FORUM

Glaciers in Patagonia: Controversy and Prospects

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Lately, glaciers have been subjects of unceasing controversy. Current debate about planned hydroelectric facilities—a US$7- to $10-billion megaproject—in a pristine glacierized area of Patagonia, Chile [*Romero Toledo et al.*, 2009; *Vince*, 2010], has raised anew the matter of how glaciologists and global change experts can contribute their knowledge to civic debates on important issues. There has been greater respect for science in this controversy than in some previous debates over projects that pertain to glaciers, although valid economic motivations again could trump science and drive a solution to the energy supply problem before the associated safety and environmental problems are understood.

The connection between glaciers and climate change—both anthropogenic and natural—is fundamental to glaciology and to glaciers' practical importance for water and hydropower resources, agriculture, tourism, mining, natural hazards, ecosystem conservation, and sea level [*Buytaert et al.*, 2010; *Glasser et al.*, 2011]. The conflict between conservation and development can be sharper in glacierized regions than almost anywhere else. Glaciers occur in spectacular natural landscapes, but they also supply prodigious exploitable meltwater.

An Example of Conflict Over Glaciers

Some controversy pertains to expensive and difficult trade-offs between economic development and environmental protection. A hallmark example of a worthwhile controversy is being played out in Patagonia, Chile, between proponents and antagonists of HidroAysén's plans for five huge hydroelectric dams on the Baker and Pascua rivers [*Romero Toledo et al.*, 2009; *Vince*, 2010]. The argument's essence is simple: development to provide sufficient hydroelectric power to drive Chile through the 21st century versus conservation of one of the world's last remaining pristine wildernesses [*Goodwin et al.*, 2006] containing extensive intact forests and suffering less population pressure than almost any other wilderness [*Mittermeier et al.*, 2003]. Patagonia's Baker River and other glacier-fed streams and wetlands host spectacular avian fauna, among other natural splendors (see Figure S1 in the online supplement to this Forum (http://www.agu.org/journals/eo/v093/i022/2012EO220011/2012EO220011_suppl.pdf)). In one bold step, the project could significantly add to Chile's energy supply for decades but at great cost to the Patagonian environment. Poorly evaluated hazards and risks of the project include seismicity, debris flows, and glacier lake outburst floods (GLOFs). While glacial meltwater would drive the turbines, the glaciers themselves and the sediment they generate contribute to both the project's engineering challenges and the pristine qualities of the landscape.

The HidroAysén project, after years of environmental review, recently has been alternately supported by Sebastián Piñera, Chile's president and approved regionally, blocked by an appeals court, and permitted by the court to proceed. On 18 January 2012 a Chilean congressional committee released a report critical of the approval process. On 4 April 2012 the Chilean Supreme Court rejected environmental appeals, but opponents are still raising legal questions about the environmental approval process and water rights. Finally, an environmental impact statement has not yet been filed for 1200 kilometers of transmission lines. Opposition to the project has been broadly based through Chilean society, having reached 60–74% according to two polls (*La Nación*, 14 May 2011, and *La Tercera*, 15 May 2011) and having spurred cycles of massive street protests.

Glacier Hazards in the Andes

Thus far, glacier-related dynamic events in Patagonia, such as GLOFs, have not been as damaging or as apt to stir controversy as those in the northern and central Andes [*Carey*, 2005]. This is due to differences in population densities and different stages of glacier retreat, which affect the distribution, types, and severity of glacier hazards [*Reynolds*, 1992].

The frequency or magnitude of GLOFs may increase as glacial lakes form and grow. Lake formation on glaciers is a normal part of steady state glacier dynamics, but on the Northern Patagonia Icefield (NPI), as on so many other glaciers around the world, glacier thinning, which could be related to global warming or to a natural climatic shift since the Little Ice Age, appears to be at work [*Willis et al.*, 2012].

Any changes in the glaciers and glacier lakes necessarily alter the hydrology, including water resources and seasonal flow. Besides climate change impacts on glacier dynamics, seismic, volcanic, and mass movement hazards in the Chilean Andes may be significant, but all are insufficiently studied [*Vince*, 2010]. While they can increase dangers, retreating or disappearing glaciers can also diminish hazards by reducing the mass of ice prone to avalanching, by decoupling glacier lakes from nearby unstable slopes, or by reducing the magnitude of potential lava-ice interaction on volcanoes. Drainage of glacier lakes, though sometimes disastrous, may permanently lower lake levels and thus reduce future hazards.

