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

4
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17 **ABSTRACT**

18

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

33

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

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37

38 1. Introduction

39

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

52

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

61

62 The Madeira is one of the World's great rivers, although it is a mere tributary of the
63 Amazon. The Madeira's average flow of 17,686 m³/s at Jirau is 24% greater than that of the
64 Yangzi at China's Three Gorges Dam. The Madeira's drainage above the dams covers parts of
65 Brazil, Bolivia and Peru totaling 984,000 km², an area larger than France, Germany, Belgium
66 and the Netherlands (Figure 1). Brazil's initial plan was to build a single high dam at the Santo
67 Antônio Falls, just upstream of Porto Velho (the capital of the state of Rondônia) (Brazil,
68 ELETROBRÁS, 1987; see Fearnside, 1995). However, the reservoir would flood part of Bolivia,
69 and the plan was altered to divide the stretch of the river between the Santo Antônio Falls and the
70 Bolivian border into two smaller reservoirs: Santo Antônio and Jirau (PCE et al., 2002). The
71 3750-MW Santo Antônio and 3750-MW Jirau Dams would be run-of-river projects with bulb
72 turbines, allowing them to have smaller reservoirs than traditional storage dams with Kaplan or
73 Francis turbines. A viability study was prepared (PCE et al., 2004) simultaneously with a report
74 on impact on the environment (RIMA) and an environmental impact study (EIA) (FURNAS et
75 al., 2005a, 2005b), jointly known as the "EIA/RIMA". These and other government and
76 technical documents cited in this paper are available at
77 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.,
78 Switkes, 2008). The technical staff of the Brazilian Institute for Environment and Renewable
79 Natural Resources (IBAMA), which is the agency under the Ministry of the Environment that is
80 responsible for licensing, submitted a 221-page technical opinion opposing approval of the
81

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 km² 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

126 not adapted to being underwater year round, and dies when permanently flooded by a reservoir.
127 The impact of the reservoir is therefore the full area flooded (271 km² at Santo Antônio + 258
128 km² at Jirau = 529 km²), about double the figures often touted in describing the project (138 km²
129 at Santo Antônio + 110 km² at Jirau = 241 km²) (e.g., Machado, 2003).

130
131 Assessing the impact of losing *várzea* forests and other riverside ecosystems depends
132 heavily on the quality of the surveys of the plant species present. Unfortunately, the botanical
133 portion of the EIA/RIMA had grave deficiencies in its use of unidentified non-botanist personnel
134 brought from botanically different parts of Amazonia and the non-adherence to protocols for
135 collecting and depositing specimens, such that it is impossible to check the on-site visual
136 identifications used in the report. This part of the EIA/RIMA received the most devastating
137 criticisms from independent experts participating in the Public Ministry's report on the EIA-
138 RIMA (Hopkins, 2006).

139 140 **4. Impact on fish and fisheries**

141
142 An extensive fish survey supported by the dam projects found approximately 800 species
143 in the Brazilian portion of the Madeira River basin; 40 of these were new to science (Lopes,
144 2011). Fortunately, a lower proportion of these are endemic to the Madeira than had been
145 thought previously, meaning that most species also occur in other Amazonian rivers and would
146 not disappear as species if the populations in the Madeira were eliminated. Needless to say,
147 classification as a non-endemic species does not mean that elimination of the Madeira population
148 would be without risks for species survival. The many other proposed dams that would convert
149 most of Brazil's Amazon tributaries into chains of reservoirs could potentially eliminate Madeira
150 River fish species that are not endemic to the Madeira.

151
152 Biodiversity impact is separate from the issue of losing the commercial fishery for the
153 large migratory catfish known as "*grandes bagres*." This group encompasses several species in
154 the family Pimeloididae, including dourada (*Brachyplatystoma rouxeauxii*), pirarara
155 (*Phractocephalus hemioliopus*), filhote (*B. filamentosum*), caparari (*Pseudoplatystoma*
156 *tigrinum*) and surubim (*P. fasciatum*) (FURNAS et al., 2005b, Tomo B, Vol. 1, p. III-147).
157 Barthem and Goulding (1997; see also Barthem et al., 1991) have made a detailed study of the
158 annual migration of dourada (*Brachyplatystoma rouxeauxii*) and piramutaba (*B. vaillantii*).
159 Prior to the dams, these two commercially important species of large catfish ascended the
160 Madeira each year to breed in the headwaters of the upper tributaries such as the Beni and Madre
161 de Dios Rivers. The fry (newly-hatched fish) drifted down the rivers and grew to maturity
162 feeding in the Lower Amazon. Fish ladders have long been used (not always with success) for
163 migratory species such as salmon, but the requirements of the multitude of Amazonian fish
164 species, including the giant catfish, are undoubtedly different, and a working fish transposition
165 device for them had not yet been tested.

