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# Impacts of Brazil's Madeira River Dams: Unlearned lessons for hydroelectric development in Amazonia

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**ABSTRACT**

The Santo Antônio and Jirau, under construction on the Madeira River, will have significant impacts, including flooding in Bolivia due to the Jirau reservoir's backwater stretch. The reservoirs eliminate natural ecosystems, and the dams block fish migration affecting both biodiversity and commercial production, especially of the giant catfish of the Madeira River that are important resources in Bolivia and Peru as well as Brazil. Changes in flooding regimes in downstream *várzea* (floodplain) lakes will also affect fisheries. Mercury methylation and greenhouse-gas emissions are additional problems. The reservoirs form part of a planned series of waterways that, if completed, would open large areas in Bolivian Amazonia to soybeans, thus stimulating deforestation. The dams have significant social impacts, including displacing riverside population and eliminating livelihoods from fishing. Despite the technical staff responsible for environmental licensing having submitted a formal opinion considering these concerns to be exceedingly serious and insufficiently studied to authorize dam construction, political appointees approved the licenses. The Madeira Dams offer important lessons for environmental control in Brazil and in many other countries facing similar challenges.


*Keywords*: Dams, Hydropower, Environmental impact assessment, Santo Antônio Dam, Jirau Dam, Global warming

## 1. Introduction

Brazil has launched a massive program of hydroelectric dam construction, most of which is focused on the country's nine-state Legal Amazon region (Figure 1). Although the plans for the dams and their construction timetable are continually evolving, the end result is conversion of essentially all of the tributaries to the Amazon River into continuous chains of reservoirs in the eastern two thirds of the region (Fearnside, 2013a). Brazil's 2011-2020 Decennial Plan for Energy Expansion called for 30 new "large dams" (defined in Brazil as > 30 MW) in the Legal Amazon region by 2020 (Brazil, MME 2011, p. 285). Several of the smaller dams in this list were postponed until after 2021 in the 2012-2021 plan, but two much larger dams were accelerated to be included by that year; the dams for conclusion in the 2012-2021 interval in the Brazilian Legal Amazon region total 17 (Brasil, MME, 2012, pp. 77-78). This will bring the number of completed large dams to 29 in the Legal Amazon region. Many other large dams are planned that are not included in the Decennial Plan (see: Fearnside, 2013a).

Dams planned in Amazonia (and in many other parts of the World) would have many impacts, all of which need to be quantified and weighed against expected benefits if rational decisions are to be made. Many of the impacts fall on local people who live along the rivers being dammed, while benefits accrue to distant cities, sometimes even located in other countries. A complete and fair impact evaluation represents an important component of a decision-making process capable of balancing these concerns. Unfortunately, this ideal is far from being attained. Examination of a specific case, that of the Santo Antônio and Jirau Dams on the Madeira River, provides a concrete example of the problems involved and the unlearned lessons for future dams.

The Madeira is one of the World's great rivers, although it is a mere tributary of the Amazon. The Madeira's average flow of 17,686 $m^3/s$ at Jirau is 24% greater than that of the Yangzi at China's Three Gorges Dam. The Madeira's drainage above the dams covers parts of Brazil, Bolivia and Peru totaling 984,000 $km^2$, an area larger than France, Germany, Belgium and the Netherlands (Figure 1). Brazil's initial plan was to build a single high dam at the Santo Antônio Falls, just upstream of Porto Velho (the capital of the state of Rondônia) (Brazil, ELETROBRÁS, 1987; see Fearnside, 1995). However, the reservoir would flood part of Bolivia, and the plan was altered to divide the stretch of the river between the Santo Antônio Falls and the Bolivian border into two smaller reservoirs: Santo Antônio and Jirau (PCE et al., 2002). The 3750-MW Santo Antônio and 3750-MW Jirau Dams would be run-of-river projects with bulb turbines, allowing them to have smaller reservoirs than traditional storage dams with Kaplan or Francis turbines. A viability study was prepared (PCE et al., 2004) simultaneously with a report on impact on the environment (RIMA) and an environmental impact study (EIA) (FURNAS et al., 2005a, 2005b), jointly known as the "EIA/RIMA". These and other government and technical documents cited in this paper are available at http://philip.inpa.gov.br/publ_livres/Dossie/Mad/BARRAGENS%20DO%20RIO%20MADEIRA.htm.The approval process of the environmental licenses was extremely controversial (e.g., Switkes, 2008). The technical staff of the Brazilian Institute for Environment and Renewable Natural Resources (IBAMA), which is the agency under the Ministry of the Environment that is responsible for licensing, submitted a 221-page technical opinion opposing approval of the preliminary license (Deberdt et al., 2007) and a 146-page opinion opposing approval of the installation license (Brazil, IBAMA, 2008), but in both cases they were summarily overruled by political appointees. The concessions for the dams were won by different consortia. Santo Antônio is being built and operated by Santo Antônio Energia, which is composed of Furnas (39%), FIP (made up of the Santander and Banif banks) (20%), Odebrecht (18%), Andrade Gutierrez (12%) and Cemig (10%). The consortium at Jirau is Energia Sustentável do Brasil, which is composed of GDF Suez (60%), Eletrosul (20%) and Chesf (20%). On 2 July 2013 the Brazilian government approved a proposed sale of a 20% share by GDF Suez (of France) to Mitsui (of Japan). Construction of the dam structures is now nearing completion at both sites, although turbine installation will continue for several years. Electricity generation from the first turbines began in December 2011 at Santo Antônio and is scheduled for July 2013 at Jirau.

