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Environmental Impacts of Brazil's Tucuruí Dam: Unlearned Lessons for Hydroelectric Development in Amazonia

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ABSTRACT / Brazil's Tucuruí Dam provides valuable lessons for improving decision-making on major public works in Amazonia and elsewhere. Together with social impacts, which were reviewed in a companion paper, the project's environmental costs are substantial. Monetary costs include costs of construction and maintenance and opportunity costs of natural resources (such as timber) and of the money invested by the Brazilian government. Environmental costs include forest loss, leading to both loss of natural ecosystems and to greenhouse gas emissions. Aquatic ecosystems are heavily affected by the blockage of fish migration and by creation of anoxic environments. Decay of vegetation left in the reservoir creates anoxic water that can corrode turbines, as well as producing methane and providing conditions for methylation of mercury. Defoliants were considered for removing forest in the submergence area but plans were aborted amid a public controversy. Another controversy surrounded impacts of defoliants used to prevent regrowth along the transmission line. Mitigation measures included archaeological and faunal salvage and creation of a "gene bank" on an island in the reservoir. Decision-making in the case of Tucuruí was virtually uninfluenced by environmental studies, which were done concurrently with construction. The dam predates Brazil's 1986 requirement of an Environmental Impact Assessment. Despite limitations, research results provide valuable information for future dams. Extensive public-relations use of the research effort and of mitigation measures such as faunal salvage were evident. Decision-making was closely linked to the influence of construction firms, the military, and foreign financial interests in both the construction project and the use of the resulting electrical power (most of which is used for aluminum smelting). Social and environmental costs received virtually no consideration when decisions were made, an outcome facilitated by a curtain of secrecy surrounding many aspects of the project. Despite improvements in Brazil's system of environmental impact assessment since the Tucuruí reservoir was filled in 1984, many essential features of the decision-making system remain unchanged.

The current paper will review environmental impacts of Brazil's Tucuruí Dam, the mitigation measures that were and were not taken, how the environmental studies were carried out and reported, and the role that these considerations played (or failed to play) in the decision-making process. Given Brazil's ambitious plans for hydroelectric development in Amazonia, much use could be made of the lessons from Tucuruí—Amazonia's most powerful existing dam (Figure 1).

The present paper is intended to serve as a complement to a companion paper addressing the social impacts of the Tucuruí Dam (Fearnside 1999). The companion paper covered impacts on indigenous people, resettlement of displaced population, loss of fish and other resources to downstream residents, and health problems such as malaria, a plague of *Mansonia* mosquitos, and accumulation of mercury in fish in the reservoir and in the people who eat them. It also explains how the subsidized aluminum industry that consumes two thirds of Tucuruí's power distorts the entire Brazilian energy economy and leads to tremendous impacts as other dams (such as Balbina) are built to supply power to cities that could have been supplied by Tucuruí had the output of Tucuruí not been committed beforehand to supplying the aluminum smelters at Barcarena and São Luís. Employment generation is minimal in the aluminum industry.

Brazilian Amazonia currently has four hydroelectric dams that are considered to be "large" (≥10 MW installed capacity): Curuá-Una (72 km^2, 40 MW, closed in 1977) and Tucuruí in Pará (2430 km^2, currently 4000 MW, closed in 1984), Balbina, in Amazonas (2360 km^2, 250 MW, closed in 1987), and Samuel, in Rondônia (645 km^2, 217 MW, closed in 1988). A total of 79 dams are planned, totaling 100,000 km^2 (Brazil, Eletrobrás 1987, p. 150, see Fearnside 1995a), or about 3% of Brazil's Amazon forest.

Tucuruí was built on the Tocantins River in the state of Pará at a propitious site for energy generation (Figure 2). The 758,000-km^2 catchment area above the dam site provides an annual mean streamflow of 11,107

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Figure 1. The Tucuruí Dam.

m^3/sec (range 6068–18,884 m^3/sec), with a vertical drop of 60.8 m at the normal pool level of 72 m above mean sea level (msl) (Brazil, Eletronorte 1989, pp. 46, 51, 64). This contrasts with the situation at Balbina, where a small catchment and flat topography result in a reservoir of similar size as Tucuruí, but with a dam that generates much less power. While the Balbina experience also contains many lessons for Brazil's future hydroelectric development (Fearnside 1989a), Eletronorte officials often (unwisely) dismiss these as irrelevant on the grounds that Balbina is so fraught with obvious faults that it is an aberration that will never be repeated due to subsequent improvements in considering the environment in decision-making.[1] Tucuruí, unlike Balbina, has always been whole-heartedly defended by Eletronorte as an example of successful hydroelectric development in the Amazon.

[1]While the president of Eletronorte at the time Balbina was built (Miguel Nunes) later admitted that "Balbina is a sin" (*A Crítica* 18 March 1989), the present head of the agency (Antônio Muniz) endorses the dam.

A second phase of the Tucuruí project, known as Tucuruí-II, is now beginning. This is one of the highest priorities in the federal government's "Brazil in Action" program (http://www.brazil-in-action.gov.br). Tucuruí-II is currently expected to raise installed capacity to 8400 MW and to be completed by 2002 (Indriunas 1998).

Monetary Costs of Tucuruí

Construction Costs

Official estimates of the cost of Tucuruí-I rose from US$2.6 billion to US$5.1 billion as the dam and its plans evolved, mainly as a result of delays and changes in design and materials (Brazil, Eletronorte 1989, p. 423). These estimates are expressed in 1986 dollars and include interest paid during the construction period (but not thereafter). Lúcio Flávio Pinto calculated a cost (as of 1991) of US$8 billion (including the full interest on the debt) for the present 4000 MW (Tucuruí-I) dam, or US$2000/kW of installed capacity. The