166
167 The EIA/RIMA does not mention what the consequences would be if the fish
168 transposition device does not work for the big catfish. The report does not draw the obvious
169 conclusion that fish populations in Bolivia and Peru would be drastically reduced. The

170 consequences for fish stocks in the Amazon River itself are uncertain, especially if other
171 tributaries are also dammed as planned.

172

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

185

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

198

199 **5. Mercury**

200

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

209

210 Within the Santo Ant nio and Jirau reservoir areas (which were the focus of the 1980s
211 gold rush), mercury from the gold rush accumulated at the point where the alluvium rests on
212 bedrock (at a depth of approximately 5 m in the gold-mining areas). So much mercury has
213 accumulated that miners digging at this level with dredges do not have to use mercury to

214 amalgamate the gold—it is already amalgamated (Bruce R. Forsberg, personal communication).
215 The possibility that mercury from the gold rush that now lies in the sediments might be
216 remobilized by a second phase of mining in these sediments was raised by dam opponents
217 (Moret, 2006). Now that gold prices have returned to record levels this mining of the sediments
218 has, in fact, begun, even in the Santo Antônio reservoir itself (personal observation).

219
220 Slowing of water flow out of tributaries creates anoxic conditions in the tributaries,
221 appropriate for methylation of mercury. Methylation transforms elemental mercury into the form
222 that is toxic to humans even in minute quantities. Mercury has accumulated in the sediments not
223 only in the Madeira River itself but also in its tributaries, especially the Mutum Paraná River
224 (Forsberg and Kemenes, 2006). The town of Mutum Paraná, at the river’s mouth, was a major
225 base for building and repairing dredges, causing additional contamination.

226
227 Damming is expected to cause the water velocity in the tributaries to slow much more
228 than in the Madeira River itself (Molina Carpio, 2008, p. 67). The consequent change in the
229 tributaries from lotic to lentic characteristics and decrease in dissolved oxygen is suggested by
230 the EIA, but analyses of the tributaries were not included and further studies were recommended
231 (FURNAS et al., 2005b, Tomo B, Vol. 7, pp. 3.10-3.11). In the Mutum Paraná River, located 55
232 km above the Jirau Dam, the water level in the Madeira is expected to increase by an average of
233 5 m, ranging from 3 m in March to 6 m in September according to the viability study (PCE et al.,
234 2005, Tomo A, Vol. 7, p. VII-15). However, the EIA does not analyze changes in water velocity
235 and water quality in this important tributary (Molina Carpio, 2006). Later this was done in the
236 proponents’ reply to IBAMA in May 2007, showing that during at least part of the year the water
237 would indeed stratify in the tributaries, resulting in anoxic water at the bottom (FURNAS and
238 CNO, 2007, Annex V). The dam proponents had denied that there would be any sedimentation at
239 the mouth of the Mutum-Paraná River (FURNAS et al., 2006b). An indication that the tributaries
240 that enter the Jirau reservoir will stratify is provided by a measurement indicating high methane
241 emission from the water surface in a tributary that enters the Santo Antônio reservoir,
242 immediately downstream of Jirau (Hällqvist, 2012, p. 25).

243 244 **6. Greenhouse gases**

245
246 Although the Jirau Dam can be expected to emit less greenhouse gases than most of the
247 existing dams in Amazonia because of its relatively small reservoir and rapid turnover time,
248 emissions will not be zero. The major impact of Jirau on global warming stems from its project
249 for carbon credit under the Kyoto Protocol’s Clean Development Mechanism (CDM). The CDM
250 Executive Board approved registry of the Jirau project on 17 May 2013, making it the largest
251 “renewable energy” project to date. The fact that construction was well underway before the
252 CDM project was prepared in April 2012 provides strong evidence that the dam would have been
253 built anyway (i.e., it is not “additional”), and the 6 million tons of CO₂ that will be emitted by the
254 countries that purchase the carbon credit will represent a net impact on global warming (see
255 Annex A).

