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Viewpoint – Decision Making on Amazon Dams: Politics Trumps Uncertainty in the Madeira River Sediments Controversy

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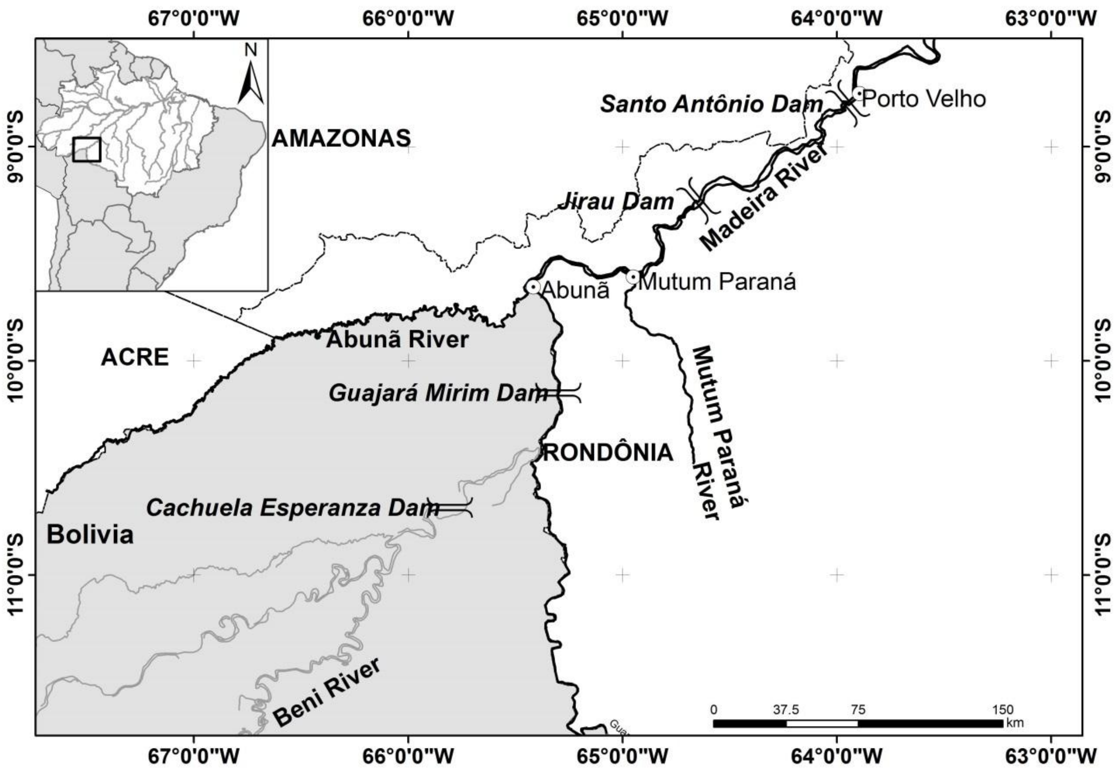
ABSTRACT: The Madeira River, an Amazon tributary draining parts of Bolivia, Peru and Brazil, has one of the highest sediment loads in the world. The questions of how these sediments would affect the Santo Antônio and Jirau hydroelectric dams, now under construction in Brazil, and how the dams would affect sediment flows, have been the subject of an extended controversy associated with the environmental licensing of the dams. Shortly before licensing the dams, the official scenario changed completely from one in which sediments would accumulate rapidly but could be contained without damage to dam operation, to one in which there would be no accumulation of sediments at all. The uncertainty of this scenario is very high. Under political pressure, the technical staff of the licensing department was overridden and the dams were licensed and built without resolving a variety of controversies, including the question of sediments. Valuable lessons from the Madeira River sediment controversy could contribute to improving decision making on dams and other major development projects in Brazil and in many other countries.