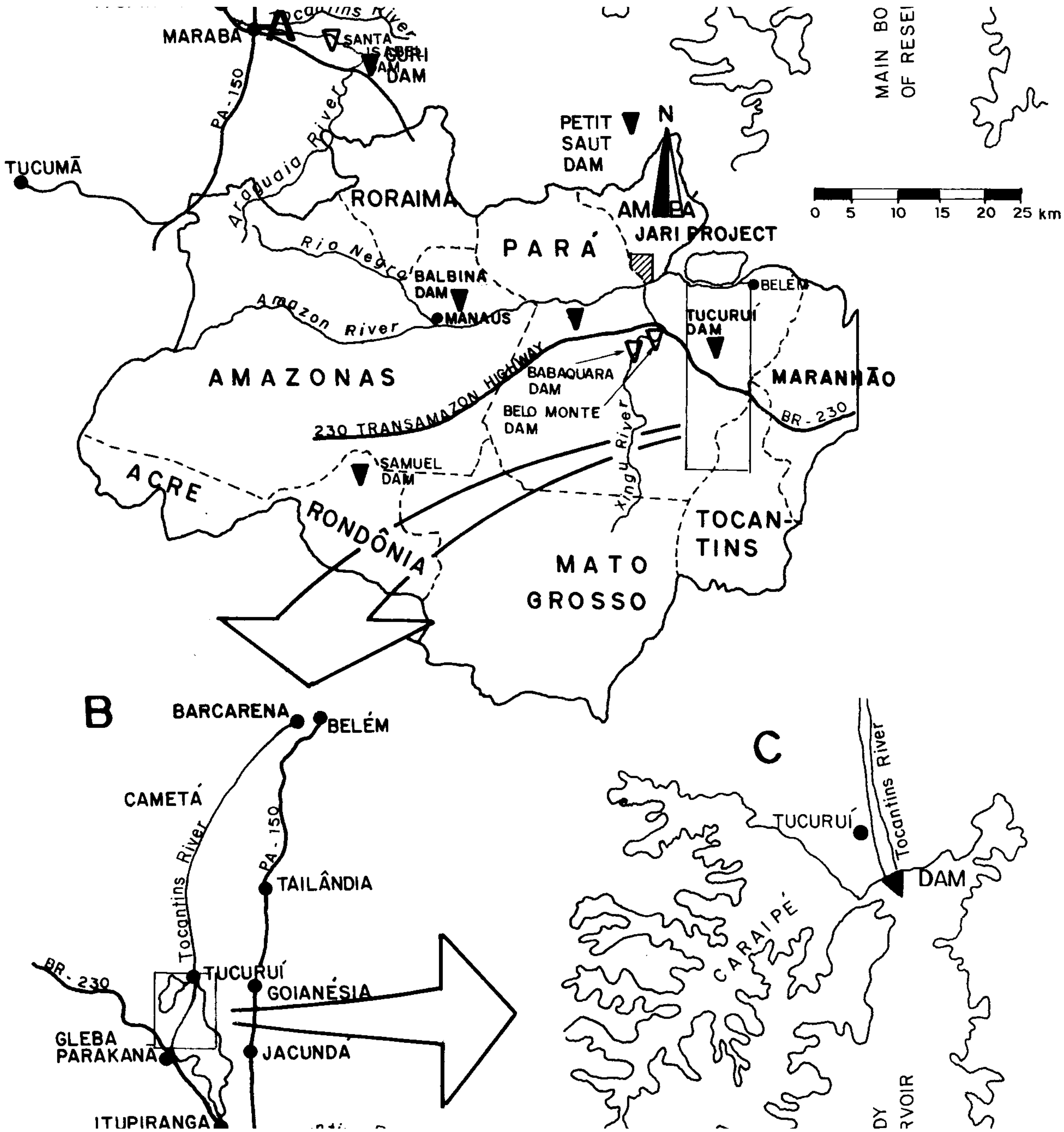

Figure 2. (**A**) The legal Amazon with locations mentioned in the text, (**B**) the Tucuruí Dam area, (**C**) lower end of the reservoir, including the Caraipé branch.

Figure 3. The Caraipé branch of the reservoir, which has a turnover time of seven years, leading to very poor water quality as vegetation decays.

cost of Tucuruí-II is expected to be US$1.25 billion (Indriunas 1998).

Maintenance Costs

The water in the Tucuruí reservoir has an average residence time of 51 days (Brazil, Eletronorte 1988, p. 124). The edges of the reservoir, however, have residence times much longer than the mean. The Caraipé branch of the reservoir is fed by a small stream and is connected to the main body of the reservoir by a narrow mouth (Figures 2C and 3). This 27,000-ha branch of the reservoir has a turnover time of seven years (J. Revilla Cardenas personal communication 1991). A portion of the bottom of the Caraipé branch was bulldozed prior to filling in an effort to minimize biomass decomposition. Slow turnover means that the decomposing vegetation produces acids that can cause corrosion of the turbines (see Fearnside 1989a).

The head of Eletronorte's Civil Engineering Department at Tucuruí says that no corrosion of the turbines themselves has occurred and that no turbines have been removed or replaced (Paulo Edgar Dias Almeida personal communication 1991). There has been some cavitation of the turbine steel, which is described as a normal event and which has been repaired by soldering with silver. Turbines are not the only equipment through which the acid water from the reservoir must pass, and some of the other pieces of equipment have suffered corrosion. Small pipes (5–8 cm diameter) have sometimes been blocked by calcium deposits caused by reaction of the water with the cement. The deposits are removed by the Civil Engineering Department's maintenance crews.

Another problem that has been reported is interference by sunken and rolling logs, affecting auxiliary structures and navigation (Monosowski 1990, p. 32). No information is available on the severity or duration of this problem.

Opportunity Costs

Part of the cost of the decision to build Tucuruí is not the money spent on construction, but what could otherwise have been done with the land, labor, and money devoted to the project. One obvious loss is the

13–14 $\times$ 10^6 m^3 of timber that were submerged (Monosowski 1990, p. 32). A modest portion of this timber has been recuperated by logging submerged portions of the trunks of valuable species using an underwater chainsaw (e.g., Brazil, Eletronorte 1992).

Timber is not the only value of the forest lost to flooding. Nontimber uses of the forest also have value. Brazilnuts *(Bertholletia excelsa)* were common in the submergence area. Many nontimber forest products are not yet exploited commercially; the uses of many potentially important products are not even known yet. Loss of forest implies both loss of the stock of potential uses and the value of biodiversity independent of utilitarian calculations. Our poorly developed ability to place a value on loss of tropical forest does not diminish the reality of these losses, although it does effectively exclude them from consideration in almost all decision-making on projects leading to forest destruction.

Other resources in the submergence area are also lost, including minerals. The area contained some diamonds that were being exploited prior to filling the reservoir (Junk and de Mello 1987, p. 371).

Money spent on the dam also has an opportunity cost. If government funds had not been spent on Tucuruí, they could have been used for health, education, or investment in productive activities that provide more employment for the local population than does the aluminum smelting powered by the dam. The same opportunity cost that applies to money also applies to use of energy from the dam, virtually any use of power other than aluminum smelting would provide much more benefit to the Brazilian people (see Fearnside 1999).

Despite recommendations that 85% of the vegetation be removed from the area to be flooded, Eletronorte adopted a plan to clear only 30% (*A Província do Pará* 1982, Monosowski 1986). Selective logging of valuable timber received higher priority, although this was carried out in only a small part of the area as a combined result of various problems. Valuable species were present at lower densities than originally foreseen: the initial estimate of 20 $\times$ 10^6 m^3 (*Brasil Florestal* 1979) fell by degrees to 11 $\times$ 10^6 m^3 and then to 6 $\times$ 10^6 m^3 (Pereira 1982). The CAPEMI (Caixa de Pecúlio dos Militares) military pension fund that held the logging concession was completely inexperienced in logging operations; among other problems, equipment ordered in a US$100 million contract with a French firm (Maison Lazard Frères) proved to be inappropriate and the contract was canceled (Pereira 1982). The short time available before filling the reservoir contributed to rendering the logging plans not viable, but the five years that elapsed between the selection of CAPEMI in 1979 (*Jornal do Brasil* 1979) and the closing of the dam should have allowed much more wood to be removed (however, the original construction schedule called for completing the dam by 1982). After beginning the logging operation, CAPEMI invited the Jari Project to join it in the venture. Jari sent its sawmill managers, who were shocked by the technical incompetence of the CAPEMI staff and opted not to join the scheme (Jari sawmill staff personal communication 1983).

CAPEMI went bankrupt in 1983 amid a financial scandal (*A Crítica* 4 February 1983) after clearing only 0.5% of the submergence area, and only 10% of the area it was contracted to clear (Barham and Caufield 1984). An additional area adjacent to the dam was cleared by Eletronorte; assuming all of this "critical" 100-km^2 area was actually cut, the cleared total would be 5% of the reservoir (see Monosowski 1986). Eletronorte has also claimed to have cleared 330 km^2 (Brazil, Eletronorte 1992) and 400 km^2 (Brazil, Eletronorte 1985, errata sheet correcting p. 9).

In addition to wood for timber, wood was also expected to be removed for charcoal. Initially, 11 $\times$ 10^6 m^3 of wood for charcoal was expected to be extracted prior to flooding (*Brasil Florestal* 1979). Virtually none was extracted. Five years after filling the reservoir four major sawmills and a pig-iron smelter in Marabá agreed to harvest from the 6 $\times$ 10^6 m^3 of usable commercial wood estimated to be present in the reservoir (Chiaretti 1990). The scrap would be used for charcoal for pig-iron manufacture. Apparently very little of this was actually harvested.

Environmental Costs

Forest Loss

Loss of natural ecosystems. The area of the reservoir's water surface at a water level of 72 m above msl is officially 2430 km^2 [Brazil, Eletronorte nd (1987), pp. 24–25]. Measurement from 1989 LANDSAT images indicates 2247 km^2 of water (Fearnside 1995a). The same study estimates the riverbed area in the reservoir at 321 km^2 based on a reservoir length of 170 km (Juras 1988) and an average width of 1891 m measured from 1:250,000-scale side-looking airborne radar (SLAR) images produced by the RADAMBRASIL project (Brazil, Projeto RADAMBRASIL 1981). Previous deforestation by farmers and ranchers in the submergence area totalled 143 km^2 (Brazil, Eletronorte 1992, p. 21). The forest lost to flooding or to the small amount of clearing done by Eletronorte prior to filling was therefore $2247 - (321 + 143) = 1783$ km^2.