256 257 **7. Downstream effects**

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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

302 *várzea* lakes, providing nutrients that are the base for the food chain leading from plankton
 303 through fish to humans. When the water level begins to rise in the Madeira River, the flow of the
 304 main river begins to increase several days before the flow increases in the tributaries feeding the
 305 lakes from behind, such as Lago de Purusinho (located downstream of Humaitá). The normal
 306 flow from the lakes outward is reversed for a period of 2-3 days (the “*repiquete*”), then stops for
 307 about one day when the two flows are in balance. At this time a large amount of sediment
 308 precipitates out in the lake. As the tributary flow increases, the normal direction of flow from the
 309 lake outward is re-established. However, the rise of the water level in the Madeira River occurs
 310 in fits and starts, depending on rainfall events in the upper part of the catchment. As the water
 311 level rises, 2-3 “*repiquetes*” normally occur, when water and sediment from the Madeira enter
 312 the lakes. During the high-water period itself little or no sediment enters the lakes despite the
 313 lakes being completely connected to the river by water. This is because the flow rate of the
 314 tributaries feeding the lakes from behind is also at a high point, and the normal direction of flow
 315 from the lake to the river channel is maintained.

316
 317 The “*repiquetes*,” especially the first one of the year, occur when the water in the river is
 318 at a very low level. The Jirau reservoir in particular is expected to be at its lowest level at this
 319 time, and part of the pulse of flow would be captured to fill the reservoir instead of being fully
 320 passed on to the lower Madeira. The extent to which the presence of the dams would attenuate
 321 the peak flow at this critical moment is a matter of uncertainty, despite the insistence of the
 322 proponents that there would be no effect (FURNAS et al., 2006a, 2006b). This could be a critical
 323 point for the lakes, since any change in the force of the “*repiquete*” would have a great impact.
 324 The extent to which this would decrease sediment inputs to the lakes has not been determined.

325
 326 The amount that the sediment input contributes to maintaining water fertility in the lakes
 327 is a key question. Sediments have been mapped in one lake: Lago de Purusinho. The sediments
 328 near the mouth of the lake are mostly mineral clays from the Madeira River, while those near the
 329 point where the tributary enters (a black-water stream) are richer in organic matter (W.R. Bastos,
 330 personal communication). Nutrients adhere both to organic matter and to mineral clay.

331
 332 The Lago do Cuniã Extractive Reserve is located 130 km downstream from Porto Velho
 333 on the left bank of the Madeira River (Figure 1). The reserve was created in 1999 and is
 334 administered by the Chico Mendes Institute for Conservation of Biodiversity (ICMBio), formerly
 335 part of IBAMA. This 55,850-ha reserve contains over 60 *várzea* lakes, especially the large Lago
 336 do Cuniã, where most of the population of 110 families depended on fishing (Brazil, IBAMA, nd
 337 [2006]). The Lago do Cuniã is especially known as the principal source of pirarucu (*Arapaima*
 338 *gigas*, a large commercially valuable predatory fish) consumed in Porto Velho. The possibility
 339 that alterations caused by the Madeira River dams might reduce the productivity of this fishery is
 340 a concern to the local population. Neither the Cuniã Extractive Reserve nor any of the other
 341 conservation units downstream of the dams was considered in the EIA/RIMA. Studies are
 342 needed to estimate the changes in supply of sediments and nutrients to the *várzea* lakes.

343 344 **8. Social impacts** 345

346 The idea that the dams would not cause the water level to rise above the natural flood
347 level was repeated so many times by the project proponents and by the press that it became a
348 myth, both among the public and among most people associated with preparations for the dams.
349 However, the amount that the water level rises varies from zero at the upper end of each
350 reservoir (i.e., near Abunã for the Jirau Reservoir and the Jirau Dam site for the Santo Antônio
351 Reservoir), to a maximum just above each dam. An average value hides the fact that the water
352 level rises above the natural flood level over a substantial area. In addition, expressing the
353 increase in comparison to the historical maximum flow level in about 100 years of monitoring
354 the Madeira River (48,800 m³/s) is misleading for riverside residents who think in terms of the
355 lower “normal” flood levels they have seen each year.

