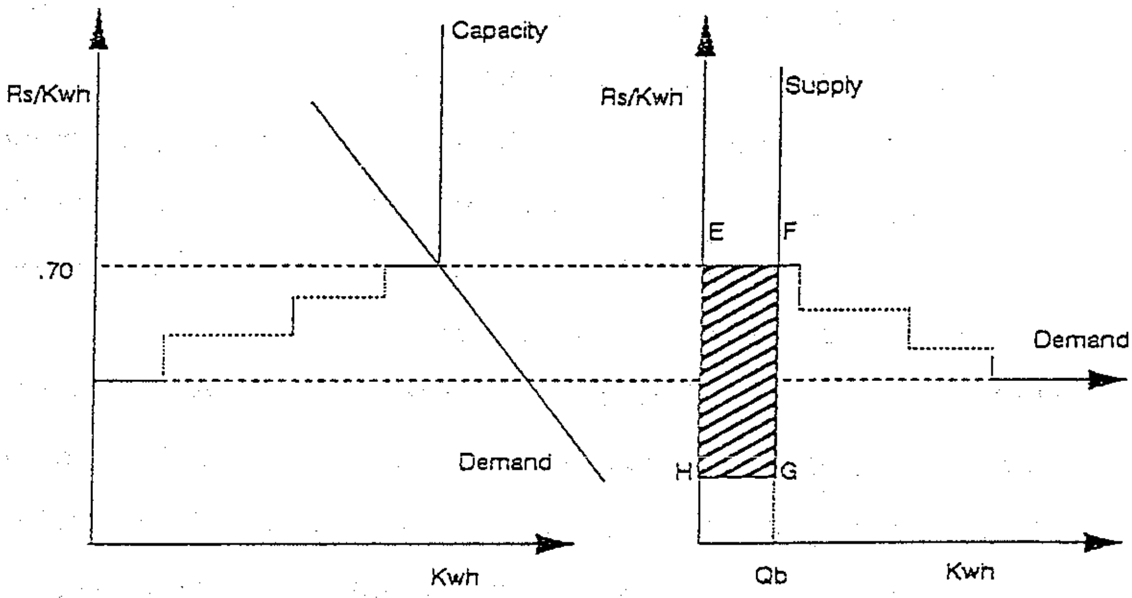


Fig. 10 Base Load Electricity Market Vis-a-Vis Chukha's Supply

reduce the availability of base hydro to India and consequently will reduce the size of EFGH proportionately. These changes could easily be reflected in the cashflow since there will be no change in the shape of EFGH.

(c) <u>Benefits of Secondary Hydro</u> Secondary hydro is generated only during the monsoon. Its supply will not prevent the need for building new plants in India since the seasonal fluctuations of energy demanded in the eastern region may not be as large as the secondary energy supply from Chukha.

Chukha generates a minimum of 1,112 million kWh as secondary energy during the monsoon. The energy is absorbed partly because there is greater demand for electricity for air conditioning in the plains. Also, India closes down some of its inefficient coal-fired plants for regular maintenance. One could argue that an electricity system should have at least a 20% greater capacity for increased reliability of the system. The secondary supply, which serves the purpose of the additional capacity, should also be considered as a substitute for the creation of new capacity.

We shall not, however, make this argument in our analysis since it is not always possible to schedule the maintenance of power plants only during the months of the monsoon. Technically, the marginal cost to generate the equivalent quantity of electricity for India is the savings in fuel costs. The fuel cost for power plants in the eastern region varies from Rs 0.27 to Rs 0.45 per kWh depending upon the distance of power plants from coal mines.[20] The 220 MW Muzafarpur and 365 MW Barauni plants in Bihar, located at a distance of about km 300 and km 280 from Calcutta, respectively, have fuel consumption costs of Rs 0.45/kWh and Rs 0.43/kWh in 1989 rupees. Since India is likely to replace the most expensive source with Chukha's secondary source, we shall evaluate the resource savings at a fixed marginal cost of Rs 0.44/kWh.[21]

The market for secondary energy could be considered partly as the demand for the excess load during the monsoon and partly as the

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[20]See Dhakal, 1990, chapter 3, p 39-45.