[Figure 1 here]

Among the controversies surrounding the Ministry of Mines and Energy's decision to build the dams and the environmental licensing by IBAMA is the adequacy of information on impacts and the degree of impartiality in its presentation and interpretation. The purpose of the present paper is to examine the possible impacts of these dams and to identify unlearned lessons that can serve to improve decision making on hydroelectric development in Amazonia. Many of the impacts and the decision-making challenges are applicable to dams throughout the World, especially in the tropical countries that are now the target of much of this type of development.

## 2. Flooding in Bolivia

The upper end of the Jirau reservoir is at the border between Brazil and Bolivia. The water management plan announced for Jirau would lower the water level during part of the year in order to avoid having the reservoir proper flood land in Bolivia. However, although not admitted in the official scenario, a "backwater stretch" is likely to form where the accumulation of sediments at the head of the reservoir impedes water flow and raises the water level in the river above the reservoir proper, thus flooding in Bolivia (see Appendix A). The official scenarios for sedimentation changed radically over the course of licensing the dams, with strong indications of an important role from political interference (Fearnside, 2013b).

## 3. Loss of natural ecosystems

It was repeated constantly in discussions of the dams that the water level would not rise above the "natural" flood level. This is not the case: as is indicated in the reports, the level in the areas just above each dam will be approximately 3.5 m above the maximum flood level (which, in turn, is significantly higher than the "normal" flood that the population has a reference). The presentation of the comparison with the natural flood implies that the real impact of the dams is only the 281 $km^2$ that extends beyond the river bed, including the natural floodplain.

Much of the Madeira's floodplain is covered by flooded forest (*floresta de várzea*), which is adapted to being underwater for a period of several months each year. However, this forest is not adapted to being underwater year round, and dies when permanently flooded by a reservoir. The impact of the reservoir is therefore the full area flooded (271 $km^2$ at Santo Antônio + 258 $km^2$ at Jirau = 529 $km^2$), about double the figures often touted in describing the project (138 $km^2$ at Santo Antônio + 110 $km^2$ at Jirau = 241 $km^2$) (e.g., Machado, 2003).

Assessing the impact of losing *várzea* forests and other riverside ecosystems depends heavily on the quality of the surveys of the plant species present. Unfortunately, the botanical portion of the EIA/RIMA had grave deficiencies in its use of unidentified non-botanist personnel brought from botanically different parts of Amazonia and the non-adherence to protocols for collecting and depositing specimens, such that it is impossible to check the on-site visual identifications used in the report. This part of the EIA/RIMA received the most devastating criticisms from independent experts participating in the Public Ministry's report on the EIA-RIMA (Hopkins, 2006).

## 4. Impact on fish and fisheries

An extensive fish survey supported by the dam projects found approximately 800 species in the Brazilian portion of the Madeira River basin; 40 of these were new to science (Lopes, 2011). Fortunately, a lower proportion of these are endemic to the Madeira than had been thought previously, meaning that most species also occur in other Amazonian rivers and would not disappear as species if the populations in the Madeira were eliminated. Needless to say, classification as a non-endemic species does not mean that elimination of the Madeira population would be without risks for species survival. The many other proposed dams that would convert most of Brazil's Amazon tributaries into chains of reservoirs could potentially eliminate Madeira River fish species that are not endemic to the Madeira.

Biodiversity impact is separate from the issue of losing the commercial fishery for the large migratory catfish known as "*grandes bagres*." This group encompasses several species in the family Pimeloididae, including dourada (*Brachyplatatystoma rouxeauxii*), pirarara (*Phractocephalus hemioliopterus*), filhote (*B. filamentosum*), caparari (*Pseudoplatystoma tigrinum*) and surubim (*P. fasciatum*) (FURNAS et al., 2005b, Tomo B, Vol. 1, p. III-147). Barthem and Goulding (1997; see also Barthem et al., 1991) have made a detailed study of the annual migration of dourada (*Brachyplatatystoma rouxeauxii*) and piramutaba (*B. vaillantii*). Prior to the dams, these two commercially important species of large catfish ascended the Madeira each year to breed in the headwaters of the upper tributaries such as the Beni and Madre de Dios Rivers. The fry (newly-hatched fish) drifted down the rivers and grew to maturity feeding in the Lower Amazon. Fish ladders have long been used (not always with success) for migratory species such as salmon, but the requirements of the multitude of Amazonian fish species, including the giant catfish, are undoubtedly different, and a working fish transposition device for them had not yet been tested.

The EIA/RIMA does not mention what the consequences would be if the fish transposition device does not work for the big catfish. The report does not draw the obvious conclusion that fish populations in Bolivia and Peru would be drastically reduced. The consequences for fish stocks in the Amazon River itself are uncertain, especially if other tributaries are also dammed as planned.

