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The Altamira hydro complex in the Amazon region

By A. Teixeira Duarte, J. L. Pettená and J. da Rocha Paes Filho
Engineering Director*, Inventory Study Co-ordinator** and Project Manager***

This gives the principal results obtained from the Hydroelectric Inventory Studies of the Xingu river basin, in the Amazon region of Brazil. The potential for installed capacity was found to be more than 20 000 MW at an average cost of about US$1000/kW, realized with a maximum of seven sites developed at various drops along the river. At the two downstream developments which constitute the Altamira complex, it is possible to develop more than 14 000 MW of installed capacity at a cost of about US$750/kW.

THE HYDROELECTRIC Inventory Studies of the Xingu river basin were carried out for Centrais Elétricas do Norte do Brasil S/A (Eletronorte) by Consórcio Nacional de Engenheiros Consultores S/A (CNEC), starting in 1976. The main objective was to evaluate the potential of the basin, which constitutes a sizeable portion of the Brazilian Amazon, and eventually, anticipate its utilization with rational planning.

A series of basic conditions were taken into account which permitted certain fundamental premises to be established; the most important of which were:

- the desire to obtain large blocks of energy concentrated in a restricted number of developments with the specific purpose of exportation of energy to other distant regions of the country;
- the adoption of capacity factors equal to 0.5, envisaging a comparison of cost indexes with other hydroelectric developments at present being designed or constructed in Brazil;
- the fact that developments with an installed capacity of under 200 MW should not be considered, as under conditions of today, they are not economically feasible, because of their high building cost as well as the non-existence of centres for local consumption;
- the need to consider and evaluate potential areas rich in minerals and minimize interferences with Indian reserves, with the city of Altamira and with existing Federal Highways.

*Eletronorte—Centrais Elétricas do Norte do Brasil S/A.; **CNEC—Consórcio Nacional de Engenheiros Consultores S/A, São Paulo, Brazil; and, ***CNEC—Consórcio Nacional de Engenheiros Consultores S/A, Brazil.

Description of the basin

The basin of the Xingu river is part of the southeast hydrographic network of the Amazon, covering areas in the States of Pará and Mato Grosso; it has an area equivalent to that of France, with a length of more than 2000 km; it is almost totally covered with dense forests and it is one of the least populated areas in Brazil, with a population of not more than 70 000 in an area of 500 000 km^2.

As well as the Xingu river, which is 1820 km long, the Iriri river, its principal tributary, is important, and from its source until its confluence with the Xingu river it is 1120 km long.

Most of the basin is composed of pre-Cambrian formations on a crystalline base. To the north, in the stretch of the lower course, Paleozoic and Cenozoic sedimentary rocks occur, from the sinicline of the Amazon. To the south, in the region where the Xingu starts, a sedimentary formation of silty-sandy composition occurs, the geo-hydrological behaviour of which explains the hydrological characteristics of the river.

The long middle course terminates in a fluvial estuary through a very rough sector which slopes downward, called the Volta Grande. In this stretch, in its length of 160 km, the river drops 85 m, which characterizes the main zone of the rapids of the Xingu river. In the remainder of the lower middle course from Altamira to São Felix do Xingu, in an extension of 500 km, the drop is 95 m. In the upper middle course in its length of 600 km, the river drops 90 m.

The average annual precipitation in the basin is about 1850 mm, occurring with lower values in the south portion and presenting a substantial increase in the northeast direction with totals exceeding 2000 mm.

The Xingu river is characterized by significant variations in flows between the flood and dry seasons. The minimum discharges are about 10 per cent of the average flow, with flood values five times larger than the average.

The crossing of the trans-Amazonian highway over the Xingu river at Belo Monte and its passing through Altamira made a regional support centre possible. Apart from Altamira, with a population of about 30 000, the only other urban centre with significant number of inhabitants is São Felix do Xingu, with an urban population of 3000.