KEYWORDS: Hydropower, hydroelectric dams, environmental impact, Santo Antônio Dam, Jirau Dam, Brazil

INTRODUCTION

Brazil has two large hydroelectric dams nearing completion on the Madeira River, a major tributary of the Amazon that drains parts of Brazil, Peru and Bolivia (Figure 1). The Santo Antônio Dam with 3150 MW of installed capacity is located 7 km from the city of Porto Velho, capital of the state of Rondônia, while the Jirau Dam, with 3750 MW, is located 117 km further upstream at the end of the Santo Antônio Reservoir. The Jirau reservoir extends to Brazil's border with Bolivia at Abunã. Two additional dams upstream of Santo Antônio and Jirau are planned: the Guajará-Mirim Dam (also known as Cachoeira Riberão) in the binational stretch of the Madeira River between Abunã and Guajará-Mirim, and the Cachuela Esperanza Dam on the Beni River, a tributary of the Madeira in Bolivia. Brazil and neighbouring countries are currently engaged in a massive programme of hydroelectric dam construction in their Amazonian territories. Brazil's 2011-2020 energy expansion plan calls for 30 additional large dams to be built over this ten-year period in the country's Legal Amazon region, or one dam every four months (Brazil, MME, 2011: 285). The 2010 Brazil/Peru accord calls for five dams in Peruvian Amazonia, and over a dozen additional dams are in the planning stages (International Rivers, 2011). Altogether 80 dams with installed capacity ≥ 100 MW are planned in the Amazonian portions of Andean countries (Finer and Jenkins, 2012). The Brazilian government consistently acts to expand hydroelectric dam construction; it is relevant to note that in January 2013 data were released by Brazil's Court of Electoral Accounts (TCE) indicating that the top four contributors to political campaigns over the 2002-2012 period were construction firms that build dams and other major infrastructure (Gama, 2013). The licensing of the Santo Antônio and Jirau dams occurred under intense political pressure on the Ministry of the Environment and the Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA) (see: Switkes, 2008). This resulted in approval of the licensing despite the agency's technical staff having formally taken a position against approval of the licence without a new environmental impact study (Deberdt et al., 2007). All government reports and technical documents cited in the present paper are available on a website.[1]

Figure 1. Locations mentioned in the text.



One of the issues in the debate over building the dams was the effect of sediments. Examination of how this issue was treated in the licensing process is important as an input to improving decision making in Brazil and in the many other parts of the world facing similar development choices. The purpose of this paper is to extract useful lessons from the history of the controversy over sediments and the Madeira River dams. The Madeira case is part of a trend in Brazil towards relaxation of environmental requirements and abbreviation of the licensing process. However, the scale of impacts of major projects and the high uncertainty under which decisions are made indicate that the licensing process should instead be strengthened.

SEDIMENTATION AND DAM VIABILITY

The Madeira River has one of the highest sediment loads in the world, with approximately half of the total sediment in the lower Amazon being contributed by this tributary (Meade, 1994; Filizola and Guyot, 2009; see also Leite et al., 2011). At the site of the Jirau Dam the river carries 2.1 million tons of sediment per day (PCE et al., 2004, Tomo 1, Vol. 1: 7.17). This fact is of great importance for both the long-term viability of the dams and impacts upstream and downstream of the reservoirs. The questions related to sediments are indicative of the high uncertainty under which decisions on the Madeira dams were made. Sediment issues have produced a continually changing series of reports and statements.

[1] See http://philip.inpa.gov.br/publ_livres/Dossie/Mad/barragens%20do%20rio%20madeira.htm

The first official scenario: Controllable sedimentation

The 2004 and 2005 viability studies (PCE et al., 2004, 2005) and the 2005 environmental impact studies (EIA) (FURNAS et al., 2005a, 2006) and report on impact on the environment (RIMA) (FURNAS et al., 2005b), known jointly as the 'EIA/RIMA', present model results indicating that sediments would accumulate very quickly in the reservoirs, with sediments accumulating at the foot of the dams to levels 30 m above the natural river bed in only ten years (FURNAS et al., 2006, Tomo E, Vol. 1: 126). However, the accumulated sediments would stabilise at levels that could be kept from affecting the operation of the dams for at least 100 years. In April 2007, just prior to environment minister Marina Silva's ceding to presidential pressure to facilitate approval of the dams, the proponents (FURNAS, which is a company that produces 40% of Brazil's electricity and CNO, which is a major construction firm) suddenly adopted the position that there would be no accumulation of sediments at all and that these dams have an infinite expected life on this count (e.g. FURNAS and CNO, 2007: 22).

