PROFILE

Brazil's Balbina Dam: Environment versus the Legacy of the Pharaohs in Amazonia

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ABSTRACT / The Balbina Dam in Brazil's state of Amazonas floods 2360 km² of tropical forest to generate an average of only 112.2 MW of electricity. The flat topography and small size of the drainage basin make output small. Vegetation has been left to decompose in the reservoir, resulting in acidic, anoxic water that will corrode the turbines. The shallow reservoir contains 1500 islands and innumerable stagnant bays where the water's residence time will be even longer than the average time of over one year. Balbina was built to supply electricity to Manaus, a city that has grown so much while the dam was under construction that other alternatives are already needed. Government subsidies explain the explosive growth, including Brazil's unified tariff for electricity. Alternative power sources for Manaus include transmission from more distant dams or from recently discovered oil and natural gas deposits. Among Balbina's impacts are loss of potential use of the forest and displacement of about one third of the surviving members of a much-persecuted Amerindian tribe: the Waimiri-Atroari. The dam was closed on 1 October 1987 and the first of five generators began operation in February 1989. The example of Balbina points to important ways that the decision-making process could be improved in Brazil and in the international funding agencies that have directly and indirectly contributed to the project. Environmental impact analyses must be completed prior to decisions on overall project implementation and must be free of influence from project proponents. The current environmental impact assessment system in Brazil, as in many other countries, has an undesirable influence on science policy, in addition to failing to address the underlying causes of environmentally destructive development processes and inability to halt "irreversible" projects like Balbina.

The Balbina Dam

Balbina is a hydroelectric dam built on the Uatumã River to supply power to the city of Manaus, in the center of Brazil's Amazonian region (Figure 1). The dam provides an example of the impediments to sound development planning in Brazilian Amazonia and illustrates environmental problems that will recur if Brazil realizes current plans for a massive expansion of hydroelectric development in the region. This article seeks to identify some of the mistakes made at Balbina and the lessons that can be learned from them.

The initial decision to build Balbina is difficult to justify in technical terms. More disturbing is the unstoppable force that the project gathered as it became "irreversible" and continued to completion. Dubbed the "notorious Balbina Dam" in the World Bank's appraisal report on the request for its funding (Environmental Policy Institute 1987), it has succeeded in circumventing environmental hurdles both at the national and state levels in Brazil and within the World Bank.

Balbina is among the projects that are known in Brazil as *pharaonic works* (e.g., *Veja* 1987a). Like the pyramids of ancient Egypt, these massive public works demand the effort of an entire society to complete but bring virtually no economic returns. Even if the structures are simply built and abandoned, they serve the short-term interests of all concerned—from firms that receive construction contracts to politicians wanting the employment and commerce the projects provide to their districts during the construction phase.

The 2010 Plan

Reservoirs for hydroelectric power generation are claiming a greater and greater share of Amazonian forest. The potential for expansion of impacts from this sector is large, as indicated by the 2010 plan published by Eletrobrás (the Brazilian government's power monopoly) outlining plans for dam construction through the year 2010. As is common in major Amazonian development proposals (Fearnside 1986a), the plans have been presented to the public as an evolving series of trial balloons, constantly being revised in the face of criticism, but remaining unchanged in their basic outline. An early version of the plan proposed 68 new dams in the Amazon (Brazil Eletrobrás 1986a, CIMI 1986). A subsequent version lists 18 of these for

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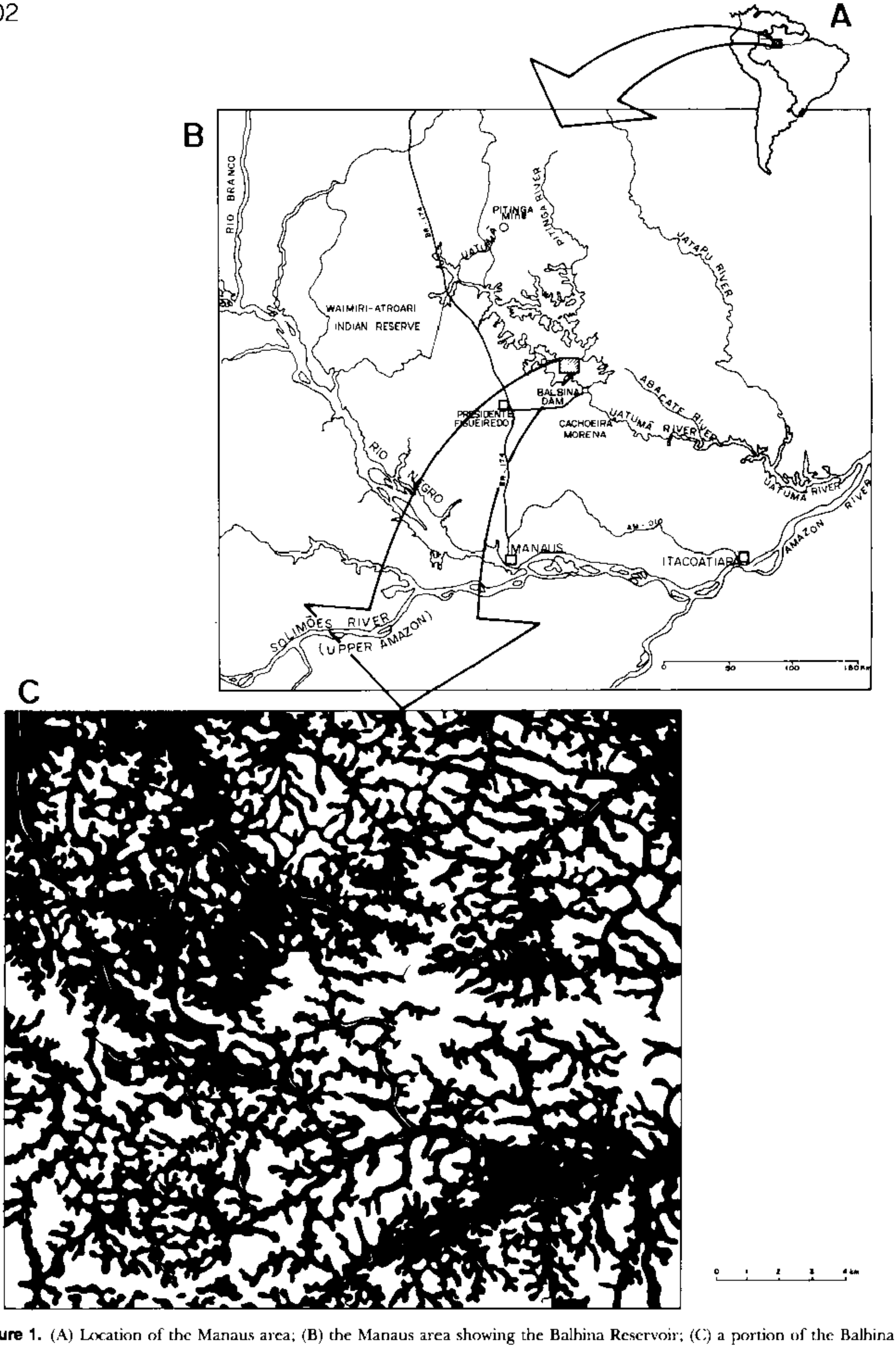

Figure 1. (A) Location of the Manaus area; (B) the Manaus area showing the Balhina Reservoir; (C) a portion of the Balhina Reservoir, showing some of the 1500 islands and the many stagnant backwaters where water quality will be poor and aquatic plants abundant. Cartographic references for B: Brazil Projeto RADAMBRASIL (1983); C: Brazil Eletronorte (1986b).

construction by 2010 (Brazil Eletrobrás 1987, pp. 152–155). Neither list includes the three dams under construction in the region at the time, apparently considering these (including Balbina) as faits accomplis. Some of the (most controversial) future dams have since been transferred from the 2010 plan to the 2020 plan, to be released in 1991 (José Antônio Muniz Lopes, public statement 1988).[1] The complete list of planned projects in Amazonia, irrespective of expected completion date, totals 80 dams (Brazil Eletronorte 1985a, pp. 25–26).

The 80 dams would flood roughly 100,000 km², an area that appears small relative to the region but that would provoke forest disturbance in much wider areas. Aquatic habitats would, of course, be drastically altered. Most of the sites that are favorable for hydroelectric development are located along the middle and upper reaches of the Tocantins, Xingú, Araguaia, Tapajós, and other rivers (Figure 2). This region has one of the highest concentrations of indigenous peoples.

The Decision to Build Balbina

A number of theories exist to explain why Balbina was initiated and why it was continued after its folly became clear. The decision was taken when global oil prices were at their highest and when the technology for long-distance power transmission was not as well developed as it is today. These facts, together with the gross underestimates of population growth and power demand in Manaus, are the official explanation for the decision, which Eletronorte (the power monopoly in northern Brazil) concedes would have been unjustifiable had the events of the last decade been known in advance (Lopes 1986). However, even with available information (Brazil Eletronorte/Monasa/Enge-Rio 1976), Balbina was questionable as a technical decision.

When the viability study was done in 1975–1976, restrictions on public communication meant that Brazil's military government had little reason to worry about questioning of its decisions. Eletronorte employees have unofficially stated that they received the order to build the dam directly from the *planalto* (Brazil's presidential office)—it was not a proposal developed on technical grounds and passed up the hierarchy for approval. The government was eager to have something to give the state of Amazonas; the nearest alternative hydroelectric site with substantially better potential (Cachoeira Porteira) is in the adjoining state of Pará.

The military political party (PDS) was in power both at the national level and in the state of Amazonas and stood to gain support in the 1982 elections from the ruling party's image as a route to central government largesse. Balbina was presented to the public as an example of the governor's ability to extract benefits from Brasília. In the 1982 election, however, the PDS lost the governorship of Amazonas; at that juncture the new majority party (the PMDB) could have cast off Balbina as a folly of the previous administration. After some initial hesitation, however, the new governor endorsed Balbina and carried it forward as a salvation of the state.