The succession of estimates of the area of the Tucuruí reservoir represents an unfortunate pattern in Amazonian dams, with areas actually flooded greatly exceeding the areas estimated at the time decisions are made on dam construction. The viability study for Tucuruí-I estimated the reservoir area at only 1630 km^2 (Brazil, Eletronorte 1974, p. 1–6). The 2247-km^2 area from LANDSAT (Fearnside 1995a) is 38% greater. Planning of hydroelectric dams passes through a sequence of stages, called "inventory" (completed in 1975 for the Tocantins-Araguaia basin), "viability" (completed in December 1974), "basic proposal" (completed in June 1975), and "executive proposal." In the first two phases, Tucuruí was expected to have a normal pool level of 70 m above msl, which was raised to 72 m in the final two design phases. The area increased from 1630 km^2 in the first two phases to 2160 km^2 in the basic proposal and 2430 km^2 in the executive proposal (Brazil, Eletronorte 1989, p. 25). In addition to the area directly flooded by the reservoir, an estimated 1800 islands totaling 3500 km^2 are present at the 72-m water level (Brazil, Eletronorte 1988, Section 2.1, p. 1).

The areas given above refer to the reservoir at the level for Tucuruí-I, 72 m above msl. The original plan for the Tucuruí-II project called for raising the water level to 74 m above msl (Brazil, Eletronorte 1989, p. 25). The area would increase from 2430 km^2 to 2635 km^2 at 74 m (Brazil, Eletronorte 1989, p. 243). Topographic maps prepared for estimating the areas that were to be flooded during the initial phase were very unreliable, and a number of areas were flooded by Tucuruí-I that were mapped as being above the 72-m mark (forcing a substantial number of farmers to be relocated a second time or to remain with part of their land underwater). In the case of the present (Tucuruí-I) impoundment, the net effect of mistakes in the topographic map was to increase the reservoir size by over 300 km^2, although some areas that were expected to be submerged remained above the water line. Eletronorte officials have reportedly recognized that raising the water above the present 72-m level would be politically impractical due to population displacement effects, and they are planning to operate the Tucuruí-II configuration without further increasing the water level (John Denys Cadman personal communication 1996) (Note: affiliations of all individuals cited are given in the Appendix). The lower amount of water storage in the Tucuruí reservoir would presumably be compensated by greater regulation of the river flow by upstream dams.

It should be remembered that the unfortunate precedent has already been set at Balbina of Eletronorte filling reservoirs to levels above those previously announced in operational plans. Balbina was to be operated at a water level of 46 m above msl (Brazil, Eletronorte 1987, Neumann 1987), but Eletronorte instead filled the dam directly to the 50-m mark, and water levels even reached 50.2 m before the floodgates were opened (Fearnside 1989a).

Whether or not more area is flooded at Tucuruí proper, the Tucuruí-II scheme would require regulating the flow of the Tocantins River by building the Santa Isabel Dam on the Araguaia River, the first major tributary upstream of Tucuruí (Paulo Edgar Dias Almeida personal communication 1991). The impacts of this must therefore be considered in evaluating the Tucuruí-II proposal.

Tucuruí-II has been presented by Eletronorte as a mere continuation of a construction project already underway prior to the 23 January 1986 requirement for environmental impact statements (RIMAs). On 15 June 1998, during a visit to Tucuruí, President Fernando Henrique Cardoso signed the order releasing funds for Tucuruí-II (Indriunas 1998), without an environmental impact study. Only 21 days before the order was signed, an Eletronorte Environment Department representative stated publicly that an environmental study was underway but not yet completed (Andrea Figueiredo public statement 25 May 1998).

The loss of forest caused by Tucuruí is not limited to the area flooded. Deforestation is also done by persons resettled from the submergence area, plus others who are drawn to the area because of its roads, market, and off-farm employment opportunities (Schmink and Wood 1992). Much of the reservoir shoreline has already been deforested. Deforestation by displaced persons has been greater than it otherwise would have been in the case of Tucuruí because a plague of *Mansonia* mosquitos caused much of the resettled population in the Gleba Parakanã to relocate to a new settlement area along logging roads built by mahogany cutters linking the Transamazon Highway with the town of Tucumã.

Greenhouse gas emissions. One of the impacts of hydroelectric dams in Amazonia is emission of greenhouse gases such as carbon dioxide (CO_2) and methane (CH_4). Hydropower is often promoted by government authorities as a clean source of energy, in contrast to fossil fuels (e.g., de Souza 1996). While fossil fuel contributions to global warming are well known, hydroelectric dams are not free of impact. The ratio of impact to benefit varies tremendously among dams, depending on their power output—Tucuruí has a much more favorable balance than does, for example, Balbina (Fearnside 1995a, 1996, Rosa and others 1996a). Tucuruí-I has 1.63 W of installed capacity per square meter of reservoir surface, whereas Eletrobrás has calculated the average power density for the entire hydroelectric potential of the Amazon Region (i.e., the 2010 Plan list) to be only 1 W/m^2 (Rosa and others 1996b, p. 6). The equivalent figure for the 5537 km^2 of water surface in the four existing large dams (whose total installed capacity is 4490 MW) is 0.81 W/m^2, or only half the power density of Tucuruí.

Greenhouse gas emissions from the Tucuruí reservoir for a single year (1990) have been estimated (Fearnside 1995a), and this analysis was subsequently extended from a single year to compute the amount and timing of emissions over a 100-year time period, which could then be compared to the emissions that would be produced by generating the same amount of energy from fossil fuels (Fearnside 1997). Factors considered included the initial stock and distribution of carbon, decay rates and pathways (leading to carbon dioxide and methane), and losses of power in transmission lines. Factors not considered included forest degradation on islands and reservoir shores, nitrous oxide sources in drawdown zones and transmission lines, additional methane emission pathways for release from standing trees, water passing through the turbines, etc. Construction-phase emissions were also not included, nor were emissions from deforestation by people displaced by (and attracted to) the project.

Hydroelectric power generation produces a large pulse of carbon dioxide emissions in the first years after filling the reservoir, while thermal generation produces a constant flux of gases in proportion to the power generated. The average carbon dioxide molecule in the atmospheric load contributed by Tucuruí enters the atmosphere 15 years earlier than the average molecule in the comparable load from fossil fuel generation (Fearnside 1997). This means that, considering a 100-year time horizon, a ton of CO_2 emitted by Tucuruí has more global warming impact than a ton emitted by fossil fuel, whether or not discounting is applied to greenhouse gases. If discounting is applied, then the relative impact of the hydroelectric option is increased. With zero discount, Tucuruí is 4.5 times better than fossil fuel generation (considering only the reservoir, as explained above). At low annual discount rates (1%–2%) the attractiveness of Tucuruí, although less than without discounting, is still 3–4 times better than fossil fuel generation. If the discount rate reaches 15%, the situation is reversed, and fossil fuel generation becomes more attractive from a global warming perspective. It is still undecided whether a discount rate greater than zero (or any alternative means of weighting for time preference) will be adopted in global warming mitigation under the Kyoto Protocol to the United Nations Framework Convention on Climate Change. A decision is likely at the sixth conference of the parties at the end of 2000.

Most of the global warming impact in the above calculations comes from CO_2 released by aerial decomposition of wood: in 1990, CO_2 contributed 83% and CH_4 17%, considering the global warming potential of 21 for CH_4 for the impact of a ton of this gas relative to a ton of CO_2 currently used by the Intergovernmental Panel on Climate Change (IPCC) (Schimel and others 1996, p. 121). In the above analysis, methane emissions were assumed to be relatively constant over the time horizon and were based on published data from floodplain *(várzea)* lakes (see Fearnside 1995a, p. 15). Recent studies in other reservoirs indicate a large peak in methane emissions in the first years after filling, followed by a decline (Duchemin and others nd).

A revised estimate of emissions from Tucuruí uses methane emission data reported by Rosa and others (1996b,c, 1997) and areas covered by floating weeds based on 1988 LANDSAT imagery interpreted by Novo and Tundisi (1994). The area of weeds is greater in the early years of reservoir formation, contributing to a greater pulse of methane emissions during these years and to increased impact of hydroelectric generation relative to fossil fuels when discounting is applied to emissions impacts.