The Indian population, in the area of interest for the inventory studies, north of the eleventh parallel, is estimated at 1700, distributed in settlements of the Kararaô, Araras, Arawetê, Kokraimoro, Gorotire, Kubenranquén, Bacajá, Menkranotire and Bau groups. In the middle sector of the basin, only diverse tribal groups were identified, separated in space, but culturally tied, situated in the National Park of Xingu, which will not be affected by the proposed developments. Fig. 1 shows the geographical location of the Xingu river basin.

Field operations

In spite of experience gained by Brazilian engineering during nearly 20 years of performance, and efforts to evaluate hydroelectric potential, the inventory of the Xingu Basin was a challenging rather than a routine study. The problem was exacerbated by the dimensions of the area, the difficult means of access, the absence of urban centres with adequate facilities, and above all, by the enormous obstacles created by the Amazon jungle. The requirement for adapting traditional methods, using new investigation techniques and becoming accustomed to the meteorological regime of the region meant that the field work took two and half years.

The reconnaissance covered 4000 km, making the preliminary identification of 47 locations possible, and the selection of interesting stretches for coverage by aerial photography.

The aerial photo montage at a scale of 1:25 000, was obtained from aerophotos at 1:60 000 scale covering 70 000 km^2 and a supporting geodetic network composed of 200 points, of which 60 were determined by Doppler tracking of satellites and the remaining ones by barometric levelling. Because the continuous and dense vegetation made it impossible to characterize details in the photographs, or to identify and implement geodetic support, it was necessary, before making the aero-survey flights, to make clearings at 200 points of the network; access was by helicopter and by river.

A hydrometric network existed at the end of 1975, consisting of four meteorological stations and six stream gauging stations, which was increased to 11 stream gauging stations and 27 rainfall stations, in spite of the difficulties in establishing them. For operation of the hydrometric network, it is necessary to travel to each station by river, by air transport and overland, depending on climatic conditions and access.

The geological reconnaissance in the field was developed in an integrated form with the mapping and

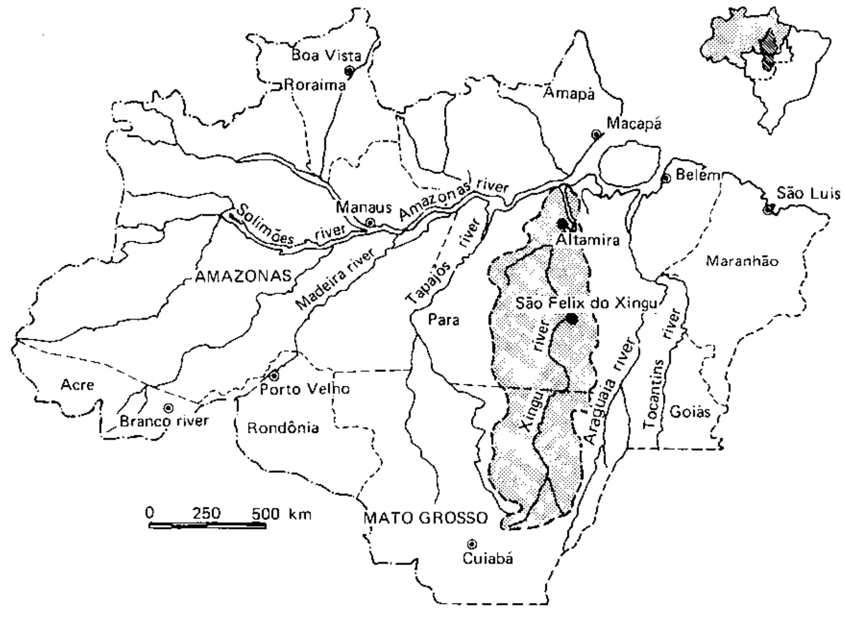

Fig. 1. Geographical location of the Xingu river basin.