The initial plans had assumed that retention of sediments would be low (but not zero) based on the large water flow and small reservoir volume: 20% retention of sediments at the beginning of the project at Jirau, but falling to 1% after 15 years and to 0% after 30 years (FURNAS et al., 2006, Tomo E, Vol. 1: 129-130). Once the sediment accumulation in the reservoir reaches an equilibrium level, further sediments entering the reservoir are assumed to be channelled downstream. The accumulation of sediment at the foot of the dam was projected to increase over 30 years, stopping at 61.63 m above mean sea level (msl) in the case of the Santo Antônio Dam, at which point 52% of the reservoir's volume would be lost to siltation (FURNAS et al., 2006, Tomo E, Vol. 1: 129-130). In order to keep these sediments from reaching the adduction canal and the turbines, a retention wall was to be left (part of the coffer-dam built during the construction phase) at an elevation of 63.00 m above msl at the crest of the wall. However, the difference of less than 2 m between the top of the anticipated pile of sediments and the top of the retention wall at Santo Antônio seems very small given the probable uncertainties in the calculation. The number of significant figures given for the elevation at which the sediment accumulation would stabilise implies that this was known to the nearest centimetre, which would appear to be unrealistic. No indication of the degree of certainty was given and no sensitivity tests were presented. Nothing was said of what the consequences might be if the sediments were to overtop the retention wall, which was intended "to guarantee that the turbine intakes will not be silted up during the time horizon of the study (100 years)" (FURNAS et al., 2006, Tomo E, Vol. 1: 23). The report explained that:

> The elevation of the sediments deposited at the foot of the dam could pass the sills of the adduction canals of both dams. To avoid the access of deposited sediment (coarser fractions) to the generating units, construction barriers to impede movement of the bed load were considered in the entrances to the adduction canals, as explained previously. In this way, only the suspended sediments, the finest fractions, will have access to the adduction canals and will be transported downstream by the flow in the canals and the turbines (FURNAS et al., 2006, Tomo E, Vol. 1: 25).

In reply to questions from IBAMA, FURNAS further clarified that the stabilisation of the accumulated sediment below the level of the retention wall "assures the expected life of the dam" (FURNAS et al., 2006; Tomo E, Vol. 1: 130). Conversely, one might say that overtopping the retention wall would represent a threat to the expected life of the dam. It would therefore have been important to know the probability that this might occur. The 2007 reply to IBAMA's questions changed this, stating that the submerged coffer-dam at Santo Antônio would instead be removed to allow the sediments to pass through the turbines (FURNAS and CNO, 2007: 20). At Jirau the coffer-dam was also to be left as a retention wall, but in 2008 the company changed this plan, informing IBAMA that the wall would be completely removed in order to facilitate sediment flow through the dam (Brazil, IBAMA, 2008a: 19).

Since the viability study and EIA/RIMA calculated an expected accumulation of sediments stabilising at 76.1 and 61.6 m above msl at Jirau and Santo Antônio, respectively, and the elevations of the sills of the adduction canals are at 62.0 m above msl at Jirau and 42.0 m at Santo Antônio, the accumulation of sediments would tower over the adduction canal entrances by 76.1 – 62.0 = 14.1 m at Jirau and 61.6 – 42.0 = 19.6 m at Santo Antônio. The first 20-30 years (when the coarse sediment passing through the turbines would be reduced by the amount that would have been deposited behind the retention walls) would represent a period of relatively easy maintenance for the turbine rotors. The number of years between replacements of the rotors was not stated. After the sediments stabilise in year 30 and particles of all dimensions are passed through the turbines, the effect of abrasion would be greater. A discount rate applied to the future maintenance costs undoubtedly makes this factor have little weight in the financial calculation used for justifying dam construction, but this increased maintenance nevertheless represents a cost that will have to be borne by future users of the power.