One popular theory holds that Balbina was built in order to facilitate the extraction of minerals from the area, particularly cassiterite (tin) ore (Garcia 1985). The Pitinga mine, located in the upper reaches of the Balbina catchment and in the adjoining Alalaú catchment, is credited with being the world's largest high-grade tin deposit. Some tin occurrences have been identified in the submergence area, but Eletronorte insists that they are not economically exploitable (Col. Willy Antônio Pereira, personal communication 1987, Junk and de Mello 1987). A survey of the Pitinga River portion of the Balbina submergence area indicated some occurrences but not vast deposits (Viega and others 1983, Vol. I-b pp. 458–462, Vol. II Anexo IIIc). The price of tin, however, is at one of its historic lows: US$7.40/kg in November 1988 compared to a former price of US$17.60/kg. No information is available on how much the price would have to rebound before the Balbina deposits became economically attractive. The presence of the reservoir would also alter the economic equation, since the ore could be scooped

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[1]Affiliations of individuals cited in the text: Frank Tadeu Ávila, head of planning department, Eletronorte, Brasília; Walter de Andrade, head of faunal salvage, Eletronorte, Balbina; Jaime de Araújo, President, National Council of Rubber Tappers, Manans; Joaquim Pimenta de Arruda, Engineer, Enge-Rio, Rio de Janeiro; Walderlino Teixeira de Carvalho, President, National Coordination of Geologists, Belém; José A.S. Nunes de Mello, Coordinator, Eletronorte/INPA bilateral agreement, INPA, Manaus; Rogério Gribel, Researcher, INPA, Manaus (participant: Eletronorte/INPA project at Balbina); Maritta Koch-Weser, Environment Sector, Brazil Division, World Bank, Washington, DC; Antônio Donato Nobre, Researcher, INPA, Manaus (participant: Eletronorte/INPA project at Balbina); Arminda Muniz, Historical Patrimony Office, Amazonas State Government, Manaus (head of archaeological salvage, Balbina); José Antônio Muniz Lopes, Coordinator of Planning, Eletronorte, Brasília; Melquiades Pinto Paiva, President, Brazilian Foundation for the Conservation of Nature (formerly consultant: Brokompondo Dam, Surinam); Col. Willy Antônio Pereira, head of environment for Balbina, Eletronorte, Brasília; Barbara A. Robertson, Researcher, INPA (Limnological studies of Curuá-Una Reservoir); Adelino Sathler Filho, head of environment, Eletronorte, Balbina.

Figure 2. Brazil, with locations of places mentioned in the text. Cartographic references: reservoirs for Tucuruí, Samuel, Cachoeira Porteira, Itaipú, Brokompondo (CIMI and others 1986); Balbiua (Brazil Eletronorte, 1986b), Babaquara and Kararaô [Brazil Eletronorte/CNEC, no date (1986)], Curuá-Una (Robertson 1980), Ji-Paraná (JP-14) (CNEC 1985); gas, oil, and mines (Brazil Projeto RADAMBRASIL 1983).

or sucked up from the bottom from dredges mounted on barges. This possibility has even been raised by the Manaus representative of the National Department of Mineral Production (*Amazonas em Tempo* 1987). Cassiterite in Amazonia is often mined from barges floating in artificial ponds built for the purpose. Dredges can operate to a depth of 30 m and so would have access to the entire reservoir (which will have a maximum depth of 21 m). Since the mineral occurrences are in the upper reaches of the submergence area, they would be in the shallowest portion most easily dredged from barges (depths less than 6 m). Mining companies have registered prospecting claims to a large part of the submergence area according to a map made by Brazil's National Department of Mineral Prodnction (map reproduced in Melchiades Filho 1987).

The submergence area also contains gold (Junk and de Mello 1987)—another mineral often mined from barges. Although Eletronorte says the deposits are not economically attractive, as late as 1983 the director of the National Department of Mineral Production (DNPM) in Manaus urged the state governor to have gold mining begin immediately because Balbina would soon flood the deposit (*O Jornal do Comércio* 1983). Eletronorte officials at Balbina point out that if the gold in the area were attractive, it would already be being exploited by the flocks of freelance prospectors that have been attracted to gold-rich areas elsewhere in Amazonia. Their absence confirms the low concentrations indicated by surveys commissioned by Eletronorte, which found an average of 0.13 g of gold per cubic meter of ore (Col. Willy Antônio Pereira personal communication 1987). A survey commissioned by the National Department of Mineral Production in the Pitinga River portion of the submergence area indicated several occurrences, but no large deposits (Viega and others 1979, Vol. II-b pp. 467–469, Vol. II Anexo III-c). As with cassiterite, the possibility of using barges and the fluctuations in mineral prices could change the economic attractiveness of the deposits in the future. Eletronorte officials deny any connection of Balbina with mining, rightly pointing out the damage that sedimentation caused by any such activity would bring to power generation at the dam.

Another theory for the motivation behind Balbina involves the indemnization that landowners would receive. Eletronorte maps show that, except for the land taken from the Waimiri-Atroari tribe, almost all of the project area is privately owned (Brazil Eletronorte nd). The payment of compensation was still under negotiation during the final months before the reservoir commenced filling. Although it is logical that those who claim property rights to the land are trying to get as much financial reward as possible, it is unlikely that this interest group influenced the overall decisions regarding the project.

The attraction of employment and of profits from supplying goods and services to the construction effort has undoubtedly been a critical force behind Balbina. The commercial sector of Manaus has been particularly strong in its efforts to prevent funds for Balbina from being cut (*A Crítica* 1985b). While many Manaus residents and politicians defend Balbina with great vehemence, such support would probably evaporate quickly were local taxpayers required to pay the project's financial cost. At present Manaus is receiving Balbina as a gift from taxpayers elsewhere—both in the rest of Brazil and, indirectly, in the foreign countries that funded the World Bank's Brazilian power sector loan.

Pressure to build dams such as Balbina comes in large part from those directly involved in constructing them: the *barrageiros* or dam builders. The engineers and other staff making up the unique *barrageiro* subculture in Brazilian society go to great lengths to influence popular opinion in favor of dams. Mostly from southern Brazil, the *barrageiros* move from project to project living in comfortable but remote colonies built at each site. The social relations of the Balbina colony to the city of Manaus are strikingly parallel to the relations that American "zonies" (who until recently ran the Panama Canal) had with the wider society of Panama. Life in the colony can appear idyllically free of the social problems of the rest of Brazil—a situation maintained by armed guards who prevent any laborers from entering the "class A" residential areas at any time other than specified periods on the weekends. Adjoining residential areas (*vilas*) (without a physical barrier) separate class A employees with a university-level education from those without this distinction; each *vila* is provided with separate schools. Separate social clubs (the Waimari and the Atroari) divide engineers from other categories: mere scientists are not allowed in the engineers' club. This isolation has encouraged formation of a strong interest group that battles furiously any who question the wisdom of Balbina—any doubt is perceived as a threat to the *barrageiro* way of life.

The Technological Folly

Severe as Balbina's impacts are, the magnitude of the environmental and financial disaster at Balbina lies in the meager benefits that the project will produce. Balbina's nominal (installed) capacity is 250 megawatts (MW): the sum of five generators of 50-MW capacity each. The amount of power that the dam will actually produce, however, is much less than this. At full capacity, each generator uses 267 m^3/sec of water (Brazil Eletronorte 1987b), or 1335 m^3/sec for all five generators. The turbines can operate with less water, but produce less power.

The amount of water flowing past the damsite is crucial to Balbina's ability to deliver the power its designers hope to obtain. The streamflow sometimes falls to almost nothing: in March 1983 the flow at Balbina reached a low of 4.72 m^3/sec according to Eletronorte's measurements at the dam site (Posto 08). The minimum registered streamflow indicated in Eletronorte's publically distributed pamphlet describing the project does not reflect this dramatic water shortage: a value of 68.9 m^3/sec is given in the October 1985 version of the pamphlet, subsequently revised to 19.7 m^3/sec in the February 1987 version (Brazil Eletronorte 1985b, 1987b). Eletronorte officials explain the discrepancy by saying that the minimum refers to

Figure 3. Part of the Balbina Reservoir while filling, with the water level at 47 m above sea level (3 m below the full reservoir level). One third of the reservoir will be less than 4 m deep.

a monthly mean value rather than to the flow on any given day. It is worth noting that the monthly mean streamflow in February 1983 was 17.51 m^3/sec.

Impressive as the contrast between water requirements and the minimum streamflows is, the stored water in the reservoir will allow the dam's operators to cushion the power plant against brief periods of low streamflow. Annual average streamflow, however, is not a limitation that can be circumvented by judicious management of the reservoir (contrary to claims of Eletronorte's public relations department at Balbina).

A severely limited supply of water is an inevitable result of Balbina's small drainage basin, which is only eight times larger than the reservoir itself—a highly unusual situation in hydroelectric development. Even a rough calculation based on drainage area and rainfall—a calculation that could have been done on the back of an envelope before undertaking the viability study—indicates that annual average streamflow will be small: the average annual precipitation registered at Balbina of 2229 mm (Januário 1986, p. 15) falling over the 18,862-km^2 basin (Brazil Eletronorte 1987b) would produce a volume of water which, allowing for 50% return to the atmosphere through evapotranspiration (Leopoldo and others 1982, Villa Nova and others 1976), would yield an average streamflow of 666 m^3/sec. This does not include evaporation from the water standing in the lake. Eletronorte's viability study had also estimated a low annual average streamflow: 657 m^3/sec (Brazil Eletronorte/Monasa/Enge-Rio 1976, p. A-21). Subsequent experience has revealed an even smaller average streamflow at Balbina: 480 m^3/sec (Rogério Gribel, public statement 1988).