356
357 The directly affected population totals 2849 (1762 at Santo Antônio and 1087 at Jirau),
358 according to the RIMA (FURNAS et al., 2005a, p. 47). These are undoubtedly underestimates:
359 just the members of the fishing cooperatives in the area total 2400 (Ortiz et al., 2007, p. 6). The
360 displaced population is largely made up of fishermen and others who depended on the river for
361 their livelihoods. In addition to providing employment, the catfish have traditionally been the
362 mainstay of the diet for the population living along the Madeira River (Doria et al., 2012;
363 Goulding, 1979). Replacement activities to provide employment, such as an artificial beach and
364 tourism center built at the former Teotônio Falls, appear to have fallen short of providing a
365 viable livelihood for this population. Signs posted at the artificial beach installed for the tourism
366 center warn that the reservoir water is unfit for swimming, providing an indication of the barrier
367 to replacing fishing with tourism.

368
369 The rapid growth of the population of Porto Velho, both from construction employees
370 and others attracted to the opportunities created by associated economic activity, results in severe
371 strain on urban services. In addition, services would obviously be overwhelmed by the release of
372 20,000 unemployed people upon conclusion of the dams (Instituto Pólis, 2006). The viability
373 study estimated that 50,000 additional indirect jobs would be created by each dam for supplying
374 goods and services during the construction process (PCE et al., 2004, Tomo 1, Vol. 1, p. 18),
375 meaning that 100,000 additional unemployed people would be released on Porto Velho. If the
376 BR-319 Highway is reconstructed and paved by this time, one could expect a substantial
377 migration of this population to Manaus (e.g., Fearnside and Graça, 2006).

378 379 **9. Madeira-Mamoré Waterway impacts**

380
381 The inventory report (PCE et al., 2002, p. 6.22) is enthusiastic about the potential benefits
382 of the dams for improving transportation: “The excellent soils of Bolivia, which have high
383 productivity and competitive operational costs, will have their potential significantly increased
384 such that they could surpass the best soils in the world. ... Considering that navigation has the
385 best cost relationship among all the transport modes we can affirm that implantation of the
386 integrated waterway system that is being proposed will, when fully utilized, be directly reflected
387 in the performance indexes of the national and regional agricultural economies”. Only the
388 benefits of the waterways are emphasized, not the impact of stimulating deforestation for
389 soybeans. The planned waterways, known as “*hidrovias*”, are shown in Figure 2.

390
391 [Figure 2 here]
392

393 The relationship of the Madeira Dams to the wider regional integration schemes based on
394 waterway construction constitutes one of the points of greatest controversy (e.g., Killeen, 2007).
395 A group of 11 non-governmental organizations (NGOs) submitted a proposal for a “motion of
396 reference” on the Madeira Dams to the National Council of the Environment (CONAMA)
397 (Maretto et al., 2006). The proposal cited the inclusion of locks in the dam design presented in
398 the RIMA as evidence that the project had “hidden behind all of this [the waterway plans] a huge
399 program for South America called IIRSA (Initiative for the Integration of the Regional
400 Infrastructure of South America), which represents the old model of development based on large
401 volumes of capital without, however, considering development as the result of interactions
402 between local populations, [leading to] exclusion of the peoples of the forest, riverside dwellers
403 and fisherfolk”. The “unexpected change of the Federal Government” regarding removal of the
404 locks from the plan [in MME statements to the press in February 2006] is described as “a
405 political manoeuver to confuse public opinion and license the undertaking, hiding from society
406 one of the major objectives of the project”. In its official communication to CONAMA
407 responding to the proposed motion, the Ministry of Mines and Energy stated that “nothing is
408 hidden” regarding the IIRSA plans and that the Ministry of the Environment’s statement
409 “consists of speculative and erroneous arguments, without any technical foundation. It is a clear
410 affront to the competency of the agency [that was reviewing the EIA/RIMA, i.e., IBAMA] and
411 an unequivocal discredit to its performance” (Brazil, MME, 2006, p. 10). The Ministry of Mines
412 and Energy claimed that the dams are not a part of IIRSA (Brazil, MME, 2006, p. 6), but the
413 dams appear as a prominent component of the IIRSA proposal, of which Brazil is a part (IIRSA,
414 2007). Benefits for IIRSA are emphasized in the viability study (PCE et al., 2005, Vol. 1, p. I-19)
415 and have often been highlighted in presentations of the project by ELETROBRÁS.