The sediment load carried by the Madeira River is not constant, but rather has increased over the years – a trend that could be expected to continue with deforestation and erosion in the watershed. The rate of increase in the sediment load is assumed to be 2%/year; an alternative calculation is also made assuming 0%/year increase (FURNAS et al., 2006, Tomo E, Vol. 1: 23). The 2%/year annual increase is intended to represent the observed rate of increase in sediment load of 1.83%/year over the 1990-2001 period; over the 1970-1990 period the sediment load did not increase (FURNAS et al., 2006, Tomo E, Vol. 1: 116). The Santo Antônio Reservoir loses half of its storage capacity after 22 years at the 2% increase rate, or after 28 years if no increase is assumed (FURNAS et al., 2006, Tomo E, Vol. 1: 23). The same time periods (22 and 28 years) apply to the Jirau Reservoir (FURNAS et al., 2006, Tomo E, Vol. 1: 25). Because these 'run-of-river' dams depend on the natural flow of the river rather than on release of stored volume for almost all power generation, volume loss is not intolerable from a water-supply perspective. Any impediment to functioning of the dam structures, however, would be a different matter.

The second official scenario: No sedimentation

Questions regarding sedimentation led the Ministry of Mines and Energy to commission an international consultant to produce a report on the problem (Alam, 2007). When the report was released in April 2007, Dilma Rousseff (then head of Brazil’s 'Civil House' and now president of the country) hailed it as showing that the problem of sediments could be "discarded" (*descartado*) (Peixoto, 2007). Unfortunately, the report did not give an endorsement of this kind, but rather suggested a complete redesign of the Santo Antônio Dam and recommended that a physical model of the dam and reservoir be constructed to test how sediments might accumulate. In addition, the report only concerned the Santo Antônio Dam, not the Jirau Dam where sediment effects are even more controversial because of their potential impacts on Bolivia.

Alam (2007) based his analysis on the Brune curve (Brune, 1953), rather than on the model used in the EIA/RIMA: the 2001 version of the HEC-6 model (current version: U.S. Army Corps of Engineers, 2012). The Brune curve provides a simple rule-of-thumb to assess average potential for sedimentation in reservoirs. It is widely used for calculating trapping efficiency (the percentage of the sediment retained in a reservoir) because of the curve’s simplicity: the only inputs required are the annual river flow, the volume of the reservoir and a rough three-level classification of the sediment particle diameters. Really, it is composed of a family of three curves graphing the trapping efficiency versus the capacity-to-inflow ratio (e.g. m^3 reservoir volume/m^3 annual inflow). The upper curve represents coarse sediments, the lower curve fine sediments, and the middle curve, which is most frequently used, represents a mixture of the two. The Brune curve is described by Dunne (2007) as a "very approximate tool", which he clearly believes should not serve as the basis for decisions on something as important as the Madeira River dams. The merits and uncertainties of different methods for predicting sediment trapping by reservoirs are discussed in Reid and Dunne (1996). More complex sediment-routing models (such as FLUVIAL-12 [Chang, 2006]) are needed to take into account nonlinear effects such as those caused by irregularities in the channel path and vertical profile, as well as the bays and other features along the river's edges (Dunne, 2007).