A large area of the reservoir bottom is seasonally exposed (Figure 4). Considering the minimum operating level of 58 m above msl for Tucuruí-I (Brazil, Eletronorte 1989, p. 64), this area occupies 858 km^2 (Fearnside 1995a, p. 13). When flooded, the drawdown area has ideal conditions for generation of methane, as well as for methylation of mercury in the soil. In the Samuel reservoir, for example, areas like this released 15.3 g $C/m^2/yr$ as CH_4 through bubbling when seasonally flooded, as compared to 7.2 g $C/m^2/yr$ among standing dead trees in permanently flooded areas and only 0.00027 g $C/m^2/yr$ in the main channel (Rosa and others 1996c, p. 150).

Approximate emissions through bubbling of CH_4 from Tucuruí can be calculated assuming that the area covered by water weeds through the annual cycle follows the assumptions of Novo and Tundisi (1994). These emissions in 1990 are estimated as follows for each habitat (in 10^3 t gas): river channel: 0.002, other open water without trees: 3.8, standing tree areas: 2.1, and water weed beds: 2.0.

Emissions from diffusion are assumed to be 50 mg $CH_4/m^2/day$, based on a personal communication by Evlyn Moraes Novo to E. Duchemin (Duchemin and others nd) for the emission through this pathway at Tucuruí when the reservoir was 10 years old; this value

Figure 4. Annual drawdown exposes large areas. Seasonal flooding provides ideal conditions for generation of methane, as well as for methylation of mercury in the soil.

is identical to a measurement at Curuá-Una at age 21 years (Duchemin and others nd). Emission from diffusion totals 39.9×10^3 t CH_4.

Recently available information allows methane emissions from water that is released through the turbines to be calculated, substantially increasing the reliability of emissions estimates. It also increases the total emission of this gas as compared to earlier emissions estimates (Fearnside 1995a, 1997), which included methane from decomposition of submerged forest, for which the assumptions used now appear to have been conservative. Based on the amount of water needed to generate the 18.03 TWh of electricity Tucuruí produced in 1991 (Brazil, Eletronorte 1992, p. 3), and a 6 mg/liter methane concentration at 30 m depth (Rosa and others 1997, p. 43), one can calculate the amount of methane exported from the reservoir through the turbines in 1991 was 0.673×10^6 t.

The fate of the methane in water passing through the turbines can be estimated based on data from the Petit Saut Dam in French Guiana (Galy-Lacaux and others 1997). Based on these data, the 1991 release from water passing through the turbines totalled 0.602×10^6 t CH_4 (0.586×10^6 t at the turbines and 0.016×10^6 t in the river). The total methane released from water passing through the turbines is 13 times the total release from bubbling and diffusion in the reservoir itself.

In summary, methane emissions at Tucuruí in 1990 (assumed to be the same as reservoir emissions in 1988 and turbined water emissions in 1991) were as follows, in 10^6 t CH_4: 0.0078 from bubbling, 0.0399 from diffusion, and 0.6024 from the turbines, totaling 0.6501. Considering a global warming potential of 21, this is equivalent to 13.7×10^6 t of CO_2 gas or 3.7×10^6 t of CO_2-equivalent carbon. Emissions of CO_2 in 1990 were estimated at 9.45×10^6 t of CO_2 gas, or 2.6×10^6 t of carbon. The contribution of methane therefore represented 59% of the total greenhouse gas impact of 6.3×10^6 t of CO_2-equivalent carbon in 1990. This significantly changes previous estimates for 1990 (Fearnside 1995a), in which CO_2 contributed 83% and CH_4 17%. The revised estimate indicates lower methane emissions from the reservoir itself (mainly due to lower values for emission from floating weeds per square meter). However, the revised estimate indicates total emissions of CO_2-equivalent carbon that are double the previous estimate when methane from water passing through the turbines is included.

Sedimentation

Sedimentation represents a potential long-term problem for operation of the dam, with implications for hydroelectric development decisions in the Tocantins/Araguaia basin and for the impacts of these decisions. Eletronorte (Brazil, Eletronorte 1988, pp. 126–127, 1989, p. 55) calculated that it would take at least 400 years for sediments at the dam face to reach a level of 23 m above msl, where they would begin to cause abrasion of the turbines. This was based on average sediment load in the upper Tocantins River of 89 mg/liter (437,332 t/day) and 77 mg/liter in the Araguaia River (188,945 t/day), which would occupy a volume of 332.0×10^6 m^3/year. The sediment data are from 1975 (at the town of Tucuruí), 1979 (at Jacundá and Itupiranga), and 1982 (at Itupiranga), prior to any significant deforestation in the watershed (Brazil, Eletronorte 1988, p. 126). The situation is now completely changed, with a substantial portion already cleared and the area standing out as Amazonia's most important deforestation hotspot (cf. Brazil, INPE 1999).

Deforestation can easily increase the rate of soil erosion by an order of magnitude on the scale of individual fields (Fearnside 1980, 1989b). Although erosion rates cannot be extrapolated directly from fields to river basins, the increase is sufficient to make sedimentation a significant worry. A tenfold increase in erosion would reduce the dam's useful life from 400 to 40 years. Sedimentation begins in the upper reaches of a reservoir, where the volume occupied reduces the reservoir's live storage long before sediment accumulation near the dam approaches the intakes for the turbines. Loss of live storage reduces power generation during low-flow periods. As Eletronorte (Brazil, Eletronorte 1989, p. 55) points out, sedimentation calculations do not include the effects of additional dams upstream, which would increase the lifetime of Tucuruí by capturing sediments before they reach the Tucuruí reservoir. However, transferring part of the impact of erosion to upstream dams does not solve the problem: the storage capacities and useful lives of the upstream dams would also be reduced by these sediments, resulting in lost power generation at both the upstream dams and Tucuruí. The role of upstream dams in reducing sedimentation at Tucuruí also adds to the motivation for building these dams, the environmental and social impacts of which will therefore be partly attributable to Tucuruí.

Aquatic Ecosystems

Closing the Tucuruí Dam radically altered the aquatic environment both above and below the dam. Prior to closing the dam, the Tocantins River supported a high diversity of fish. The National Institute for Research in the Amazon (INPA) identified over 350 fish species at Tucuruí; this high diversity poses problems different from those at other tropical locations where large dams have been built, as in African dams where typically only about 80 species are present (Leite and Bittencourt 1991).

Water quality in the reservoir is a major problem. Because of vegetation decomposing in the impoundment, both from remains of the forest left uncut when the lake was filled and from aquatic weeds that proliferated on the surface, the water becomes acid and anoxic (Garzon 1984), which renders the water unsuitable for many fish species.

No fish ladder was built at Tucuruí. This possibility was briefly considered while the dam was under construction but was discarded both due to cost and uncertainty about its potential effectiveness.

The diversity of fish species in the impoundment declined drastically, with the communities becoming dominated by a few species (Leite and Bittencourt 1991). The changes in abundance of fish species resulted in a radical alteration of the relative abundance of fish in the different trophic levels. While primary consumers had been most abundant, the population of predators exploded immediately after closing: in the first year piranhas (*Serrasalmus* spp.) made up 40%–70% of fish caught in experimental sampling done by INPA (Leite and Bittencourt 1991). The dominance of predators was maintained during the three first years, although some primary and secondary consumers were able to make a partial recovery. The biomass of fish present fluctuated wildly in the first three years (the period for which monitoring data are available): by January 1986 fish biomass had increased to a level above that present prior to closing, followed by a crash in the third year. This is probably due to the predatory fish that made up much of the biomass starving for lack of prey, but conclusions are complicated by the increasing transparency of the water rendering the experimental nets more visible to the fish (Leite and Bittencourt 1991).

