

February 3, 2006

The Dam Debate and its Discontents

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A few issues back, *Climatic Change* played host to a discordant pair of articles on the emissions of greenhouse gases from hydroelectric reservoirs in Brazil. The debate, which continues to simmer, is important because most greenhouse gas inventories and policy strategies assume that hydro dams are essentially benign with respect to climate change. A thin but growing body of research suggests that assumption is wrong, though the magnitude of the error has so far proved elusive. Sadly, although the technical issues appear tractable, the unfolding dispute seems unlikely to spawn the normal mechanisms for scientific resolution.

The debate on these pages began with an editorial by Fearnside (2004) explaining some of the methods used in previous studies (Fearnside, 1995, 1997, 2002). This earlier work focused on a single large Brazilian reservoir at Tucuruí, in the eastern Amazon. Fearnside reports Tucuruí as having a global warming impact “greater than that of the fossil fuel burned by the city of São Paulo” (2002, page 92). He also suggests that political interests favoring dams in Brazil coordinated work sympathetic to their cause (2004, page 6). Following that editorial, Rosa et al. (2004) report new estimates for a series of Brazilian reservoirs.

The issue at hand is not whether dams produce greenhouse gases, but whether the magnitude of their emissions is comparable to (or even greater than) traditional thermal power technologies, such as natural gas turbines or coal boilers. Comparing the emissions from gas and coal-fired power plants with those of hydroelectricity, Rosa et al. conclude that in most cases “hydro power plants are better” (2004, page 18). Fearnside is more equivocal and points to striking examples where hydro dams appear worse.

The outcome is important for Brazil, where the government is presently in the midst of planning new investment to satisfy the growing demand for electricity (de Oliveira, 2006). As a developing country, Brazil faces no obligation under the Kyoto Protocol to reduce greenhouse gas emissions. However, some in the country are wary of investing in projects that could become liabilities when the country is eventually expected to control its emissions.

Moreover, the Protocol’s Clean Development Mechanism (CDM) allows Brazil to seek financial compensation for projects that yield low emissions of greenhouse gases. Currently, Brazil has 18 applications for CDM hydroelectric facilities, all 160 MW or less, with most projects smaller than 20 MW. The financial integrity of these CDM projects rests on the assumption that greenhouse gas emissions from dams are low; indeed, the methodology used by the CDM in this case assumes that greenhouse gas emissions are zero.

Anatomy of a Dispute

The recent articles by Fearnside and Rosa et al. were not the first to diverge significantly on the subject of Brazilian hydro emissions. In fact, Rosa and Fearnside have been publishing conflicting reports for over ten years (Rosa and Schaeffer, 1994; Fearnside, 1995). Disagreement is not alarming, for disputes are the stuff of refutation and scientific progress (Popper, 1963; Lakatos, 1972). Yet it is disturbing that the transparency and comparability of methods and assumptions—the substrate for healthy scientific debate—appears to be declining. In the time since the first papers (Rudd et al., 1993; Kelly et al., 1994), reports on tropical reservoirs have become less comprehensive in their accounting methodologies, less clear in their assumptions and less assertive in their findings.

The worrisome state of research on tropical dams contrasts starkly with some of the studies performed by other research groups elsewhere in the world. Duchemin et al. (1995) observed a series of hydroelectric reservoirs in Quebec, using a standardized measurement procedure with multiple visits per site. Research on emissions from boreal reservoirs, notably in Canada, has in general been well documented, culminating in the recent publication of a book (Tremblay et al., 2005a) that is comprehensive in coverage yet striking for its lack of a consensus view on the emissions from tropical Brazil. It features a report from the Rosa et al. research team (dos Santos et al., 2005) but does not properly confront the scientific controversy around Brazilian emissions.

Success in developing global estimates (for example, St. Louis et al., 2000) depends on the credible resolution of the increasingly polarized debate in the tropics. What is needed now is an open and transparent examination of accounting methods and measurement techniques.

Understanding Reservoir Emissions Processes

Unlike emissions from thermal power projects, hydroelectric emissions are considerably more difficult to measure or estimate. Emissions depend on complex chemical cycles within a hydro reservoir, driven by factors that vary by dam, season and region.

The basic processes are as follows. Carbon dioxide and methane are released through diffusion into the air at the reservoir surface, as well as through the migration of gas bubbles produced below the surface. These gases result from the decomposition of dissolved organic carbon (DOC) and particulate organic carbon (POC). The original sources of this carbon are numerous: the biomass in the region before filling the reservoir, organic matter that washes in from upstream, plants that grow on the surface, and fluxes from the shores and soils of the reservoir.

Gas fluxes are generally measured using on-site floating chambers, although Lambert and Fréchette (2005) describe some alternative theoretical and empirical methods. Each approach has known sources of error, and none is completely accepted. Floating chambers, for example, restrict wind access to the air-water interface. In theory, this

technique should underestimate actual emissions by reducing the measured rate of diffusion. Bubble collection presents additional challenges, as bubble formation is random and dispersed, thus requiring care in the scatter and sampling of collection chambers over space and time.

One reason the larger debate over reservoir emissions has not reached closure is the claim that the current state of scientific understanding is insufficient for the computation of net emissions (e.g. Hillaire-Marcel, 2005). Indeed, sorting out these effects is a complicated and arduous task because it must occur at the resolution of individual reservoirs or regions. However, in practice, Fearnside's methods (2002) suggest such estimates are feasible.