The fish-transposition device is not a ladder, but rather a channel with obstacles and water velocities similar to those in the natural river in the case of the Santo Antônio Dam. In the case of the Jirau Dam, the fish do not ascend a passage all the way to the reservoir: the passage ends in a large metal container that is then transported by truck and emptied into the reservoir above. The best that can be expected is that these devices might work for the adult fish to migrate upstream, but they would not work for the descent of the eggs and larvae that drift with the current downstream. Normally, the larvae float downstream, and, after two years of growth, the fish are able to migrate up to the spawning grounds. Were the fish passages at the Santo Antônio and Jirau Dams completely successful, the fate of catfish migration to Peru would still not be assured because it also depends on fish passing the planned Cachuela Esperanza Dam in Bolivia. In addition, fish would have to successfully pass the proposed Guajará-Mirim (Cachoeira Riberão) Dam for spawning to occur in either Bolivia or Peru.

The mass fish migration (*piracema*) was completely blocked in 2011 and partially blocked beginning in 2012. One of two planned fish passages at Santo Antônio was completed in time for the 2012 fish migration, but most catfish species such as dourada were not seen ascending the passage. If thousands of these giant catfish were migrating through the passage it would be obvious without need for any special monitoring devices. The catfish are capable of ascending the passage as shown by tests with captured individuals released at the bottom of the passage. However, the small water volume in the passage is apparently insufficient to attract the fish to the entrance since their instinct is to follow the main current of the river. At Jirau a fish passage was opened in July 2012; unlike Santo Antônio, the Jirau fish passage does not ascend all the way to the reservoir, but rather ends in a large iron container that is periodically transported by truck and emptied into the reservoir above. Many reports that the fish have "disappeared" have come from communities along the upper Madeira and its tributaries.

## 5. Mercury

The Madeira River and its tributaries have been the scene of an extended gold rush where miners use mercury to amalgamate gold particles and separate them from the alluvial sediments (e.g., Malm et al., 1990; Martinelli et al., 1988; Pfeiffer et al., 1989, 1990). During the gold rush of the 1980s approximately 100 t of mercury was released into the environment in the Madeira region (Bastos et al., 2006). Although most gold-mining activity was in the upper Madeira (above Porto Velho), the fish and the human population in the entire lower Madeira between Porto Velho and the confluence with the Amazon River had high levels of mercury over a decade after the end of the 1980s gold rush (Bastos et al., 2006).

Within the Santo Antônio and Jirau reservoir areas (which were the focus of the 1980s gold rush), mercury from the gold rush accumulated at the point where the alluvium rests on bedrock (at a depth of approximately 5 m in the gold-mining areas). So much mercury has accumulated that miners digging at this level with dredges do not have to use mercury to amalgamate the gold—it is already amalgamated (Bruce R. Forsberg, personal communication). The possibility that mercury from the gold rush that now lies in the sediments might be remobilized by a second phase of mining in these sediments was raised by dam opponents (Moret, 2006). Now that gold prices have returned to record levels this mining of the sediments has, in fact, begun, even in the Santo Antônio reservoir itself (personal observation).

Slowing of water flow out of tributaries creates anoxic conditions in the tributaries, appropriate for methylation of mercury. Methylation transforms elemental mercury into the form that is toxic to humans even in minute quantities. Mercury has accumulated in the sediments not only in the Madeira River itself but also in its tributaries, especially the Mutum Paraná River (Forsberg and Kemenes, 2006). The town of Mutum Paraná, at the river’s mouth, was a major base for building and repairing dredges, causing additional contamination.

Damming is expected to cause the water velocity in the tributaries to slow much more than in the Madeira River itself (Molina Carpio, 2008, p. 67). The consequent change in the tributaries from lotic to lentic characteristics and decrease in dissolved oxygen is suggested by the EIA, but analyses of the tributaries were not included and further studies were recommended (FURNAS et al., 2005b, Tomo B, Vol. 7, pp. 3.10-3.11). In the Mutum Paraná River, located 55 km above the Jirau Dam, the water level in the Madeira is expected to increase by an average of 5 m, ranging from 3 m in March to 6 m in September according to the viability study (PCE et al., 2005, Tomo A, Vol. 7, p. VII-15). However, the EIA does not analyze changes in water velocity and water quality in this important tributary (Molina Carpio, 2006). Later this was done in the proponents’ reply to IBAMA in May 2007, showing that during at least part of the year the water would indeed stratify in the tributaries, resulting in anoxic water at the bottom (FURNAS and CNO, 2007, Annex V). The dam proponents had denied that there would be any sedimentation at the mouth of the Mutum-Paraná River (FURNAS et al., 2006b). An indication that the tributaries that enter the Jirau reservoir will stratify is provided by a measurement indicating high methane emission from the water surface in a tributary that enters the Santo Antônio reservoir, immediately downstream of Jirau (Hällqvist, 2012, p. 25).

## 6. Greenhouse gases

Although the Jirau Dam can be expected to emit less greenhouse gases than most of the existing dams in Amazonia because of its relatively small reservoir and rapid turnover time, emissions will not be zero. The major impact of Jirau on global warming stems from its project for carbon credit under the Kyoto Protocol’s Clean Development Mechanism (CDM). The CDM Executive Board approved registry of the Jirau project on 17 May 2013, making it the largest “renewable energy” project to date. The fact that construction was well underway before the CDM project was prepared in April 2012 provides strong evidence that the dam would have been built anyway (i.e., it is not “additional”), and the 6 million tons of $CO_2$ that will be emitted by the countries that purchase the carbon credit will represent a net impact on global warming (see Annex A).

