GLACIER RUNOFF MODELLING BY LINEAR RESERVOIRS

Tohoku University Graduate Student O Freddy SORIA
Tohoku University Fellow Member So KAZAMA

1. INTRODUCTION

Glaciers are natural water reservoirs fundamental in the equilibrium of surrounding ecosystems, as the regions downstream benefit from runoff variations. Current climatic trends indicate a rise of temperature and radiation around the globe, and climate change has been pointed as the main responsible. Hydrological systems in the tropics (latitude +30^{o} to -30^{o}) with influence of glacierized environments are more sensitive to mentioned climatic variations, as ablation and accumulation periods coincide. From a practical and scientific hydrological perspective, the response of those systems is worth studying as they constitute an important contributor to river flow, hence our interest.

The aim of this paper assess the estimation of glacier response in terms of ice and snow melt discharge, from a water resources perspective, through the concept of lineal reservoirs. The study area is located in the Huayna Potosi glacier, Cordillera Real Western Bolivia, Central Andes, in a region dominated by dry austral currents from the south-west and humid amazonic currents from the north-east. Our interest is to compare two reservoir arrangements (Figure 1), as a mean to understand and find a suitable representation within a poorly gauged environment.

2. LINEAR RESERVOIR MODELS

In a general hydrologic system, the amount of water stored in a system (*S*) can be related to the inflow *I* and outflow *Q* by the continuity equation for unsteady and constant density flow. Linear reservoir models are a popular concept that simplify a hydrological system and require moderate data (Hock and Jansson, 2005). They represent the storage effect and the response delay of the glacierized system through tree simple steps: *i)* identification of linear reservoirs (i.e. analysis of recession curves), *ii)* modeling of outflow from the linear reservoir, and *iii)* performance evaluation. The general storage equation is derived from mentioned concepts, and leads to the expression used to estimate the response in linear reservoirs (Equation 1).

$$Q_{(t)} = Q_{(O)} e^{-(t-to)/K} + I_t (1 - e^{-(t-to)/K}) \qquad (1)$$

where *t* and *o* are subindices that indicate current and previous time steps; *K* is the storage constant estimated through recession analysis (i.e. the hydrograph slope in a *lnQ vs t* graph), or through Equation 1 for non-inflow conditions (i.e. *I=0*). We arranged the reservoirs within the two schemes presented in Figure 1, for *K* variable an invariable in time, and compared the suitability of them in the representation of the system response.

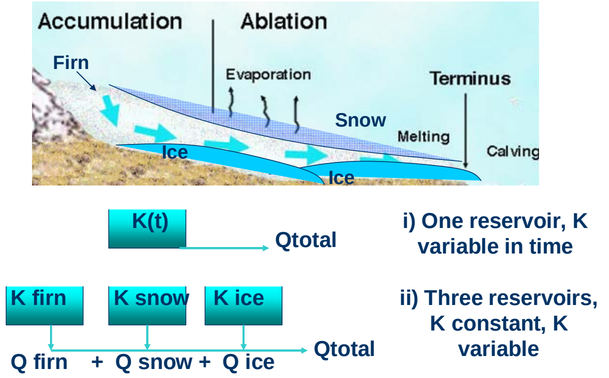


Fig.1. Two schemes of reservoirs arranged in series utilized to understand glacier response.

3. DATA AND MODELING RESULTS

3.1 Input data processing

The evaluation is done in a monthly basis, using observed precipitation as data input, and observed discharge to calibrate the results. The digital elevation model to describe topographical characteristics was constructed from the Shuttle Radar Topography Mission SRTM products available released to the public by the program.

Variations in horizontally projected glacier areas were observed from Landsat images obtained in the period 1999-2000. Optical imagery corrected for atmospheric and topographic effects, was semi-automatically processed using short wavelength infrared false color composites. Glacier melt was estimated from constantly varied ice cap thickness that was used to derive variations in glacier volumes.

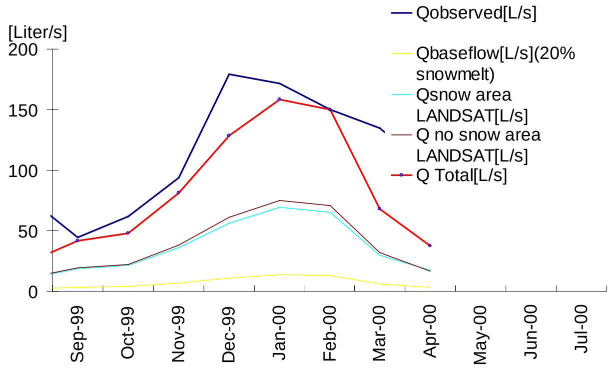
Recession analysis was done through *lnQ vs t* graph in the period 1991-2000. Three reservoirs were identified: a slow (i.e. firn reservoir *FR*), middle (i.e. snow reservoir *SR*) and fast response (i.e. ice reservoir *IR*). Recession constants varied as: 2.0 to 4.0 for the FR, 0.5 to 3.0 for the IR, and 0.5 to 2.1 for the SR. Final recession values were determined from manual calibration, averaged for the single reservoir arrangement (scheme *i)* as presented in Figure 1).