The *annual* average flow of the Uatumã River at the dam site, as estimated in the viability study, is slightly more than that needed for two turbines (on average). Since 13% of the annual total discharge is expected to be passed over the spillway without generating power, an average output of 112.2 MW is expected (Brazil Eletronorte/Monasa/Enge-Rio 1976, p. B-51). Of this, 64 MW represents "firm power" at a water level depletion of 4.4 m, the maximum for which the turbines were designed (Brazil Eletronorte/Monasa/Enge-Rio 1976, p. B-47). An assumed 2.5% loss in transmission reduces the firm power delivered to Manaus to only 62.4 MW (Brazil Eletronorte/Monasa/Enge-Rio 1976, p. B-49). Some Eletronorte calculations assume a 5% transmission loss (Brazil Eletronorte/Monasa/Enge-Rio 1976, p. B-47), which would imply a firm power in Manaus of only 60.8 MW. Although all dams generate less than their nominal capacity, at 26%, Balbina's firm output at the damsite is less than usual.

The small streamflow of the Uatumã River could serve as justification for another environmentally damaging engineering project: diversion of the Alalaú River to flow into Balbina. The Alalaú, a tributary of the Rio Negro, flows through the Waimiri-Atroari Indian Reserve providing a vital fishing resource—especially since Balbina has now destroyed the tribe's only other river: the Uatumã. Building the 30-km diversion canal, which would be entirely within the reserve, would also cause major perturbation from the presence of construction crews.

The history and present status of the Alalaú diversion plans are unclear. The diversion appears on a

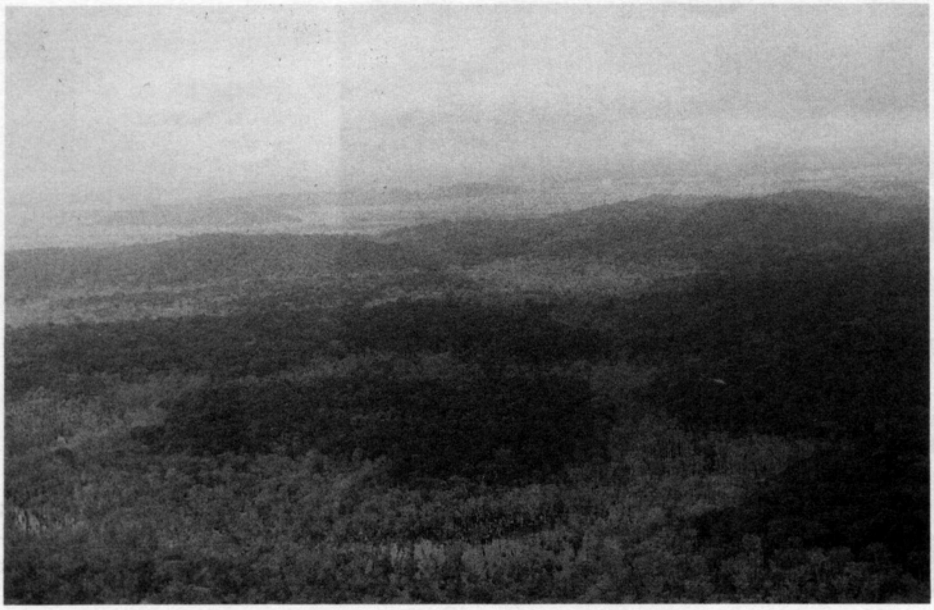

Figure 4. Some of the 1500 islands in the Balbina Reservoir. The light-colored trees are dead or dying.

map included in the viability study for Balbina (Brazil Eletronorte/Monasa/Enge-Rio 1976, illustration 19). The diversion was not included in Balbina's budget, nor were any of its impacts included in the environmental studies. During the slow filling of the Balbina reservoir in 1988, the possibility of diverting the Alalaú River returned to consideration in some sectors of Eletronorte (although not in the planning department: Frank Tadeu Ávila, public statement 1988).

Balbina's 250-MW nominal capacity is itself minuscule for a reservoir of this size—about as large as the 2430-km² Tucuruí reservoir that will support a nominal capacity of 8000 MW. Balbina sacrifices 31 times more forest per megawatt of generating capacity installed than does Tucuruí. Much of the Balbina reservoir will be extremely shallow because the terrain is quite flat. One third of the reservoir's 2360-km² area at the 50-m level will be less than 4 m deep (Figure 3). Average depth when full will be 7.4 m (Brazil Eletrobrás 1986b, p. 6. 12). The large shallow areas can be expected to support rooted aquatic vegetation, adding to the problem of floating weeds that could affect the entire reservoir. Aquatic vegetation, together with the large surface area per volume of water in a shallow reservoir will lead to heavy losses of stored water to evaporation and transpiration.

Promotional efforts by Eletronorte include breeding a herd of manatees as an antidote to weeds and a comic book distributed in Manaus in which a parrot explains the marvelous trip of the light to your house [Brazil Eletronorte nd (1987)]. The staff at the National Institute for Research in the Amazon (INPA) responsible for the manatee program view it strictly as a research effort rather than as a means of controlling the weeds since the manatees breed very slowly (Vera da Silva, personal communication 1988). Manatees have a long gestation period (Best 1982), which, together with inhibited fertility during lactation, restricts reproduction to one calf per female every three years (Best 1984, p. 376, Vera da Silva, personal communication 1988). In the meantime, Eletronorte has begun pulling out some weeds by hand and removing them from the area using outboard motorboats and trucks—a method that is unlikely to be financially sustainable.

The Balbina reservoir will be a labyrinth of canals among the approximately 1500 islands and 60 tributary streams (Figure 4). The residence time in some of these backwaters will be many times more than the already extremely long average of 11.7 months calculated in the viability study (Brazil Eletrobrás 1986b, p. 6.12), or 14.0 months if measured discharge values are used. Water in Tucuruí, by contrast, has an average residence of 1.8 months, or 6.4 times less than the official figure for Balbina. Some parts of the Balbina reservoir may only turn over once in several years. In addition to Balbina's reticulate arrangement of interconnecting backwaters (Figure 1C), which resembles a cross section of a human lung, the residence time at the bottom of the reservoir (where decomposing leaves are concentrated) would be greater than the reservoir's average because of an expected thermal stratification (Fisch 1986). The water entering the reservoir flows toward the dam in the surface layers (Branco 1986), although some mixing will occur near the dam since the water removed from the reservoir will be taken from the bottom where the intakes for the tur-

Figure 5. The Balbina Dam and part of the 2% of the reservoir area from which the forest was cleared.

bines are located. The slow turnover means that the decomposing vegetation will produce acids that cause corrosion of the turbines. In Tucuruí, despite the relatively rapid average turnover in the reservoir dominated by flow through the main channel, one side arm that communicates with the main reservoir through a narrow neck is fed by streams so small that, in dry years, water entry corresponds to a turnover time on the order of 50 years. Prior to closing the dam, Eletronorte bulldozed the vegetation in this bay, known as the Lago do Caraipé, in order to render the area as sterile as possible, thereby minimizing eutrophication (Col. Willy Antônio Pereira, personal communication 1987; Brazil INPA 1983 pp. 32–34). Special treatment was undoubtedly also motivated by the bay's proximity to populated areas near the dam. Even with bulldozing, the bay was quickly covered by mats of floating macrophytes (Cardenas 1986a, pp. 9, 17).

Acid water caused by decomposing vegetation can make maintenance costly. Tucuruí has already had repairs to its turbines, costing an undisclosed amount. At the Curuá-Una Reservoir near Santarém, Pará, power generation had to be halted temporarily in 1982 (only five years after the dam began to produce electricity) to allow repairs to corroded turbines at a cost of US$1.1 million (Brazil Eletrobrás/CEPEL 1983, p. 34). The cumulative cost of maintenance in the first six years totaled US$2 million, or US$16,600 per installed megawatt per year—70 times the cost per megawatt for a comparable dam in the semiarid northeastern part of Brazil (Brazil Eletrobrás/CEPEL 1983, p. 44). The report is richly illustrated with photographs of the deeply pitted turbines at Curuá-Una. Lost generating time is not included in the costs of maintenance reported. The average residence time of water in the Curuá-Una Reservoir is about 40 days (Robertson 1980, p. 10); Balbina's turnover time, on the order of 10 times longer, means that water quality and corrosion problems will be worse than at Curuá-Una. The greater number of stagnant bays and channels at Balbina will further accentuate the difference. At the rate experienced at Curuá-Una, Balbina's maintenance would cost US$4.15 million per year, or 4.3 mils (US) per kilowatt-hour of electricity delivered to Manaus (about 10% of the tariff charged consumers). In its first 13 years of operation, repairs due to similar corrosion in the Brokompondo Dam in Surinam totaled US$4 million, or over 7% of the construction cost (Caufield 1983, p. 62). As at Brokompondo and Curuá-Una, vegetation is being left to decompose in most of the Balbina submergence area: only a token 50 km^2 (2%) of the reservoir was cleared before the dam was closed (Figure 5).

The material used in the turbines originally ordered for Balbina was changed to stainless steel while the dam was under construction. Incurring the additional cost of using harder steel was motivated by fear of corrosion. Direct comparison of Balbina's maintenance costs with those at Curuá-Una is complicated by two opposing factors: better steel and worse water. Given the unprecedented acidity of Balbina's water, maintenance costs will undoubtedly be high.

The failure of Eletronorte to clear the submergence area at Balbina is a matter of legal controversy. Brazil's law No. 3824 of 23 November 1960 states that it is "obligatory to destump and clear the basins of dams, reservoirs or artificial lakes." Eletronorte did not attempt such a clearing in the submergence area at Tucuruí, claiming that the law referred only to reservoirs intended for water supply, not for power generation. The precedent of Tucuruí was subsequently applied to justify not clearing at Balbina (*A Crítica* 1985d). Prior to Tucuruí, the forest had been left uncut in the 86-km² Curuá-Una Dam iu Pará closed in 1976, and only 50% of the submergence area was cleared in the 23-km² Coaracy Nunes (Paredão) Dam in Amapá closed in 1975 (Paiva 1977). When vegetation left in reservoirs decomposes, the water becomes acidic and anoxic (Garzon 1984).