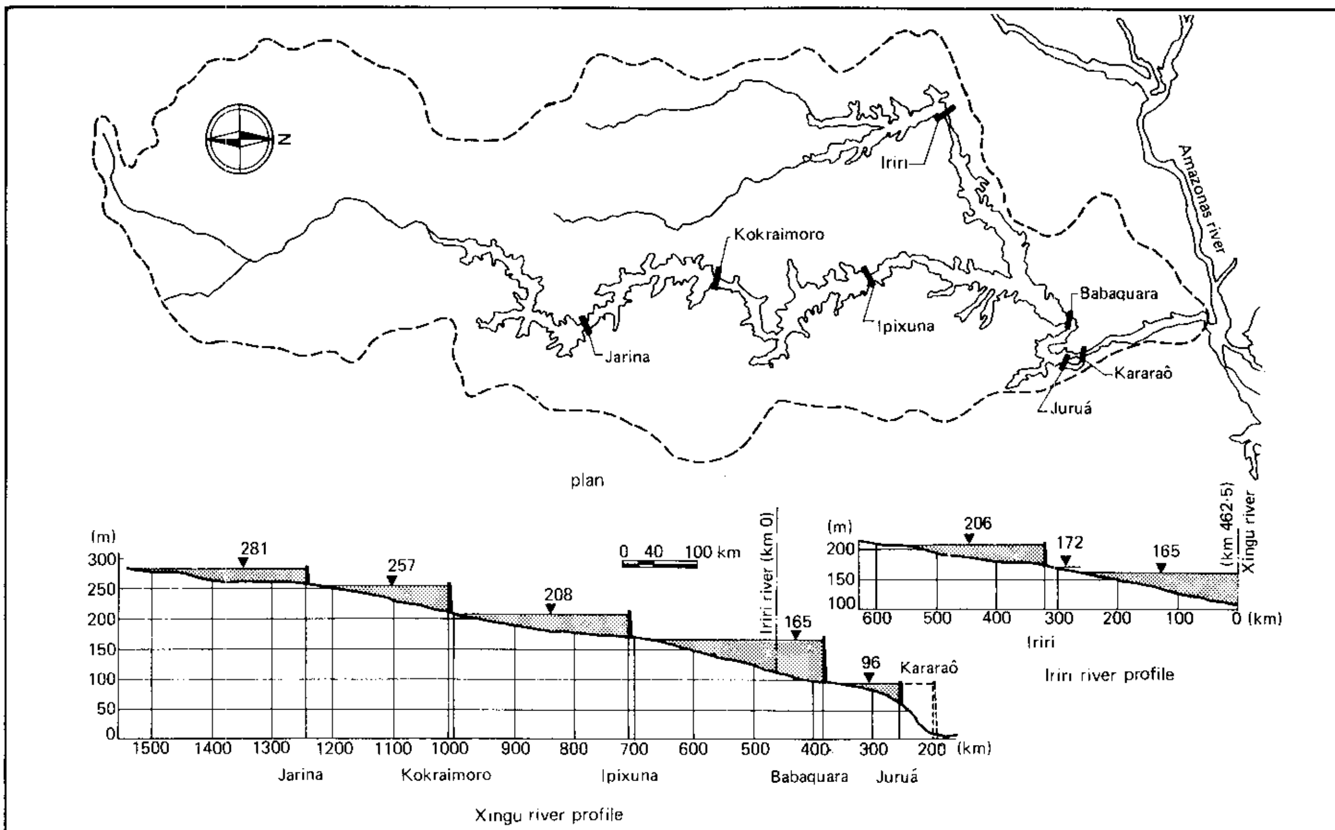

Fig. 2. Version A for the division of the river head.

hydrometric activities based on maps from the RADAM project and DNPM, and the interpretation of satellite pictures and mosaics from radar pictures. Investigations were made at 225 places in the jungle and a distance of 5000 km was travelled by road in the south area of the basin, where the typical lithography of geological data were verified and sampling of soils and rocks were made. The geological-geotechnical studies of the dam axes which appeared most promising were further investigated for foundation conditions and the availability of natural construction materials, based on surface and sub-surface investigations, including geophysical prospection.