3.2 Arrangement *i):* One reservoir, baseflow rate as a certain percentage of the snowmelt.

The inputs of the single reservoir arrangement are composed by snowmelt, and direct precipitation; abstractions are related to the variations in the areal projection of the glacier; other abstractions such as evapotranspiration were assumed not significant due to the size of the watershed. Under such considerations, estimation of the total discharge

Keywords: Poorly gauged watershed, El Nino event
Tohoku University, 6-6-06 Aoba, Sendai 980-8579, Japan. Tel & Fax: +81-22-795-7451

observed is relatively simple through using Equation 1 and manual calibration of the baseflow contribution as a percentage of the total snowmelt rate, in our case about 20% (Figure 2). Our objective is to understand the internal response of the system, hence this configuration is not helpful when evaluating the response of the firn, and the ice layers, hence its utility in poorly gauged catchments is unlikely. Different configurations seem necessary.



. **Fig.2**. Results for 1 reservoir scheme, considering a variable baseflow rate (20% of the snow melt).

3.3 Arrangement *ii):* Three reservoirs, K variable in every reservoir, not variable in time.

The general response of the model arranged as shown in Figure 1 does not differ much from the one-reservoir presented above. The difference is that calibration can be done considering separately the probable response of each reservoir, hence it might be possible to see through the ice core. Particularly as shown in Figure 3, was observed that FR response took the place of the groundwater reservoir in the case of the one-reservoir scheme evaluated above. It was also interesting to observe that the ice response (the fastest) was unlikely to be the one dominating the peak discharge as it would have been expected within non-glacierized environments. This aspect was confirmed when observed that discharge records presented a delay not explained by the observed precipitation (perhaps driven by the incident radiation), for instance unlikely to be simulated by concepts that would be applied within non-glacierized environments. In general, this scheme helped us to better understand the response.

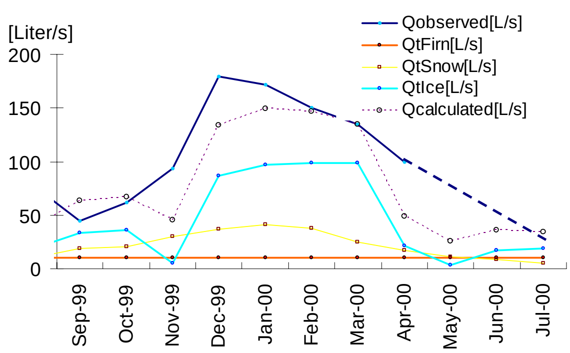


Fig.3. Results for 3 reservoir scheme, K variable in every reservoir, not variable in time.

3.4 The effect of El Nino in glacier response

To observe the delay between observed discharge and precipitation, forced us to consider the importance of temperature, presented in Figure 4, which seemed to settle the main difference between a glacierized and a non-glacierized environment, and the destructive impact of climate change.

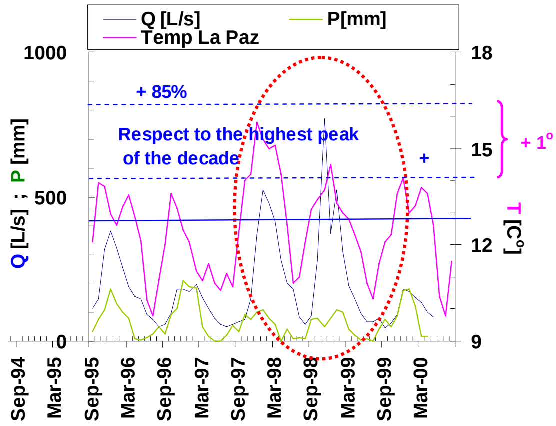


Fig.3. Influence of El Nino on glacier melting.

4. CONCLUSIONS

The overall responses from both schemes were similar, although considering the second option helped us understand the response of each layer separately, hence leading to a more meaningful model calibration fundamental towards poorly gauged conditions. Those were only circumstantial results. We consider that the major contribution from our work was to present that to model systems with high influence of glaciers, is very important to understand that the watershed response can be done using similar concepts than those learned from analog non-glacierized environments, with the main difference observed to be at the time of evaluating the peak delay, which seemed to respond only slightly to the observed precipitation, being highly sensitive to variables such as temperature and radiation, when the consideration of external phenomena such as El Nino would state the major difference. Climate change would then play a major role.

ACKOWLEDGMENTS

The work was supported by the Global Environment Research Fund (S-4) of the Ministry of Environment.

REFERENCES

Gallaire, R. Consecuencia de la Tendencia climática de los últimos 50 años en los glaciares andinos, *Tercera Jornada del Foro Internacional Cambio Climático–Glaciares y Océanos*.

Hannah D. and Gurnell A. 2001: A conceptual, linear reservoir runoff model to investigate melt season changes in cirque glacier hydrology, *Journal of Hydrology*, Vol. 246, pp.123-141.

Hock R. and Jansson P. 2005: Modeling glacier hydrology, *Encyclopedia of Hydrological Sciences*, Anderson M.G. Editor, Wiley & Sons, pp. 2647-2654.