[21]The actual cost for India will be higher than the fuel cost if we include the cost of pollution control. For more discussion on pollution control costs, see Fay J. A. and D. Golomb, 1988, "Air Pollution Control for Indonesian Fossil-Fuel Power Plants," Report to the HIID, RM-255/88/055.

demand created because of the need to do repair and maintenance in old coal-fired plants. We shall consider that India's capacity to meet electricity requirements in such situations is adequate and the market is in equilibrium at a price equal to Rs 0.45/kWh. This situation is represented in Figure 11. The area IJKL, the estimate of benefit to India, is computed by taking the difference between the marginal cost of fuel consumption and the cost of hydro supply to India. Since Bhutan does not have the capacity to utilize seasonal energy, the benefit is projected to remain constant throughout the project's life span.

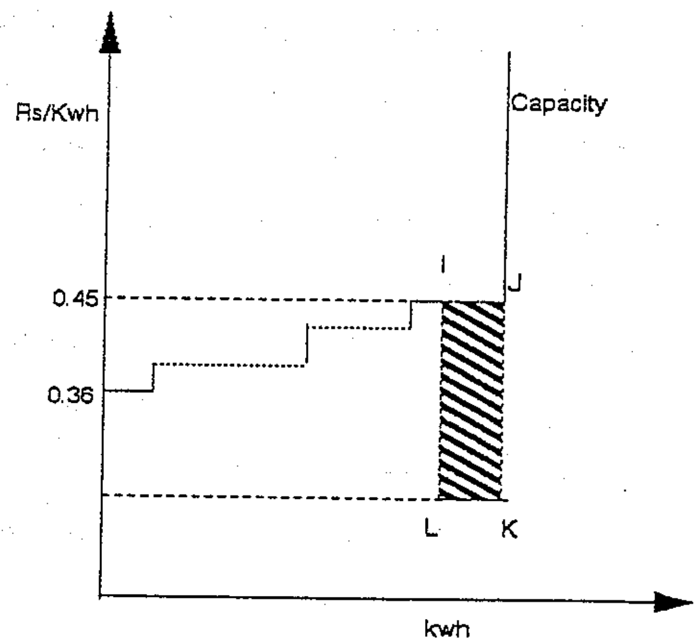


Fig. 11 Resource Savings from the Supply of Secondary Energy, India

The availability of secondary hydro (Qs) is 1,112 million kWh. The supply cost is given by the height of LK. Its height is the same as in the case of peak and base supply with the exception of the purchase price: Rs 0.14/kWh in 1989 prices. With this information plus the assumption that IJKL approximates a rectangle with height 0.45, we can calculate the benefit of secondary hydro.

(d) Loan Repayment In addition to these benefits, India gets the repayment of a loan in twelve equal installments with a 5% interest rate and the perpetuity. The perpetuity in this context is the present value of the resource savings beyond the 35th year, since Bhutan has given India the right to use the site for 99 years. Even after 35 years of commissioning the project, India will import about 65% of the total energy. Bhutan is unlikely to absorb more power from this project since this area has limited development potential and is not likely to take power from this project for use in other regions. The contract does not mention the replacement of machinery or repairs. However, it is understood that Bhutan will have to do the necessary repair or replacement with the resources from the project revenue. Therefore, we can count the benefit of the 35th year to India as its perpetuity in the cashflows.

After adjusting the relevant historical costs and entering benefits and cost streams in the economic cash flow, the NPV and IRR of the project are calculated from India's viewpoint. The economic NPV at a 9.1% real discount rate is estimated at 1202 million in 1980 rupees and the IRR is 15%.

Summary Results: Economic Analysis

At a 9.1% discount rate the economic NPV is Rs 561 million for Bhutan and Rs 1202 million for India in 1980 rupees. Although Bhutan received a large sum of money in grants, its economic NPV is smaller than India's because of smaller electricity demand in Bhutan.

A summary of the results of Financial and Economic analyses is presented in table 3:

Table 3 Net Present Value and Average Revenue Flows

(Figures in million rupees)

**Financial Analysis** : Discount Rate 8%

| | NPV | ARF |
|---|---|---|
| Case (a)* | 708 | 164 |
| Case (b) | 633 | 145 |

**Economic Analysis** : Discount Rate 9.1%

| | NPV |
|---|---|
| Bhutan | 561 |
| India | 1202 |

*Case (a) refers to annual adjustment of prices for inflation. In case (b), adjustment takes place after every four years.

