2008-2009 GLACIAL-LAKE OUTBURST FLOODS IN PATAGONIA, CHILE

A. Dussaillant[1,2], G. Benito[3], W.Buytaert[4], P. Carling[5], C. Meier[1,2], F. Espinoza[6], A. Siviglia[7]

1. U. Concepción, Chile 2. CIEP, ale.dussaillant@gmail.com 3. CSIC, Madrid, Spain 4. Imperial College, UK 5. U Southampton, UK 6. Dirección General de Aguas, Aysén, Chile 7. U. Trento, Italy

1 BAKER RIVER BASIN

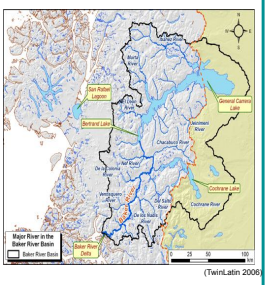


Fig 1: Baker basin (Nef, Colonia and Ventisquero flow from NPI)

- Annual precipitation 300 mm East vs. >3000 mm West
- North Patagonian Icefield (NPI)
- Western tributaries have glacier regimes

1.1. FLOW RÉGIMES

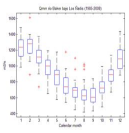
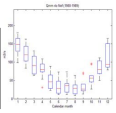


Fig 2: Monthly flows at Baker main stem (above) versus glacierized catchment (below)



- Baker basin and western catchments governed by snow/ice melt seasonal dynamics.
- Spring-summer melt: *Dec-Feb.*

1.2. COLONIA GLACIERS

NPI eastern glaciers retreated considerably (Aniya 2007)

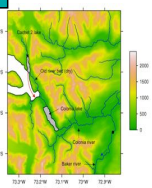


Fig 3: Elevation map of the study basin (m). Glaciers are indicated in white. Arrows: flow direction of the jökulhlaups. • = location of the DGA hydrometeorological station on the Baker river

1.3. CACHET 2 LAKE GLOFs

(1) April 7-8, (2) Oct 8-9, (3) Dec 21-22
(4) March 5-6, (5) Sep 16-17 2009

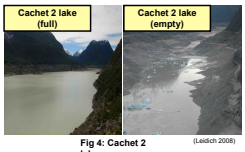


Fig 4: Cachet 2 lake (Leidich 2008)

PRESENTED HERE:

- Flood estimation for Oct 2008 event
- Ongoing detailed modelling study

2 CACHET 2 LAKE GLOFs

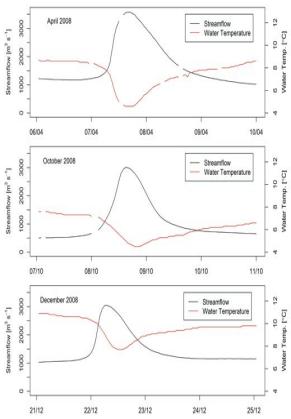
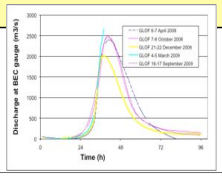


Fig 5: (ABOVE) Discharge and water temperature during the 2008 jökulhlaup events of April, October and December; (RIGHT) Comparison of 2008-2009 GLOFs, and with hydro-meteorological floods

- Flow gauge in Baker River downstream of Colonia River confluence (Fig 4).
- Colonia is gravel-bed braided river, 30 km long, 1 km wide plain, slope=1%
- 200 hm³ Cachet 2 Lake outburst (in <24 h) increased flow in the Baker several fold.
- Peak flow of Colonia into Baker: 2500 - 3000 m³/s. Cachet 2 refilled in 2 months.
- Past GLOFs: not in 1968-2007 record. Palaeofloods: 1897, 1917, 1928, 1944, 1953, 1955-56, 1958, 1963-1967 (last).
- Impacts due to flooding, animal deaths, damaged roads and barges



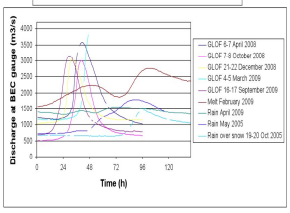


Fig 6: Colonia Valley: winter low flow (left) and receding outburst flood (right)

2.1. Empirical equation methods

$$Q_p = A \times V^{0.66}$$

Q_p m³/s, V lake volume hm³; A=46 (Walder & Costa 1996) or A=75 (Clague & Mathews 1975)

1,500 – 2,500 m³/s

2.2. Walder & Costa (1996) tunnel method

$$h = \left(\lambda \frac{L}{D} + K\right)\frac{U^2}{2g}$$

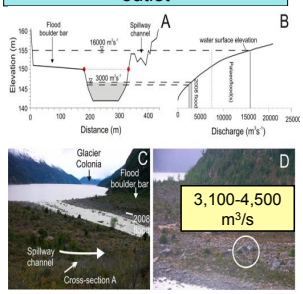
$$\frac{1}{\sqrt{\lambda}} = -2.0\log_{10}\left(\frac{k_s}{3.7D}\right) + \frac{2.51}{Re\sqrt{\lambda}}$$

$$h_f, D\left(\bar{T}_w - T_f\right) = 0.065 k_s\left(\bar{T}_w - T_f\right)\left(\frac{\rho_w U D}{\eta_w}\right)$$