## 7. Downstream effects

### *7.1. River scouring*

The viability study and the EIA/RIMA assume that no scouring of the riverbed and banks will occur below the dams as a result of reduced sediment load. The possibility of scouring merits careful study because of the severity of potential impacts if it does occur. Best known is the disastrous erosion downstream of the Aswan Dam on the Nile River in Egypt (e.g., Shalash, 1983). The sediment load carried by the Madeira River (750 million tons/year at Jirau) is 15 times greater than the sediment load carried by the Nile prior to the Aswan Dam (50 million tons at the mouth in 1964)(Shalash, 1983). The Madeira Dams would have much less impact than the Aswan Dam, since the percentage of sediment retained will be less (20% retention in the early years at Jirau, plus 20% of the remainder at Santo Antônio = 36% total) (FURNAS et al., 2006a, Vol. 1, p. 21). Note that this value for percentage retention in the early years is substantially higher than the 12% value given in the RIMA (FURNAS et al., 2005a, p. 56). Presumably the 12% value is an average over a longer time period. In the Nile, the sediment discharged into the estuary was only 5-6% of the pre-dam load, even after recuperation of some sediment load by scouring below the dam (Shalash, 1983). In the case of the Madeira Dams, more studies would have been needed to evaluate effects in the lower Madeira, especially in the first years (Molina Carpio, 2006). It should be noted that construction of the Cachuela Esperanza Dam on the Beni River is expected to result in substantial sediment retention; this would be added onto the effects of Jirau and Santo Antônio to produce as-yet unanalyzed risks of increased scouring and of reduced nutrient flows in the lower Madeira and lower Amazon Rivers.

Release of water through the spillways with great force in 2012 (prior to installing most of the turbines) resulted in erosion of the waterfront of the city of Porto Velho, located just below the dam. Approximately 300 houses were destroyed or condemned due to damage. The consortium building Santo Antônio insists that the erosion had nothing to do with the dam, but nevertheless built a crushed-rock embankment along part of the waterfront and paid to house the displaced population in hotels. Erosion forced Porto Velho’s port to close for several weeks, causing chaos from the over 500 soy trucks that were unable to unload, among other consequences. The inadequacy of the EIA/RIMA’s consideration of downstream impacts was dramatized by these events.

### *7.2. Sediments in várzea lakes*

The EIA/RIMA only considers the “area of direct impact” for environmental parameters to extend for a distance of 12 km below the Santo Antônio Dam (FURNAS et al., 2005b, Tomo A, Vol. 1, p. III-7). An area of study for direct impacts on the human population extends substantially further below Porto Velho (FURNAS et al., 2005b, Tomo A, Vol. 1, p. III-5). This human population will be affected by any changes in the river, which is the source of life for the human economy as it is for the natural ecosystems.

The seasonal pulse of water flow and of sediment movement controls almost all aspects of *várzea* ecosystems, or Amazonian white-water floodplains (Junk, 1997). Sediments enter the *várzea* lakes, providing nutrients that are the base for the food chain leading from plankton through fish to humans. When the water level begins to rise in the Madeira River, the flow of the main river begins to increase several days before the flow increases in the tributaries feeding the lakes from behind, such as Lago de Purusinho (located downstream of Humaitá). The normal flow from the lakes outward is reversed for a period of 2-3 days (the "*repiquete*"), then stops for about one day when the two flows are in balance. At this time a large amount of sediment precipitates out in the lake. As the tributary flow increases, the normal direction of flow from the lake outward is re-established. However, the rise of the water level in the Madeira River occurs in fits and starts, depending on rainfall events in the upper part of the catchment. As the water level rises, 2-3 "*repiquetes*" normally occur, when water and sediment from the Madeira enter the lakes. During the high-water period itself little or no sediment enters the lakes despite the lakes being completely connected to the river by water. This is because the flow rate of the tributaries feeding the lakes from behind is also at a high point, and the normal direction of flow from the lake to the river channel is maintained.

The "*repiquetes*," especially the first one of the year, occur when the water in the river is at a very low level. The Jirau reservoir in particular is expected to be at its lowest level at this time, and part of the pulse of flow would be captured to fill the reservoir instead of being fully passed on to the lower Madeira. The extent to which the presence of the dams would attenuate the peak flow at this critical moment is a matter of uncertainty, despite the insistence of the proponents that there would be no effect (FURNAS et al., 2006a, 2006b). This could be a critical point for the lakes, since any change in the force of the "*repiquete*" would have a great impact. The extent to which this would decrease sediment inputs to the lakes has not been determined.

The amount that the sediment input contributes to maintaining water fertility in the lakes is a key question. Sediments have been mapped in one lake: Lago de Purusinho. The sediments near the mouth of the lake are mostly mineral clays from the Madeira River, while those near the point where the tributary enters (a black-water stream) are richer in organic matter (W.R. Bastos, personal communication). Nutrients adhere both to organic matter and to mineral clay.