**Sensitivity and Risk Analysis**

The above analyses suggest that the distribution of project benefits are sensitive to inflation rates. A higher inflation rate will erode a larger portion of the sale prices since the agreement stipulates revision of prices only once every four years. It will be more appropriate to do a sensitivity analysis of the results for the changes in inflation rates since the two governments could avoid fluctuations of the results by agreeing to revise prices for inflation every year.

On the other hand, the project was designed based on the last 20 years' data on the flows of the river. There are wide fluctuations in daily, monthly, and even yearly flows in the river. Such fluctuations would affect the total energy generation and consequently the estimates of NPV or the annual revenue flow (ARF). The fluctuations are beyond the control of the two governments; hence, risk analysis is considered appropriate.

Other factors like sale price of electricity are invariable over the life of the project under the contract and operating costs are too small to make any substantial difference. At this point in time, the capital costs also are known with certainty. Hence, from the point of view of both India and Bhutan, a sensitivity analysis on the river flow and inflation rate parameters will adequately capture the risk that is inherent in this project.

The results of sensitivity analysis are presented in Table 4. It is clear that with higher inflation rates, there is an increasing reallocation of Bhutan's share of the project resource rent in favor of India.

Bhutan's economic NPV is decreased by 9.27% when the inflation rate rises from 8% to 10%. It is decreased by 16.10%, when the inflation rate becomes 12%. Similarly, with inflation rate rising to 15%, 18%, and 20%, the economic NPV is decreased by 23.42%,

Table 4 Sensitivity Analysis

(figures in billions of 1980 rupees)

| Inflation | NPVe(B) | ARF | NPVe(I) |
|---|---|---|---|
| 0.10 | 509 | 115 | 1246 |
| 0.12 | 470 | 96 | 1277 |
| 0.15 | 429 | 80 | 1310 |
| 0.18 | 401 | 70 | 1332 |
| 0.20 | 386 | 66 | 1343 |

28.53%, and 31.15% respectively. The effects are more dramatic on the average annual revenue flow (ARF) of case (b). For inflation rates of 10%, 12%, 15%, 18%, and 20%, the corresponding reductions in ARF are 20.1%, 33.2%, 44.4%, 51.4%, and 54.2%. Such changes in ARF will not only deprive Bhutan of a large chunk of the project benefits, but will also affect other development plans in the

Kingdom since Chukha is the main source of revenue to the government.

Conversely, India's economic NPV increases by 3.65% when the inflation rate becomes 10%. With an inflation rate of 12%, the rise in NPV is 6.25%. Similarly, when the inflation rate becomes 15%, 18%, and 20%, the economic NPV of India goes up by 8.96%, 10.81%, and 11.76% respectively. Though desirable to have a larger share of the project benefits, in a sense it will be less beneficial to India than Bhutan; the former reaps the benefits only in terms of consumer surplus and resource savings, but the latter uses the revenue for productive investment.

The above estimates are based on the estimated energy generation potential of 1,944 million kWh: 832 million kWh as firm and 1,112 million kWh as secondary energy. Should the quantity of annual energy generation decrease, there is a risk of change in the estimates of the NPVs and ARF. So, we are interested in knowing how reliable our estimates are, given the probability of changes in energy generation due to fluctuations in river flows.

Figure 12 shows the results of risk analysis over a period of 12 months. On an annual basis, the total average energy generation potential is 2,163 million kWh with a mean standard deviation of 116 million kWh for a 12 month period. The energy generation range varies from 1,857 to 2,607 million kWh, with a 97% confidence level for generating 1,944 million kWh. At such a high confidence level, our estimates of generation seem robust.