Activities such as the opening of the clearings, the barometric levelling, the Doppler tracking of satellites, the installation and operation of the hydrometric network, the regional geological reconnaissance, the geological-geotechnical investigations of dam axes, and the topographic mapping and underwater surveys, were all made possible by the precise establishment of logistic procedures in the area of studies in the area, which has 2700 km of rivers, two fixed bases of operation and 17 auxiliary bases for the supply of foodstuffs and fuel. A radio communications system was installed with five stationary instruments and five portable ones which, permitted direct contact between bases and with the central office.

A total of 2300 h of helicopter time and 1300 h of aeroplane time were used for air transport. The transport of water, food, equipment, replacement parts and personnel from Altamira to the various locations on the Xingu, Iriri, Curua and Bacajá rivers, was responsible for the consumption of 250 000 l of aeroplane fuel, and 100 000 l of gasoline and diesel oil.

Development of available head

In preliminary studies eight options were analyzed which divided the river drop within various possible combinations between the most promising dam axes. Their selection was based on the pre-established criteria, which stipulated obtaining large blocks of energy concentrated in a restricted number of developments, and not considering any development that presented an installed capacity of less than 200 MW.

The existence of Volta Grande at Xingu, at which a substantial drop in water levels occurs, together with the large available flow rate, make it possible to plan a large-capacity generating system, the definition of which influenced the overall scheme for the division of the river drop upstream of Volta Grande.

The preliminary studies were concluded with a selection of two choices for the division of the head, based on a series of more accurate analyses of capacities and relative costs, complemented by technical, social-economical, physical and territorial considerations.

Subsequently, the results from the topographic mapping and underwater surveys at the dam axes, geophysical investigations, drilling and inspections pits, and geological surface maps were used. It was then possible to improve the general arrangements of the developments, to determine the characteristics of each site, and to try to use the most convenient natural materials for construction of the dams.

In the general arrangements, provision was made for the possibility of implementing interior navigation for the future. Access to the dam sites was conceived so as to take advantage, where possible, of routes of existing or planned State and Federal highways.

The sizes of reservoirs and the definition of installed capacities were obtained from simulated hydro energy studies. For each way of dividing the head, the firm energy is available 100 per cent of the time, resulting in firm energy for each development, and the respective maximum reservoir drawdown.

The two selected options, designated A and B, differ basically only in the normal maximum reservoir level for Babaquara, which in A is at el. 165 m and in B is el. 153. These elevations influenced the choice of upstream developments: Ipixuna, Kokraimoro, Jarina e Iriri for A,