The Lago do Cuniã Extractive Reserve is located 130 km downstream from Porto Velho on the left bank of the Madeira River (Figure 1). The reserve was created in 1999 and is administered by the Chico Mendes Institute for Conservation of Biodiversity (ICMBio), formerly part of IBAMA. This 55,850-ha reserve contains over 60 *várzea* lakes, especially the large Lago do Cuniã, where most of the population of 110 families depended on fishing (Brazil, IBAMA, nd [2006]). The Lago do Cuniã is especially known as the principal source of pirarucu (*Arapaima gigas*, a large commercially valuable predatory fish) consumed in Porto Velho. The possibility that alterations caused by the Madeira River dams might reduce the productivity of this fishery is a concern to the local population. Neither the Cuniã Extractive Reserve nor any of the other conservation units downstream of the dams was considered in the EIA/RIMA. Studies are needed to estimate the changes in supply of sediments and nutrients to the *várzea* lakes.

## 8. Social impacts

The idea that the dams would not cause the water level to rise above the natural flood level was repeated so many times by the project proponents and by the press that it became a myth, both among the public and among most people associated with preparations for the dams. However, the amount that the water level rises varies from zero at the upper end of each reservoir (i.e., near Abunã for the Jirau Reservoir and the Jirau Dam site for the Santo Antônio Reservoir), to a maximum just above each dam. An average value hides the fact that the water level rises above the natural flood level over a substantial area. In addition, expressing the increase in comparison to the historical maximum flow level in about 100 years of monitoring the Madeira River (48,800 $m^3/s$) is misleading for riverside residents who think in terms of the lower "normal" flood levels they have seen each year.

The directly affected population totals 2849 (1762 at Santo Antônio and 1087 at Jirau), according to the RIMA (FURNAS et al., 2005a, p. 47). These are undoubtedly underestimates: just the members of the fishing cooperatives in the area total 2400 (Ortiz et al., 2007, p. 6). The displaced population is largely made up of fishermen and others who depended on the river for their livelihoods. In addition to providing employment, the catfish have traditionally been the mainstay of the diet for the population living along the Madeira River (Doria et al., 2012; Goulding, 1979). Replacement activities to provide employment, such as an artificial beach and tourism center built at the former Teotônio Falls, appear to have fallen short of providing a viable livelihood for this population. Signs posted at the artificial beach installed for the tourism center warn that the reservoir water is unfit for swimming, providing an indication of the barrier to replacing fishing with tourism.

The rapid growth of the population of Porto Velho, both from construction employees and others attracted to the opportunities created by associated economic activity, results in severe strain on urban services. In addition, services would obviously be overwhelmed by the release of 20,000 unemployed people upon conclusion of the dams (Instituto Pólis, 2006). The viability study estimated that 50,000 additional indirect jobs would be created by each dam for supplying goods and services during the construction process (PCE et al., 2004, Tomo 1, Vol. 1, p. 18), meaning that 100,000 additional unemployed people would be released on Porto Velho. If the BR-319 Highway is reconstructed and paved by this time, one could expect a substantial migration of this population to Manaus (e.g., Fearnside and Graça, 2006).

## 9. Madeira-Mamoré Waterway impacts

The inventory report (PCE et al., 2002, p. 6.22) is enthusiastic about the potential benefits of the dams for improving transportation: "The excellent soils of Bolivia, which have high productivity and competitive operational costs, will have their potential significantly increased such that they could surpass the best soils in the world. ... Considering that navigation has the best cost relationship among all the transport modes .... we can affirm that implantation of the integrated waterway system that is being proposed will, when fully utilized, be directly reflected in the performance indexes of the national and regional agricultural economies". Only the benefits of the waterways are emphasized, not the impact of stimulating deforestation for soybeans. The planned waterways, known as "*hidrovias*", are shown in Figure 2.

[Figure 2 here]

The relationship of the Madeira Dams to the wider regional integration schemes based on waterway construction constitutes one of the points of greatest controversy (e.g., Killeen, 2007). A group of 11 non-governmental organizations (NGOs) submitted a proposal for a "motion of reference" on the Madeira Dams to the National Council of the Environment (CONAMA) (Maretto et al., 2006). The proposal cited the inclusion of locks in the dam design presented in the RIMA as evidence that the project had "hidden behind all of this [the waterway plans] a huge program for South America called IIRSA (Initiative for the Integration of the Regional Infrastructure of South America), which represents the old model of development based on large volumes of capital without, however, considering development as the result of interactions between local populations, [leading to] exclusion of the peoples of the forest, riverside dwellers and fisherfolk". The "unexpected change of the Federal Government" regarding removal of the locks from the plan [in MME statements to the press in February 2006] is described as "a political manoeuver to confuse public opinion and license the undertaking, hiding from society one of the major objectives of the project". In its official communication to CONAMA responding to the proposed motion, the Ministry of Mines and Energy stated that "nothing is hidden" regarding the IIRSA plans and that the Ministry of the Environment's statement "consists of speculative and erroneous arguments, without any technical foundation. It is a clear affront to the competency of the agency [that was reviewing the EIA/RIMA, i.e., IBAMA] and an unequivocal discredit to its performance" (Brazil, MME, 2006, p. 10). The Ministry of Mines and Energy claimed that the dams are not a part of IIRSA (Brazil, MME, 2006, p. 6), but the dams appear as a prominent component of the IIRSA proposal, of which Brazil is a part (IIRSA, 2007). Benefits for IIRSA are emphasized in the viability study (PCE et al., 2005, Vol. 1, p. I-19) and have often been highlighted in presentations of the project by ELETROBRÁS.