416 417 **10. Conclusions** 418

419 The Santo Antônio and Jirau Dams on Brazil’s Madeira River have severe impacts, but the
420 decision to build the dams was made before impacts were evaluated and the licensing proceeded
421 under political pressure despite concerns raised by technical staff in the licensing agency.
422 Guaranteeing effective independence of the licensing agency is essential.
423

424 International impacts were ignored in the case of the Madeira dams, such as the blocking of fish
425 migration to Bolivia and Peru. Information on mercury and downstream sediment and
426 streamflow alterations was also insufficient. No consideration was given to impacts of related
427 infrastructure projects; for the Madeira dams these include planned waterways and associated
428 expansion of soybeans in both Brazil and Bolivia.
429

430 The official presentations of expected dam impacts in the environmental impact study (EIA) and
431 other reports show a systematic tendency to minimize the importance of these concerns. When
432 benefits are presented, the tendency is to exaggerate. The present system where impact reports

433 are funded and controlled by the companies that expect to build and operate the dams needs to be
 434 replaced by one in which the reports are effectively independent of the proponents.

435
 436 Decision making on dams (and other projects) needs to be reformulated so that the information
 437 gathered in environmental impact studies fulfills its role as an input to a rational comparison
 438 between impacts and benefits before the decision is made to build the dam and commit the
 439 government's financial and political capital to the project.

440

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442

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 451 of the article rests with the author.