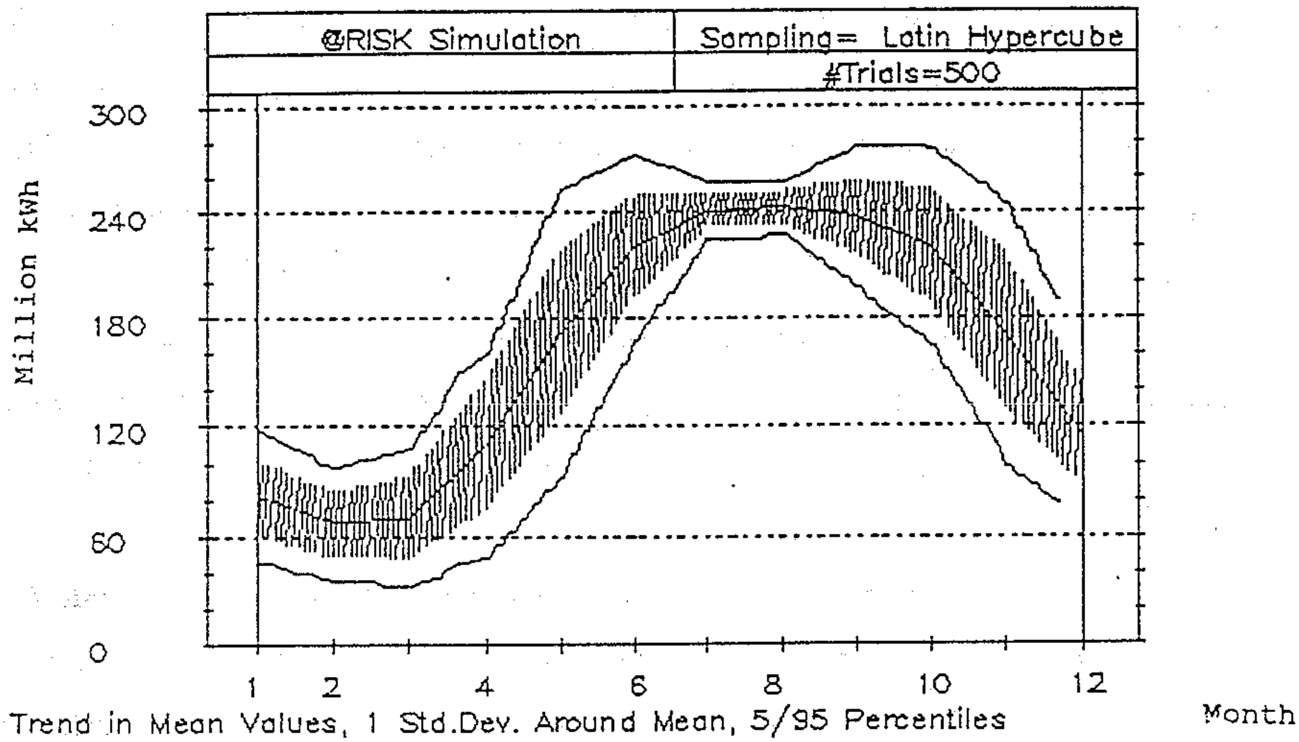


Fig. 12 Fluctuations in Monthly Energy Generation: Simulations with Historical Data*

* A Monte-Carlo simulation test was applied using the "At Risk" program. The analysis conducted tests the effect of the uncertainty associated with one risk variable (fluctuation of river water) on our projections of energy generation.

**Engineering Risks and Environmental Impact**

According to a report by the Geological Survey of India, the foundation of the dam is located on a highly sheared zone. In addition, the left abutment wall is on marshy land which was tightened with a breast wall during the construction period. Today, the land mass is sliding toward the dam's foundation and poses a hazard to the civil structures.

The project geologists had differences of opinion in the selection of the HRT alignment and the site for the power house complex. Uncertainty about the depth and the age of the Mebari slip and the impact of the geological thrust to the power house complex created a problem for the project geologists. Different experts suggested different schemes. In fact, no one knew with certainty their potential impact on the project at the time of a major tectonic movement in the region. The current sites were decided after considerable debate.

The thrust, however, is a less serious concern than the Mebari slip. The Mebari slip was perhaps triggered by an earthquake of larger Richter scale magnitude than has been experienced in recent history in the region. The CPA has recorded a 5.1 Richter scale tremor at the Chukha Dzong area and one of 5.7 at Taktichu, which is within a 20 mile radius of the project site. Current observations, however, provide no clues to future events because major disturbances in the Earth's crust are created by cyclic events which have not been well documented. The head race tunnel, which passes below the Mebari slip with only 20 m of protective cover, could easily break in an earthquake of the magnitude which caused the Mebari slip.

So far as environmental damage is concerned, it is minimal in the Chukha Project area. First, it is a run-of-the-river project which requires a small dam for water impoundment. Other types of projects would have created extensive environmental damage. Second, its water conduit and power house complex are built underground, thus avoiding the problems of cutting down vegetation and open excavations. Because of its unique design, the environmental damage is small and restricted to the sites of the diversion dam, approach roads, and residential areas.