## 10. Conclusions

The Santo Antônio and Jirau Dams on Brazil's Madeira River have severe impacts, but the decision to build the dams was made before impacts were evaluated and the licensing proceeded under political pressure despite concerns raised by technical staff in the licensing agency. Guaranteeing effective independence of the licensing agency is essential.

International impacts were ignored in the case of the Madeira dams, such as the blocking of fish migration to Bolivia and Peru. Information on mercury and downstream sediment and streamflow alterations was also insufficient. No consideration was given to impacts of related infrastructure projects; for the Madeira dams these include planned waterways and associated expansion of soybeans in both Brazil and Bolivia.

The official presentations of expected dam impacts in the environmental impact study (EIA) and other reports show a systematic tendency to minimize the importance of these concerns. When benefits are presented, the tendency is to exaggerate. The present system where impact reports are funded and controlled by the companies that expect to build and operate the dams needs to be replaced by one in which the reports are effectively independent of the proponents.

Decision making on dams (and other projects) needs to be reformulated so that the information gathered in environmental impact studies fulfills its role as an input to a rational comparison between impacts and benefits before the decision is made to build the dam and commit the government's financial and political capital to the project.

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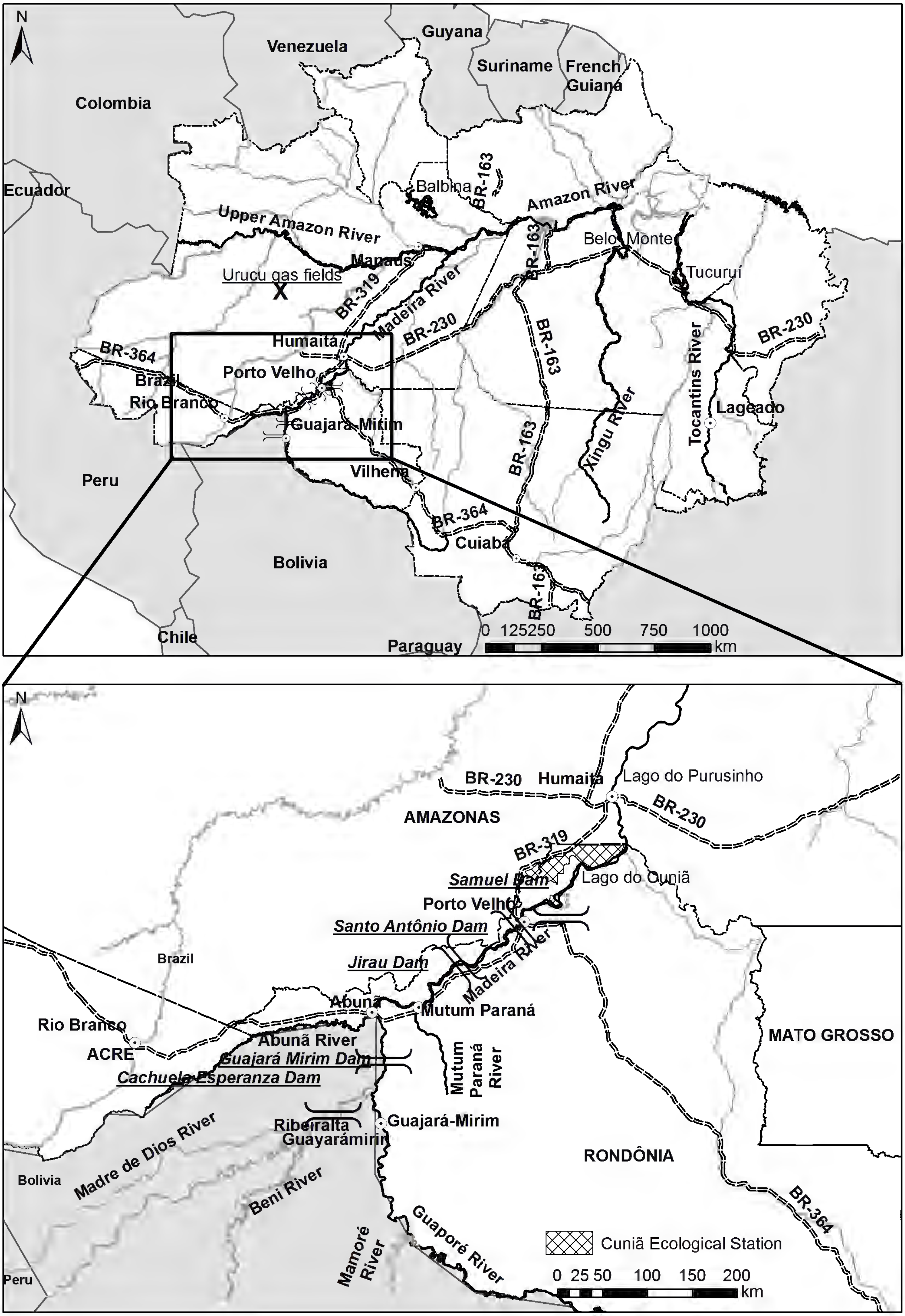
## FIGURE LEGENDS

Figure 1. Locations mentioned in the text.

Figure 2. Planned waterways (hidrovias) indicated by the viability study for the Madeira dams (redrawn from: PCE et al., 2004, Tomo 1, Vol. 1, p. 1.16).


