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THOMAS DUNNE, PROFESSOR

July 8, 2007

Glenn Switkes, Latin America Program Director
International Rivers Network
São Paulo
By email to glenns@superig.com.br

Dear Mr. Switkes:

**Re: Response to analyses of flow and sedimentation at the sites of proposed Rio Madeira Hydroelectric Projects**

In response to your inquiry about hydraulics and sediment transport conditions associated with hydroelectric projects on the Madeira River, I have reviewed and made some general comments on the following reports:

Analisis de los Estudios de Impacto Ambiental del Complejo Hidroeléctrico del Rio Madera Hidrología y Sedimentos by Jorge Molina Carpio, La Paz-Bolivia, April 2006, 47 pp.

Rio Madeira Project Hydraulic and Sediment Management Studies, Draft report by Sultan Alam, January 2007.

Respostas às Perguntas Apresentadas Pelo IBAMA no Ambito do Processo de Licenciamento Ambiental do Complexo Madeira, by FURNAS Centrais Eletricas S.A., Contrutora Nobero Odebrecht S.A., Informações Técnicas Nos. 17, E 20/2007, INFORMAÇÕES TÉCNICAS Nos. 17, 19 E 20/2007, COHID/CGENE/DILIC/IBAMA May 11, 2007, 316 pp.

I did not have access to the original FURNAS/Odebrecht report, which I presume to contain a lot of detailed material on the sediment transport modeling, uncertainty analysis, and quality of field data that drives the calculations. My understanding of this original work is largely based on the summary by Molina.

My first comment is that I would not rely on estimates of the accumulation rate and the distribution of sediment in a run-of-river reservoir from the Brune curve. Although it may have been useful for the initial estimates of sedimentation volumes, the

Brune curve itself is a very approximate tool, for which I have never seen any original data points or uncertainty analysis in the literature, and its predicts nothing about the spatial distribution of the predicted sediment accumulation. Instead, it is more appropriate to view the sedimentation potential as the result of dynamic fluvial sediment transport, to be predicted with a sediment routing model.

Thus, the more appropriate method was the sediment routing conducted with HEC-6 that Molina summarizes from the EIA group's report. The modeling predicts, quite reasonably, that most of the suspended sediment load of the Madeira will be transported through the impounded reaches, but that some will be deposited in the 430 km long reach, some re-mobilized, and that there will be long-term accumulation of up to 15-20 meters of sediment 100-200 km upstream from Jirau. Accepting the accuracy of such a prediction for the moment, I don't know how deep the channel is or what the level of the floodplain is, and thus I am unable to assess what the impact is likely to be on the channel or floodplain. Figure 3.6 (p 36 in Molina) predicts that the deposition should increase the water level in the typical December flow by up to about 6 meters at the mouth of the Rio Abuna. Again, lack of information on the topography and other conditions in that reach and upstream make it difficult to speculate about the impact of the impoundment, but the potential consequences for settlements and ecosystems seem to warrant more detailed analysis.

However, it is clear, and the EIA group has pointed out, that there are considerable uncertainties in the data incorporated into the model, and although the results are useful for a first-order analysis, they leave important uncertainties about the upstream influence of the Jirau impoundment for the reach upstream of the River Abuna confluence. Of course, my reaction might reflect only that I don't have access to the original full report by the FURNAS group. However, neither Alam nor Molina refer to any uncertainty analysis.

There are five main areas of uncertainty in the prediction of the magnitude and location of sand accumulation to be expected in a run-of-river impoundment. These are: (1) the initial sediment input to the reach; (2) the grain-size distributions of the suspended and bed load at various discharges; (3) the sediment transport equations for suspended and bed load transport to be used in the sediment routing model, HEC-6; (4) the channel and overbank topographic cross sections used in the model; and (5) some subtle uncertainties introduced by decisions of the modeler concerning such steps as how the model run at the upper end of the reach is initialized and how the sediment concentration is equilibrated with the grain size of the bed at the upper end of the model domain.

(1) There is always great uncertainty about the sediment load of large tropical rivers because of temporal sampling limitations and logistical difficulties in the field measurement methods themselves, but the Guyot et al (1995) estimate for the load at Porto Velho could be updated with Guyot's more recent measurements in the HYBAM project. His measurements are surface concentrations and therefore will need some conversion to estimate the sand load, but Guyot has the best available data and long-term knowledge of the reaches under study here.

(2) There is no description in the various reports of how the percentage of sand in the suspended load was determined. Were the samples vertically averaged concentrations,

or near-surface samples? Was there any systematic variation of the sand percentage with flow? These details could have significant effects on the predictions of HEC-6.

(3) Various sediment transport equations incorporated by default into the HEC-6 software package can give very different predictions. Choice of which equation to use for bed load and suspended load transport has to be made by the model user. Reid and Dunne (*Rapid evaluation of sediment budgets*; Geo-Ecology Texts, Catena Verlag, Reiskirchen, Germany, 164 pp., 1996) discuss these choices and the performance of various equations. The problem is not solved, but the text gives some idea of the magnitude of the problem and ways to provide checks on the magnitude of the uncertainties. The reports that I have seen give no indication of which equation or equations were selected and compared for the Madeira routing calculations.

(4) The reports do not illustrate the typical nature of channel and floodplain cross sections, but Molina refers to there being considerable uncertainty about the topography at the upper, trans-border end of the routing domain, which probably needs to be resolved before important decisions are made. The shape of the cross sections affect not only calculated flow depths and velocities and therefore transport rates, but also whether sediment can be stored overbank and on bars rather than in horizontal layers, as HEC-6 predicts. It is not specified in the summary reports whether HEC-6 was implemented with a single cross-channel average depth or with incremented, variable depth cross sections. Given the potentially contentious nature of interpretations of these results, it would be worth defining the cross sections in some detail (*if* this has not already been done.). Although there is no need to go to the extra effort at this point, if future, refined HEC-6 calculations predict important volumes of sediment accumulating and aggravating flooding problems in the trans-border reach, it would be relatively straightforward to apply a slightly more complex flow and sediment routing model such as FLUVIAL-12, which requires the same data inputs as HEC-6, but takes account of the curved nature of river channels to predict whether the sediment will accumulate in bars, cause bank erosion, or be deposited uniformly across the channel. Such extra detail is usually of interest for ecological assessments, rather than for hydraulic engineering and sediment budgeting of reservoirs.

(5) Subtleties of the model implementation will not be described in detail here, as I am sure the EIA specialists are familiar with them, but users of the information should be aware that such complications exist.

Although it was an interesting illustration of the probable nature of transport through the reaches at various flows, I did not find the Rouse equation analysis by Alam to be useful for analyzing 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. Sediment transport (i.e. the flux rate, --- not simply the nature of the transport mechanism) is related to flow in a very non-linear way, and 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. This is not to say that Alam will eventually be proven wrong. His qualitative judgment may well be right, especially for the lower impoundment; in fact it is supported by the more complete routing analysis by EIA. But, I would not extend qualitative arguments about accumulation and remobilization to the critical upper reaches

above the Jirau impoundment from a few cursory observations and calculations of sediment transport conditions (not flux) near the Santo Antonio impoundment site and the Cachoeira Sao Teotonio. The original EIA transport-based sediment budget is much more reliable, even if it merits refinement in the critical upper reach. The consultant seemed to be much more concerned about (and knowledgeable about) the lower impoundment and its engineering structures, for which he made some very useful suggestions.

Sincerely

Thomas Dunne
Professor of Earth Sciences
Professor of Environmental Sci. & Mgmt