452

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676 **FIGURE LEGENDS**

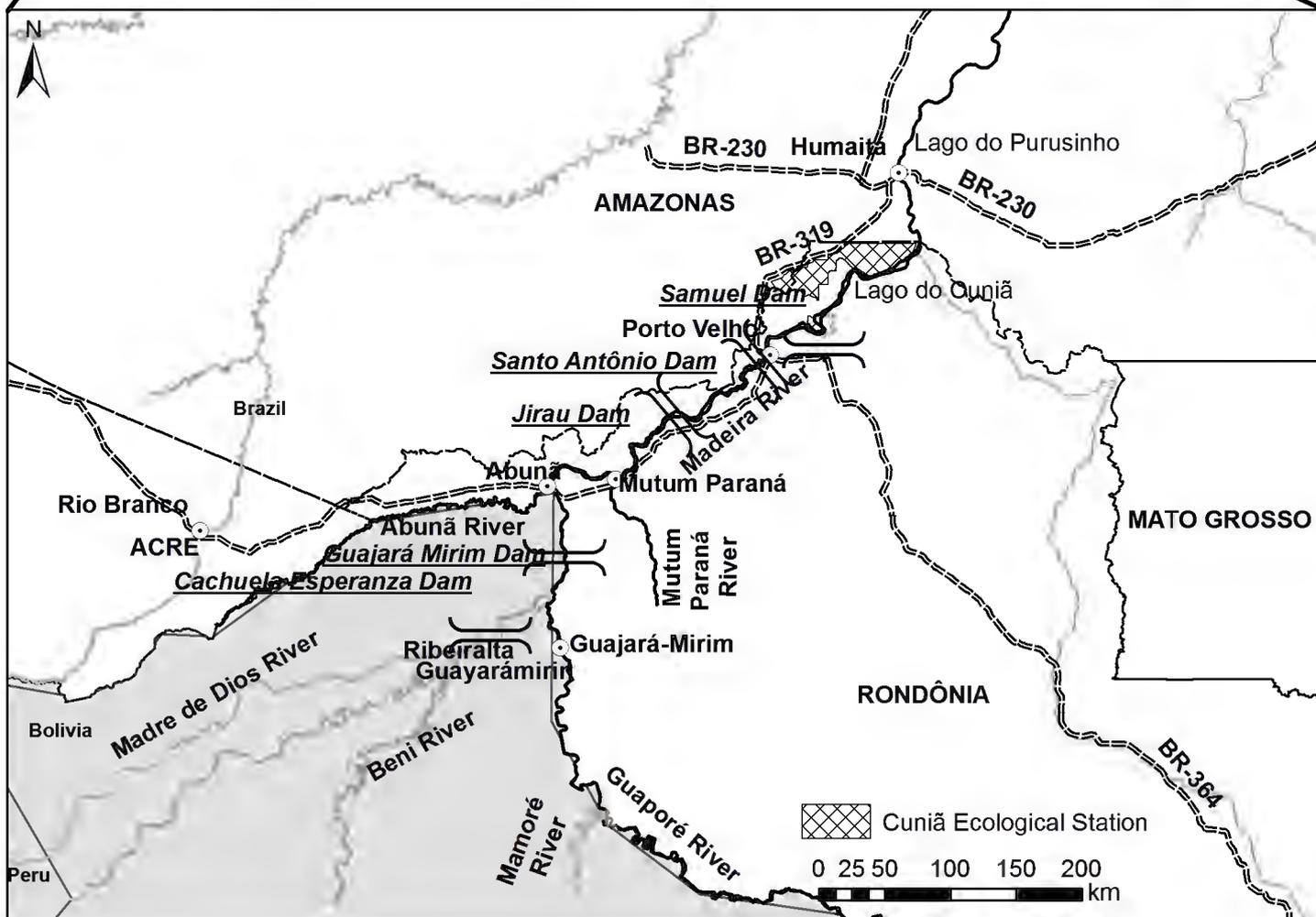
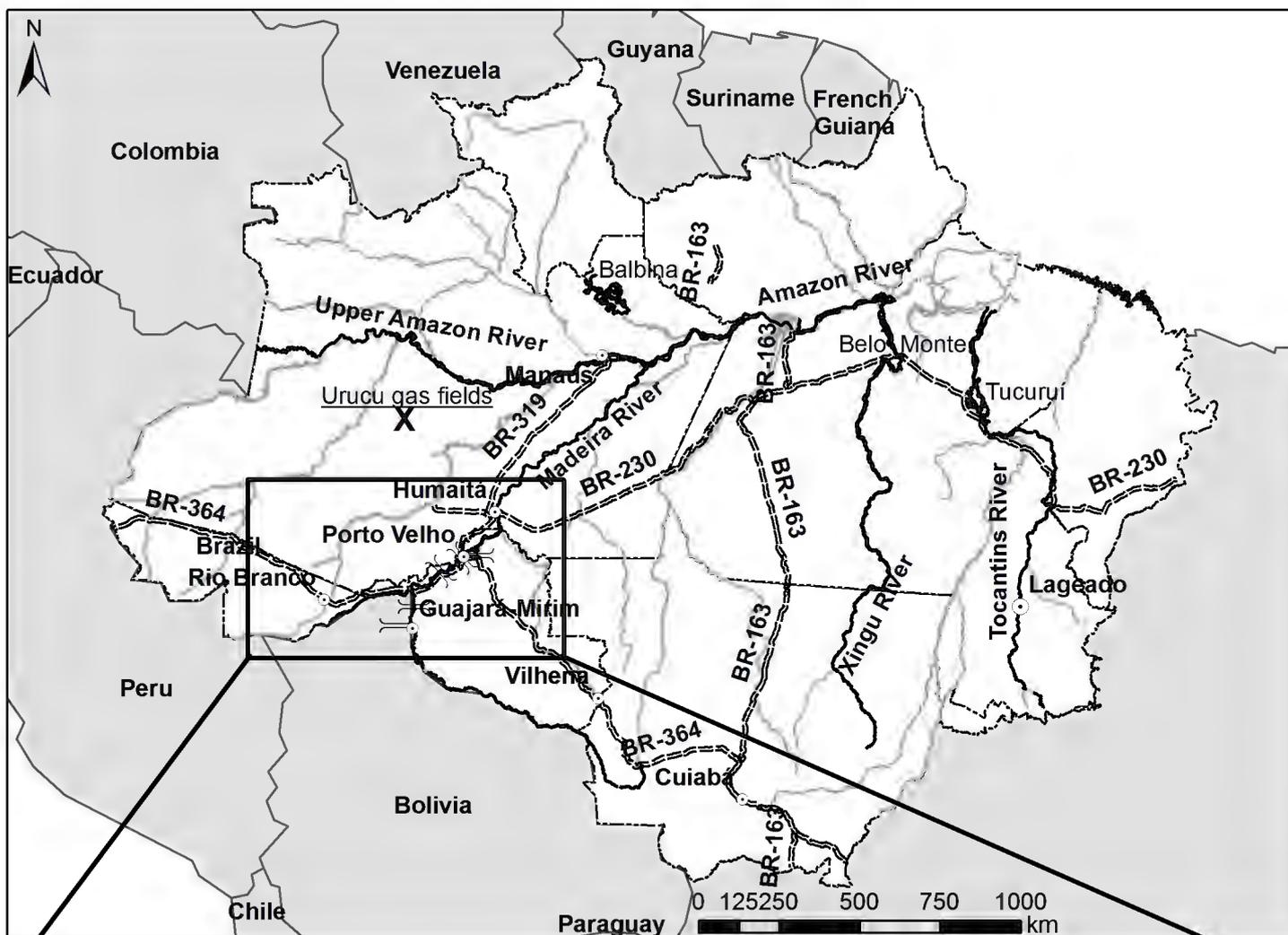
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678 Figure 1. Locations mentioned in the text.