Commercial fishing was prohibited in the reservoir until the end of 1985. During 1986 the commercial catch climbed rapidly, at the same time that fish biomass present in the reservoir was declining (as indicated by experimental netting) (Leite and Bittencourt 1991). The predator tucunaré (*Cichla ocellaris* and *C. temensis*) made up over 50% of the commercial catch in 1986. In 1987 the catch per unit effort began to decline. Sharp declines in tucunaré catches have also occurred at other reservoirs, such as Balbina.

Based on water fertility estimates and data on primary and secondary production in natural waters in Amazonia, Junk and de Mello (1987, p. 377) calculated that Tucuruí should produce about 40 kg/ha/yr of fish, and concluded that "consequently, the contribution of Amazonian reservoirs to supplying the population with protein will only be of local importance." Fish production in the reservoir has indeed proved to be modest, although it has been enough to supply some fish to Belém. Fish production downsteam of Tucuruí was decimated by the dam due both to the poor quality of water passing through the turbines and to blocked fish migration (de Carvalho and de Merona 1986, Odinetz-Collart 1987, see Fearnside 1999).[2] In Cametá, downstream of the dam, freshwater shrimp harvest fell from 179 t in 1981 to 62 t in 1988, while fish landings fell from 4726 in 1985 to 831 in 1987 (Odinetz-Collart 1993, pp. 161–163). Eletronorte's official history of Tucuruí describes the effect on fisheries as follows: "From monitoring of the effects on the ichthyofauna caused by damming the Tocantins River, it was concluded that upstream the situation was satisfactory in the first two years of operation of the power plant [1985–1986] . . . downstream the conditions were a little less satisfactory . . . " (Brazil, Eletronorte 1989, p. 436).

Defoliants

The use of defoliants has been a source of persistent controversy surrounding Tucuruí. CAPEMI was accused of "secretly using defoliants to clear the forest" (Barham and Caufield 1984). CAPEMI reportedly stockpiled barrels of defoliants for use in this task, which were then hidden in the forest near the company's camp and later flooded by the reservoir. CAPEMI denied these allegations, as did Eletronorte [e.g., Brazil, Eletronorte nd (1984)]. The closest that this author was able to come to confirming this story was one person at Tucuruí who stated emphatically that, on separate occasions, two laborers who had worked for CAPEMI told him that they had helped to hide barrels of poison in the forest before a government inspection. An inspection of the camp area in June 1983 by Eletronorte and accompanying consultants found 373 barrels, "almost all of them empty" [Brazil, Eletronorte nd (c. 1984), p. 3]. The consultants added that they saw "no desertification or devastation of plant species" [Brazil, Eletronorte nd (c. 1984), p. 2]. The herbicides found {[(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid [Triclopyr], 2,4-dichlorophenoxyaceticacid [2,4-D], and pentachlorophenol [Tordon-101 BR]} were being injected into the trunks of girdled Brazilnut trees, rather than being sprayed from airplanes. One month after flooding the reservoir, Eletronorte hired additional consultants to sample and analyze water from over the site where the CAPEMI camp had been. No herbicides were found in the water analyzed, although this can hardly be taken as proof that barrels do not exist on the bottom of the reservoir.

The question of herbicides was one of the most polemical issues surrounding Tucuruí as the time for filling the reservoir approached. One report even claimed that 7000 people had been killed in a genocidal test of poisons carried out on behalf of the Pentagon (the US military headquarters near Washington, DC) in the area to be flooded by Tucuruí (Perez 1985). Newspapers in Belém claimed that Agent Orange (the defoliant used by the US military in Vietnam) could even be carried down the Tocantins River and contaminate Belém (*O Liberal* 1984a). Soon after the reservoir had begun to fill, an essay published in a Belém newspaper chided critics and implied that these exaggerations about herbicides invalidated all environmental concerns regarding Tucuruí (Bemerguy 1984). Eletronorte reproduced the essay widely in leaflets, posters, and other publicity.

A second controversy involving herbicides was a research proposal drafted in 1982 by the director's office of the National Institute for Research in the Amazon (INPA), at the request of Eletronorte, for a test of herbicides {Tordon-101 and Tordon-155, which contain 2,4-D and 2,4,5-T [(2,4,5-trichlorophenoxy) acetic acid], respectively} with a view to evaluating their potential usefulness in clearing the forest in the submergence area through aerial spraying. The existence of the proposal was denounced to the press by Paulo Nogueira Neto, head of the Special Secretariat for the Environment (SEMA, later merged with other agencies to form IBAMA: the Brazilian Institute for Environment

[2]It is worth noting that at the Petit Saut Dam in French Guiana (closed in 1994) an underwater dike was built parallel to the dam 60 m upstream to immobilize the lower half of the water column and draw only relatively well-oxygenated surface water into the turbine intakes. The intake for the turbines at Tucuruí is at 26.5 m above msl, about one third of the height of the water column (72 − 3 = 69 m) (Brazil, Eletronorte 1989, p. 154); Petit Saut has its intake at the bottom, as at Balbina. According to preconstruction simulations of Petit Saut, the dike results in sufficiently high water quality to maintain fish stocks downstream (Sissakian and Desmouline 1991). However, to this author's knowledge, measures such as this are not currently being considered for dams planned in Brazilian Amazonia.

and Renewable Natural Resources) (Caufield 1983, p. 64, Sun 1982). The proposed herbicide test did not go ahead as a result of public outcry (Sun 1982). Eletronorte was ordered not to pursue its plans for using herbicides by Minister of the Interior Mário Andreazza (Sun 1982). Although Brazil was not yet a democracy in 1982, Andreazza was preparing to launch his presidential candidacy for the 1984 electoral college; the defoliant controversy represents one of the few instances where public opinion had a discernible influence on decision-making regarding Tucuruí.

One of the sequelae of the herbicide controversy illustrates a fundamental problem with the system of consulting firms used to address environmental problems. A consulting firm (Structure S.A.) was contracted to study the question of forest biomass removal and recommended that at least 85% of the biomass be removed prior to filling the reservoir. The principal specialist for the firm (Samuel Murgel Blanco) was dismissed when he sent a letter to the government confirming his opposition to using defoliants on the forest in the reservoir area (Barros 1982).

A third controversy involving herbicides was their use in maintaining the transmission line right-of-way free of woody vegetation. In 1984 Eletronorte contracted a company (Consórcio ENGEVIX/Cetenco) whose subcontractor (AGROMAX) used Tordon-101 BR, Tordon-155, and Banvel-450 to kill dicotyledonous plants under the transmission line [Brazil, Eletronorte nd (1984)]. Although Tordon-101 BR (the main herbicide used) is frequently referred to as Agent Orange, it is important to remember that the chemical sprayed in Vietnam in US military operations contained higher levels of contamination with dioxin than does commercial Tordon. Dioxin is one of the most deadly poisons to humans, causing birth deformities, among other kinds of damage. While Tordon is frequently used in Amazonian pastures without causing widespread human deaths, it is toxic to humans and invariably is sold in Brazil with stern (but seldom heeded) warnings for caution. In March 1982 the owner of a ranch (Fazenda Ipê) located on the transmission line between Tailândia and Goianésia requested compensation from Eletronorte for six head of cattle that he claimed had been poisoned by herbicides. Eletronorte contracted consultants to analyze samples of grass, soil, and water in puddles, as well as the blood, bones, and feces of selected animals. No toxins were found, and the consultants diagnosed a cow with similar symptoms as suffering from worm infestation and acute phosphorus and zinc deficiencies [Brazil, Eletronorte nd (c. 1983)]. In the laboratory (in Jaboticabal, São Paulo) "high" doses of Tordon were fed to a sample of rats, rabbits, and cattle without resulting in death. The lethal dose at which 50% die (LD_{50}) for rats, mice, and rabbits is 3.75, 1.5 and 2.0 g/kg of body weight, respectively (Merck Index 1983, p. 7287).

The 1982 transmission line poisoning incident has been claimed to have taken the lives of human victims as well as cattle. Two new graveyards at "Inocêncio" (Vila Bom Jesus) and "Jutuba" were hastily established to accommodate the dead along the 92-km stretch of the BR-150 highway from Tailândia to Goianésia, according to a delegation of the Order of Attorneys of Brazil (OAB) that visited the area two years later (OAB 1984). The president of Eletronorte and the Minister of Mines and Energy denied that any deaths had resulted from herbicide spraying (*O Liberal* 1984b).