The diversion dam does not require a large reservoir. The water impoundment, which stretches up to 3 km upstream from the dam, is confined to the river-bed. The submerged area was neither agricultural land nor forested area with rich flora and fauna. The creation of the reservoir, therefore, incurred little environmental cost. Instead, the impoundment created a natural reservoir and increased the aesthetic value of the gorge by providing picnicking, fishing, and rowing facilities.

Construction of roads for the project created some environmental damage by burying bushes and trees under soils, talus materials, and cobbles from the road cuttings and excavation dumps. Such loose materials, unless bound together either by reforestation or natural vegetation growth, create problems during the monsoon. Swept down in the monsoon rains, they serve as agents of erosion, sometimes changing the profile of a river bed with clogging and sometimes expanding the river-bed by increasing bed-loads. Although debris fans and gully formations were common along the road dumps in the Chukha area, the damage to the downstream environment was limited to a distance of 100 m or less.

The damage done to vegetation is also recovering fast. The barren rocky slopes have a fresh growth of Alnus nepalensis[22] and the clear-cut areas are covered with Phoebe spp., Artemesia sp., Zanthoxylum acanthopodium, and other bushy undergrowth. These species do not have much commercial value. Nevertheless, they serve the purpose of slope stabilization and soil conservation, which is a major environmental concern.

More damage to the natural environment is evident in the housing and office areas, which were created in some cases by clearing forests. The project had six residential colonies. Of the six, only Tshimalakha, Chukha, and Chimakoti have permanent or semi-permanent buildings. In the Tshimalakha and Chimakoti areas the endemic forests, which had certain commercial value, have disappeared. The forest has been replaced by bushy growth that has neither commercial nor aesthetic value. A reforestation program started by the CPA during project construction appears to be less successful from an ecological viewpoint, as they had attempted to plant eucalyptus and other commercial species that were not endemic to the region. A well adapted species would not only provide timber

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[22]This is an endemic species of the Himalayan foothills and middle hills, known locally as "Utis". This species colonizes exposed area by major landslides or road cuttings. It grows fast but is reported to have poor capacity to retain moisture in its environment.

and firewood at maturity, but would also maintain moisture balance to nurture a unique eco-type in its surroundings. Chukha has created such ecological problems in various localized areas. There is no generally accepted method, however, to measure the cost of micro-environmental changes or lost species. We consider the cost of this loss or damage to be negligible in this analysis.

The construction of permanent and semi-permanent buildings was undertaken without proper planning. The severity of its climate and the need for acclimatizing the imported laborers required the construction of many semi-permanent residential quarters which were abandoned after the project was completed. Some resources are required either for the demolition of these quarters or their conversion into usable units. Whatever the final choice, its cost will not be large.

## Conclusions

The Chukha Hydel project is an excellent example of bilateral cooperation in which both parties can expect to gain economically. It would not have been possible for Bhutan alone to develop the project. India provided the technology and the finances and received, in turn, low-cost hydroelectricity for the eastern region, where its major heavy engineering industries are concentrated.

On the other hand, Bhutan agreed to a mega-engineering project in the fragile Himalayan environment, accepting the risks of seismic hazards and environmental degradation. The fruit of the cooperation is that Bhutan receives about Rs. 300 million in 1990 rupees in annual revenue to finance its economic development, and India conserves its scarce fossil fuels while obtaining a 15% economic rate of return on the investment.

In net present value terms, the distribution of rent in 1980 rupees is Rs 561 million for Bhutan and Rs 1202 million for India under the current agreement. The distribution, however, will be favorable to India with a higher inflation rate unless the agreement is modified to adjust for inflation at the end of every year instead of every fourth year.

## Appendix A

### Explanation of Expenditure Items in Table I

(1) Preliminary work includes all the expenses for hydro-meteorological data collection, site survey, exploratory drilling, and preparation of the project report. Surveying, data collection, and report preparation continued throughout the construction period. Consequently, the expenditure under this account head continued until the completion of the project, peaking at the early and late stages of the civil works.

(2) Before signing the project document, the project paid land compensation to the farmers. This money was repaid to the project by Bhutan once it agreed to provide the land at no cost.

(3) The civil works account for 43% of the total cost. To provide a picture of the distribution of costs of different items, they are divided into the following sub-heads:

(i) The diversion dam, intake structure, and hydro-mechanical gate together cost approximately Rs 400 million. The hydro-mechanical gate is a mechanism built within the dam to release excess water during the period of floods. The intake structure is also a part of the diversion dam as it is used to control the flow of water from the reservoir into the HRT.