679

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

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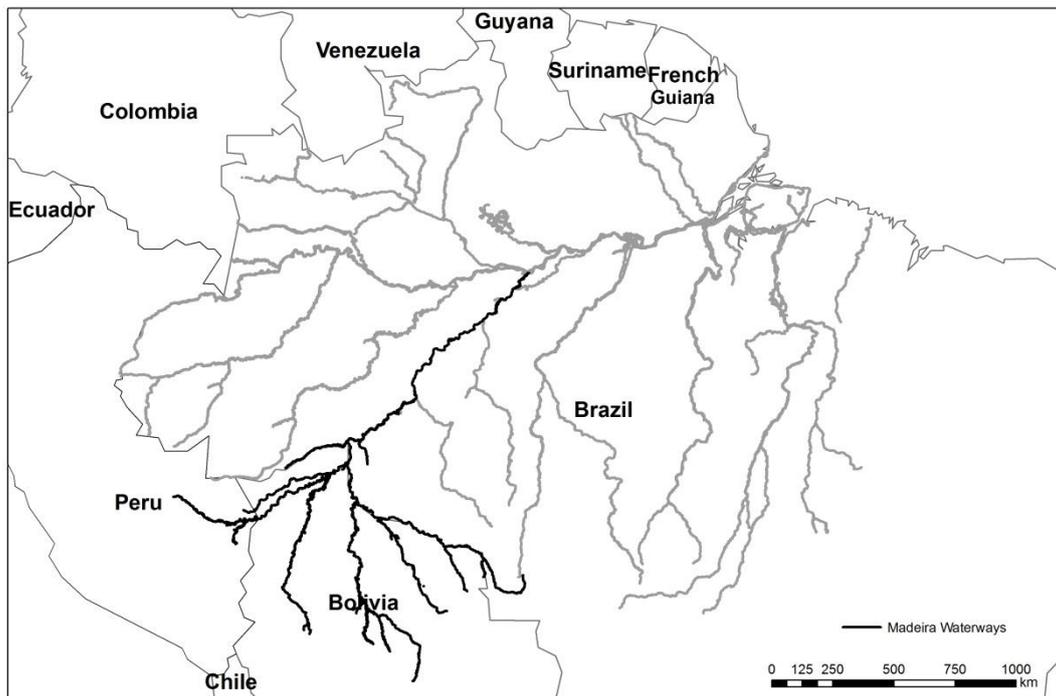


Figure 2. Planned waterways (*hidrovias*) indicated by the viability study for the Madeira dams (redrawn from: PCE et al., 2004, Tomo 1, Vol. 1, p. 1.16).

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 CO₂) 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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