N
Venezuela
Guyana
Suriname
French Guiana
Colombia
Ecuador
BR-163
Balbina
Amazon River
Upper Amazon River
Belo Monte
Manaus
Urucu gas fields
X
Tucuruí
BR-319
Madeira River
BR-230
BR-163
BR-364
Humaitá
Porto Velho
Brazil
Rio Branco
Guajará-Mirim
Tocantins River
Lageado
Xingu River
Peru
Vilhena
BR-364
Cuiabá
Bolivia
Chile
Paraguay
0 125250 500 750 1000
km
N
BR-230
Humaitá
Lago do Purusinho
BR-230
AMAZONAS
BR-319
Samuel Dam
Lago do Cuniã
Porto Velho
Santo Antônio Dam
Madeira River
Brazil
Jirau Dam
Abunã
Mutum Paraná
Rio Branco
ACRE
Abunã River
Guajará Mirim Dam
Cachuela Esperanza Dam
Mutum Paraná River
MATO GROSSO
Ribeiralta
Guajará-Mirim
Guayarámirin
RONDÔNIA
Madre de Dios River
Bolivia
Beni River
BR-364
Guaporé River
Mamoré River
Cuniã Ecological Station
0 25 50 100 150 200
km
Peru

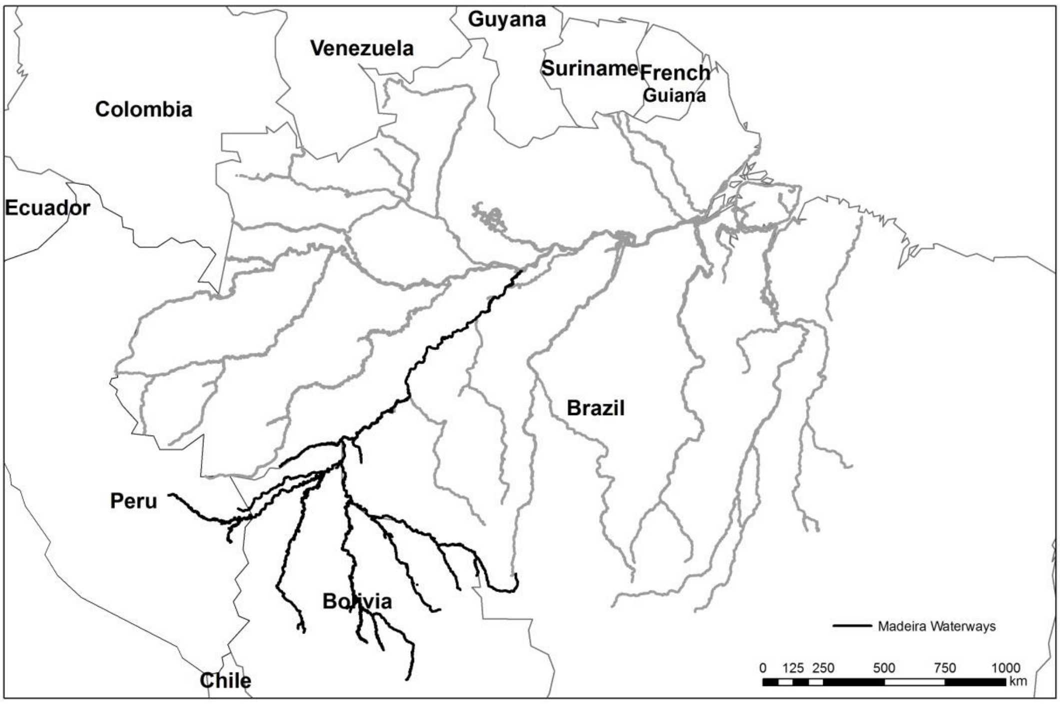



Figure 2. Planned waterways (*hidrovias*) indicated by the viability study for the Madeira dams (redrawn from: PCE et al., 2004, Tomo 1, Vol. 1, p. 1.16).

## APPENDIX A: SUPPLEMENTARY ONLINE MATERIAL

**Impacts of Brazil's Madeira River Dams: Unlearned lessons for hydroelectric development in Amazonia**

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## 1. Flooding in Bolivia

The Madeira has one of the highest sediment loads of the world's rivers, contributing about half of the total carried to the Atlantic by the Amazon River (e.g., Meade, 1994). The questions surrounding the impacts of sediments were symptomatic of the high uncertainty under which the licensing took place. The viability study and EIA/RIMA calculated a rapid accumulation of sediments in the reservoirs, but concluded that dam viability could be guaranteed by leaving the coffer dams in place as underwater barriers to prevent the accumulation of sediments from reaching the turbines (FURNAS et al., 2006, Tomo E, Vol. 1, p. 23). Shortly before approval of the preliminary license for the Santo Antônio and Jirau Dams, a consultant report commissioned by the Ministry of Mines and Energy (Alam, 2007) led to the official scenario being changed completely to one in which there would be no accumulation of sediments at all in the reservoirs (FURNAS and CNO, 2007, p. 22). The reliability of this conclusion has been strongly contested (Dunne, 2007; Molina Carpio, 2007, Tucci, 2007). The controversy surrounding the official scenarios for sediment accumulation shows both the high uncertainty under which the dams were licensed and the tendency to selectively adopt interpretations favorable to the dams (Fearnside, 2013a).