Alam (2007) argued that the lower curve, corresponding to fine sediments (< 0.25 mm in diameter), should be used for the Madeira dams. However, the Madeira River annually carries approximately 3.75 × 10^6 tonnes/year of sediments in the 1-3 mm diameter range, plus an additional amount in the 0.25-1 mm range (Alam, 2007: 8). Although not mentioned by Alam (2007), if the standard Brune curve procedures were applied to these sediments, either the middle or the upper curve would have to be applied to them, and in neither case would the amount of sediment trapped be zero at the Madeira dams. Alam (2007) uses a different justification for the coarser sediments, namely that peak flows would flush them. For movement of sand, Alam (2007: 22) used calculations based on Rouse equations. This is criticised by Dunne (2007), who writes:

> I did not find the Rouse equation analysis by Alam to be useful for analysing the probable fate of the impoundments. Though based on a fairly well established equation, Alam's analysis takes no account of the magnitude and duration of the main control on sediment transport, which is the flow regime.

The technical note written for the proponents by Tundisi et al. (2007: 7) summarises the Brune curve results as follows:

> The independent analysis carried out by Dr Sultan Alam corroborates the observation that the use of the lower path of the Brune curve applied to the case of fine sediments of the Madeira River foresees zero retention of sediments, that is, the absence of permanent sedimentation that would provoke a future raising of the water levels because of sediment deposition.

The technical note extends Alam's conclusion to Abunã (i.e. including Jirau):

> The analysis carried out by Dr Sultan Alam allows one to conclude that the stretch of the Madeira River between Abunã and Porto Velho has the capacity to transport practically all of the sediment of the Madeira River, even with the construction of the Jirau and Santo Antônio projects. The fine sediments (clay, silt and part of the sand with diameter < 0.25 mm), even with the reservoirs, will be transported in suspension or by saltation, in a continuous manner because of the high capacity for transport in all of the months of the year. The larger-diameter sediments are also transported during the flood months (at least four months of the year) when they are mobilised, as occurs at present.

The technical note further rules out sediment accumulation at the top of the Jirau Reservoir (and consequently the formation of a backwater affecting Bolivia):

> From the characteristics of the reservoirs, which are classified as 'channel reservoirs', deltas will not be formed by sedimentation upstream of the reservoirs. This condition occurs in storage reservoirs and not in those typical of 'run-of-river' (dams), with high energy gradients.
>
> Thus, the correct forecast is that all of the sediments of the Madeira River will continue to be transported downstream, even after construction of the dams at Jirau and Santo Antônio (Tundisi et al., 2007: 4).

During the critical days in 2007 when pressure was mounting to approve the dams, Sultan Alam was asked to endorse the dams as free of limitations from sediments. Email correspondence with Alam is reproduced as evidence of his endorsement in the proponent's reply to the IBAMA queries (FURNAS and CNO, 2007, Annex IV). Alam's email reads:

> TO WHOM IT MAY CONCERN. I Sultan Alam, Independent consultant hereby certify that I fully agree with the text in Portuguese answering various questions asked by IBAMA. Sultan Alam, May 10, 2007.

Although his email mentions that the document he was endorsing was in Portuguese (not a language he speaks), one can assume that the content of the 239-page text was adequately explained to him, particularly the relevant technical notes (Carvalho et al., 2007; Tundisi et al., 2007). The technical notes in question are, in large part, devoted to the Jirau Dam (especially to issues involving Bolivia), rather than the Santo Antônio Dam that was the subject of Alam's (2007) consultant report. The consultant report (p. 4) indicates that Alam's visit (15-17 December 2006) was confined to the first 17 km of the future Santo Antônio Reservoir.

The endorsement by Alam was a key factor in overruling the concerns raised by IBAMA. It should be noted that, although Sultan Alam is repeatedly referred to in the Brazilian press as "the World Bank consultant", he was not working in this capacity here (nor should his report be considered as representing an opinion of the Bank). However, the World Bank reportedly loaned the Ministry of Mines and Energy a 'package' of US$250,000 to hire consultants, one of whom was Sultan Alam (Salomon, 2007).