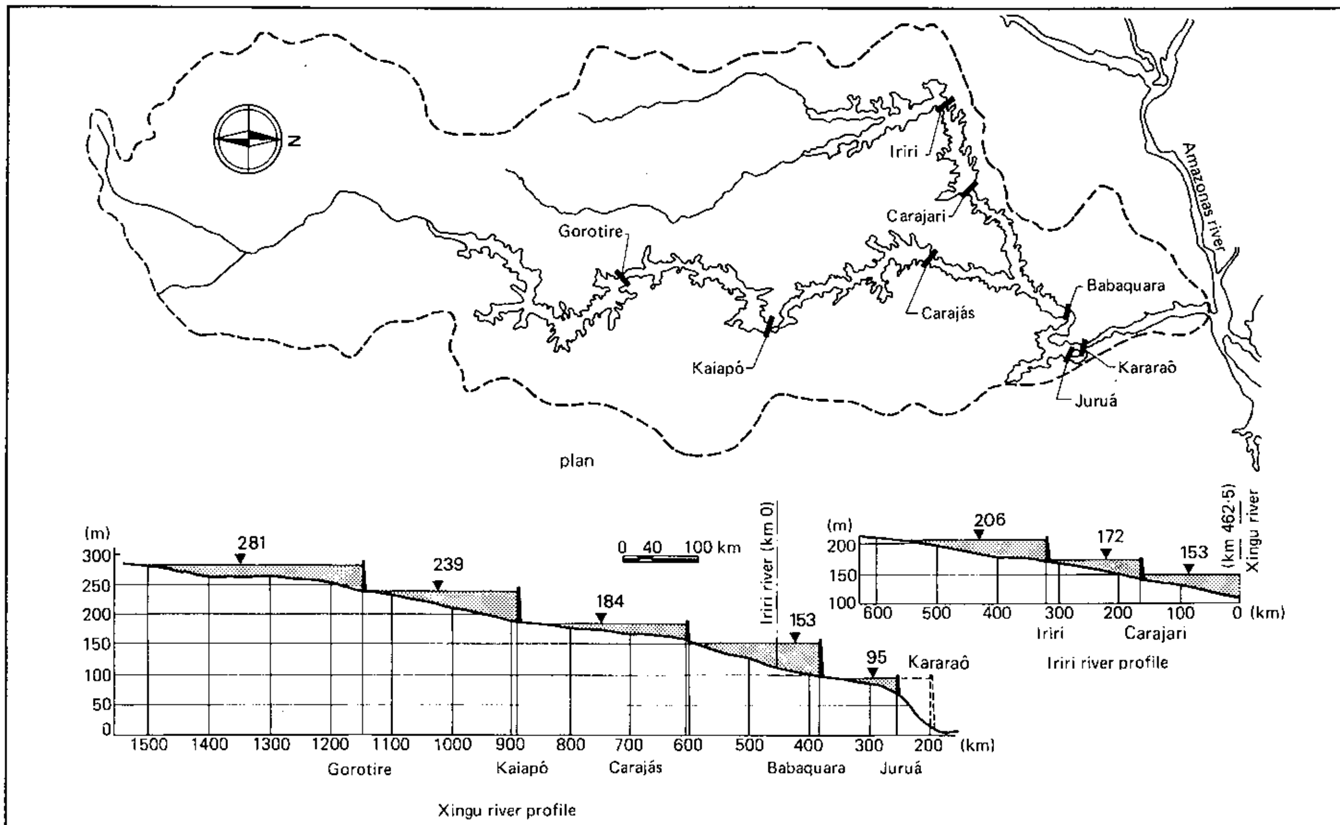

Fig. 3. Version B for the division of the river head.

and Carajás, Kaiapó, Gorotire, Carajari e Iriri for B.

The principal characteristics of A and B are shown in Figs. 2 and 3.

The studies carried out until now, and still being refined, have produced some significant data of great importance.

For A, the inventory capacity is 9500 MW firm and 20 400 MW installed (capacity factor = 0.5); the total estimated cost for implementation of the developments is US$16.3 billion for the basin, with an average cost index for installed capacity of approximately US$800/kW.

For B, the inventory capacity is 9800 MW firm and 20 600 MW installed; the total cost of the developments is US$18.3 billion, giving an average cost index for installed capacity of about US$980/kW.

The firm energy obtained refers to an isolated basin without considering interconnection with the National Energy System. The costs are based on prices as of January 1979.

The total areas flooded by the reservoirs were estimated at 18 300 km^2. Of this total, 3200 km^2 are located in the beds of the Xingu and Iriri rivers, and the rest of the areas effectively submerged, 14 600 km^2, represents only about 3 per cent of the total area of the basin.

Hydroelectric complex of Altamira

The Xingu river presents an average drop of 0.15 m/km in its intermediate course as it flows approximately in the south-north direction. As it passes by the city of Altamira, it deflects abruptly in an easterly direction, initiating the Volta Grande (which means large bend) that develops over an accumulated length of 160 km and terminating at a change of water level of 85 m, giving an average drop of 0.53 m/km. Starting at the locality of Belo Monte and until its mouth in the Amazon river, the river returns in a northerly direction and the water is calm and influenced by the tides.

In the Volta Grande stretch, the possibility of obtaining a large block of energy not only because of the concentration of the drop in river levels, but also because of the large volume of water available was visualized from the start of the studies. The Xingu river at Altamira already drains nearly 90 per cent of the basin area, and consequently already receives the inflows of its main branches.