The Environmental Folly

Impacts on Natural Systems

Forest loss is one of the primary environmental costs of large dams like Balbina. The area disturbed is much greater than the 2360 km² actually flooded, since the inclusion of islands roughly doubles the area affected. Despite Eletronorte's promotion of the islands as having "conditions for life of animals and plants" [Brazil Eletronorte nd (1987), p. 18], forest divided into tiny fragments is known to lose many species of animals and plants as the isolated patches degrade (Lovejoy and others 1984).

The area to be flooded is not known with any certainty, despite the apparent precision of Eletronorte maps and statements. The topographic information in the maps, and in the area calculations derived from them, is based on aerial photographs. The photographs record the level of the tops of the trees in the forest, not the ground underneath; since a substantial part of the reservoir will be only a meter or two deep, errors of this magnitude can easily alter the final result.

The possibility has been suggested that the flooded area at the 50-m level might be about double the area officially acknowledged. "Sources in the economic sector of the federal government" reportedly revised the area from 1600 to 4000 km² (Barros 1982). One congressman charged the government with deliberately underestimating the area to be flooded (*A Crítica* 1982). Eletronorte promptly denied that the reservoir would flood more than 1650 km². The origin of the 1650 km² figure is unknown, although it also appears in an early forest survey report (Jaako Pöyry Engenharia 1983, p. 3). Eletronorte had at first expected the reservoir to occupy only 1240 km² when full (Brazil Eletronorte/Monasa/Enge-Rio 1976, p. B-55). The official figure for the reservoir area at the 50-m water level is currently 2360 km² (Brazil Eletronorte 1987b), almost double the original value. The current value was calculated in 1980 (Brazil Eletronorte 1981), and so does not reflect any refinements in topographic information that may have been made since that time. Engineers who worked on Balbina's topographic survey have told INPA researchers that the survey's margin of error is so great that a 4000-km² reservoir is within the range of possibility (Antônio Donato Nobre, personal communication 1988). That the reservoir could flood an area much larger than the official estimate has not been independently confirmed; it remains only a persistent rumor. Only mapping the reservoir when full will reveal the impoundment's true size.

The decomposition of the vegetation in the water produces hydrogen sulfide (H_2S) gas, giving it a rotten smell. The Brokompondo Reservoir in Surinam produced H_2S that forced workers at the site to wear masks for over two years after the dam was closed (Melquíaides Pinto Paiva, personal communication 1988, Paive 1977, Caufield 1982). In the much smaller Curuá-Una Reservoir in Pará, the smell was even apparent to people overflying the area in small airplanes (Barbara A. Robertson, personal communication 1988). Despite popular concern over this aspect of the environmental impact, air pollution from H_2S is a relatively temporary and restricted phenomenon.

The shallow reservoir with a large land area alternately flooded and exposed will also produce methane (CH_4) gas. Balbina has been suggested as a potential contributor to this problem (Goreau and Mello 1987). Methane contributes to the greenhouse effect now warming global climate (Dickinson and Cicerone 1986). Amazonia has recently been identified as one of the world's major sources of atmospheric methane; the *várzea* (floodplain) is the principal contributor (Mooney and others 1987). The *várzea* occupies about 2% of Brazil's 5 million km² administrative region known as the "Legal Amazon" (Fig. 2), or about the same percentage that would be flooded hy the 80 dams under consideration for construction in the region over the next few decades. Were these reservoirs to contribute an output of methane on the order of that produced by the *várzea,* they would together represent a significant contribution to global atmospheric problems.

Fish death at the closing of the dam is one of the impacts that attracts the most attention. Eletronorte has made it difficult for observers to witness this aspect by not informing researchers and others of when the dam would actually be closed. Balbina was closed without warning 30 days before the announced date of 31 October 1987. Some researchers were present at the time, however. Fish mortality occurred downstream of the dam at Balbina (José A.S. Nunes de Mello, personal communication 1988). At Tucuruí, Eletronorte closed the dam without warning on 6 September 1984—one day before the National Independence Day and a three-day holiday. An INPA team was able to reach the site by 10 September, and some fish mortality was observed. Fish mortality at Tucuruí occurred when water was first allowed to pass through the turbines in a test prior to the dedication ceremony. The blast of anoxic water killed many fish in the area immediately below the dam; Eletronorte removed these by truck in order to improve the area's visnal and olfactory appeal for the dedication ceremony. At Balbina, turbine intakes at the very bottom of the reservoir will inevitably take water virtually devoid of oxygen.

Impacts on Nonindigenous Residents

Relatively few people live near Balbina, as compared to many other hydroelectric projects. Eletronorte recognized only one non-Amerindian family with seven people in the submergence area. A survey by three organizations opposed to the dam concluded that 217 families totaling over 1000 people would be directly affected (MAREWA 1987, p. 23). A business publication favorable to the dam reported the nonindigenous population in the submergence area to be 42 people in 11 families (*Visão* 1986).

Part of the Manaus-Caracaraí (BR-174) highway would also be flooded; property owners in the area calculated as likely to flood once in 1000 years are to be paid compensation by Eletronorte. One Eletrobrás report recognizes 65 properties and squatter claims in the reservoir area, with a total of 250 people (Brazil Eletrobrás 1986b, pp. 6–13). The nonindigenous residents of the Balbina submergence area were offered land in a government settlement project.

Residents along the river below the dam opted to stay where they were in exchange for benefits to compensate for the loss of fish and potable water during the filling phase: the 50 families closest to the dam (those located above Cachoeira Morena, 30 km below the dam) would be supplied with solar dryers for use in preserving the fish expected to be trapped in ponds formed in the dry riverbed; these families plus the 50 additional families between Cachoeira Morena and the Abacate River would receive wells and water tanks. Eletronorte only completed about one third of the 100 wells before the dam was closed. Eletronorte promised to supply water from tank trucks to those who had not received wells (about half were on lots with access to a road that had been built from Balbina to Cachoeira Morena). Only one delivery of water was actually made (Jaime de Araújo, personal communication 1988).

The number of downstream residents benefiting from the assistance program was redneed during the course of dam construction. Originally 177 families below the dam were interviewed for inclusion in the benefit program; a more detailed snrvey stopped at 151 families, indicating families only as far downstream as the Jatapú River, or 145 km below the dam (Brazil Eletronorte 1986a). The survey was halted in December 1986 when Eletronorte decided to restrict assistance to the 100 families living above Abacate River, 95 km downstream. A climate of distrust has prevailed between downstream residents and Eletronorte.

Impact on Amerindians

The flooding of part of the Waimiri-Atroari tribe's reserve is the most dramatic of the reservoir's nonmonetary costs. Two of the tribe's 10 remaining villages will be flooded: Taquari (population 72) and Tapupunã (population 35) [Brazil FUNAI/Eletronorte nd (1987), p. 11]. This represents 29% of the tribe's population, now totaling 374 individuals. This total is divided into 223 Waimiri and 151 Atroari (Brazil Eletrobrás 1986b, pp. 6–12). The 107 people in the two flooded villages are all Waimiris, representing 48% of this group's population. Since the groups move within their territory to hunt and fish, the number affected is greater than those in the flooded villages.

The area to be taken from the reserve is calculated on the basis of the height to which the reservoir is likely to reach with a frequency of once in 1000 years. The level so calculated is 53 m above sea level, or 3 m above the normal full level of the reservoir. Higher flooding is expected in the upper part of the reservoir, where the reserve is located, because the narrow neck that divides the Balbina reservoir into two parts (Figure 1) restricts water flow to the dam (Col. Willy Antônio Pereira, personal communication 1987, Brazil Eletronorte 1986b). It should be noted that sedimentation will begin at the upper end of the impoundment. If sediments should partially block the narrow passageway between the two parts of the reservoir, then the chance of higher and more frequent floods in the Waimiri-Atroari area would be greatly increased.

At the 53-m level, 311 km^2 of the reserve would be flooded (Brazil, Eletrobrás 1986b, pp. 6–13). Of the presently proposed reserve's 24,400-km^2 area, this represents 1.3%. While the flooded portion is very small as a percentage of the reserve area, it includes a significant part of the tribal population and their food resources.The riverside fishing locations of the two villages will not be moved inland when the riverbank is replaced with a stagnant bay or a vast mudflat covered with standing skeletons of dead trees. The turtles whose eggs form a staple of the tribe's diet have been prevented from reaching the area by the dam now blocking their yearly ascent of the Uatumã River.

Brazil's agency for Amerindian affairs (FUNAI: the National Foundation for the Indian) took a delegation of Waimiri-Atroari leaders to visit the Parkanã tribe, which had had much of its territory flooded in 1984 by the Tucuruí Reservoir. The visit quickly convinced the Waimiri-Artroari that they would have to leave their villages and cooperate with FUNAI—something oral explanations and a demonstration using a mock-up of a dam and reservoir had failed to do. Two new villages were built by the tribe itself elsewhere in the territory. The population that moved received a variety of gifts from FUNAI, such as outboard motors and aluminum boats to replace their traditional dugout canoes. The individuals who have led in collaborating with FUNAI are not the traditional tribal leaders; the sudden material wealth of the gift recipients has created internal tensions within the tribe (Adolfo 1987). Anthropologists working in the area have been shocked by the alacrity with which the recipients of the gifts have cast off their former customs and lost their self-sufficiency (Arminda Muniz, personal communication 1987).

The moving of two indigenous villages and loss of part of a reserve would appear to be a small matter against the background of affronts that Amerindians have suffered throughout the region in recent years. The case of Balbina is significant, however, because of the particularly dramatic decimation of the tribe in question in the decade prior to beginning construction.