Mitigation Measures

Archaeological Salvage

As part of Eletronorte's efforts to mitigate the impacts of Tucuruí, 24 archaeological sites were identified in the submergence area. Eletronorte collected 27,369 ceramic pieces plus 4446 lithic pieces, which are housed at the Museu Paraense Emílio Goeldi in Belém. A charcoal sample from one of the sites was dated as being 70–1000 AD (Brazil, Eletronorte 1985, p. 28).

Faunal Salvage

Eletronorte collected 284,000 animals, mostly mammals and reptiles, in the faunal salvage operation known as Operation Curupira. This massive operation had over 600 direct participants, dozens of boats, plus helicopters, radios, and installations for sorting and quarantine of the animals collected. Gribel (1993) compared the numbers and biomass of collected mammals with those found in studies of Amazonian forests in other locations and concluded that only a small percentage of the mammals were captured. Even those captured and moved were not saved for long. One problem is the stressed and debilitated state of the animals when released. Another is that relocated animals enter into competition with animal populations already present in the area where they are released. In the case of Tucuruí, the additional lease on life given by being "saved" by the Curupira Project in the 1984 was even more ephemeral: a report of a 1986 field survey by Eletronorte indicates that all of the nature reserves created for the rescued fauna had been invaded by loggers and hunters (Monosowski 1990, p. 33).

The principal rationale for the faunal salvage operation appears to be its role in public relations. It is featured in media coverage of the dam, in television reporting, and in glossy photo-oriented magazines.

Gene Bank

Creation of a gene bank was also considered a mitigation measure. This project, carried out by INPA, planted specimens of different tree species collected in the submergence area in 28 2.4-ha parcels on an island in the reservoir near the dam. Only a small part of one parcel received any maintenance. The headquarters of the area served mainly as a picnic spot for high-level employees from the Eletronorte compound at Tucuruí and as a stop for reception of visitors being shown environmental activities in the area.

Decision-Making

Environmental Impact Assessment

The dam was built before 23 January 1986, when Brazil's National Council of the Environment (CONAMA) established its Resolution no. 001 to operationalize Federal Law no. 6938 of 31 August 1981 by requiring environmental impact statements (RIMAs). Compilation of available environmental information (Goodland 1978) was commissioned by Eletronorte. The World Bank refused to finance the dam construction because of environmental concerns (Robert J. A. Goodland personal communication 1986). A more detailed series of reports was compiled by INPA (under commission for Eletronorte) during the period when the dam was under construction (Brazil, INPA/Eletronorte 1982–1984). Even the earlier study (Goodland 1978) was only carried out in a one-month field visit in December 1976 after construction was underway: construction began on 24 November 1975 and the river was diverted on 6 October 1976.

The scope of both environmental studies was very narrow, confining themselves to immediate effects of the dam. The focus was on environmental problems that might affect functioning of the dam, rather than trying to protect the environment and the human population from impacts that the dam might cause. No studies were done on associated infrastructure, such as access roads and transmission lines.

Many items studied were only included at the last minute under pressure of public opinion. For example, studies to assess the possibility of salinization of the estuary and of Belém's water supply in the Guamá River were made only a few weeks before the Tucuruí Dam was closed. Eletronorte undertook the studies under strong pressure from public opinion, which was concerned about closing the dam in the period immediately before the low-water period at Belém, (Monosowski 1990, p. 31).

The impact studies never considered the "no-project option" (Monosowski 1990, p. 30). This procedure guarantees that input from the studies will be limited to assisting in the implantation of plans laid without consideration for environmental and social impacts.

One unfortunate aspect of the environmental studies at Tucuruí is the restriction of consideration to the initial phase of a development plan that would have much greater impacts than those resulting from the first step alone. In this case, Tucuruí-I would be followed by Tucuruí-II and then by a chain of other dams on the Tocantins/Araguaia river system. The problem of early projects, which in isolation may be beneficial, setting in motion a chain of disasters in a basin development scheme is a common one in hydroelectric development. The most dramatic case in point is Brazil's Xingu River, where one proposed dam (Belo Monte, formerly called Kararaô) would make a series of upstream dams attractive to regulate the river flow and increase the first dam's output. The upstream dams, including the 6140-km^2 Altamira Dam (formerly called Babaquara), would flood large areas of indigenous land and have much more severe environmental impacts than the first dam in the series (Santos and de Andrade 1990). The Altamira (Babaquara) Dam is listed in Brazil's current decennial plan for completion in 2013 (Brazil, Eletrobrás 1998, p. 148).

The Role of Research

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 the misadventures that now characterize so much of the development process in Amazonia. The public-relations focus of many of the environment-related activities, such as the highly publicized effort to rescue drowning wildlife, is a matter of intense controversy. Research is used for similar purposes: for example during a public demonstration in Belém against closing the Tucuruí Dam, leaflets (Figure 5) 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)]. The same claim was made in a document sent to the municipal government of Cametá, downstream of the dam (Brazil, Eletronorte 1984). No such endorsement had been given either by INPA or by the individual researchers involved in the study. Publication of results by the 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.

A specific case in point is the prohibition by

TUCURUÍ, URGENTE.

TUDO O QUE VOCÊ PRECISA SABER SOBRE A HIDRELÉTRICA E SUAS CONSEQÜÊNCIAS.

LEIA COM ATENÇÃO, E COMENTE COM OS SEUS FAMILIARES, AMIGOS, VIZINHOS E COLEGAS.

1 O enchimento do lago da Hidrelétrica de Tucuruí somente acontecerá em setembro vindouro.
O que estamos fazendo, no momento, é fechando as adufas.

2 Quando as comportas fecharem, o Rio Tocantins não vai secar mesmo abaixo da barragem e mesmo sem a passagem das águas durante o período de enchimento do reservatório.
O que vai acontecer é o seguinte: entre Tucuruí e Baião, o nível da água vai ficar mais baixo. Mesmo assim, ainda será possível a navegação de pequenas embarcações. Nas outras áreas, o Rio Tocantins vai continuar o seu curso normal, sem problema nenhum. Os barrancos não vão cair, e os peixes não vão morrer. Os peixes terão todas as condições de viver no reservatório e abaixo dele.

3 Não há a menor possibilidade de a água do Tocantins ficar salgada por causa da barragem de Tucuruí. O responsável pelo bloqueio das águas do mar é o Rio Amazonas, não o Tocantins.

4 O Utinga não será afetado de forma alguma: a tomada d'água para abastecimento de Belém é feita no Rio Guamá.

5 Todas as famílias que moravam acima de Tucuruí, onde vai ser formado o grande lago, já foram ou estão sendo deslocadas pela Eletronorte para novos núcleos urbanos, dotados de escolas, igrejas, postos de saúde, água, luz e esgoto, entre outros serviços públicos. Cada morador recebeu casa nova e novo terreno rural, se ele era proprietário de um.

6 Não existe veneno algum na área que vai ser transformada em lago. Existem, sim, muitos boatos a respeito. Mas apenas boatos. Nenhuma verdade.

7 A floresta não vai apodrecer dentro d'água. Com base nos estudos realizados pelos cientistas do INPA, chegou-se à conclusão de que a água do reservatório será de boa qualidade, inclusive para a vida dos peixes, até abaixo da barragem.

8 Instituições científicas da maior respeitabilidade, sediadas no Pará, e até fora do Estado, foram solicitadas a apurar as denúncias havidas contra o uso de herbicidas que teriam provocado a morte de animais — e todas concluíram, unanimemente, que nenhum herbicida foi responsável pela morte de gado no Pará.
Quanto à morte de pessoas pelo mesmo motivo, a Eletronorte não recebeu nenhuma denúncia concreta. Sabemos que chegaram a exumar cadáveres na busca de provas, mas nada ficou provado.

9 Em resumo, ninguém vai perder a caça por causa do fechamento da barragem e do funcionamento da Hidrelétrica de Tucuruí.
Nem vai perder a pesca.
Nem vai beber água salgada, muito menos envenenada.
Ninguém vai respirar gases venenosos.