The development with the special conditions peculiar to Volta Grande was initially analyzed for raising the natural water level of the Xingu river downstream of Altamira, with a dam in the course of the river and outflow structures. With this raising of the water level it became possible to divert the water into a secondary basin to exploit the more favourable topographical conditions, and the water is conducted to a dam near Belo Monte where it is possible to locate the intake structure, generating facilities and navigation locks. The water returns to the Xingu river downstream of Belo Monte. It is then regulated by a development upstream of Altamira where the head will also be used for power generation, and where navigation locks may also be constructed.

The hydroelectric system, composed of a development for storage and generation upstream of Altamira, and the development of Volta Grande only for generation is called the Hydroelectric Complex of Altamira.

The studies were continued from the topographical and geological-geotechnical points of view to identify the best conditions for location of the dams for the developments of Volta Grande.

As a result of extensive analysis, the layouts for the complex at Altamira, comprise the Babaquara development, with its large storage capacity and generation, and the Kararaô powerplant, where generation is made at constant reservoir level taking advantage of the regularization from Babaquara.

The axis of the dam at Babaquara is on the Xingu river, 10 km upstream of Altamira at a location designated Babi. For the reservoir formation, retention dykes will be necessary, notably on the right side of the reservoir in the

Table I—Altamira complex (high version): capacities and costs for isolated operation				
Development	Firm capacity (MW)	Installed capacity (MW)	Total cost (US$×10⁶)	Index cost (US$/kW)
Babaquara	2900	7190	6063	844
Kararaô	4370	8740	4268	489
Total (Complex)	7270	15 930	10 331	649
Base date: January 1979				

Table II—Altamira complex (low version): capacities and costs for isolated operation				
Development	Firm capacity (MW)	Installed capacity (MW)	Total cost (US$×10⁶)	Index cost (US$/kW)
Babaquara	1800	4500	4396	972
Kararaô	3300	6600	4024	610
Total (Complex)	5100	11 100	8393	757
Base date: January 1979				

Table III—Altamira complex: principal characteristics of developments

Developments	Drainage area (km^2)	Max. normal upstream level (m)	Max. drawdown (m)	Flooded area at max. normal water level (km^2)	Live volume (10^6m^3)	Net head (m)	Diversion flood (m^3/s)	Design flood (m^3/s)	Average annual flow (m^3/s)	Regulated flow (m^3/s)
		165	23	6140	96 700	58.6				5900
Babaquara	446 000						44 500	75 900	7920	
		153*	19*	3940*	54 900*	48.2*				4500*
Kararaô	477 000	96	0	1160	0	88.2	47 200	80 400	8900	5900
										4500*

*Value valid for low alternative

low natural saddles.

The concept of the Kakaraô development is as follows: provision for a dam called Juruá at Volta Grande on the Xingu river, where the structures for diversion and spillways will also be located; this is 121 km downstream of the city of Altamira; the basic function of the Juruá dam is to raise the water level of the Xingu river to improve conditions for delivery of the water to the intake; the delivery is made by diverting the water from the natural channel of the Xingu river by a system of associated canals and intermediate reservoirs to Kararaô where the intake and powerhouse will be built; these structures are downstream of Volta Grande on the left abutment and on the natural channel of the Xingu river.

The hydro complex of Altamira, as described above, is shown in Fig. 4.

More detailed studies of the complex are now in progress. Basically, two schemes exist for exploration of the hydro potential, conditioned by the normal maximum water level of the reservoir for Babaquara. Each scheme is associated with the division of the upstream head, constituting options A and B as already described. The reservoir at Kararaô has a constant normal water level at el. 96 m, operating without drawdown, so that it is a run-of-river plant.

In view of the importance of the energy produced from the complex and the fact that it is more than 50 per cent firm energy, it is convenient to evaluate and analyse its operation as being isolated, without counting on regulation by upstream reservoirs, which will only be built in the remote future.