The tribe had a population of 6000 in 1905 according to an estimate by the German naturalists Georg Hübner and Theodore Koch-Grünberg (CIMI 1979, p. 5, Garcia 1985, MAREWA 1987). By that time the tribe had already suffered a long series of massacres (Martins 1982, p. 284). The 6000 turn-of-the-century population was reduced to 3500 by 1973 through a series of violent encounters (cataloged by Martins 1982, pp. 284–286). Violent contacts have continued np to the present decade. In 1970, the Manaus-Caracaraí (BR-174) highway was begun to link Manaus with Venezuela. The highway bisected the tribe's territory; access to the area was restricted by the military while the highway was under construction and for several years thereafter. In 1975, FUNAI decided that so many hostile encounters had taken place that the agency's efforts to pacify the tribe were suspended (Martins 1982, p. 278). The following year Eletronorte contacts with FUNAI began in order to clear the area for Balbina (Garcia 1985).

The 3500 population in 1973 was reduced to 1100 by 1979 (by FUNAI esrimates, see Athias and Bessa 1980) and further to 374—mostly children—by 1986. As Garcia (1985) states: "in twelve years more than three thousand Indians disappeared, killed by epidemics of measles or by the bullets of adventurers, hunters, and the gunslingers hired by large landholders, with the clear support of federal and state authorities." These events are not academic facts from a distant historical period; they have occurred a mere 200 km from Manaus over a period that most of the city's adult population can remember.

The Waimiri-Atroari tribe's reserve has been decreased whenever this proved convenient. The reserve was created by Decrees 69.907/71, 74.463/74, and 75.310/75 (of 1971, 1974, and 1975). In 1981 President Figueiredo revoked these through process BSB/22785/81 when he signed decree 86.907/81. This abolished the reserve, transforming it into a mere "temporarily interdicted area for the purpose of attraction and pacification of the Waimiri-Atroari Indians" [Brazil FUNAI/Eletronorte nd (1987), p. 15]. In this transformation the area not only lost some of its legal protection but also decreased by 526,000 ha, which was given to Timbó Mineradora Ltda—a subsidiary of Parapanema, the firm that is mining cassiterite at Pitinga in the upper reaches of the Balbina catchment. Eletronorte funds are helping speed the demarcation of the reserve by surveying and marking its borders on the ground.

The key event in transforming Balbina from a sheaf of papers into a 2360-km^2 reality of bleached tree trunks and foul-smelling water was the Brazilian–French accord signed by Brazilian President Ernesto Geisel and French President Valery Gisgard D'Éstang during a 1978 visit to Brasília. The French were sharply attacked by Amerindian rights groups for having signed an agreement that would flood tribal lands; the French responded the the Brazilian government had assured them that there were no Amerindians in the area (*A Folha de São Paulo* 1978). Information on the existence of the Waimiri-Atroari was not difficult to obtain at the time.

Because of the impact on the Waimiri-Atroari implied by the plans for Balbina, France and Brazil were accused of genocide at the Fourth Bertrand Russell Tribunal in Rotterdam in November 1980. Severe as the impacts of the reservoir may be, the strength of the charges was probably colored by the events associated with (Brazilian) road-building activities in the tribe's territory prior to the first preparations for Balbina, especially 1974–1975. Eletronorte officials are quick to point out the unfairness of criticizing Balbina for flooding a small part of the tribe's territory when nothing is said about most of the group having been killed only a few kilometers away (Adelino Sathler Filho, personal communication 1987). However, this background does not alter the fact that Balbina will have a negative impact on the surviving Waimiri-Atroari. International sources providing the dam's financing have apparently not considered this impact. In the case of the World Bank, declared policies require that heavy consideration be given to any effects that loans may have on tribal peoples (Goodland 1982).

The Economic Folly

Construction Costs

The cost of building the dam has approximately doubled since the initial estimate of US$383 million (Brazil Eletronorte/Monasa/Enge-Rio 1976, p. A-24). Eletronorte admits to a cost of US$750 million, exclusive of the transmission line. The construction cost of Balbina is US$3000/kW of installed capacity, compared to US$675/kW at Tucuruí (4.6 times less than Balbina) and US$1206/kW at Itaipú (2.6 times less than Balbina) (Tucuruí and Itaipú costs from *Veja* 1987, p. 30). Power at Balbina may actually cost more than double this already astronomical figure since the calculation assumes that 250 MW will be generated rather than the average power of only 109.4 MW to be delivered to Manaus. Also not included in the calculations are maintenance costs, replacement of parts, and depreciation of the dam as a whole over its expected useful life. Interest paid on the debt assumed to build the dam is also not included.

The Brazilian–French Accord

The Brazilian–French accord provides for technical assistance and a special credit line for purchasing the turbines from France. The first turbine was made in France by Neyrpic, a company belonging to the Creusot Loire Group; the other fonr turbines are being made in Taubaté (in the state of São Paulo) by Mecânica Pesada, a Brazilian subsidiary of the same Creusot Loire Group.

The temptation to order more turbines and generators than necessary is great when purchase agreements for these form part of a generous financing package: Paulo Maluf, former governor of São Paulo, provoked a major financial scandal when it was discovered that more turbines had been purchased than needed for the Três Irmãos Dam (*Isto É* 1986). The Três Irmãos turbines came from the same French factory that snpplied Balbina's imported turbine. Although five 50-MW turbines on a river as small as the Uatumã is considered supermotorized by Eletronorte, officials insist that it is within the normal range. Two justifications are cited: (1) the fact that power demand in Manans so greatly exceeds the dam's generating capacity that all power can be sold (most dams pass water over their spillways during flood season because extra power is not needed), and (2) the lack of a regional network to cover demand during periods when one of the turbines is under repair. Rather than 10% excess installed capacity, the Brazilian norm in a regional grid, a full spare turbine is planned for Balbina (i.e., 20% excess capacity). Eletronorte's projection of energy production indicates that all five turbines would operate for, at most, one month per year, and the dam could operate with four turbines for only one additional month during the flood season (Brazil Eletronorte 1987b).

Costs of the Rush to Fill the Reservoir

The most evident waste from Eletronorte's haste to fill the reservoir is loss of forest products, especially timber. The potential value of forest sacrificed is not included in calculations of the reservoir's cost and has been a focus of public attention (e.g., *A Crítica* 1984, 1985c). A timber survey by INPA revealed 28.8 m^3 of valuable wood per hectare (Higuchi 1983, p. 20), or approximately 6.8 million m^3 in the 2360-km^2 reservoir area. A survey by a consulting firm concluded that wood volume of all species averaged 161 m^3/ha for trees over 10 cm diameter at breast height (dbh) and 58 m^3/ha for trees over 50 cm dbh (Jaako Pöyry Engenharia 1983, p. 50). This reportedly was regarded as insufficient and discouraged logging efforts (*Visão* 1986). The short notice given to potential logging contractors also made any serious commercial exploitation unlikely: logging firms had less than two years between the date that bids were solicited and the original date set for closing the dam.

The inability of Eletronorte to interest commercial logging firms in exploiting the reservoir area represents an embarrassment given the high visibility of the loss involved. The president of Eletronorte emphasizes that the flooded timber is not lost, suggesting that during the low-water period loggers can cut the trees on the exposed ground and return by boat to tow logs away during the high-water period (Lopes 1986). At Tucuruí some loggers have done cutting for valuable species using divers with a special underwater chainsaw; the costs are much lower than for traditional dry-land logging because of the ease of towing away the cut logs. Officials at Balbina say that loggers could cut dead trees standing in the shallow water. The danger is great for the person sawing the trees, however. When trees die standing in pastures in Amazonia, they are left untonched because dead branches are likely to fall on anyone who saws the trunk below.

Nontimber forest products are also lost. Rubber and rosewood were being exploited up to the last months before filling Balbina. The potentially most valuable products of the forest in Amazonia have barely begun to be identified, especially pharmaceutical compounds (Myers 1976).

The order in which the various segments of the project were constructed could have been changed with possible environmental benefits and financial savings. The transmission line was the last item built, whereas if this had been the first item, thermoelectric plants at the dam site could have used the wood in the future reservoir area and transmitted the energy to Manaus. Aboveground biomass dry weight estimated as a weighted average over forest types in the area is 400 metric tons/ha (Cardenas 1986b, p. 27). Considering the percentage of the total represented by trunks in the sample plots (Cardenas 1986b, p. 16), the dry weight of trunks would average 267 metric tons/ha, or 63 million metric tons in the 2360-km^2 submergence area. Plans for wood-burning power plants to be installed in small cities in the state of Amazonas have considered wood to contain an average of 2500 kcal/kg and power generatiou to require 4000 kcal/kWh of electricity (Brazil CELETRA 1984). The trunks of trees to be flooded at Balbina are therefore equivalent to approximately 39.4 gigawatt-hours (GWh) of electricity. To generate this from petroleum with the mix of diesel and fuel oil used in Mauaus would require the equivalent of over 161,000 barrels of crude oil (calculated from Brazil Eletronorte 1985c, p. 19), worth US$3.2 million at the present low price of US$20/barrel.

Despite the noncompetitiveness of using firewood instead of oil at current low oil prices, it should be remembered that oil represents a physical resource, not merely a given amount of money. By throwing away the forest that could have been used for power generation instead of oil today, one is also throwing away the opportunity to keep that amount of oil in the ground until the time when petroleum is in short supply and, consequently, its price is much higher. Using the forest in the submergence areas also would have reduced the water quality problems caused by rotting vegetation in the impoundment. Any plan to convert forest biomass in future reservoirs to thermoelectric power should be accompanied by strict requirements that the power plants be moved elsewhere once the submergence areas have been harvested, lest the plants contribute to deforestation beyond the limits of the reservoirs.