QUEM DIZ ISSO NÃO É A ELETRONORTE. SÃO OS ESTUDOS E CONCLUSÕES DAS MAIS RESPEITADAS INSTITUIÇÕES CIENTÍFICAS DO PAÍS.

ORGULHE-SE DISSO: A HIDRELÉTRICA DE TUCURUÍ É OBRA DE BRASILEIROS.

Alguém já disse a você o que a Hidrelétrica de Tucuruí vai trazer de bom para você, sua família, seus amigos e colegas, enfim, para a sua gente e a sua terra?
Diga a eles:
Com a hidrelétrica funcionando, o Pará, em particular a região do Tocantins, vai ganhar novas indústrias, novos negócios, novos empregos.
O Estado do Pará vai aumentar a sua arrecadação de impostos.
A luz farta dificilmente faltará como antes.
Eletricidade é progresso.

Ministério das Minas e Energia
Eletrobrás Centrais Elétricas Brasileiras SA
Eletronorte Centrais Elétricas do Norte do Brasil SA

Figure 5. Leaflet dropped by helicopter by Eletronorte claiming the Tucuruí Dam would have virtually no negative impacts.

Eletronorte of release of information at the Third Brazilian Congress of Limnology, held in Porto Alegre, Rio Grande do Sul, in 1990 (*Zero Hora* 1990). Eletronorte did not allow its researchers to speak on the results of their work on environmental impacts at Tucuruí, according to statements made at the congress by Evlyn Moraes Novo, a senior researcher at Brazil's National Institute for Space Research (INPE) who works on satellite image interpretation for the area.

Limitations on the flow of scientific information have considerably reduced the benefits that the experience at Tucuruí might have in improving the planning of hydroelectric developments elsewhere. For example, in 1981 this author met one of the people responsible for environmental studies at Guri Dam in Venezuela, and naively invited the Venezuelans to visit INPA to learn more about the Tucuruí research then underway. When a delegation from Venezuela appeared at INPA a few months later, they had to leave virtually empty-handed because of Eletronorte restrictions on divulging the information.

The connection of scientific research to development projects is encouraging but is not sufficient and does not enter into the decision-making process at the time needed to affect either the basic structure or the existence of the projects in question. The events at Tucuruí offer a good example. Ecologists are virtually never consulted before decisions are made on large-scale projects such as this. Information on environmental questions is only requested later, with the limited intention of suggesting ways of minimizing environmental damage caused by developments already being executed. Ecologists are brought in to deal with the unpleasant task of minimizing environmental messes, rather than being considered as sources of information basic to making the initial decisions. This "gunslinger approach" to ecology is unlikely to be effective in assuring sustainable development and preserving environmental quality.

It should be mentioned that research carried out under Eletronorte contracts as part of environmental studies at Tucuruí, as at other Amazonian dams, was extremely inefficient as a source of published scientific knowledge. Emphasis was on providing extensive lists of species and measurements rather than answering specific scientific questions. Hypothesis-oriented research was virtually absent. Providing the mass of data needed for the reports was a much more important objective than producing published studies in the scientific literature. In addition, the financial stimulus of per diems offered to participants from research institutions in sample-collecting expeditions contributed to maintaining large numbers of people engaged in this activity for extended periods (particularly technical support staff, for whom the per diems represented a significant portion of their earnings).[3] Of course, the stimulus of per diems only applied to collecting expeditions in the field, not to subsequent analysis of material and data and publication of results. The legacy of this can still be seen in row after row of shelves containing bottles of virtually unanalyzed samples in the INPA fish collection.

Regardless of inefficiencies in the research program at Tucuruí, research is fundamental to diagnosing potential environmental impacts and improving decision-making. As compared to the vast majority of Brazil's Amazon region, the research program at Tucuruí resulted in one of the greatest concentrations of knowledge on biodiversity; unfortunately, very little link existed between research results and mitigation actions (Rosa and others 1996d). Construction of the Tucuruí Dam simultaneously with the environmental studies guaranteed that the maximum effect that the findings could have would be to suggest minor modifications in procedures once the dam was already a *fait accompli* (see Fearnside 1985). Relegating research to a merely token role is an unfortunate tradition in Amazonian development planning (Fearnside 1986).

The Influence of Construction Firms

In testimony before the parliamentary commission of inquiry (CPI) on hydroelectric dams held in the Pará State Legislative Assembly in April 1991, Lúcio Flávio Pinto described the situation as follows:

> Policy on the construction of hydroelectric dams and energy policy in Brazil is a subsidiary of the construction contractors *[empreiteiras];* it is the contractors that decide. In the case of Tucuruí, for example, there is a scandal. First, at the beginning of construction, as is very common with dams, a secondary contractor—which was Camargo Corrêa—prepares the infrastructure for the entry of the principal contractor, but when the secondary contractor enters into a dam project in Brazil one already knows that this will automatically be the principal contractor because, when it [the secondary contractor] does the initial work, it invests so much beyond the value of the contract that no contractor, even if it should want to break through that informal arrangement *[esquema de acerto]* [like the one] that became public with the revelation of the North–South Railway scandal, it won't be able to do it, because the other one has already invested beyond what it should have invested on account of government funds. So, Camargo

[3] For example, between 11 February and 31 August 1984, Museu Paraense Emílio Goeldi (MPEG) staff and their assistants spent 2161 person-days in the field at Tucuruí with Eletronorte per diems (Brazil, INPA, MPEG and Eletronorte 1984, p. 9). Additional teams were present from INPA, Instituto Evandro Chagas (IEC), Instituto Butantã (IB) and Universidade Federal do Pará (UFPa).

Corrêa, from secondary contractor, became immediately the principal contractor [Pinto 1991a].[4]

Lúcio Flávio Pinto (1991a, Bloco 12, p. 2) pointed out the association between the Tucuruí contract and Sebastião Camargo (principal owner of the Camargo Corrêa construction firm) rising to billionaire status. *Forbes* magazine attributes the sharp increase in the number of billionaires in Latin America to an "extraordinary wave of capitalist energy" in that region (*Folha de São Paulo* 1992). In the case of Brazil, however, it is probably not a coincidence that three of the country's five billionaires in 1992 were owners of large construction firms that contract for major public works in Amazonia: Sebastião Camargo (Tucuruí Dam), Andrade Gutierrez (Balbina Dam), and Antônio Emírio de Morais (Grupo Votorantim: North–South Railway).

Part of the explanation lies in the extraordinarily high profitability of administering subcontracts associated with construction projects. Lúcio Flávio Pinto (1991a, Bloco 12, p. 2–Bloco 13, p. 1) states with reference to Tucuruí:

> Its [Camargo Corrêa's] profit was US$500 million, and this represents almost 10% of the total cost of the project, excluding the interest paid after construction; this is because it had an administrative fee on everything it administered in the project. It was very common to arrive at Tucuruí at night, for example, and find work teams tending a garden. If a gardener earned a minimum wage, Camargo Corrêa earned 2.9 times what the gardener earned. If it build a house, it earned 2.9 times the value of the house. If it paid the salary of a school teacher, it earned twice the salary of the teacher. That is why the salary of one teacher in the project—the annual salary—sometimes was as much as the funds in the municipality's education budget.

For a period of seven years, from the closing of the Tucuruí Dam in 1984 until late 1991, Camargo Corrêa maintained a vast parking lot filled with idle earthmoving machinery. This was located immediately adjacent to the dam, and thus was readily apparent to all visitors. Much of the heavy equipment was broken and unserviceable. Eletronorte was nevertheless paying rent on the parked machinery during all of this period according to officials at the dam.

An additional source of financial return is a metallic silica plant located near the town of Tucuruí, with an annual production of 32,000 t (Brazil, Eletronorte 1988, Vol. 1, p. 25). The plant is a "preferential client" of the dam (Seva 1990, p. 23). Since September 1988 Camargo Corrêa Metais S.A. has used energy from the dam at subsidized rates (*Corrente Contínua* 1989, p. 11). Camargo Corrêa's subsidized rates will last until 2018 (Lobo 1989).