An extensive programme of geological-geotechnical and topographical investigations is in progress to get a better overall knowledge for the selection of the best option. One of the main considerations for this analysis concerns the volumes in the retention dykes for the reservoir of Babaquara. In the high Babaquara dam, it would require about 96 000 000 m^3 of earthfill along 50 km of dykes, whereas in the low Babaquara dam, the volume of earthfill is 35 000 000 m^3 along 33 km of dykes.

On the other hand, the firm energy available from the complex of the high dam is 40 per cent greater than that of the low dam. The analysis made until now, with some anticipation, has indicated some impressive results.

With the high Babaquara dam, the capacity of the complex for isolated operation is 7270 MW firm and 15 930 MW installed; the total cost of the undertaking was estimated at about US$10 billion, giving a cost index for installed capacity of around US$650/kW. With the low Babaquara dam, the capacities are 5100 MW of firm energy and 11 100 MW installed; the total cost of the undertaking is estimated at about US$8.5 billion,

Fig. 4. The hydroelectric complex of Altamira.

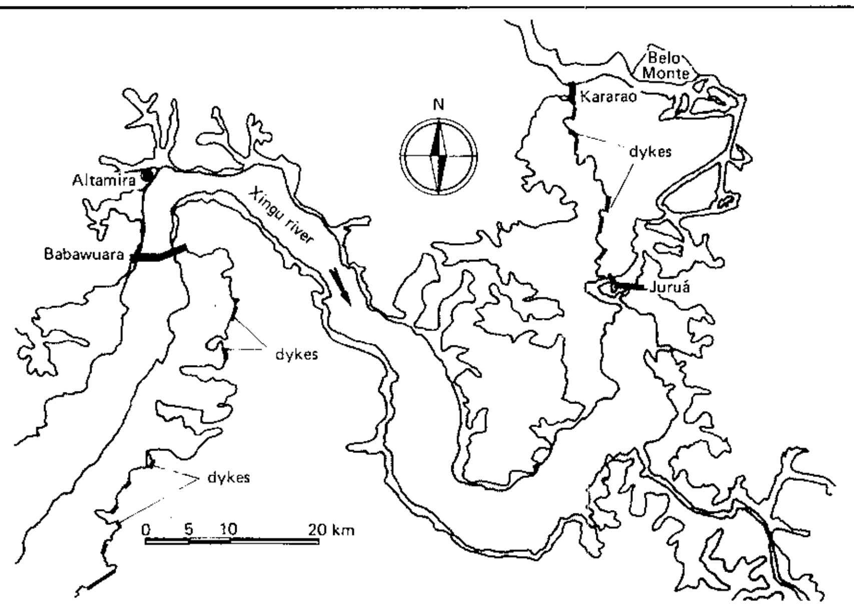

Table IV—Altamira complex (high version): main civil works quantities

Development	Eathfill—main dam (10^3 m^3)	Rockfill—main dam (10^3 m^3)	Concrete (10^3 m^3)	Earthfill—dykes (10^3 m^3)	Excavation (10^3 m^3) Earth	Rock
Babaquara (supply level = 165 m)	15 015	29 950	5410	95 840	16 820	6250
Kararaô (supply level = 96 m)	12 730	6870	2460	38 110	33 990	25 230
Complex (Babaq. + Kararaô)	27 745	36 820	7870	133 950	50 810	31 480

Table V—Altamira complex (low version): main civil works quantities

Development	Earthfill-main dam (10^3 m^3)	Rockfill—main dam (10^3 m^3)	Concrete (10^3 m^3)	Earthfill—dykes (10^3 m^3)	Excavation (10^3 m^3) Earth	Rock
Babaquara (supply level = 153 m)	7620	21 490	3780	35 280	9400	6100
Kararaô (supply level = 96 m)	12 730	6870	2460	38 110	33 990	25 230
Complex (Babaq. + Kararaô)	20 350	28 360	6240	73 390	43 390	31 330