(González 2008)

3,800 – 4,500 m³/s

2.3. Hydraulic model for lake outlet



3,100-4,500 m³/s

Fig 7: Lake Colonia outlet reach containing field evidence of 2008 flood water marks and of previous catastrophic flooding.
A: Cross-section used on 1D hydraulic model calculations, showing flood water level for the 2008 flood(s) and evidences of ancient jökulhlaups (spillway channel and boulder bar). Ancient flood discharge estimation based on current topography and likely pre-incision topography with channel elevation matching boulder bar surface (point line between two gray dots).
B: Rating curve from hydraulic analysis showing minimum discharge ranges associated with 2008 GLOFs and with previous palaeoflood stage indicators.
C: Upstream view of the Colonia outlet showing the 2008 flood level, the boulder bar and the flood-scoured channelways.
D: Boulder bar containing large boulders (4-5 m in diameter) related to high-energy catastrophic outburst floods

OCTOBER 7-8 2008 GLOF EVENT

Given information of October 2008 flood (air photos, flow record, field inspection), used various methods to estimate Qp:

1. Downstream gage at Baker river indicates that Cachet 2 lake flood at least 2,500 m³/s (Fig 5, centre), integrating flow and considering the lake volume drained.

2. Walder & Costa (1996) method, based on fitting similar tunnel-flow events, underestimated: 1,500 m³/s. Clague & Mathews (1975) equation gave better estimate: 2,500 m³/s.

3. Equations based on energy, considering heat exchange by flowing water on the ice tunnel, gave a more realistic estimate c. 4,000 m³/s

4. Hydraulic model based on a quick topographic survey, done a week after the October flood, at the Colonia lake outlet into the Colonia river - simple 1D hydraulic approximation given critical flow observed was used (Fig 7). A peak flow of approx. 3,800 m³/s was estimated.

3 CONSIDERATIONS

COLONIA-BAKER CONFLUENCE

Colonia - Baker confluence probably with 2D storage effects.

SEDIMENT TRANSPORT

Confluence flooded upstream (October 2008, DGA, CECS)

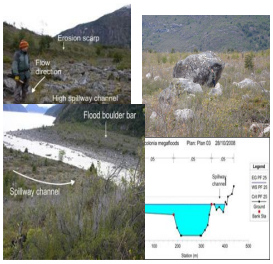
GLACIER RETREAT & GLOFs?

- Retreat of NPI glaciers, accelerated during last decades (Aniya 2007; Winchester & Harrison 2000), related to climate change (Villalba et al. 2003)

- Similar behaviour in other regions related to increased jökulhlaup frequency (Richardson & Reynolds 2000).
- Interaction needs: glaciology, hydrology, ecology, engineers.

PALAEOFLOODS IN COLONIA?

Preliminary estimations for palaeflood related to Arco lake in the Colonia valley: 7,500 – 16,000 m3/s



4 SUMMARY

GLOF 7-8 OCT. 2008

- 2008-2009 repeated Cachet 2 Lake GLOFs to Colonia River
- Drained 200 hm³ of glacial lake
- Streamflows in Baker main stem increased abruptly (stage by 4m)
- Flooding of fields, roads and settlements
- Death of cattle, and evacuations
- Infrastructure damaged
- Using flow gauge data, empirical equations and hydraulic methods to estimate order of magnitude of Oct 2008 flood: estimated peak 3,000-4,000 m³/s

IMPLICATIONS FOR DAMS

- 6 hydropower dams (2,500 MW) projected, one immediately downstream of Baker-Colonia
- Design has not considered GLOFs, absent for >40 years (6,700 m³/s used for spillway design).
- Risk of outburst mode change - Walder & Costa relation for open breach >11,000 m³/s

$$(Q_p = 1100 \times V^{0.44})$$

- 5 recent events (+ risk of GLOFs of >7,500 m³/s) and sediment: need to re-design (feasibility?)

ONGOING WORK

Flood analysis & modelling

- LIDAR & bathymetry processing
- 1D vs. 2D models (confluence)
- Sensitivity analysis (roughness)
- Image and other sensor installation in Colonia valley

Mobile bed modelling

- Sediment and morphodynamics (Siviglia et al. 2008)
- Effect of extreme floods on large, pristine braided system

Deglaciating valleys and river/fjord

"Tipping effect" in relation to river & floodplain ecosystem (vegetation, aquatic biota), and fjord (temperature, sediments, nutrients)?

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- CIEP Patagonian Ecosystems Research Centre (www.ciep.cl)

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