An important question regarding sedimentation is whether sediment deposits will form at the upper end of the Jirau reservoir, causing increased water levels in a backwater stretch above the reservoir proper. This would cause flooding in Bolivia, as the river is binational above Abunã. Effects in the backwater stretch are not considered in the viability study and EIA, despite emphatic claims that Bolivia would not be affected by the dams (FURNAS et al., 2005, Tomo 1, Vol. 1, p. 7-103, 2006a, Vol. 1, p. 13; PCE et al., 2004, Tomo 1, Vol. 1. p. 1.6 and p. 7-103, 2005, Tomo A, Vol. 7, pp. VII-15-16). However, the HEC6 model used in the EIA/RIMA indicates sedimentation above Abunã after 50 years, even if the Jirau Reservoir is operated at a normal pool level of 87 m above msl rather than the 90-m level expected for most of the year (PCE, 2007, p. 6.32).

In addition to flooding in Bolivia by the backwater stretch, there is also a possibility that the water level in the reservoir proper might be raised to flood land in that country despite the current official plan indicating the contrary. The original plan in the 2004 viability study would have kept Jirau's water level constant at an elevation of 90 m, which would flood in Bolivia during part of the year. The 2005 environmental impact study changed this to a variable water level, with levels below 90 m for 8 months of the year (FURNAS et al., 2005b, Tomo A, p. VII-13). Jirau's 2011 proposal for carbon credit from the Clean Development Mechanism would further lower the water level to avoid flooding in Bolivia (Energia Sustentável do Brasil, S.A. and GDF Suez Energy Latin America Participações, Ltda., 2012). The lower water levels imply lost power generation. Operation of the Jirau Dam with a constant (higher) water level represents something that could be done without any additional engineering works beyond the present dam. The past record in parallel situations is not promising: the Balbina Dam was licensed to operate at a water level 46 m above msl, but instead was filled directly to 50 m (Fearnside, 1989), while the Tucuruí-II project was undertaken without an EIA/RIMA on the grounds that it would operate without increasing the water level beyond the previous (Tucuruí-I) level of 72 m above msl, but since 2002 the reservoir has been operating at 74 m above msl (Fearnside, 2006).

In the case of Jirau, Brazil may well be able to secure permission from Bolivia to allow raising the water level to 90 m or even beyond as a part of negotiations for the binational Guajará Mirim Dam, also known as Cachoeira de Ribeirão. An informal accord was reached between Brazil's president Lula and Bolivian president Evo Morales, whereby Brazil would finance the construction of both the Cachuela Esperanza Dam and the Guajará Mirim Dam (Época, 2008). The understanding is that the Bolivians would cease their objections to the Santo Antônio and Jirau Dams. Presumably this might include not objecting to the water level in Jirau being kept at the level planned between the viability study (PCE et al., 2005) and the 2007 answer to IBAMA's queries (FURNAS and CNO, 2007), which would have allowed a backwater stretch to form and affect Bolivia. It might even include turning a blind eye to the original constant 90 m elevation specified in the 2004 version of the viability study being maintained, which would involve some direct flooding in Bolivia by the reservoir in addition to the backwater stretch. On 2 July 2013 Brazil's National Agency for Electrical Energy (ANEEL) requested that the Ministry of Mines and Energy (MME) negotiate with Bolivia to allow the increase in the water level at Jirau (Tavares and Fariello, 2013).

## 2. Greenhouse gases

The Madeira dams would emit substantially less methane than existing Amazonian dams because the relatively rapid water flow is expected to prevent thermal stratification in most of the reservoirs' area. Mean turnover times are 1.34 days in Santo Antônio and 1.32 days in Jirau (FURNAS and CNO, 2007, p. 4). This would result in much less production of methane at the bottom of the reservoir and would help prevent any anoxic water that does form from reaching the turbines. However, emissions would not be zero, since stratification is expected in bays and tributary mouths along the edges of the reservoirs (Forsberg and Kemenes, 2006; FURNAS and CNO, 2007, Annex V). Measurements of methane emission from the water surface at Santo Antônio using floating chambers indicate significant emissions in the tributaries, but much less in the main body of the reservoir (Hällqvist, 2012, p. 25). However, methane concentration measured in the water downstream of the dam is high (Grandin, 2012, p. 28), which suggests that not all of the methane produced in the anoxic portions of the reservoir was oxidized before reaching the turbines. In addition to methane emissions, carbon dioxide is also emitted because trees cut or killed by flooding decompose in the presence of oxygen (Fearnside and Pueyo, 2012).

Both dams have submitted proposals for obtaining carbon credit from the Clean Development Mechanism (CDM) of the Kyoto Protocol. The Jirau project was approved by the CDM on 17 May 2013 allowing it to sell 6.2 million carbon credits (representing tons of $CO_2$) per year for the next 7 years, making it the largest "renewable" energy project ever approved by the CDM (Thomson Reuters Point Carbon, 2013). Credit for dams like this represents an impact on global warming since the dams would be built anyway without subsidy from sale of carbon credits (both Madeira dams were almost complete at the time the proposals were submitted). This is a general problem affecting the CDM, with non-additional dams accounting for a significant part of the CDM’s total mitigation expenditure (Fearnside, 2013b).

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