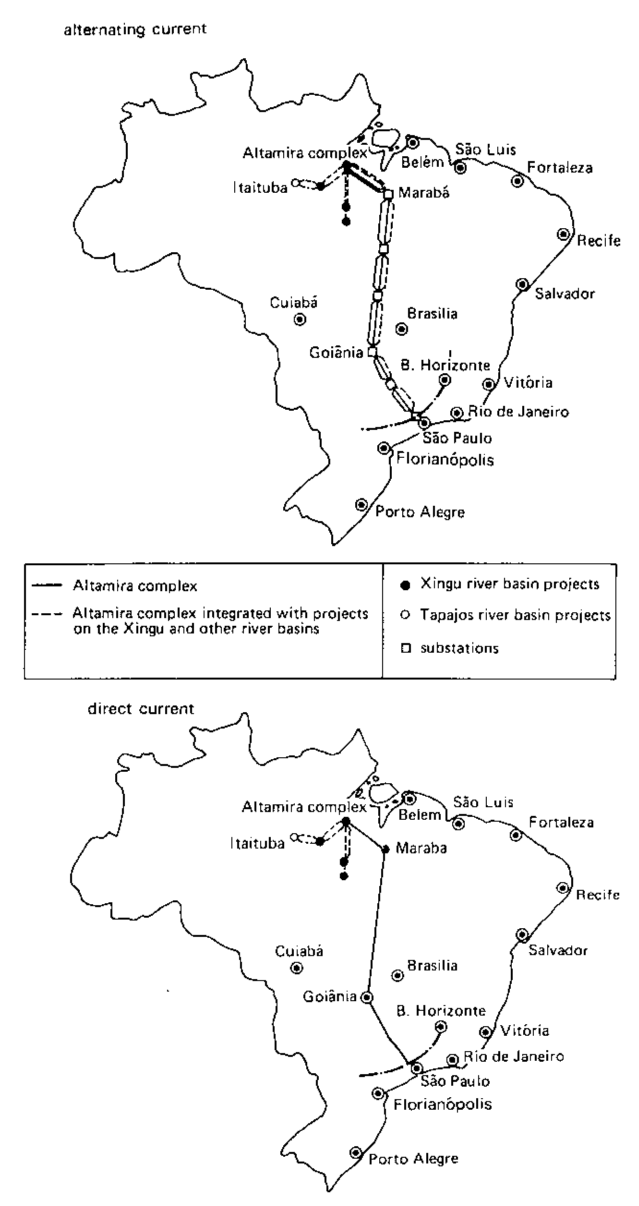

Fig. 5. Plans for the transmission of energy from the complex.

giving a cost index for the installed capacity of around US$760/kW. Tables I and II present the capacities and costs of the complex, assuming isolated operation.

Table III presents other data relating to characteristics of the complex reservoirs, such as drainage areas, reservoir areas, storage and estimated flows for sizing of structures. In Tables IV and V, estimated quantities for major civil works items of the complex, for both the high and low alternatives, are presented.

Transmission of energy

The lack of centres for local consumption and the large amount of energy which can be produced from the hydro complex of Altamira, mean that the tendency will be to export this energy in the future to supply other regions in Brazil.

To evaluate the technical and economical aspects of this supply, a preliminary study was made that considered the possibility of transmission of the energy generated by the complex by direct current as well as alternating current with load factors equal to 0.70, 0.85 and 1. In a conservative form, line routing was established using the routes of existing roadways.

The transmission line route started at Altamira (Babaquara) along the existing trans-Amazonic and Belém-Brasília-Goiânia highways for a total of 2000 km and from there for another 800 km to the main reception centres of the Southeast (see Fig. 5).

Based on isolated operation until reaching the southeast region, the transmission costs of energy generated at the complex for the three load factors considered in the preliminary studies reveal them to be very attractive as they do not exceed US$7/MWh.

The next approach will be to consider the integration of the powerplants in the basin and of the complex with the Brazilian inter-connected system. The inter-connection will substantially increase the available firm energy in view of the diversified critical hydrological periods. □