Expert opinion and the official scenarios

The high uncertainty regarding sediments and their impacts is indicated by the opinions of a series of experts who have examined the different reports. Carlos Tucci (2007: 15), in a consultant report commissioned by IBAMA, found the HEC-6 model results in the EIA/RIMA "inconsistent". For example, the model gives the 'strange' result of indicating that some stretches of the river to be flooded by the Santo Antônio Reservoir would have more sedimentation in the un-dammed river than with the reservoir (Tucci, 2007: 11). He also considered a 30% downward adjustment that the EIA/RIMA applied to the model output for sedimentation to be "apparently arbitrary" (Tucci, 2007: 11). He concluded that further studies of the sediments were needed and called for the formation of an international panel of experts to examine the problem (Tucci, 2007: 15).

José Tundisi and Takako Matsumura-Tundisi (2006), on behalf of the Public Ministry in Rondônia, called attention to the inconsistency between different estimates of suspended sediments versus bed load in the Madeira River and the dependence of the EIA/RIMA's conclusions on the single value the authors chose to use: "[a]ll of the calculation of sedimentation carried out by the project designers is based on the ratio of 95% suspended load to 5% on the river bed". Tundisi and Matsumura-Tundisi pointed out several factors that could increase sediments and called for information on sediment sources in the entire basin upstream of the dams. Later, José Tundisi endorsed Alam's (2007) Brune-curve analysis indicating no accumulation of sediments (FURNAS and CNO, 2007, Annex III).

Jorge Molina Carpio (2007) criticised the Alam (2007) consultant report for assuming that the Madeira has a flow of over 40,000 m^3/s for 1.5-2 months per year (Alam, 2007: 20), allowing sediments up to 3 mm in diameter to be flushed from the reservoir (Alam, 2007: 8). However, Molina Carpio (2007) pointed out that flows at this rate last for an average of only 1.5 weeks per year, and these large flows are often absent for periods of several years, meaning that sediment would accumulate in the reservoir beyond what the brief flow peaks could remove. A March 2007 revision of the flow data substantially reduced the estimate for the occurrence of very high monthly mean flows (PCE et al., 2007: 11). Alam later claimed that a flow of only 18,000 m^3/s would be sufficient to flush the sediments (FURNAS and CNO, 2007, Annex IV). However, at 18,000 m^3/s, only particles up to 0.5 mm in diameter would be transported through the reservoir (Alam, 2007: 39).

Thomas Dunne (2007), in an opinion for the NGO International Rivers, stated that the Brune curve that Alam (2007) used to conclude that the reservoirs would not accumulate sediments on an annual basis is less appropriate than the sediment-routing simulations done with the HEC-6 model that were the basis of the conclusions in the viability study and EIA/RIMA. Dunne also pointed out the high uncertainty in the information on sediment grain sizes, especially the percentage of sand in the suspended load, as well as the lack of information on sampling methods (e.g. vertically-averaged measurements versus calculation from surface samples). He also emphasised the lack of an uncertainty analysis. In addition, with respect to Alam's conclusion that all sediments accumulated during low-flow periods will be flushed by the peak flows, Dunne (2007) states that "it is simply not adequate to make qualitative judgments about the net effect on the sediment accumulation of many low-flow days and a smaller number of high-flow days".