One way that construction contractors influence developments in ways that may not be in the best interests of the country is in spreading out development over many river basins. Because the present system makes it likely that the firm that gets the contract for the first dam on a given river will also get the contracts for future dams on the same river, competition (which does not necessarily take the form of lower bids) is fierce for the initial contracts. Each construction firm would like to stake its claim to as many river basins as possible, rather than fully developing one basin before moving on to the next. The behavior of the construction firms is sometimes likened to male dogs urinating on objects to mark their territories. This may be a poor strategy for the country's hydroelectric development, as the transmission and other expenses are greater when dams are dispersed, the advantages of one dam regulating the water flow for the next are lost, and the biological impacts are increased by blocking fish migration in more rivers.

The Influence of the Military

The choice of CAPEMI to do the logging is one of several ways in which the developments at Tucuruí have been associated with the National Information Service (SNI), a much-feared internal espionage agency that maintained dossiers on thousands of Brazilians during the military dictatorship that governed the country from 1964 to 1985. Lúcio Flávio Pinto (1991a, Bloco 12, pp. 1–2) described the relationship as follows in his testimony before the CPI:

> A company [CAPEMI] was created three months before taking the bids [for the logging concession]—I speak of CAPEMI Agropecuária—a company linked to the SNI, this because the head of the SNI, who was General [Octávio de] Medeiros, wanted to be President of the Republic. So using the wood was a business to produce income for the campaign of General Medeiros. The man who was manager of the project couldn't have told a lettuce plant from an Ipê [*Tabebuia* spp.] tree. . . . CAPEMI spent much more money buying things [than it earned from the timber]. The scheme was so bad that it quickly cracked . . . [leaving a financial] hole that was covered by the Brazilian government through the BNCC [National Bank of Cooperative Credit].

The Influence of Foreign Interests

Tucuruí was constructed specifically to supply power to the ALBRÁS and ALUMAR aluminum smelters (Pinto 1991a). Lúcio Flávio Pinto (1991a, Bloco 2, p. 4, see also 1991b, p. 144) presented the following testimony to the CPI:

[4]Contract DT-TUC-009/75 for the first-phase cofferdam, permanent roads, airstrip and earthmoving for the residential village and construction site was signed 21 November 1975. The main contract for building the dam (DT-TUC-015/1976) was signed 24 January 1977 (Brazil, Eletronorte 1989, p. 24).

> The decision to build Tucuruí was not made in Brazil; in reality it was made in Tokyo in a negotiation which, at the time, the Brazilian Minister of Mines and Energy, Shigiaki Ueki, carried out with a group of companies from the Government of Japan. It was decided in Tokyo because the Japanese consortium decided to implant 40 km from Belém, in Barcarena, what, at that time, was the largest aluminum mill in the world.

Part of the foreign influence came from France, and the form that this took is a subject about which only the most indirect suppositions are possible. Once again, the best source of information is Lúcio Flávio Pinto's testimony before the CPI in Belém. The information must be taken seriously because Lúcio Flávio Pinto has a reputation for having correct information on such matters. Its presentation as part of testimony at a parliamentary hearing further adds to its credibility. In his book *Amazonia: A Fronteira do Caos,* Pinto (1991b, p. 143) describes the events as follows:

> There are dramatic cases, such as the Tucuruí Dam, the largest public work in the history of Amazonia and one of the largest in the history of Brazil. There the level of indebtedness was 70%, and it was not by chance that the person who negotiated the loan was [Antônio] Delfim Netto [later Minister of Planning while the dam was under construction; also one of Sebastião Camargo's most intimate friends (Marques 1994)], at the time Brazil's ambassador to France living in a golden exile at the time of General [Ernesto] Geisel [Brazilian dictator, 1973–1979]. So he negotiated, and the person who best told the story of how this negotiation took place was a journalist allied with the ambassador at the time—Alexandre von Baumgarten—who wrote a novel because he didn't have the courage to write the real thing as an essay. He wrote a novel called *Yellowcake,* where he tells how the commission was paid and how the loan for Tucuruí was negotiated in Paris.

Alexandre von Baumgarten, who became famous in association with the CAPEMI case (de'Carli 1985), was murdered, and General Newton Cruz [former head of the National Information Service] was tried as the perpetrator of von Baumgarten's assassination.[5] Von Baumgarten's (1983) novel, published after his death, "gives fictitious names to real facts that he witnessed, since he had a great deal of contact with the government security agencies; he says that this ambassador received a bribe to negotiate the debt" (Pinto 1991a, Bloco 5, p. 2).

Half of the turbines were purchased from Neyrpic of Grenoble and Creusot-Loire of Le Creusot, France. The other half were made at Mecânica Pesada Ltda., in Taubaté, São Paulo—a Brazilian subsidiary of the same French group. The French financed these through "supply credits"—loans that carry the requirement that the equipment be bought from the French suppliers and at the prices stipulated by them. By 1991 the debt to the French totaled US$3 billion, and none of it had been paid back (Pinto 1991a, Bloco 5, p. 2).

Lúcio Flávio Pinto's charges of corruption among some of the most powerful men in Brazil, and a link to one of the country's most notorious political assassinations, remain unproven. However, they have also never been properly investigated.

The Role of Public Discussion

One of the greatest impediments to informed public discussion of Tucuruí has been the policy of secrecy that applies to much of the information related to hydroelectric dams in Brazil. Even the massive 2010 Plan (Brazil, Eletrobrás 1987) for hydroelectric expansion in Brazil was only made public in December 1987 after it had already leaked into the public domain. This plan indicates that 10 million ha (100,000 km^2) would be flooded if all planned dams are built (Brazil, Electrobrás 1987, p. 150). The plans have subsequently evolved with the 2015 Plan and 2020 Plan. This author once had the rare opportunity to publicly question the head of Eletrobrás on why copies of these documents could not be provided, resulting in a most remarkable explanation: Brazil's multibillion dollar electrical authority could not afford photocopying (Frederico Magalhães Gomes public statement 7 November 1989).

Secret and continually evolving plans offer an ideal means of avoiding any questioning. When plans come to light and are questioned, authorities can always allege that the plan has changed.

Conclusions: The Lessons of Tucuruí

The contrast between the potential benefits of Tucuruí and the real benefits for Brazil could hardly be greater. Examination of the specific impacts of this or any other dam is insufficient for decision-making unless the question of for whom the benefits accrue is satisfactorily answered. Unfortunately, this did not occur in the case of Tucuruí, which mainly benefits multinational aluminum companies. Tucuruí has severe impacts, including loss of forest, displacement of indige-

[5]The case against General Cruz was dismissed in 1993 on the basis of testimony from a witness (the wife of an SNI agent) who came forward 10 years after the fact to assert that she had seen the general in Brasília at the precise time (7:30 AM, 2 October 1982) that another witness had seen him in Rio de Janeiro near the dock where von Baumgarten was embarking on the fishing trip on which he was assassinated (Briguglio 1994, p. 21). The witness in Rio maintained his version until his own death in an apparently unrelated murder (*Amazonas em Tempo* 22 June 1996). It is generally believed that von Baumgarten was assassinated to ensure his silence on the Riocentro bomb explosion that had occurred the previous year (Contreiras 1999). The possibility of a contributing motive from Tucuruí is implied by Pinto (1991a, Bloco 5, p. 2).

nous peoples and riverside residents in the submergence area, elimination of downstream fisheries, creation of breeding grounds for a plague of mosquitos, and methylation of mercury with grave potential public health consequences for the local population and for consumers of fish in urban centers such as Belém.

The decision-making process for hydroelectric development is perverted in a variety of ways with the result that the environmental and human impacts of dams have very little weight in the actual decision to implant the projects. The influence of construction firms and foreign financiers and equipment suppliers contribute to giving minimal consideration to the environmental and social impacts of the project. The curtain of secrecy that Eletronorte maintained over many aspects of the Tucuruí project has hindered understanding of its impacts. The association of Tucuruí since its inception with a shadowy world of military and security agencies has reinforced this aspect of the project. The need for fully informed public discussion of the ambitious hydroelectric plans that have been made for Amazonia is urgent. Unfortunately, many of the lessons of Tucuruí have not yet been learned.

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