Gross emissions are simply the total flux from the reservoir surface for CO₂ and CH₄. Computing net flux is more difficult, because soils are heterogeneous in their chemical cycles. Some tropical soils, for example, are a source of nitrous oxide (N₂O, a relatively strong greenhouse gas) as well as a sink for carbon dioxide. For those soils, a hydro reservoir could have net emissions lower than gross emissions, when factoring in the avoided N₂O flux. Fearnside's estimates for Brazil's Tucuruí reservoir (2002) include soil adjustments, which cause only a 1-2% decrease in net impacts. Rosa et al. only measure gross fluxes, and do not account for soil effects.

In addition to the local soils, the operation of the dam itself can affect emissions. At Tucuruí, water exits the reservoir not at the surface, but rather at depth from the spillway (20m) and the turbine intakes (35m). The pressure on the water drops sharply as it is released in the downstream waterway. With a decline in pressure, the solubility of CH₄ also decreases, resulting in degassing to the atmosphere. Fearnside argues that this operational effect, when weighted for the relative strength of methane as a greenhouse gas, accounts for 57-70% of observed emissions at Tucuruí (Fearnside, 2002, page 85).

Rosa et al. (2004, page 15) dispute Fearnside's results along two main lines. First, they criticize Fearnside for assuming that a change in methane solubility from a drop in pressure leads to the full emissions predicted by theory. While we believe empiricism is generally preferable to theory in these cases, Rosa et al. offer no explanation as to how the gas would stay in solution, and the well-mixed tailrace at Tucuruí would seem to offer ample opportunity for degassing as the water reaches a new equilibrium solubility.

Future experiments should attempt to explain the location and magnitude of the gas emerging from solution, which has not been done to date. For now, it seems prudent to assume that the degassing caused by the decline in pressure intrinsic to the operation of the dam is the largest single source of methane emissions.

A second criticism concerns the pattern of emissions over time. To construct seasonal patterns of methane concentration in the Tucuruí reservoir, Fearnside (2002) used data from the nearby Petit Saut dam in French Guyana (Galy-Lacaux et al., 1997). However, the age of the two dams is significantly different. The data for Petit Saut were collected during the first and second years of operation of that dam, while Fearnside's estimates are

from seven years after the Tucuruí reservoir was filled. According to Rosa et al., this gap “invalidates [Fearnside’s] estimates” (2004, page 14).

Mixing data from separate dams of significantly different ages requires careful analysis, as the biological forces driving emissions factors are known to vary over time. When reservoirs are first filled, a large quantity of biomass is readily digested into CO₂ and CH₄. Thus, the first few years of operation should correlate with higher-than-average levels of emissions of these gases. Then, as the smaller and more easily converted biomass fragments are consumed, emissions levels should taper off towards lower values. Methane concentrations are particularly susceptible to change as oxygen levels fall over time, increasing the proportion of anaerobic decomposition in the reservoir (Tremblay et al., 2005b).

Contrary to the claims of his detractors, Fearnside does not simply substitute the methane concentrations in Petit Saut for those at Tucuruí. Lacking time series data, Fearnside used the relative fluctuations of gas concentrations at Petit Saut to extrapolate a seasonal pattern from a single period of measurement at Tucuruí (2002, page 77). It is now possible to correct or confirm Fearnside’s calculations as the Petit Saut research team has recently published new time series data (Delmas et al., 2005). As expected, these trends show that absolute gas concentration fluctuations dampen over time. However, according the model published by Delmas et al. (2005, page 298), the relative gas concentration fluctuations appear to be more or less constant. This finding suggests that Fearnside’s method merits confidence.

A Path Forward?

In preparing this editorial we have found it exceptionally difficult to align the methods and discern the true nature of the dispute. Furthermore, most published work has only considered point estimates of emissions. Fluxes from a reservoir are not constant; they vary seasonally and decrease over time. As of yet, there is no accepted method to integrate these emissions for comparison with fossil fuel alternatives. We worry that these complications, along with the large stakes, will make it difficult to settle this dispute through normal scientific processes.

Apart from the technical complexity of the issues, two other forces are poised to cloud the debate. One is national interest. Brazil relies on hydropower for 90% of its electricity; its power sector is dominated by hydro interests. The other is industry. A large proportion of the published work in this field comes directly from researchers connected to hydroelectricity companies, such as Eletrobrás or Hydro-Québec. We do not claim that the industrial connection has caused bias; indeed, we applaud some key firms for funding the essential scientific base for this debate. We do claim, however, that a mechanism is needed to remove any taint of interest so that CDM projects and national inventories can earn confidence.

The international community has a mechanism readily at hand to fix the problem: a special report of the Intergovernmental Panel on Climate Change (IPCC). The recent

IPCC report on carbon dioxide capture and storage offers a useful model, as it synthesized highly technical and politically sensitive research (IPCC, 2005). The effort, like much of what IPCC does, has met with wide approval and also focused constructive attention on the issues. The IPCC is the only forum that could sustain the scientific integrity and transparency needed to synthesize the full international debate over emissions from hydroelectricity, as well as to make the information from such assessments available to climate policy makers in governments and international organizations.

All told, we expect that the concerns over methodologies and data will prove less severe than the polar debating positions that have been presented on these pages. An organized scientific debate, rooted in the IPCC apparatus that has performed so well on such topics in the past, is the best way to resolve the remaining questions.

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