DAM IMPACTS

Sedimentation and flooding in the upper backwater

The deposition of sediments at the upper end of the Jirau Reservoir is of particular concern. When water from a river enters a reservoir, the velocity of the water slows suddenly and the largest of the suspended particles precipitate to the bottom; at the same time, the largest particles in the bed load (such as coarse sand) stop moving downstream and form sand bars. Large accumulations of material generally form at the upper ends of reservoirs even in rivers where the level of solids being transported is only a tiny fraction of that in the Madeira River. The accumulation of sediment acts as a form of dam, backing up water in the stretch of river immediately above the reservoir proper. Unlike sedimentation within the reservoir itself, which eventually reaches an equilibrium beyond which further sediment does not accumulate, the deposition in the backwater (*remanso*) behind the accumulation of sediments at the upper end of the reservoir will continue to grow further and further upstream, thereby continually expanding the backwater (e.g. Morris and Fan, 1998). The backwater will have higher water levels than the natural river, thus causing flooding laterally from this backwater stretch. This, for example, is one of the concerns with the Three Gorges Dam in China, where the backwater stretch increases flooding in riverside portions of Chongqing, one of the world's largest cities (Luk and Whitney, 1990). In the case of the Madeira River, the town that stands to be affected is Abunã. The flooding would also affect land in Bolivia, located across the river from Abunã, including the Bruna Racua/Frederico Román protected area. Both the EIA (FURNAS et al., 2005, Tomo 1, Vol. 1: 7-103; FURNAS et al., 2006: 13) and the viability study (PCE et al., 2004, Tomo 1, Vol. 1: 1.6 & 7-103; PCE et al., 2005, Tomo A, Vol. 7: VII-15-16) emphatically claim that neither Abunã nor Bolivia will be affected but do not take into account any potential effect of the sedimentation expected at the top of the reservoir.

Simulations using the HEC-6 model indicate substantial sedimentation in the binational stretch of the Madeira River after 50 years, even if the Jirau Reservoir is operated at a normal pool level of 87 m above msl, or 3 m lower than the 90-m level expected for most of the year (PCE, 2007: 6.32). This sedimentation will raise the level of the Madeira's river bed at the mouth of the Abunã River, thereby creating a damming effect that will raise water levels in the Abunã River as well. The Abunã River is binational, forming part of the border between Brazil and Bolivia. Effects in this river were not included in the viability study and in the EIA and RIMA reports.

Non-sediment impacts

The Madeira River sediments issue, which is the subject of this paper, is only one of the many controversies surrounding the decision to build the Madeira River dams and the manner in which they were licensed. One of the expected impacts of the dam, although not officially recognised, is loss of much of the fisheries production of the Madeira River, most importantly the giant catfish (especially *Brachyplatatystoma Rouxeauxii* and *B. Vaillantii*) that ascend the river each year to spawn in the headwaters in Peru and Bolivia (Barthem and Goulding, 1997; Fearnside, 2009). A population of fisherfolk depends on the river, including 2400 members of fisheries cooperatives in the Brazilian portion of the river (Ortiz et al., 2007). Other impacts include deforestation stimulated by the dams, both by population displaced by or attracted to the dams and by agriculture spurred by planned waterways or *hidrovias* (e.g. Vera-Diaz et al., 2007; Escada et al., 2013). Although waterways were excluded from consideration in the environmental impact studies, these dams are central to plans for making the Madeira River and its tributaries navigable to barge traffic with waterways being built to soy-growing areas in Brazil's state of Mato Grosso and to large parts of northern Bolivia, where over 4000 km of waterways are planned that would open vast new areas of rainforest for conversion to soy (i.e. PCE et al., 2002; Killeen, 2007). Deforestation and loss of aquatic and terrestrial habitats from flooding by the reservoirs affect biodiversity in this highly diverse area (Fearnside, 2006). Another concern is mercury methylation in anoxic sediments in the tributaries, where many tons of mercury had been deposited during the gold-mining boom in the 1980s (Forsberg and Kemenes, 2006). Methylation converts metallic mercury into the form that is highly toxic to humans and other animals. Both Santo Antônio and the Jirau have applications pending for carbon credit under the Kyoto Protocol's Clean Development Mechanism (CDM). These, like many CDM projects for hydroelectric dams, represent a setback in efforts to combat global warming because the dams would be built regardless of the carbon projects (Fearnside, 2013). The social consequences, in addition to elimination of the main source of livelihood for the local population, include relocating towns and rural residents. Urban impacts from migration for dam construction were also expected (Instituto Pólis, 2006). There are possible additional impacts on nearby indigenous peoples, including several 'isolated' groups (Algayer et al., 2008; Zagallo and Lisboa, 2011).