Alternatives to Balbina

Balbina is particularly unfortunate because it is unnecessary. The dam is expected to produce firm power that could be counted on for only about one third of the 218-MW level of power demand of Manaus (Brazil Eletronorte 1987b); the average power delivered in Manaus (109.4 MW after 2.5% transmission loss) would be half the 1987 demand. In relation to the approximately 130 MW actually consumed in 1987, it represents 84%. The dam will never supply this percentage (50%) of the Manaus demand.

The percentage of power consumed in Manaus supplied by Balbina will shrink with each succeeding year as the city continues to grow: Balbina's average output (at the 50-m level) delivered to Manaus will be only 26% of the 420-MW aunual power demand that Eletrouorte projects for the city in 1996 when another dam, to be built 500 km from Manaus at Cachoeira Porteira on the Trombetas River, is expected to make up the city's power deficit (Brazil Eletronorte 1987b). Cachoeira Porteira is to have 1420 MW of installed capacity and produce an average of 760 MW (Brazil Eletronorte 1985b), or about seven times that of Balbina. Rather than building both dams, only one dam (Cachoeira Porteira) could have been built—with half the cost and half the impact.

The futility of Balbina becomes even more apparent when one considers that natural gas 500 km from Manaus in the Juruá River basin could supply Manaus with power. This is proposed as an alternative to Balbina by Brazil's leading expert on energy matters, José Goldemberg (1984, Melchiades Filho 1987). Recent discovery of oil and gas at Urucú, nearer Manaus, could also supply the city with power without Balbina (Falcão Filho 1987). The magnitude of the Juruá gas deposits only became apparent while Balbina was under construction. Even so, Balbina's construction could have been stopped years before completion, saving several hundred million dollars that would be better spent on transmitting energy from Juruá. Preliminary studies have even been made for transmission of power from Juruá to the Grande Carajás area in eastern Amazonia, where it would be used in pig-iron smelting. The distance traversed in such a scheme would be much greater than from Juruá to Manaus. The 500 km distance from Manaus to the Juruá gas fields is about the same as the distance from Manaus to Cachoeira Porteira, although transmission from Juruá would require the additional expense of crossing either the Amazonas (Lower Amazon) or both the Solimões (Upper Amazon) and the Rio Negro. Building a dam is also expensive, however. Gas pipeline routes have also been proposed from Juruá (Brazil CEAM 1985) or from Urucú (Brazil Eletronorte 1986c, p. Amazonas-6). The president of Eletronorte has reportedly stated that it was a decision of the population of Manaus to build Balbina rather than use gas or build transmission lines and that generating from gas and building transmission are technologically feasible (Lopes 1986). No public debate on energy options was held, however, since Balbina was begun at a time when Brazil's military regime limited such discussions (see Brazil INPA, Núcleo de Difusão de Tecnologia 1986).

Transmission from major hydroelectric generating areas in the Tocantins, Xingú, and Tapajós River basins is also possible. These large tributaries flow into the Amazon River from the south, descending from Brazil's central plateau. Their power-generating potential is enormous. Dams in that region would cause major environmental impacts as well, but the area flooded per megawatt of energy produced would be much less than at Balbina. Constructing transmission lines to these hydroelectric sites would provide a virtually permanent solution to supply power for Manaus and would be cheaper than Balbina has turned out to be.

Part of the distance from Manaus to Tucnruí and other hydroelectric sites on the rivers south of the Amazon will be provided with transmission lines anyway because the Cachoeira Porteira Dam lies along one of the possible routes. The lines from Balbina also make up part of this trajectory. A study by Eletronorte done in about 1976 estimated that building a transmission line from Tucuruí to Cachoeira Porteira would cost US$600 million (Joaquim Pimenta de Arrila, personal communication 1987). This total is cheaper than the US$730 million spent for Balbina, but dollar inflation since the estimate could reduce or eliminate the difference. What makes transmission substantially less expensive than this calculation is the fact that reasons other than supplying Manaus have justified much of the cost, including crossing the Amazon River.

About half the cost of a Tucuruí–Cachoeira Porteira link would be for crossing the Amazon River. The crossing could not be done with a submerged cable because of the river's strong current. For a suspended line, the river is too wide for crossing in a single span even at its narrowest point in Óbidos— the towers required would be too high to be practical. The crossing would therefore be made at a wide, shallow point using either a chain of towers built in the river bottom or a system of floating towers. Possible locations for such a crossing are at Almeirim (Pará) and Itacoatiara (Amazonas). Direct current would be used for the crossing; the electricity would be converted to and from alternating current in substations on either side of the river at a cost of about US$100 million per substation. Advances in power transmission technology since these estimates were made could lower the costs substantially (Pires and Vaccari 1986).

Preliminary plans for the Altamira complex on the Xingú River include maps implying that transmission lines would link Altamira and Cachoeira Porteira [Brazil Eletronorte/CNEC, nd (1986), p. 36]. One Eletronorte map of expansion plans for transmission lines indicates a link between Tucuruí and Monte Dourado in the Jari project area north of the Amazon River, with a crossing near Almeirim (Brazil Eletronorte 1987c, p. Pará-30). This was Eletronorte's preferred means of supplying energy to the Jari project until August 1988 when Jari obtained permission to build a private hydroelectric facility (José Antônio Muniz Lopes, public statement, 1988). About 520 km of transmission line would be needed to link Almeirim with Cachoeira Porteira. Since the 190-km transmission line from Manaus to Balbina is expected to cost US$33 million (*A Crítica* 1985a), the US$174,000 cost per kilometer implies a cost of US$90 million to link Cachoeira Porteira with Almeirim. Including US$300 million for crossing the Amazon River would bring the cost to abont half the US$750 million spent on Balbina. The head of Eletronorte's planning department cites lower cost estimates: US$60–100 million for crossing the Amazon River at Almeirim and US$700 million for the entire system to link Manaus with Tucuruí (Frank Tadeu Ávila, public statement 1988). It is worth noting that US$700 million is also the expected cost of the Cachoeira Porteira Dam, which could itself be dispensed with if Manaus were linked to Tucuruí. Eletronorte will only consider linking Manaus to Tucuruí and other dams south of the Amazon River after 2005 because the Belém area is classified as deficient in energy (Frank Tadeu Ávila, public statement 1988). The deficiency in Belém is the result of all available energy being committed to smelting aluminum at Barcarena (Pará) and São Luis (Maranhão). Indirectly, Balbina and Cachoeira Porteira become necessary because of the special concessions that have been granted to the foreign firms processing aluminum elsewhere in the region. Aluminum smelting is also questionable as a development option because it creates almost no employment and few of its financial rewards remain in the country.

Providing power from alternative sources is not the only way to substitute for the 109.4-MW average power that Balbina would deliver to Manaus. Energy conservation could reduce the need for a substantial percentage of the power used. Except for efforts to discourage use of gasoline, Brazil has done little to promote energy conservation (Goldemberg 1978). Electrical appliances and industrial equipment could be made much more efficient with modification already in use in other countries (Goldemberg and others 1985). Especially in the case of Manaus, where energy is supplied from high-cost sources such as Balbina, eliminating inefficient uses of energy is the logical first step (Branco 1987). Even under average conditions in developing countries, rather than the extreme case of Balbina, investment in increasing energy efficiency is much more cost effective than investment in new generating capacity (Goldemberg and others 1985).

Power tariffs in Brazil are, on average, much lower than the cost of energy production. This discourages energy conservation and provides substantial subsidies to energy-intensive industries such as aluminum smelting. Aluminum production in the Grande Carajás program area is particularly favored, since Eletronorte has agreed to supply power to the plants at a rate tied to the international price of aluminum, rather than to the cost of producing the energy: for the Alunorte/Albrás plant in Barcarena, Pará (owned by a consortium of 33 Japanese firms together with Brazil's Companhia Vale do Rio Doce), only US 10 mils/kWh is charged, while the power, which is transmitted from Tucuruí, is estimated to cost US 60 mils/kWh to generate (Walderlino Teixeira de Carvalho, public statement 1988). The rate charged the aluminum firms is roughly one third the rate paid by residential consumers throughout the country, and so is heavily subsidized by the Brazilian populace both through their taxes and their home power bills. Albrás consumed 1673 GWh of electricity in 1986, or 1.7 times as much as the city of Manaus consumed in the same year (Brazil Eletronorte 1987c, pp. Amazonas-23, Pará-12). Expansion plans will more than triple the annual consumption by Albrás to 5225 GWh by the end of the decade (Brazil Eletronorte 1987c, p. Pará-19).

The United States representative on the World Bank Board of Executive Directors, who led an unsuccessful attempt to defeat the Brazilian Electric Power Sector Loan in 1986, described Balbina as an example of "totally unacceptable investments" both because of environmental concerns and the lack of any requirement that Brazil's electrical sector raise its tariffs sufficiently to cover its costs (Foster 1986). Although not a condition for its loans, the World Bank has been urging Brazil to increase tariffs in order to give the power monopoly a profit of at least 6% (*O Globo* 1988). Eletronorte has little motive to transform itself into a highly profitable operation because the enterprise is legally required to give any profits over 10% to the national treasury as part of the Global Guarantee Reserve, (RGG). This cap on profitability has been suggested as an explanation for why the company's executives have often opted for expensive and inefficient investments (*Veja* 1987b, p. 26). Eletronorte runs little risk of making a profit at Balbina.

Policy Implications

Balbina and Science Policy

Balbina and other hydroelectric dams in Amazonia have had a strong and not always beneficial effect on Brazilian science and science policy. The availability of money and employment through Eletronorte and its associated consulting firms has guided much of the research undertaken in Amazonia because almost no funds can be obtained to support research through traditional channels such as the National Council for Scientific and Technological Development (CNPq) and the budgets of research institutions and universities.