(ii) The HRT is not required in all hydroelectric projects. It is a water conduit that can be replaced with an open cut channel or avoided altogether as is the case in most high dam projects.

Depending upon the nature of rock strata, HRTs are sometimes lined with concrete and sometimes not. In the case of Chukha, it was necessary to provide a concrete lining with rock bolting and rib-support at places, thus requiring a higher capital cost. It cost about Rs 283 million, including the cost of the surge shaft, desilting chambers, and the butterfly valves.

(iii) A power house can be located either above or below the surface. Sub-surface power houses, to some extent, increase the availability of water head and are safer than power houses located on the surface. In the case of Chukha, the power house is located at a depth of 300 m and at a horizontal distance of 500 m from the rock face. It is quite spacious, accommodating four turbines, control panels, and other accessories required in the power house. Its walls and the roofs are heavily bolted but not lined with concrete. Total expenditure was about Rs 328 million, including the cost of two inclined shafts for feeding the penstocks.

(iv) Tunnels and adits are not used frequently except during the time of development. For example, a diversion tunnel is never used again after the completion of construction of the main dam. Also, it is necessary to build approach tunnels or adits to simultaneously open many working faces in order that construction of a long tunnel be accelerated. In the case of Chukha, such adits or tunnels were necessary. Furthermore, the water from the power house is released through the tail race tunnel and electricity from the power house is tapped through a cable tunnel. Access to the power house and its ventilation is provided by two separate tunnels. In total, such adits and tunnels cost about Rs 41 million.

(4) Both permanent and temporary buildings are needed in all major engineering works. Administrative offices and residential quarters are required even after project completion. Some engineers, technicians, and clerical staff are stationed permanently at the project site for administrative and maintenance purposes. In addition, temporary buildings are required for construction staff and laborers who will not be involved in the project after its completion. In the case of Chukha, additional permanent buildings were necessary for hospitals, schools, and engineering shops as these facilities were not available within a distance of 80 km. Laborers and staff brought from India had no previous experience of living in the harsh mountain climate: wet and foggy in summer and cold and windy in winter. The construction staff and laborers were provided with semi-permanent residences to help them acclimate slowly to the extreme conditions. In total, the cost of buildings was about Rs 86 million, 3.5% of the total investment.

(5) More resources should have been allocated for restoration of the natural environment affected by the project. For example, only Rs 0.78 million was used for the reforestation program.

(6) Expenditures incurred for widening the Thimphu-Phuntsholing highway, establishing a telephone network, and developing the access roads approaching the offices, residential areas, power house, surge shaft, and the dam site are booked under communication. Total expense was only about Rs 51 million.

(7) Construction of the 66 KV transmission lines from the project to the capital city, Thimphu, and to the border town, Phuntsholing, is considered a part of the project cost. In addition, a 220 KV transmission line was constructed to transmit power from the project to the NHPC's sub-station at Birpara for power distribution in India. At a later stage of project construction, a 220 KV transmission line to Thimphu was also added. The expenditures of these transmission lines as well as the 66 KV and 220 KV substations in Thimphu and Phuntsholing, are included in the transmission cost. About Rs 246 million is booked under the transmission account, representing 10% of the total investment.

(8) Overhead expenses for the establishment include office maintenance, and medical and project allowances.

(9) The "suspense accounts" were used for inventories bought by the project and later sold to the contractors when needed for the project. In fact, the total cash outflow on the suspense account in the earlier years is equal to the total inflow at the later years, about Rs 166 million.

(10) Expenditures on electrical equipment, such as turbines, generators, and transformers are booked under production equipment. Its total amount is about Rs 579 million, representing 24% of the total cost.

(11) Tunnelling, raising, excavation, and land development required special types of equipment which were useful only during the construction period. Expenditures on these types of machinery are booked under the special equipment categories: dozers, shovels,

compressors, rollers, dumpers, alimack climbers, and jack drills. The total expenditure on both imported and local equipment was about Rs 63 million.

(12) Expenditures that did not fall in any of the above categories are booked under the miscellaneous account, about Rs 232 million.

(13) Cost of buildings, vehicles, and furniture repairs are booked under the maintenance account. The total maintenance account is about Rs 26 million.

(14) Except for the initial development work, all the construction at the project was done by sub-contractors who used the machinery on a rental basis.

(15) Interest during construction was not included in the project cost.

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