A satellite image mosaic of NPI (Figure S1a) shows effects of continuing glacial retreat (Figure S2). As historic, sometimes deadly events in the Cordillera Blanca, the Himalaya, and Alaska attest, glacial lakes tend to be unstable and commonly but unpredictably release catastrophic GLOFs and debris flows. In Peru, thousands of people have been killed by such outbursts [*Reynolds*, 1992; *Carey*, 2005]. Outburst frequency has recently increased around NPI; for instance, at least nine GLOFs have occurred from one NPI lake, Cachet 2, since April 2008 [*Dussaillant et al.*, 2010]. So far, there have been limited consequences for livelihoods, as there are still few residents and little infrastructure in the NPI area. Recognizing the potential hazards, in 2009 the Chilean Water Authority installed a new radio-based early warning system to monitor lake levels. However, more scientific research would help to improve assessments of the glacier-related threats facing large projects such as HidroAysén's, particularly as the region develops and climate changes.

Need for More Research

Assessing the geotechnical merit of HidroAysén's plans in Patagonia requires an understanding of active Earth processes, such as GLOFs and ice avalanches [*Romero Toledo et al.*, 2009; *Vince*, 2010; *Dussaillant et al.*, 2010]. GLOFs may shorten reservoir life spans and reduce energy production by mobilizing and redepositing glacial stream sediment. The glacier and seismic hazards facing the proposed Patagonian dams are still poorly understood [*Dussaillant et al.*, 2010], but the evolving glacial risk should be considered by engineers and political proponents and opponents of the dams. However, opponents, besides considering environmental impacts, should also weigh the consequences of energy production from alternative sources, which might have impacts equal to or worse than those of the dams.

U.S. president Barack Obama and President Piñera in March 2011 agreed in Santiago on an imperative for increased research and monitoring of glaciers and their impacts throughout the Andes. Chile has made a substantial commitment to general glaciological research with its National Strategy on Glaciers [*Centro de Estudios Científicos*, 2009].

The links between Andean glaciers and climate, hydrology, land surface processes, hazards, ecology, and sociology must be better understood through monitoring and modeling of the transport of ice, water, and sediment and of future glacier changes, as they may affect people and infrastructure [*Alho and Aaltonen*, 2008; *Harrison*, 2009; *Buytaert et al.*, 2010; *Dussaillant et al.*, 2010]. The HidroAysén plan is not the region's last development proposal. As the Andean region develops, and as conservation plans are improved, there will be a continuing need for improved information about glaciers and hydrological/sedimentary systems.

Needed are further observations from satellite sensors and field researchers; scientific input to land use planning and water management; and enhanced training of university students, especially in glacierized developing nations. The geotechnical engineering community requires detailed knowledge of the region's glacier lakes. Improvements are also needed in scientific communication with policy makers and the media to make better use of science to inform regional and local debates about glacier-related development issues and climate change impacts. Deliberations over the proposed Baker and Pascua river hydroelectric projects highlight these needs for objective scientific information from interdisciplinary investigations. The quest for actionable information and understanding does not come free; indeed, two researchers recently were lost in a boat capsizing in NPI (see the online supplement for more information).

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—J. S. Kargel, University of Arizona, Tucson; E-mail: kargel@hwr.arizona.edu; P. Alho, University of Turku, Turku, Finland; W. Buytaert, Imperial College London, London, UK; R. Célleri, Universidad de Cuenca, Cuenca, Ecuador; J. G. Cogley, Trent University, Peterborough, Ontario, Canada; A. Dussaillant, University of Greenwich, Greenwich, UK, and Centro de Investigación en Ecosistemas de la Patagónicos (CIEP), Coyhaique, Chile; Z. Guido, University of Arizona; W. Haeberli, University of Zurich, Zurich, Switzerland; S. Harrison, University of Exeter, Penryn, UK; G. Leonard, University of Arizona; A. Maxwell, Natural Resources Defense Council, Washington, D. C.; C. Meier, Universidad de Concepción, Concepción, Chile, and CIEP; G. Poveda, Universidad Nacional de Colombia, Medellín, Colombia; B. Reid, CIEP; J. Reynolds, Reynolds International Ltd., Mold, UK; C. A. Portocarrero Rodríguez, Unidad de Glaciología y Recursos Hídricos, Huaraz, Peru; H. Romero, University of Chile, Santiago, Chile; and J. Schneider, University of Natural Resources and Life Sciences, Vienna, Austria