Much of the research done is simply collection of specimens, making of lists, and preparation of reports. Hypothesis-oriented research is virtually nonexistent. The information is centralized within Eletronorte to the point where one frequently encounters people both inside and outside of Eletronorte who do not have information directly relevant to their assigned tasks. For example, the engineer responsible for alleviating downstream effects of closing the dam had no information on the discharge of the various streams entering the Uatumã River below the damsite—the survey had been done by one of the consulting firms and the report was unavailable at Balbina. Eletronorte headqnarters at Balbina has no library: even Eletronorte's own engineers can only consult reports of the various consulting firms and research groups by sending a written request to the Brasília office. Many reports are even rarer than medieval manuscripts copied by hand: only three copies exist of one report on macrophytes at Tucuruí according to the secretary who curates the original at INPA.

The role of research in planning, authorizing, and executing major engineering projects such as hydroelectric dams is a critical matter if decision-making procedures are to evolve that prevent future misadventures. The public relations focus of many environment-related activities, such as the highly publicized effort to rescue drowning wildlife, is a matter of intense controversy. Moving wildlife to forest outside the submergence area yields little net benefit in terms of animal lives saved: the animal populations already present normally compete with the newcomers so that numbers of each species quickly decline to approximately their former levels. At Balbina, the wildlife rescue operation, called *Operação Muiraquitã*, was allotted a staff of 300 people equipped with 38 boats with 45 new 45-horsepower outboard motors (Walter de Andrade, personal communication 1987). INPA researchers, in contrast, had to fend for themselves by renting the dilapidated equipment of local fishermen.

The research effort itself is used for public relations purposes. The parrot that explains Balbina in Eletronorte's comic book claims that "environmental conditions will be rigorously controlled by research and constant studies!" [Brazil Eletronorte nd (1987), p. 20]. In the case of Tucuruí, during a public demonstration in Belém against closing the dam, leaflets were dropped by helicopter reassuring readers that INPA's research in the area guaranteed that there would be no environmental problems [Brazil Eletronorte nd (1984)]. No such endorsement had been given either by INPA or by individual researchers involved in the study. Publication of results by researchers was subject to approval by Eletronorte, according to terms of the funding contract. It is essential that both the studies themselves and their subsequent dissemination take place free of interference from any source.

The research program at Balbina began after construction was underway, meaning that the maximum effect that the findings could have would be to suggest minor modifications in procedures once the dam was a fait accompli (Fearnside 1985). Restricting the role of research to mere decoration on already foreordained projects is an unfortunate tradition in Amazonian development planning (Fearnside 1986b).

The fact that research is being done in the area has been used extensively in Eletronorte's advertising on television, radio, and the print media. The implication is that Balbina will be beneficial to the environment—a conclusion contrary to that reached by any researchers involved. In one radio advertisement broadcast in Manaus at 15-min intervals in August 1987, the voice of Curupira—the spirit of the forest—assured listeners that he would not allow Balbina to exist were the dam not good for a long list of familiar species of fish and wildlife. In one television commercial a cavewoman is clubbed over the head with a large bone in a representation of how, without Balbina, Manaus would revert to neolithic times. Many of the advertisements on all media carried the explicit statement that "whoever is against Balbina is against you" (e.g., Brazil Eletronorte 1987a).

Despite the problems of current research funded through the hydroelectric projects, this money is essential to expanding the base of knowledge about the region. Mechanisms need to be developed to maintain the flow of money while eliminating impediments to free exchange of information and to reaching conclusions that might be heretical from the point of view of Eletronorte. One solution would be to have a percentage of funds allocated to dam building and other forms of power generation go to an independent fund, which would then distribute money to research institutions and laboratories on a competitive basis, possibly with some provision to give priority to institutions located in Amazonia. A mechanism is needed to ensure that researchers and institutions receiving funding are not encouraged to submit favorable findings in order to assure continued support for their work either in the development project in question or on future projects. At the same time, those receiving funds need to fulfill adequate reporting requirements for minimal standards of quantity and quality of scientific work. An independent fund would encourage better scientific design, make more efficient use of funds, and eliminate diversion to public relations efforts of funds intended for environmental protection and research.

The mandate for distributing the funds must be broad enough so that alternatives to the proposed schemes are considered. For example, in evaluating the advisability of building Balbina, one must look at such alternatives as oil, gas, transmission lines to other dams, energy conservation, and simply not producing the energy.

The use made of the research results in drafting the environmental impact report (RIMA) required for each hydroelectric project must ensure that the recommendations reflect the conclusions of the scientists conducting the studies. At present, most of the data are collected by research institutions (such as INPA) and delivered to the private consulting firms that Eletronorte has contracted to write the reports. These firms are wholly dependent on Eletronorte and other major patrons for their economic survival and are therefore subject to a strong built-in motivation to minimize their criticism of environmental dangers.

Resolution No. 001 of Brazil's National Council of the Environment (CONAMA), which initiated the requirement of RIMAs, specifies that these reports be prepared by a "qualified multidisciplinary team that is not dependent, either directly or indirectly, on the project's proponent." Mechanisms to ensure this independence need to be created.

Environmental Impact Assessment

The history of Balbina makes clear the imperative of having a genuine environmental impact study completed and publicly discussed prior to any actions that make a project a real or imagined fait accompli. The way that environmental impact studies have been done at Balbina lends itself to highly selective and misleading use of the results. Ultimate responsibility for environmental analysis rests with Eletronorte—the same agency charged with promoting electric power. Consulting firms contract the services of institutions (such as INPA) to collect data; interpretation of data to draw any wider conclusions about the advisability of the overall project is discouraged. Data from each of the subprojects are submitted separately, any global view being reached in Rio de Janeiro or Brasília rather than in the institutions directly involved in data collection. Data from other subprojects are then released in small amounts on a need-to-know basis as judged by Eletronorte. Secrecy throughout the undertaking has severely hampered any enlightened planning or decision making.

The momentum of the construction effort at Balbina succeeded in crushing Brazil's embryonic environmental review process. Balbina was strongly opposed by Paulo Nogueira Neto, who headed Brazil's Special Secretariat of the Environment (SEMA) from 1974 to 1986. On leaving office (for reasons unrelated to Balbina), he said of the dam: "One foresees there the greatest ecological disaster ever provoked by a reservoir" (*Veja* 1986, p. 91). His successor also opposed Balbina, but beginning in 1986, authority on environmental monitoring and licensing has been progressively passed from SEMA to state government agencies. In the case of the state of Amazonas, this is the Development, Research and Technology Center of the State of Amazonas (CODEAMA). Balbina was exempt from obtaining an environmental impact report (RIMA) because construction was initiated prior to Brazil's 23 January 1986 regulation requiring RIMAs for all major development projects. However, the dam was required to obtain a License for Operation from CODEAMA. CODEAMA's director was suddenly replaced only nine days before the dam was licensed (Melchiades Filho 1987). This license was granted on the same day (1 October 1987) that the last sluice base (*adufa*) was closed blocking off the Uatumã River. The precedent of making the environmental review process a mere formality is perhaps the most far-reaching impact of this highly questionable project.

Balbina and the World Bank

The World Bank was approached for funding Balbina, but refused on environmental grounds. Subsequently Brazil obtained a sector loan to supply imported equipment for increasing electric power generation capacity throughout the country, thereby circumventing the bank's environmental review of individual projects. Such loopholes will clearly have to be plugged if the World Bank's recently created Department of the Environment is to prevent future Balbinas from receiving funds channeled through that agency.

World Bank officials say that the turbines and other equipment for Balbina had already been bought before the loan was granted in mid-1986 so that no bank money was used directly for this purpose (Maritta Koch-Weser, personal communication 1988). The turbines arrived in Manaus after that time, bnt confirmation is lacking as to when payment was made. At the least, the injection of funds into the sector freed Brazilian government monies that would otherwise have been spent on higher priority projects elsewhere. It is difficult to assess how much this indirect effect speeded construction at Balbina. Balbina has long been a marginal project in Brazil's overstretched federal budget: in June 1985 Balbina was to have been suspended because of budget cuts following an agreement with the International Monetary Fund (IMF) on Brazil's foreign debt; only urgent appeals to President Sarney by the governor and other state representatives averted the cutoff (*O Jornal do Comércio* 1985, *A Notícia* 1985). Limited funds have delayed the project several times—plans called for beginning construction in 1979 and power generation for 1983, but work did not begin until 1981. On 16 April 1988, with the filling process already underway, it was announced that US$85 million had not been liberated and vital equipment remained undelivered, including the electrical panels, filters, cables, and the refrigeration system for the turbines. No information is available concerning whether any of the remaining equipment had to be imported.

If no World Bank money was spent directly at Balbina, then this was avoided by sheer luck rather than by any control that the bank's environmental policies might have had over how the money was spent. Since these funds ultimately come from taxpayers in countries contributing to the World Bank's budget, the environmental policies of contributing countries also potentially affect how the money is applied. Contributions to the budget are roughly proportional to the number of shares each conntry owns in the bank: the United States holds 20%, the United Kingdom, West Germany, France, and Japan together hold 25%, and the 146 other member countries hold the remaining 55%.

National Priorities for Development

If one ignores for the moment the political and other nontechnical considerations entering the decisions to initiate and to continue building Balbina, the project represents a common dilemma in national development planning: the choice between responding to increased population through a series of carefully escalated responses versus major jumps in anticipation of future growth. In favor of measured responses is the tendency of massive growth to become a self-fulfilling prophecy if facilities are built to supply demand before it exists. Population would be attracted to Manaus until the limiting resource (in this case urban industrial employmeut) is again in short supply. On the side of larger projects in anticipation of demand is the extraordinarily low efficiency and great environmental cost of Balbina as an interim solution: not only will Balbina's costs and impacts be incurred in full, but the transmission lines to more powerful but distant dams will be built anyway. The existence of Balbina merely subtracts from the economic viability of tapping sooner these topographically more appropriate hydroelectric sites.