DECISION MAKING

Environmental licensing for dams in Brazil proceeds through a series of steps. The preliminary licence allows bidding to be held for the construction project, followed by an installation licence allowing the physical structures to be built, and an operating licence allowing power to be generated. The Environmental Impact Study (EIA) was done jointly for the Santo Antônio and Jirau dams (FURNAS et al., 2005b). Complementary studies were completed in the following year (FURNAS et al., 2006). On 21 March 2007 the IBAMA technical staff submitted a 221-page opinion to the head of the licensing department recommending that a new EIA be required (Deberdt et al., 2007). Just two days earlier president Luiz Inácio Lula da Silva had stated that he would have a "very tough" meeting with the minister of environment to press for speedy approval of the dams (OESP, 2007). On 30 March 2007 the head of the licensing department issued an order that requested some further information but rejected the need for a new EIA (Kunz Júnior, 2007). On 12 and 23 April 2007 the technical staff submitted a series of questions on the numerous gaps remaining in the environmental impact studies (Brazil, IBAMA, 2007a, b; Franco and Campos, 2007). The 239-page response on 11 May 2007 (FURNAS and CNO, 2007) was largely a 'cut-and-paste' of sections of the EIA. Coincident with the April-2007 submission of questions by the technical staff, the head of the licensing department was removed from his post. On 4 July 2007 his replacement issued a 'definitive opinion' that restated the rejection of requiring a new EIA and declared as resolved a number of the pending issues, including sediments (Franco, 2007). The preliminary licence was granted on 9 July 2007. The same person who approved the preliminary licence as the new head of the licensing department was subsequently promoted to head IBAMA as a whole, in which capacity he approved the installation licence for the Santo Antônio Dam on 13 August 2008 (Franco, 2008). This came only five days after the technical staff had formally opposed granting the installation licence in a 146-page opinion because most of the 33 'conditionalities' that had been stipulated as requirements had not been met (Brazil, IBAMA, 2008b). A similar sequence of events accompanied the licensing of the Jirau Dam: on 25 May 2009 the IBAMA technical staff issued a 127-page opinion opposing approval of the installation licence because 12 of the 32 conditionalities remained unmet (Brazil, IBAMA, 2009). Only 8 days later, the same head of IBAMA issued the installation licence for Jirau on 3 June 2009 (Franco, 2009). On 29 June 2009 the Federal and Rondônia State Public Ministries entered a civil public suit against the head of IBAMA for "administrative impropriety" in licensing the Madeira dams. The suit stated: "Licence No. 621/2009, issued by the National President of IBAMA, violating the Federal Constitution, the Law on Public Bidding, due process for environmental law, and the principles of legality and morality, culminates in *one of the greatest environmental crimes ever imposed on society*…" [emphasis in the original] (MPF-RO and MPE-RO, 2009, Section 2.1; see: Zagallo and Lisboa, 2011). The suit was dismissed by the federal government's Attorney General of the Union (AGU) on 16 December 2009, as is the fate of many such suits.

Construction of both dams is now nearly complete; power generation by the first turbines at Santo Antônio began in December 2011 and at Jirau it is scheduled for June 2013.

CONCLUSIONS

Questions remain unresolved regarding the effect of sediments on the functioning, maintenance costs and environmental impacts of the Madeira River dams and the effect of the dams on the sediment and nutrient flows to downstream ecosystems. These questions were not adequately resolved prior to licensing the Santo Antônio and Jirau dams.

Decision-making on major infrastructure projects such as dams requires application of the most complete technical tools available, including assessment of the magnitude and consequences of uncertainties. Interpretation of the results of such analyses must be exempt from predetermined conclusions. These ideals are compromised when political pressures are applied to accelerate the approval process and to guarantee that decisions that have been taken on non-technical grounds are ratified.

Despite a trend in Brazil towards relaxation of environmental requirements and towards abbreviation of the licensing process, the scale of impacts of major projects and the high uncertainty under which decisions are made indicate that the licensing process should instead be strengthened. These lessons also apply to many other countries.

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