Balbina raises the question of the extent to which Amazonian development should be subsidized by the rest of the country. Brazil's policy of a unified tariff for electricity means that industry and population can locate themselves where they choose, and the power authority is then obliged to take heroic measures to supply electricity. Were electricity sold at rates reflecting its cost of generation, industrial centers would relocate themselves nearer the better hydroelectric sites, thereby significantly increasing the total amount of urban employment. The fixed rate charged for electricity throughout the country means that consumers in Manaus are being subsidized by the consumers in southern and central Brazil. The subsidy is similar to the one consumers in the south give to road transport in Amazonia: the same price is charged for gasoline in São Paulo's port of Santos as in the most distant corners of Amazonia. The national economy can tolerate these subsidies so long as Amazonia's population remains relatively insignificant (about 10% of Brazil's total population in 1987). These subsidies will become increasingly impractical if the population balance shifts substantially, as it will if the present flood of migration to Amazonia continues. The time may already have arrived to question whether a major industrial and population center like Manaus should be encouraged to continue growing on the strength of outside subsidies. Between 1970 and 1980 Manaus grew at an annual rate of 7.1%, corresponding to a doubling time of only 9.8 years (Brazil IBGE 1982, p. 111). The population reached approximately 1.3 million in 1987.

Were electricity sold at a rate reflecting its cost, people and industries would probably leave Manaus, thus eliminating the need for additional generating capacity or transmission lines. The mechanisms used to induce population to move from one place to another need to be carefully thought through and pricing policies established accordingly. If so decided, industrial rates could be tied strictly to generation costs, while residential rates continue to receive full or partial subsidies. Cost-based rates need not imply that the poor will be reduced to candlelight: graduated rate schedules could easily be devised that provide a modest amount of power at a cheaper rate followed by stepped increases for heavier users. Manaus today illustrates the extreme of subsidized growth.

The power from Balbina will largely benefit the international companies that have established factories in the Manaus Free Trade Superintendency Zone (SUFRAMA). That power will be subsidized for these firms at the expense of residential consumers throughout the country is an irritant to many Brazilians. SUFRAMA was established in Manaus in 1967 to compensate western Amazonia for the concentration in eastern Amazonia of investments channeled through the Superintendency for the Development of Amazonia (SUDAM) (Mahar 1976, p. 360). Financial and environmental costs are high when political decisions lead to location of industrial centers in places where power generation is difficult. All the consequences of supporting industries and population need to be considered before the initial decisions are made.

The inefficiency of locating industry where energy generation is expensive contributes to Brazil's chronic inflation, just as loans obtained to build Balbina contribute to the country's international debt crisis. Inflation results from expenditures on projects that produce little return. Money is put into the pockets of the people who have worked on the dam or supplied goods and services to those working on the dam, but the project produces little for these consumers to buy in the marketplace. Prices rise when demand increases while supply remains the same. The burden of lost purchasing power due to inflation is shared by all Brazilians.

"Irreversible" Projects vs Rational Planning

The dogma that Balbina is "irreversible," repeated ad nauseum since its very inception, has become so powerful that it appears natural that no cost–benefit calculations have been made at any time after launching the construction effort. Eletronorte has been unable to consider abandoning Balbina, although the folly of continuing to build the dam has long been apparent to most disinterested observers: because of the cost to their own private careers and to their personal pride, politicians and government officials who have promoted the project cannot reverse their positions for the sake of public interest. As former United States President Lyndon Johnson said under similar circumstances with reference to continuing to wage a costly war in Vietnam, Eletronorte cannot "leave like a dog with its tail between its legs." Solutions proposed during the Vietnam era apply here, such as to reduce the project to caretaker status until a "decent interval" has elapsed, after which it would be abandoned.

The reservoir could have been left unfilled but, with the closing of the last sluice base (*adufa*), the next best solution would have been to fill the reservoir only to the 37-m elevation mark (the level of the open spillway), producing an impoundment of 370 km^2 (Brazil Eletronorte 1981) but no electricity. The filling process could even have been interrupted before the water level reached the spillway level were the river allowed to flow through the openings at the base of the dam that had been left for installing the turbines.

The reservoir reached the spillway level (37 m) in February 1988. Halting the filling at this point would have meant flooding only one sixth of the forest in the full submergence area and would have allowed water quality to improve before considering any further filling. If left at this level, US$120 million worth of electromechanical equipment would be freed for use in another dam. The US$33 million transmission line would also not be lost, since it will be used for power from Cachoeira Porteira. The approximately US$610 million spent for the remainder of the construction at Balbina would not be lost by abandoning the project, since most of this money is lost anyway. What would be lost is the value of at most 109.4 MW per year of average contribution to Manaus for the seven-year period before Cachoeira Porteira comes on line. This corresponds to 6992 GWh. Since thermoelectric power generation yields 3 kWh/liter of oil, each 159-liter barrel produces 477 kWh (Brazil Eletronorte/Monasa/Enge-Rio 1976, p. B-53); at the current US$20/barrel price the lost power is worth US$293 million. Writing off this sum as the price of the lesson from Balbina should have been considered a bargain. Not only the lesson would have been gained, but also much of the forest in the submergence area and the freedom from maintenance and other expenses of this highly problematical dam.

Once the floodgates were closed, the next best solution would have been to halt filling anywhere between the 37-m spillway level and the 46-m level necessary to produce electricity. Failing this, filling the reservoir should have been halted permanently at the 46-m level, thereby producing a token amount of electricity but sparing the last 780 km^2 of forest and freeing some of the generators and turbines for use elsewhere. If Balbina had been left with only two turbines at the 46-m level, the dam would have had a 100-MW installed capacity. Filling the reservoir to the 50-m level and installing the remaining three turbines yields only 0.19 MW of additional nominal capacity per square kilometer of forest sacrificed. The gain is poor compared to 1.56 MW/km^2 at Cachoeira Porteira or 3.29 MW/km^2 at Tucuruí. If three of the generators and turbines had been transferred to another dam, the approximately US$70 million saved could have been better applied to constructing other dams. However, after over 16 months of filling, the option to leave the reservoir only partially filled was lost forever. When filling was halted on 11 February 1989, the water level in the reservoir had reached 50.6 m above sea level (0.6 m above the full level). Eletronorte's having already casually exceeded the 50.0-m full mark indicates the importance of measures to prevent the agency from ever filling the reservoir to a higher level (the water could reach the maximum maximorum at 51.17 m, thereby flooding a substantially larger area).

The example of Balbina serves as a warning that much stronger guarantees are needed to assure that environmentally damaging projects are irrevocably canceled rather than merely postponed. Eletronorte began to fill Balbina promising to stop once the water level reached 46 m above sea level; the reservoir was to be held at this level for several years to allow water quality to stabilize, at which time a separate decision would be taken on completing the filling process to the 50-m level. During the months prior to closing the dam, the 1580-km^2 figure (which corresponds to the 46-m water level) was used by Eletronorte whenever describing the area to be flooded by Balbina—including Eletronorte's widely distributed comic book [Brazil Eletronorte, nd (1987)]. When the water level reached 46 m on 15 July 1988, the filling process did not pause for a single second, continuing without fanfare toward the full 50-m level. Statements that controversial decisions will be taken at a later time cannot be interpreted as meaning that plans in question will be abandoned, or even that they will be postponed pending a more thorough environmental review. Currently, plans for the 6140-km² Babaquara Dam, which would flood several Amerindian tribes on the Xingú River (Santos and de Andrade 1988), are described by Eletronorte as postponed.

Balbina's greatest benefit may be the lesson it provides of how *not* to make public policy. If this lesson is well learned, many misadventures could undoubtedly be avoided as Brazil decides how much of the power monopoly's 80-dam master plan should be implemented. These lessons cannot be presumed to have been learned. The pattern has repeatedly recurred of major Amazonian developments being launched with explicit recognition of previous failures, whereupon the same errors are repeated. Examples include the Polonoroeste project, which recognized the problems of colonization on the Transamazon Highway (Fearnside 1986c); the Grande Carajás project, which recognized the environmental and social devastation caused by the SUDAM's financing of ranches (Fearnside 1986a); and the Interamerican Development Bank-financed highway paving program in Acre, which recognized the disastrous effects of the World Bank's Polonoroeste project in Rondônia (Fearnside 1987). Mário Penning Bhering, president of Eletrobrás, now recognizes Balbina as a "bad project" (Adams 1988, p. 34). However, it is insufficient to simply acknowledge that Balbina was a mistake and state that it will not be repeated in the 2010 plan—structural changes are needed.

Despite the tremendous needs for change, Brazil has made great advances in protecting examples of its natural ecosystems and incorporating environmental factors into development procedures. At the time of the Stockholm Conference on the Environment in 1972, Brazil was labeled the "villain of Stockholm" for its role in leading the countries of the developing world in condemning any suggestion that these nations should protect their environments (Sanders 1973). Today Brazil has an Institute for the Environment and Renewable Resources, a system of national parks and ecological reserves, and a law requiring an environmental impact report (RIMA) prior to approving any major development project. The legal and legislative advances in protecting the environment must be further fortified by building a corps of qualified people to carry them out and a tradition of serious consideration of the environment in development planning—especially in the early phases of project formulation before major developments become irreversible faits accomplis.

Conclusions

Balbina is indefensible on technical grounds because of its high environmental, human, and financial costs and its meager potential for power output. The many beneficiaries of the public funds spent in constructing the dam form a strong interest gronp promoting the project regardless of the ratio of costs to benefits from the viewpoint of society as a whole. Amazonian development frequently takes the form of such pharaonic works, which, like the pyramids of ancient Egypt, absorb the resources of society for little worldly benefit to the conntry's population. Balbina demonstrates the urgency of fortifying procedures for environmental review of development projects both within Brazil and in international funding agencies that have contributed to the scheme. Balbina could have been profitably halted at any point during the filling process. Filling should never be permitted beyond its current level. Under no circumstances should the electrical authority be permitted to reactivate plans for diverting the Alalaú River to increase water flow to Balbina. Balbina stands as a monument whose most important benefit will be its lesson on how decision making should not be done. Balbina is a pyramid to folly.

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